Final Programmatic Report
NRCS – CIG Water Transactions Agreement
69-3A75-10-141

An Overview of Agreement **69-3A75-10-141**
between the National Fish and Wildlife Foundation (NFWF)
and the U.S. Department of Agriculture's
Natural Resources Conservation Service (NRCS)

Report Created by the National Fish and Wildlife Foundation | **December 2013**

Final Agreement Programmatic Report

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Final Agreement Programmatic Report

NRCS – CIG Water Transactions

Agreement 69-3A75-10-141

The National Fish and Wildlife Foundation (NFWF) and the U.S. Department of Agriculture's (USDA) Natural Resources Conservation Service (NRCS) established a grant agreement, **69-3A75-10-141**, for the purpose of designing and demonstrating active water management and transaction tools with agricultural producers implemented through emerging ecoystem markets that result in real water quality and quanitty improvement to benefit rivers and streams with federally listed anadromous fish species. This serves as the final programmatic report for this grant agreement.

Project Title:	Establishing an Ecosystem Market Credit for Flow Restored in Northern California
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Period Covered by Report:	9/24/2010 – 9/24/2013
Project End Date:	9/24/2013

Executive Summary

In order to accomplish our Conservation Innovation Grant (CIG) objectives, we focused our project work in two primary areas: (1) Strengthening, organizing and designing a transactions framework for non-governmental organizations, agencies and landowners currently operating in fledgling environmental water markets; and (2) Designing, developing and then sharing the necessary technical tools and monitoring protocol required to quantify the effectiveness of flow restoration projects and the calculation of tradeable "flow credits".

Equally important for the project's overall success, are the political and social conditions under which transactions occur. Owing to the contentious nature of the Klamath Basin, where regulators, environmentalist and agricultural water users have been fighting for years over poor water quality and dewatered stream habitat conditions for Endangered Species Act (ESA) listed fish species, the timing of our project was a challenge. Due to conditions on the ground, we were forced to modify a small area of the original proposed work and project objectives (previously reported FY 2011).

Originally our goal was to develop two types of "flow credits" based on flow restoration transaction outcomes. They were: (1) Salmon Credit (Aquatic Habitat Credit); and (2) Water Quality Credit (Thermal Credit). We shifted emphasis exclusively to the development and trade of only a Water Quality Credit. This shift was due primarily to comparable ripeness of water quality credit trading compared to Salmon credit trading, as well as the challenging political landscape surrounding ESA listed fish. Additionally, this effort originated as a two-year grant; however, an additional 1-year extension (no additional funding) was requested so we tightened our focus.

The overarching goal of this project was to design and demonstrate active water management tools with agricultural producers, implemented through "emerging ecosystem markets" which benefit water quality and habitat for ESA listed anadromous fish species.

Our specific project deliverables, as described in section V. of the grant agreement, were to:

1. **Develop voluntary flow restoration projects on the Scott and Shasta Rivers in the Lower Klamath Basin and key tributaries utilizing new and/or existing programs. This will be accomplished through a series of meetings with landowners and partnering agencies.**
2. **Develop key elements of an environmental credit calculator, which will be used to produce Salmon and water quality credits from restored flow for sale and purchase in the regulatory market.**
3. **Develop and provide to NRCS the "Transaction Verification Protocol" used to verify the environmental benefits being sold**
4. **Develop and provide to NRCS the "Monitoring Verification Protocol" used to verify annually the environmental benefits being purchased.**

5. **Test environmental credit calculator on 20 potential credit sellers.**
6. **Issue Salmon and/or Water Quality credits on 10 committed sellers and actively seek buyers.**
7. **Provide environmental credit calculator for NRCS use.**
8. **Attend at least one NRCS CIG Showcase or comparable NRCS event during the period of the project agreement.**
9. **Semi-annual performance progress report and a final report documenting project results.**
10. **Fact sheet describing the new technology or approach.**

With respect to these goals and objectives, this project accomplished:

Develop voluntary flow restoration projects on the Scott and Shasta Rivers in the Lower Klamath Basin and key tributaries utilizing new and/or existing programs.

Our project work supported flow transactions in the Scott, Shasta and Sevenmile Creek sub-basins of the greater Klamath Basin. This was done primarily through existing programs of our project partners, the Scott River Water Trust (SRWT), The Nature Conservancy (TNC), Shasta River Program, and the Klamath Basin Rangeland Trust (KBRT). These group's flow transactions proved to be the laboratories for testing our project monitoring protocol and flow-temperature tool, while improving water quality and quantity for ESA listed Coho Salmon, Chinook and Steelhead. Additionally, ESA listed bull trout and sucker species benefited from flow transactions on Sevenmile Creek.

Develop key elements of an environmental credit calculator, which will be used to produce Salmon and water quality credits from restored flow for sale and purchase in the regulatory market.

Our project team developed both the Instream Flow Crediting Protocol (IFCP) and the Water Temperature Transaction Tool (W3T), both utilized to calculate "thermal credits" for trade. The IFCP presents the elements for calculating a credit, while the W3T works project data inputs to quantify the thermal impact of a transaction.

The IFCP and the W3T model are currently being reviewed by State of Oregon, Department of Environmental Quality (DEQ) with regards to its application and abilities of potential trading of "Thermal Credits", as part of their state water quality credit-trading program.

Develop and provide to NRCS the "Transaction Verification Protocol" used to verify the environmental benefits being sold.

The Transaction Verification Protocol is now referred to, as the "Instream Flow Crediting Protocol (IFCP)." This technical document gets into the specifics of credit-tradingand, project effectiveness verification.

Develop and provide to NRCS the "Monitoring Verification Protocol" used to verify annually the environmental benefits being purchased.

The Monitoring Verification Protocol is now referred to as the Water Transaction Monitoring Protocol (WTMP). These were developed and tested by our CIG Team, and applied with project partners to several of their flow restoration project sites to test implementation and effectiveness. Additionally, our CIG Team held trainings in the Shasta and Scott subbasins for respective project partners and assisted with their on-the-ground project monitoring throughout this grant.

Test environmental credit calculator on 20 potential credit sellers.

The W3T model was tested and applied to 20 different flow transactions in a range of geographical areas, including key transactions in the Scott, Shasta, and Sevenmile Creek watersheds. Additionally, the W3T has been applied to several projects outside the basin such as the John Day and Grand Ronde basins of Oregon, and a project in the upper Missouri Basin in Montana. These additional tests were conducted to further calibrate the W3T model on other stream system types, advancing its development.

Issue Salmon and/or Water Quality credits on 10 committed sellers and actively seek buyers.

Due to comparative ripeness of water quality credit-trading, we shifted our work from Salmon and Water Quality credit development to exclusively water quality/thermal credits. We are now working with DEQ to integrate our CIG developed tools such as the IFCP, WTMP and W3T Model into their water quality credit-trading program.

Provide environmental credit calculator for NRCS use.

The current W3T application is ready for NRCS use and dissemination, in addition to the IFCP, and WTMP.

Attend at least one NRCS CIG Showcase or comparable NRCS event during the period of the project agreement.

This CIG project work was presented at multiple events:

In 2011, the Soil and Water Conservation Society annual meeting in Washington, D.C. The meeting was attended by many NRCS representatives.

In 2012, the 2012 Western Water Transactions Meeting held in Reno, NV. This conference included attendees from the National Resource Conservation Service (NRCS) including Astor Boozer and James Gore from headquarters in D.C., as well as 2 other USDA personnel.

In 2013, the W3T model was presented and shared with stakeholders in the Klamath Basin, at the Klamath Basin Monitoring Program (KBMP) meeting in March. (www.kbmp.net)

In 2013 this work was again presented to the 2013 Western Water Transactions Workshop Meeting held in Bend, Oregon. This CIG presentation focused primarily the rollout of the W3T model where it received good feedback and interest.

Additionally, in 2013, the W3T model and NFWF CIG work objectives were presented at the 2013 American Water Resources Association (AWRA) Conference in Portland, OR.

Semi-annual performance progress report and a final report documenting project results.

All performance progress reports will be made available here in the final report as part of our reporting requirements.

Fact sheet describing the new technology or approach.

A fact sheet will be presented in this final report and with our final product deliverables for NRCS.

We believe that the project deliverables developed under this grant will provide interested Federal and State agencies, as well as local groups, access to the tools necessary to adequately quantify environmental outcomes resulting from flow restoration projects. The tools, methodologies and applications, will increase flow monitoring outcome resolution to the level necessary to provide certainties for emerging "flow credit" trading programs. In addition to providing support to the regulatory agencies and groups involved with water quality credit-trading, the W3T model developed for this project can immediately assist stakeholders and groups investigating and planning alternative irrigation management strategies designed to enhance stream flow conditions and/or on-farm irrigation.

From our project team's experience, several recommendations were identified which would increase implementation and advancement of flow-based ecosystem services:

- Quantification of flow restoration project benefits, both spatially and temporally are achievable with the right tools and technical approach, and they can be implemented at reasonable cost.
- For "flow credit" trading to occur, reliable quantification and verification of a project's flow enhancement outcomes is necessary so as to establish a high degree of market certainty for stakeholders and participant actors.
- Implementing water policy innovation will take a concerted shift in approach by many agencies involved, both Federal and State, requiring cooperation between Agencies and Stakeholders alike.

Introduction

This three-year project (2010-2013, with one-year extension) focused on the advancement of ecosystem service tools designed for developing tradable “flow credits’ based upon restored flow. Project actions and efforts were concentrated in the Scott River and Shasta River systems in California, and Sevenmile Creek in Oregon, all sub-basins of the greater Klamath Basin. This project was initiated and led by the National Fish Wildlife Foundation (NFWF), which focused on collaborating with regional agencies, and directly supporting several non-governmental organizations (NGO) working in water quality and water quantity issues in this area.

Owing to the interdisciplinary demands of water management and ecosystem service work, NFWF assembled a diverse project team composed of NFWF staff, private consultants and non-governmental organizational partners:

Andrew Purkey (Project Director). NFWF, Director of Western Water Programs, Portland, OR.
Key expertise: Water Policy, Water Transactions, Water Rights and Ecosystem Services.
www.nfwf.org

Claire Thorp, NFWF, Assistant Director of Southwestern Partnership Office, San Francisco, CA.
Key expertise: Water Policy, Environmental Compliance, Program and Project Coordination.

Mike Deas, P.E. and Ph.D. (Project Technical Lead). Watercourse Engineering Inc., Davis, CA.
Key expertise: Water Quality Monitoring, Hydrologic and Environmental Monitoring.
www.watercourseinc.com

Rankin Holmes (Project Coordinator). Principal, Farm-Stream Solutions, Missoula, MT.
Key expertise: Water Transactions, Project Management and Hydrologic Monitoring.
www.farmstreamsolutions.com

Ann Willis, P.E., Watercourse Engineering Inc., Davis, CA.
Key expertise: Water Quality Monitoring, Hydrologic and Environmental Monitoring.

Andrew Nichols, Watercourse Engineering Inc., Davis, CA.
Key expertise: Geomorphology, Water Quality and Hydrologic Monitoring.

Carson Jeffries, Watercourse Engineering Inc., Davis, CA.
Key expertise: Fisheries Biologist, Environmental Monitoring.

Bobby Cochran, Executive Director, Willamette Partnership, Portland, OR.
Key expertise: Ecosystem Service Markets, Ecosystem Service Tools, and water quality policy.
www.willamettepartnership.org

David Pilz, Flow Restoration Director, The Freshwater Trust, Portland, OR.
Key expertise: Flow Restoration, Water Transactions and Ecosystem Services.
www.thefreshwatertrust.org

Project goals were to design and demonstrate emerging ecosystem market tools with agricultural producers, implemented through flow restoration actions benefitting instream water quality and quantity conditions for ESA listed anadromous fish species, with the following specific project deliverables:

1. Develop voluntary flow restoration projects on the Scott and Shasta Rivers in the Lower Klamath Basin and key tributaries utilizing new and/or existing programs. This will be accomplished through a series of meetings with landowners and partnering agencies.
2. Develop key elements of an environmental credit calculator, which will be used to produce Salmon and water quality credits from restored flow for sale and purchase in the regulatory market.
3. Develop and provide to NRCS the "Transaction Verification Protocol" used to verify the environmental benefits being sold
4. Develop and provide to NRCS the "Monitoring Verification Protocol" used to verify annually the environmental benefits being purchased.
5. Test environmental credit calculator on 20 potential credit sellers.
6. Issue Salmon and/or Water Quality credits on 10 committed sellers and actively seek buyers.
7. Provide environmental credit calculator for NRCS use.
8. Attend at least one NRCS CIG Showcase or comparable NRCS event during the period of the project agreement.
9. Semi-annual performance progress report and a final report documenting project results.
10. Fact sheet describing the new technology or approach.

To achieve these deliverables, NFWF worked with existing NGO partners on the ground in our three target subbasins, to utilize their existing flow restoration programs implemented in cooperation with agricultural producers. Additionally, partnering with these entities helped facilitate real world monitoring opportunities and stakeholder demands to develop the robust but practical tools and science necessary to achieve project success. These organizations and collaborators included:

Scott River Water Trust (SRWT). Based in Fort Jones, CA, the SRWT collaborated with the NFWF Team with providing flow restoration projects to develop and test the monitoring tools developed under the grant. Additionally, SRWT Board of Directors and Executive Director provided invaluable feedback on stakeholder perspective and demands of project monitoring, such as costs and capacity.

Klamath Basin Rangeland Trust (KBRT). Based in Klamath Falls, OR, KBRT worked with NFWF by providing flow restoration project opportunities for testing our monitoring protocol and W3T model development. Additionally, KBRT collaborated and shared monitoring and tool application challenges for flow practitioners on the ground, which were integrated into final deliverables.

The Nature Conservancy (TNC), Shasta River Program. Based in Mt. Shasta City, CA, TNC's Shasta River Program has been operating and managing the Big Springs Ranch located in the upper reaches of the Shasta River. This approximately 4,534-acre working ranch covers the most important and last remaining cold-water refugias for Salmon, Steelhead and other species on the Shasta River system. TNC facilitated water management alternatives on their ranch for our CIG Tool testing, as well as assisted with coordinating drought response flows and environmental monitoring during this grant work.

Additional grant outreach and communications to the local communities were achieved through collaboration with the Shasta Valley Resource Conservation District and the Siskiyou County Resource Conservation District Staffs, and their respective Board of Directors meetings.

CIG project support from the NRCS totaled approximately $384,000 for this effort, with NFWF required to match with direct and in-kind support totaling $415,000.

Project Background

This project initiated by NFWF was designed to address the emerging environmental market need to effectively integrate flow restoration actions and practices, which were currently occurring independently on the ground, into a greater ecosystem service market "toolbox". We focused on these restoration project outcomes for the development of a "flow credit" for potential trade in regulatory water quality credit trading arenas, and/or an aquatic habitat, or salmon credits to address stream impairments.

Although complicated, groundbreaking and ambitious, the aim of this endeavor was to take existing pieces of the puzzle and arrange them in an organized and beneficial framework to compliment stakeholder's work on the ground in the areas of water quality impairments and fishery habitat enhancements. While agencies are working to formally recognize "watershed improvements", other entities (lead primarily by NGOs) have been working independently to address stream reach scale habitat and water quality impairments through water transactions with agricultural producers.

For nearly 12 years, NFWF's successful work with agricultural producers to voluntarily restore flow to tributary streams and rivers through the Columbia Basin Water Transactions Program (www.cbwtp.org) has restored aquatic habitats critical for survival and recovery of imperiled *salmonids*. NFWF funds a wide range of approaches and methods implemented by Columbia Basin producers, including dryland production, reservoir water releases, point of diversion changes, source switches, and split-season water use. For the past four years, NFWF has implemented the Walker Basin Restoration Program to restore inflows to Walker Lake in Nevada.

These supported restoration actions, project partner collaborations and experiences have put NFWF in a unique position to spearhead and develop water restoration efforts. NFWF and our partners have seen the need to develop tools for quantifying Aquatic Habitat and/or Water Quality Credits generated by voluntary flow restoration activities. Creation of tools to convert restored flow into marketable Aquatic Habitat and Water Quality Credits should facilitate water transactions in emerging ecosystem markets, and produce potential new revenue sources for agricultural producers and offer affordable real actions for improving stream waterways.

To address water quality impairments and actions, municipalities in Oregon have historically had to buy expensive "chillers" to cool wastewater discharge into stream systems. These actions require expensive energy consumptive engineering fixes to obtain their “discharge permits”, however, they typically equate to no on the ground environmental benefits once the discharged water instream warms.

Recognizing the immediate need to do mitigation better, The Freshwater Trust (TFT) recently negotiated contracts with the cities of Ashland and Medford in the Rogue Basin of southern Oregon to develop Water Quality Credits and sell the credits to the cities for temperature derived from riparian tree planting. TFT will plant a riparian buffer along 35 miles of Bear Creek and tributaries. The Oregon Department of Environmental Quality (DEQ) has adopted a water quality trading program that facilities that discharge wastewater to a stream or river to meet regulatory obligations by:

- Purchasing equivalent or larger pollution reductions from another source; or
- Taking action to protect or restore riparian areas, wetlands, floodplains, and aquatic habitat to reduce the impact of pollutants.

Thus, purchase of these Water Quality Credits derived from riparian tree planting will allow Ashland and Medford to satisfy their total maximum daily loads (TMDL) under the Clean Water Act as administered by Oregon DEQ.

While NFWF applauds our project partners TFT for leading this innovation, it is our belief that through this CIG work, we can provide another opportunity for stakeholders by building out more robust project options in the “toolbox” and integrate flow transactions and “flow credits” to improve water quality conditions in these and other basins.

Generally there has been less of an effort to establish an Aquatic Habitat credit from restored flow. It has been our observation and experiences that both state and federal fish and wildlife agencies in the west implementing regulatory actions under ESA have not been as interested in developing and implementing ecosystem credit market-based responses.. In addition, ESA enforcement actions have been controversial. This has created numerous challenges for the NGO actors on the ground attempting flow restoration projects, where agricultural producers have been hesitant to work with any NGO for fear of regulatory reprisal. Attempting to collaborate with and assist both Federal and State Agencies working under the ESA was viewed as a huge challenge going into this work; however, attempting to organize and develop a framework around this unrest became impediment for progress in developing salmon habitat credits.

It is our belief that harnessing and attempting to sync the regulatory objectives with voluntary flow restoration efforts, and budding water markets can achieve better projects and results in the highest priority locations. Additionally, it’s our belief that irrigated agricultural producers will be able to integrate water conservation practices into revenue streams for their operation and thus stand to gain from emerging markets. This approach will encourage water efficiency by putting a price value on the water and providing for regulatory certainties, through verification, monitoring and accounting for water.

Review of Methods

Innovation

From the beginning, our effort to bring innovation to project partners on the ground faced several obstacles. First, we observed that not all partner groups conducting flow restoration work utilized a "standardized" monitoring approach. Some groups simply monitored for water right compliance, others monitored habitat gains alone without doing compliance or water right monitoring, and others did a variety of random data selection or all of these. NFWF worked to bring better science and standardization of monitoring techniques to all groups through the designed and developed **Water Transaction Monitoring Protocol (WTMP)** (Appendix IV). The collection of data from the WTMP has full recommendations and suggestions for doing these techniques in a cost-effective but scientifically sound approach, demonstrating that quantification of environmental changes can be achieved by NGOs on the ground.

Additionally, the development and sharing of the Water Temperature Transaction Tool (W3T) (Appendix VII), which is a spreadsheet based program, with a range of modest data inputs to advanced data-inputs, took some convincing for certain entities in the beginning. However, once most saw this tool utilized, they began to realize that they didn't have to have a hydrologist on staff to manage and run it, and that it could assist with day-to-day project decisions as well as assessing stream temperature changes from potential project actions. The latter alone has been enough for most groups to desire to utilize this tool, and if "flow-temperature credits" are ever part of the water quality credit trading market, the tool will be in even greater demand.

The framework and design of the Instream Flow Crediting Protocol (IFCP) (Appendix III), also has been innovative in the water quality credit trading area. This set framework and design for issuing flow credits or "thermal credits" based on water temperature, is much of the leg work a regulatory agency would have to do on their own if they wanted to integrate flow restoration in their agency "toolbox". Oregon DEQ has mentioned at public meetings where we've been in attendance that they do not currently have the capacity to develop new tools, as they are simply trying to keep current approaches moving with current budget restraints. Oregon DEQ also expressed the need for collaboration with NGO groups such as NFWF in these areas so that we might all be able to solve these real world problems together as opposed to waiting for the agency to come up with answers on their own. NFWF believes that the tools and methodologies developed during this CIG work have made great progress in innovation for groups and entities working on the ground in local communities.

Project Evolution

This project was broken down into three distinct phases coinciding with each project year (FY2011-13). Attached semi-annual progress reports have full project details (Appendix VIII); however, notable actions and achievements can be seen here:

Phase I (FY 2011)

- Defined the geographic project area: Shasta River, Scott River and Wood River Sub-basins of the Klamath Basin were selected and approved by NRCS.
- NFWF Staff conducted outreach to meet with collaborating NGO's, agencies and other key stakeholders to introduce and make them aware of the CIG objectives, approach and goals.
- NFWF assembled the technical team (presented in the introduction of this report), to develop the Flow Calculator or Water Temperature Transactions Tool (W3T), and Water Transactions Monitoring Protocol (WTMP) for restoration project quantification.
- The NFWF Team went to the basin and met with partnering groups: (1) identified CIG project goals; (2) Flow restoration projects for testing the WTMP; and (3) Implementation timeline.
- Projects were selected in the Scott Basin with an over-summering habitat project on Patterson Creek, and an autumn main-stem passage project on the Scott River. Additionally, a water quality and habitat improvement project on Sevenmile Creek of the Wood River Basin was selected as well as some flow enhancement projects on the TNC Big Springs Ranch in the Shasta Basin.
- The NFWF Team developed a draft version of the WTMP to be utilized in summer 2011, then travelled to the basin and conducted "field training" for participating project partners.
- NFWF Team and several project advisors worked to develop a working draft of the Verification Protocol, and a Flow Credit Market Framework.
- Flow restoration projects were monitored and data acquired through autumn 2011.
- Throughout the year it began to become clear that agencies in the State of California were less interested in developing credit-trading approaches than Oregon DEQ. While the Federal Agencies working in the regulatory ESA arena were also less interested in credit-based tools.

Phase II (FY 2012)

- NFWF Team began to analyze monitoring data collected under the WTMP guidelines.
- NFWF Team began to update and incorporate WTMP suggestions and feedback from project partners who implemented the WTMP on the ground in 2011. Several additions and edits were made to and an updated version was issued to partners in April for summer irrigation season.
- NFWF brought in Bruce Aylward, Director of Ecosystem Economics to conduct a "Water Transactions Training" held in Yreka, CA for project partners such KBRT, SRWT and TNC.
- NFWF Team continued stakeholder outreach and communications through local NGO Board of Directors meeting, as well as the Siskiyou County and Shasta Valley RCD meetings for acting members.
- NFWF Team again worked with partnering NGOs to identify and select summer 2012 projects for testing. In the Scott Basin, an over-summering transaction on French Creek was implemented as well as the autumn passage project on the main-stem of the Scott River. This autumn Chinook return turned out to be the largest in the basin since 1977. In the Shasta Valley, flow projects

were assessed on the TNC Big Springs Ranch, in addition to an autumn passage flow request done by the Shasta Valley RCD and TNC.

- NFWF conducted another WTMP training in April in the Shasta Basin for project partners.
- NFWF and partners continued developmental work on the Instream Flow Crediting Protocol, and determination of a “Flow Credits”.
- NFWF Team began to build and test the W3T application for summering monitoring work in the Shasta Basin.
- NFWF partners implemented the WTMP on deals selected during the 2012 irrigation season, and collected data passed along to be analyzed.
- During the course of FY 2012, NFWF backed off attempting to push for the trading of “Aquatic Habitat Credits” as there was not great agency interest and the California Department of Fish and Game’s “incidental take permit” program was very controversial.

Phase III (FY 2013)

- The NFWF Team began to assess all monitoring data from 2012 and incorporate into an Aquatic Habitat document and well as additions to the final version of the WTMP.
- NFWF Technical team presented the W3T on numerous occasions to project partners for feedback in area such as functionality, data demands, robustness, and user friendliness.
- The NFWF Technical team continued testing the W3T on multiple flow transactional projects.
- The NFWF Team presented the W3T to the Klamath Basin Monitoring Program in Yreka as well as the Western Water Transactions Workshop held in Bend, OR.
- NFWF continued outreach to Oregon DEQ regarding the W3T and accompanying monitoring protocol for development of a water quality credit for trade.
- Watershed Sciences Inc., based in Portland OR, conducted an independent review of the W3T for its applicability, science and functionality.
- The NFWF Team finalized the WTMP.
- The NFWF Team finalized the IFCP.
- The NFWF Team finalized the W3T.

What worked and what didn’t

We believe our overall project design, the need for additional ecosystem service tools, and the integration of flow restoration actions into an ecosystem market framework to be sound and successful. Stakeholder and peer feedback has been extremely positive, with high interest for guidance in many of these areas. Hopefully the tools and advancements managed through this grant will further assist these efforts.

Areas of the grant, which were not fully realized, include development of credit approaches on the California side of the border. We were assuming an “Oregon” atmosphere when setting targets of selling “flow credits” for Aquatic Habitat and Water Quality services in this initial proposal. Nonetheless, the water quality (flow-temperature) credit tool is advancing in Oregon as we are scheduled to meet with Oregon DEQ next month to seek approval of the tool.

Discussion of Quality Assurances

Tools

Our project goal, to develop these ecosystem service tools while supporting real world voluntary flow restoration projects in the Shasta, Scott and Sevenmile Creek Sub-basins of the Klamath Basin, is documented in the Appendix I of this report, per our list of project deliverables.

As previously expressed flow restoration transactions can be highly contentious in basins like the Klamath, where some view the water politics as “fish versus farms”. Others, like our project partners SRWT, KBRT and TNC in the basin, are willing to work in the middle, attempting to address the environmental issues instream and provide support for innovative and water efficiency assistance on-farm. Included in the Appendix I will be project monitoring reports provided by these groups, where CIG WTMP were developed and implemented, in addition to our Aquatic Habitat assessment reports. Due to the contentious nature over water in the area, these strategically selected projects must support both fish and producers. These reports effectively demonstrate these projects were benefiting the anadromous fishery in these basins, as well as other fish species as required per our agreement and project goal.

The development of key elements of a “flow calculator”, were demonstrated in both the IFCP (Appendix III) and the W3T application (Appendix VII). Elements of credit calculation were developed and presented more in depth in the IFCP, which takes a “potential project stream” and breaks it down into five steps of understanding to develop potential flow credits. Additional steps for project verification would be required for final flow credit determination, however, the basic elemental approach is:

1. <u>Natural Hydrograph Variability</u>: For credit calculation purposes, where data quality allows (data quality is discussed in more depth in IFCP), hydrographic variability can be accounted for using accepted statistical methodologies to develop what are called exceedance flow levels (expressed as percentages).
2. <u>Water Right Reliability and Regulation Patterns</u>: Western water law relies on a priority system to determine what water rights are entitled to continue diverting water during times of shortage. This “first in time, first in right” system has major implications for the calculation of temperature credits from projects. Depending on the transacted water right’s seniority, it may or may not be in priority or available during low flow periods of the year when transaction objectives are likely to be focused. Carrying out this system of water right priority requires state employees to coordinate and enforce the system among and between water right holders. This is achieved by

regulatory actions that include ordering out-of-priority junior water rights to shut off to allow water to flow to in-priority senior water rights.

3. Hydrographic and Water Right Reliability Data Presence and Quality: The ability to derive meaningful predictions from hydrographic and water reliability data to aid in credit calculations depends heavily on data presence and quality that vary from basin to basin. Data availability and quality, therefore, are major drivers in the calculation process. Credits are calculated in three different ways depending on whether the transaction takes place in a High Data Confidence scenario (HDC), a Medium Data Confidence scenario (MDC), or a Low Data Confidence scenario (LDC).

4. Timing of Project Objectives: Depending on the specifics of the relevant TMDL or other restoration driver, project objectives will often be targeted at specific periods during the year. For instream flow restoration projects, the precise timing of objectives is vital to the calculation process. Project objectives therefore will dictate the precise time period during which instream benefits from projects can count toward credit generation

5. Calculating Temperature Credits from Flow Using the W3T: The W3T model uses a combination of river and landscape characteristics to estimate the hourly heat loss or gain experienced by a defined river reach, from which it predicts temperature changes in that reach. The models uses three parameters: (1) physical channel characteristics such as river depth, width, length, gradient, and bed roughness; (2) topographical and vegetation features such as surrounding zones of vegetation that provide shade and inhibit solar radiation; and (3) meteorological conditions affecting heat transfer at the air-water interface such as air temperature, humidity, and cloudiness. To run the model, project developer’s import measured inflow water temperatures and discharge for a defined reach. As water travels downstream from the top to the bottom of the reach, W3T estimates incoming solar radiation and atmospheric heat exchange, incorporating tributary inputs and meteorological information to calculate a net change in temperature. Calculations may be expressed in raw temperature or kilocalories/day.

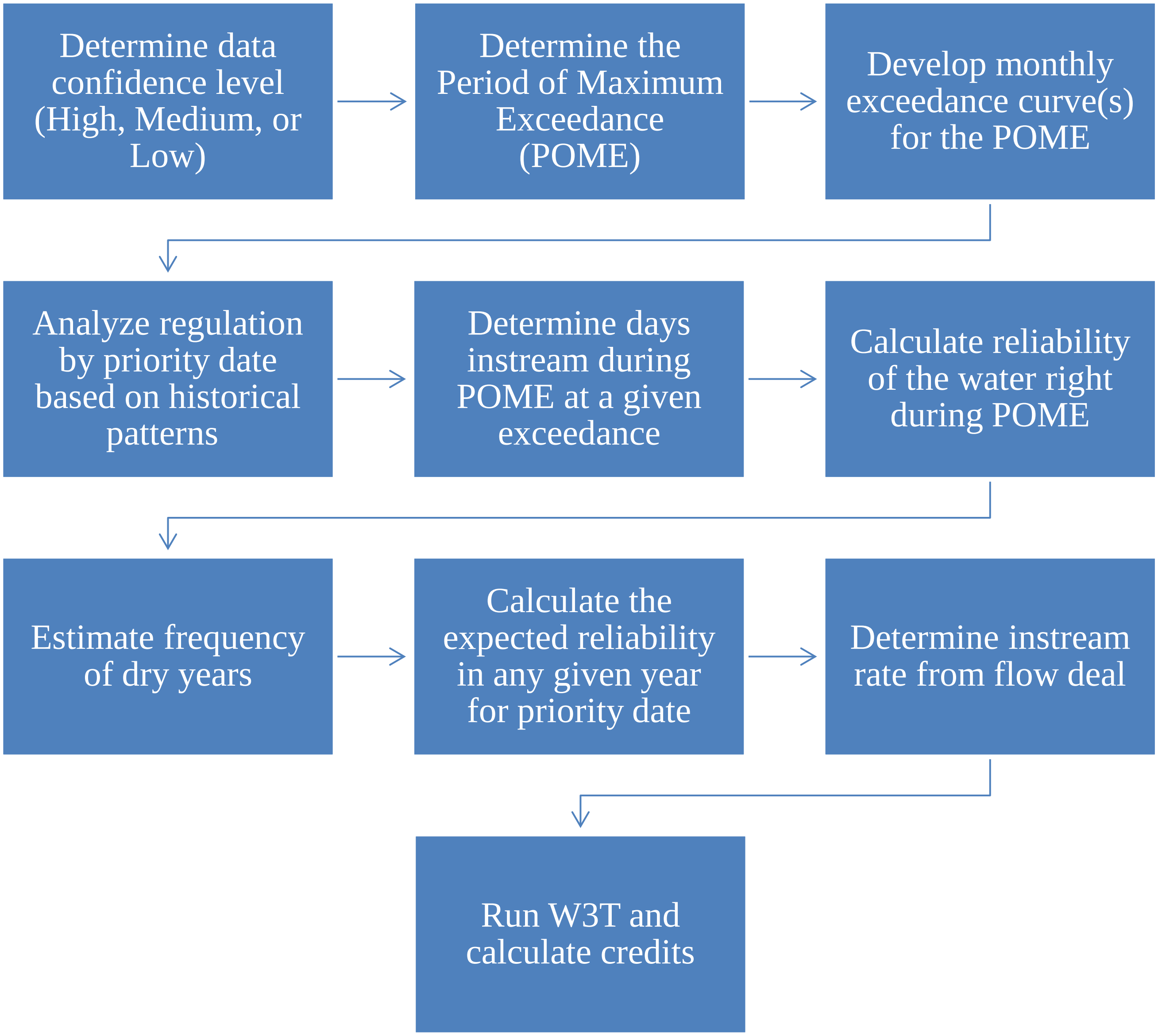

Figure 1. Credit Calculation Process

Additionally, the development of IFCP and related framework documents under Appendix III, will support this work, although we recognize until fully "tested" through an actual flow credit trade, they remain somewhat conceptual.

Our project development of the WTMP for "Monitoring Verification Protocol", designed for project field crews to collect the necessary data for quantification of project response, will be more fully supported in the Appendix I and Appendix IV deliverables. Our step-by-step approach to create the WTMP were:

1. Practical and cost-effective
2. Standardized and Transferrable

3. Scientifically Supported to:
    a. Quantify hydrologic discharge changes over the duration of the flow transaction
    b. Quantify water temperature changes over the duration of the flow transaction
4. Integrate W3T data collection needs

Steps 1 and 2 were achieved through on the ground monitoring testing during the irrigation seasons of 2011 and 2012 with project partners. Modifications were made to slightly scale back areas, due to "extensive field times", per questions posed and feedback from our field crews.

Step 3a, was achieved through literature review and the premise, or general acceptance that by applying hydraulic rating methods, the relationship between stream flow and habitat may be evaluated. After testing multiple hydraulic methods in 2011, we ended up going with a widely accepted approach, the "wetted-area" method by 2012, due to system response evaluation and to comply with our Step 1 objective.

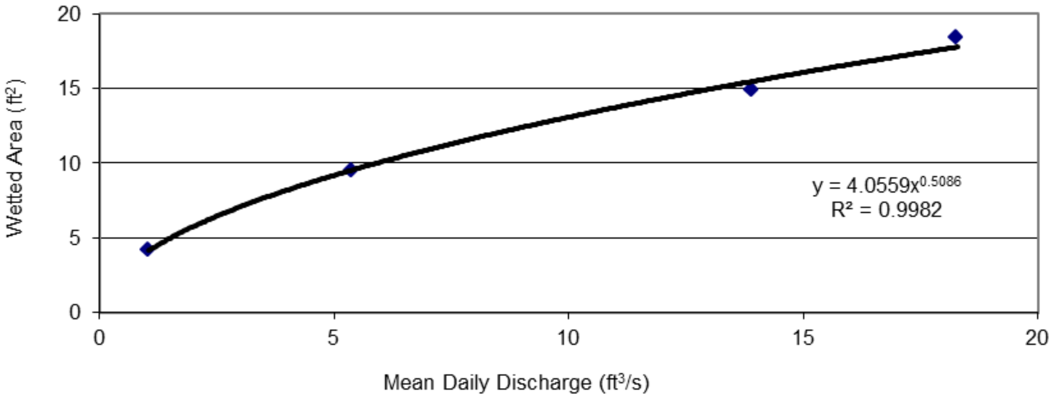

Figure 2. An example of an aquatic habitat-rating curve, where the wetted area of the monitoring location is related to mean daily discharge.

Step 3b was more straightforward as temperature hobos, which are designed to be deployed instream and can record water temperature every 15 minutes (if desired), are relatively affordable and easy to use. Our goals were to guide the correct placement of these instruments to the project layout to optimize the data collected. Additionally, other supplemental data method collection is suggested to allow full integration of the W3T model, per our Step 4 objective.

The development of the W3T, and its application and testing on numerous project sites are presented more in depth in Appendix V and Appendix VII. A third party review of the W3T was conducted by Watershed Sciences Inc, based in Portland OR. Watershed Sciences Inc is owned by Matt Boyd one of the primary developers of the Heat Source Model, which is currently used by the Environmental

Protection Agency (EPA) and State DEQ agencies, implementing rules and regulations under the Clean Water Act (CWA). This WSI independent review will be provided in Appendix V of this document.

W3T is based on a steady flow approach (e.g., based on the Manning equation) requiring basic stream parameters (velocity, depth, cross sectional area, and surface area). Subsequently, this information is used to model water temperature based on energy transfer to and from the water across the air-water interface and accounts for transport of heat energy in the downstream direction. The current model for heat budget is consistent with Heat Source (v 7) and includes simulation of topographic and riparian shade (see Figure 3).

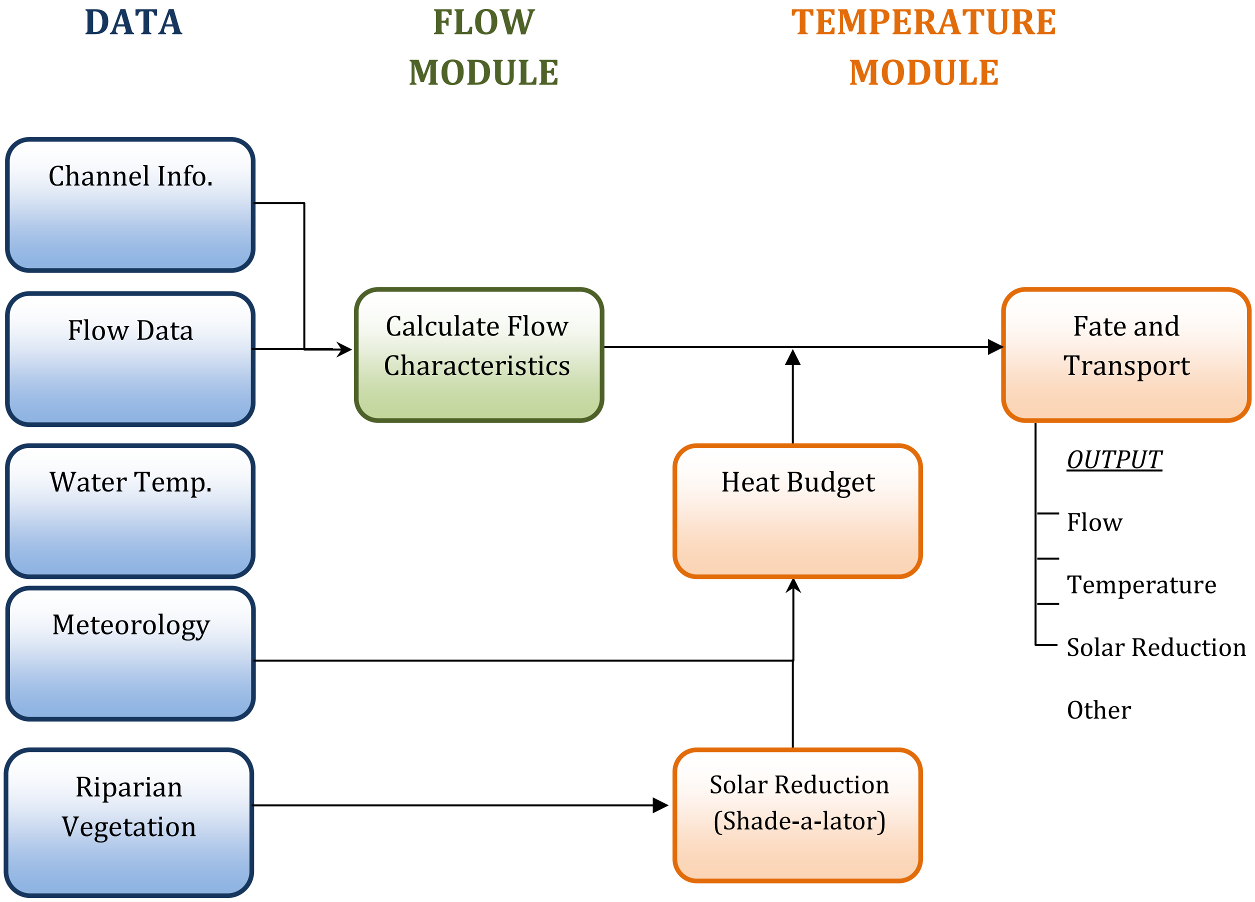

Figure 3. W3T schematic of data and flow and temperature modules.

The objective of W3T is to provide a simple, transparent tool to quantify the effects of flow transactions on water temperature and utilize existing shading logic included in Shade-a-lator. The tool was developed in a spreadsheet to provide a transparent and uncomplicated environment that can readily be shared with stakeholders, resource managers, and others involved in flow transactions where water temperature may be affected. The W3T model approach, aims to strike a balance that provides sufficient accuracy to support and inform a transaction program and minimize data needs and computational time.

The tool allows users to define a simple river reach and change basic characteristics, such as surrounding shade, cross-section form, channel slope, and tributaries and diversions, to evaluate potential benefits of flow transactions as they relate to river temperature. In defining the river reach, tributaries and diversions may be placed anywhere along the reach length and can be moved, removed, or added to develop different scenarios for comparison. Users may interactively specify reach length, inflow, tributary flow, and diversion amount. Water temperature can be assigned within W3T from a list of records and assigned to each inflow. Unique shade scenarios can be developed within W3T and assigned to individual sections of a reach.

Findings

Here are our findings per project goals and deliverables as follows:

Develop voluntary flow restoration projects on the Scott and Shasta Rivers in the Lower Klamath Basin and key tributaries utilizing new and/or existing programs.

> Our project accomplished this goal, through existing programs of our project partners SRWT, TNC and KBRT. These groups are located in the Scott River, Shasta River and Upper Klamath sub-basins respectfully, and all project directly support ESA listed fish species, and specifically anadromous species in the two Lower Klamath sub-basins.
>
> While we found this to be politically challenging at times, all of these partnering groups were outstanding. Given the contentious nature of this work, when creating changes to historical use of water management diversions, and then adding ESA listed species and environmental regulations, the landscape was a tough but real laboratory for innovation development.

Develop key elements of an environmental credit calculator, which will be used to produce Salmon and water quality credits from restored flow for sale and purchase in the regulatory market.

> We were successful in achieving the development of key elements of a credit calculator for water quality (temperature) credits. This was accomplished through the development of both the IFCP, which outlines a framework basis for quantification of preliminary “flow credits”, and as well with the W3T model, which assists with this calculation.
>
> Development of a “Salmon Credit or Aquatic Habitat Credit” as previously reported and discussed, proved to be more challenging. Similar elements and components that went into the development of the W3T model could be modified to achieve something comparable; however, at the time of this grant, we could find no consensus or interest from agencies and stakeholder groups alike in the Klamath Basin to develop such a credit.
>
> Regarding, the credit calculator quantification and potential sale of a water quality credit, or thermal credit, using the products and tools developed under this CIG work, NFWF is currently in discussions and collaborating with Oregon DEQ. Oregon DEQ has expressed a desire for these tools and

methodologies so final outcome will be forthcoming, which we are excited about, as things are extremely positive.

Develop and provide to NRCS the "Transaction Verification Protocol" used to verify the environmental benefits being sold.

The Transaction Verification Protocol is now referred to, as the "Instream Flow Crediting Protocol (IFCP)". This and some additional technical documents will make up a package addressing trading framework, credit development, project effectiveness, and credit verification.

These documents were co-produced by our partners at the Freshwater Trust, Willamette Partnership as well as the core NFWF project team. We believe these to be highly useful for "thermal credit" trading based upon flow restoration, and likely a foundational basis and guide for an eventual Aquatic Habitat Credit, if regulatory agencies and stakeholders desire in the future.

Develop and provide to NRCS the "Monitoring Verification Protocol" used to verify annually the environmental benefits being purchased.

The Monitoring Verification Protocol, which is now referred to as the Water Transaction Monitoring Protocol (WTMP) were developed and tested on flow restoration projects in the project areas. We developed these to practical, transferrable, scientifically driven and accurate. We feel through field-testing and feedback, we have stuck a balance between science / data collection / practicality. Additionally, the WTMP compliments the W3T model allowing for additional project analysis outside of field observational results.

Test environmental credit calculator on 20 potential credit sellers.

The W3T model was tested and applied to 20 different flow transactions in a range of geographical areas. As previously mentioned, due to not being able to produce and sell "flow credits" during the period of this grant, tests were conducted on actual transactions and flow enhancement projects to assist with W3T calibration and testing. W3T applications will be provided per our agreement in Appendix V.

Issue Salmon and/or Water Quality credits on 10 committed sellers and actively seek buyers.

As previously mentioned, due to unforeseen political and social complications, stakeholder and agency support for a "Salmon Credit" was not to be found in the Lower Klamath Basin. Due to regulatory battling over ESA and CWA compliance, this was simply too complicated and controversial, to bring stakeholder together to collaborate on solutions.

While in Oregon, NFWF is in discussions with Oregon DEQ about the integration and use of the ecosystem service tools developed under this grant into their water quality credit-trading program.

Provide environmental credit calculator for NRCS use.

We have submitted the Water Temperature Transactions Tool (W3T) for NRCS use and dissemination (Appendix VII).

Attend at least one NRCS CIG Showcase or comparable NRCS event during the period of the project agreement.

We presented our CIG project work and W3T Model at the following conferences and workshops:

1. 2012 Western Water Transactions Workshop in Reno, NV.
2. 2013 Western Water Transactions Workshop in Bend, OR.
3. 2013 Klamath Basin Monitoring Program, spring meeting in Yreka, CA.
4. 2013 American Water Resource Association Conference in Portland, OR.

Semi-annual performance progress report and a final report documenting project results.

All performance progress reports will be compiled in Appendix VIII.

Fact sheet describing the new technology or approach.

A fact sheet will be presented in Appendix IX of this final report.

Conclusions and Recommendations

Based on our project experience and achievements over the last three years, we feel that many states and areas are ready for the ecosystem service tools created here, as well as ready to integrate flow restoration into ecosystem service world through regulatory trading of "flow-temperature credits". We feel the tools we've created are highly useful, especially in locations such as Oregon, where collaboration and innovation has been more the norm for agencies, agricultural producers and other stakeholders, when working on water resources. In locations such as California, we feel ecosystem service tools and "flow credits" may still a bit pre-mature.

We are encouraged by the recent NRCS CIG awarded to our partners at the Willamette Partnership to assist their work on standardizing water quality credit trading rules in Oregon, Washington and Idaho. We feel this type of effort is needed for ecosystem service development, as it will help assist to standardize rules for credit trading, and also empower budget restricted state agencies that lack the resources to lead technological innovation.

Although we feel strongly that we have achieved success with this grant, primarily in the development of solid ecosystem service tools, and designs for "flow-temperature credit" development and trading, we'd welcome agency input and further discussions on tool or calculation improvement for implementation. We're hoping this is where our current discussions with Oregon DEQ will lead, and we hope to assist them in their review and assessment of our product tools.

Appendix I

Voluntary Flow Transactions

NFWF CIG WATER TRANSACTION MONITORING ASSESSMENT:
2011-2012 AQUATIC HABITAT ANALYSIS

Photo credit: Sue Maurer

A Report for National Fish and Wildlife Foundation

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MAY, 2013

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Executive Summary

The National Fish and Wildlife Foundation (NFWF) with support from a Natural Resource Conservation Service (NRCS) Conservation Innovation Grant (CIG) has been working to develop an environmental market credit based upon flow restoration actions, with regards to a programmatic framework, monitoring verification system and credit development guidelines. Part of the effort to establish the environmental market flow credit includes developing a method to quantify and account for the effect each flow transaction has on a specified stream reach. Project partners and stakeholders were tasked with implementing draft monitoring protocols to quantify experimental flow transactions (referred to hereafter as transactions) that occurred in 2011 and 2012. The results of those monitoring programs were analyzed to evaluate the effectiveness of the protocols at capturing changes to physical aquatic habitat characteristics. In addition, the changes to physical aquatic habitat were analyzed to evaluate the benefit of the flow transaction using specific metrics. The results of those transactions illustrated key conclusions:

1. The monitoring protocols effectively capture changes to physical aquatic habitat in both short-term and long-term flow transactions.

2. Some metrics are more effective at describing the benefit of a flow transaction to physical aquatic habitat than others. Discharge-wetted area relationships were the most robust metric.

3. Channel geometry is the principal factor affecting the application of metrics across various channel types.

The results of the transactions also helped identify considerations when implementing the aquatic habitat monitoring protocols. These considerations included:

1. Short duration, “snap-shot” transactions require stable stream flows prior to and during the course of the transaction to effectively quantify changes in conditions.

2. Streambed alterations (e.g., gravel movement by spawning salmon), complex channel morphologies (e.g., multi-channel streams), or changing bed roughness conditions (e.g., in-channel vegetation growth) can hinder or altogether prevent the development of statistically robust aquatic habitat-discharge rating curves

3. Poor quantification of streamflows preclude an accurate assessment of habitat-discharge relationships.

NFWF CIG Water Transaction Monitoring Assessment: 2011-2012 Aquatic Habitat Analysis

1. Introduction

National Fish and Wildlife Foundation (NFWF), in collaboration with Farm-Stream Solutions and Watercourse Engineering, Inc. (Watercourse), is establishing the framework and system for an environmental market flow credit with the support of a Natural Resources Conservation Service (NRCS) Conservation Innovation Grant (CIG). Part of the effort to establish a framework for administering an environmental flow credit includes developing a method to quantify and account for the effect each flow transaction has on a specified stream reach. Project partners and stakeholders were tasked with implementing draft monitoring protocols to quantify experimental flow transactions (referred to hereafter as transactions) that occurred in 2011 and 2012. This report documents the results of the implementation efforts and includes an analysis of the transactions in terms of aquatic habitat benefits. These benefits are quantified in terms of physical aquatic habitat metrics. This document addresses the suitability of potential metrics, as well as limiting factors identified during the 2011 and 2012 experimental transactions.

2. Monitoring protocols

A draft of the National Fish and Wildlife Foundation – Natural Resource Conservation Service Conservation Innovation Grant (CIG) Field Monitoring Protocols (Holmes et al., 2011) were developed to monitor four potential components of a transaction:

1. flow,
2. aquatic habitat,
3. water temperature, and
4. water quality.

The draft was distributed to project partners, and protocols were selectively implemented to monitor flow transactions in the Scott River, Shasta River, and Sevenmile Creek basins. The protocols that were implemented for each transaction depended on the transaction's objective. The transaction objective (e.g., to provide passage, oversummering habitat, or other instream changes) was identified by the project partners, and protocols to monitor these transactions were identified in collaboration between the NFWF project team and project partners. Details regarding other potential objectives, monitoring methodologies, reporting requirements, and other components of the monitoring protocols are included in Holmes, et al. (2011).

The NFWF project team and project partners focused on implementing and assessing the flow and aquatic habitat protocols across a range of basins and hydrologic conditions. Following the 2011 transactions, an assessment of how successfully project partners were able to implement protocols and whether the implemented protocols could effectively assess the component was provided in Willis, et al. (2012). Having determined whether the protocols effectively detected changes in aquatic habitat during the 2011 flow transactions, the NFWF project team analyzed the 2011 and 2012 field data to quantify those changes. This document presents the results of that analysis.

3. Flow transactions

The monitoring protocols were implemented in the Scott River, Sevenmile Creek, and Shasta River basins. These basins were selected as they represent a range of hydrologic regimes and had existing transactions that could be monitored for a range of objectives. Monitoring transactions in different hydrologic settings is important to determine how well the protocols effectively quantify changes across a range of basin types. Protocols that are applicable across a range of hydrologic regimes can increase the opportunities for participation in a future flow transaction program. Protocols were implemented in basins with previously established transactions, allowing the protocols to be implemented in a "real" transaction framework rather than an idealized framework. Separate monitoring teams were used in each basin, which provided an opportunity to examine how well monitoring groups could follow the protocols with minimal support by the protocols' authors. An overview of each basin's hydrologic characteristics and transactions are provided.

3.1. Scott River Basin

The hydrologic regime in the Scott River Basin is primarily defined by snowmelt runoff and is characterized by baseflows that are seasonally augmented by winter precipitation and snowmelt runoff during the spring. The Scott River Water Trust (SRWT) developed four transactions for the CIG project: a summer 2011 transaction in upper Patterson Creek – a small snowmelt-runoff dominated tributary to the Scott River; fall transactions in the mainstem Scott River in both 2011 and 2012; and a summer 2012 transaction in French Creek – another small snowmelt-runoff dominated tributary to the Scott River. For each 2011 transaction, the monitoring protocols were implemented by the Siskiyou Resource Conservation District (Siskiyou RCD). Transaction monitoring efforts in 2012 were implemented by SRWT. Details of each transaction, its objective, and the protocols that were implemented are described below.

3.1.1. Patterson Creek (2011)

The SRWT established a partial season flow transaction with a local irrigator to cease diverting the entire water right of 5.0 ft^3/s from Patterson Creek beginning July 7, 2011, and extending through September 2011 (the end of the irrigation season). No other diversions exist above this leased site (SRWT, 2012b). During the 2011 flow transaction, the amount of water available for diversion declined until baseflow was reached in the late summer. Consequently, quantities of water leased for in-stream dedication varied between 5.0 ft^3/s at the start of the transaction and 0.2 ft^3/s by late August (Yokel, 2012). The objective of the transaction was to address oversummering habitat availability during juvenile salmonid rearing for coho and steelhead. Flow and aquatic habitat monitoring protocols were implemented by the Siskiyou RCD during the transaction period.

3.1.2. Mainstem Scott River below Scott Valley Irrigation District (SVID) diversion (2011 and 2012)

During fall 2011, the SRWT leased approximately 8 ft^3/s of the fall (i.e., post-irrigation season) stockwater right from the Scott Valley Irrigation District (SVID) and an adjacent landowner at their joint diversion at Young's Dam, located at river mile (RM) 47. The leased water remained instream (i.e., not diverted) from October 15, 2011 through November 28, 2011 (SRWT, 2012b). Before the lease began on October 15, the Siskiyou RCD measured 17.17 ft^3/s in the ditch. After the headgate was closed down, a portion of their stockwater right, measured at 4.53 ft^3/s, remained in the ditch (SRWT, 2012b). The objective of the transaction was to support fall passage availability to upstream spawning areas during adult Chinook and coho salmon migration. Flow and aquatic habitat protocols were implemented by the Siskiyou RCD during the transaction period.

During fall 2012, the SRWT leased approximately 12 ft^3/s of the fall (i.e., post-irrigation season) stockwater right from the Scott Valley Irrigation District (SVID) and an adjacent landowner at their joint diversion at Young's Dam. The leased water remained instream (i.e., not diverted) from October 1, 2012 through November 13, 2012 (SRWT, 2012a) . Due to low flows, no water was being diverted at the SVID POD when the lease began (SRWT, 2012a). Measured streamflow below the SVID POD on October 1, 2012 was 3.91 ft^3/s and rose to over 50 ft^3/s over the course of the transaction. Similar to 2011, the objective of the transaction was to support fall passage availability to upstream spawning areas during adult Chinook and coho salmon migration. Flow and aquatic habitat protocols were implemented by the SRWT during the transaction period.

3.1.3. French Creek (2012)

The SRWT established a partial season flow transaction with a local irrigator to cease diverting the entire water right of 0.76 ft^3/s from French Creek beginning July 18, 2012, and extending through September 2012. During the 2012 flow transaction, the amount of water in French Creek at the diversion point declined until baseflow was reached in the late summer. September 2012 baseflows generally ranged from 0.62 to 1.0 ft^3/s.

3.2. Sevenmile Creek Basin

The Sevenmile Basin's hydrologic regime is primarily defined by groundwater-fed springs. This regime is characterized by relatively steady flows that vary with seasonal water use and minimal influence by aquatic vegetation (aquatic vegetation can play large roles in a spring-fed streams seasonal flow, aquatic habitat, water temperature, and water quality – see Willis et. al (2012) for details). The monitoring protocols were implemented by the Klamath Basin Rangeland Trust (KBRT) in collaboration with Graham Matthews & Associates (GMA) for one transaction. This transaction occurred on Sevenmile Creek and involved a spring, called Blue Springs, which contributes flow to Sevenmile Creek and is seasonally diverted for irrigation.

Few details about the Sevenmile transaction were provided by KBRT. The KBRT leased an unknown volume of spring water from a local irrigator during summer and fall of 2011; the beginning and end dates of the transaction were not provided. The objective of the transaction was not identified. Flow, water temperature, and aquatic habitat protocols were implemented. Monitoring efforts focused on quantifying aquatic habitat available when all of the leased water was discharged into Sevenmile Creek, as well as quantifying aquatic habitat changes following both planned diversions from Blue Springs and changes in upstream diversion on Sevenmile Creek. The lack of information describing the transaction prevented a meaningful analysis of the protocol implementation and suggests that additional resources should be dedicated to administering each transaction.

3.3. Shasta River Basin

The Shasta Basin includes a range of hydrologic regimes, including snowmelt runoff and groundwater-fed spring flow. During 2011 and 2012, four transactions were conducted in the Shasta River Basin. The monitoring protocols were implemented by Watercourse. Three transactions were conducted along Big Springs Creek and involved the release of the full flow of Little Springs Creek, which had been previously completely impounded for irrigation purposes, into Big Springs Creek. The fourth transaction involved monitoring pool volume changes in the lower Shasta River Canyon following voluntary actions by local irrigators to cease irrigation withdrawals in late September 2012.

3.3.1. Big Springs Creek (2011 and 2012)

Big Springs Creek is a spring-fed tributary to the Shasta River. The hydrologic regime in Big Springs Creek is strongly influenced by aquatic vegetation (Jeffres et al., 2009; Jeffres et al., 2010; Willis et al., 2012), eliminating the possibility of developing habitat-flow relationships over time period greater that several weeks. As such, flow transactions in Big Springs Creek were conducted over time period ranging from 4 to 6 days, providing the opportunity to utilize the monitoring protocols in a “snap-shot” transaction where aquatic habitat monitoring data are only collected twice: once before the transaction, and once immediately following initiation of the transaction. Each 2011 and 2012 flow transaction in Big Springs Creek was established to measure aquatic habitat conditions in Big Springs Creek: 1) with zero-flow contributions from Little Springs Creek; and 2) full flow of Little Springs Creek.

In late fall 2011, The Nature Conservancy stopped all diversion activities in Little Springs Creek and released approximately 8 ft^3/s of spring water from Little Springs Creek into Big Springs Creek. Pre-release aquatic habitat measurements were conducted on September 27, 2011, and post-release aquatic habitat measurements were conducted on September 28, 2011. Identical transactions were repeated during both the spring and summer of 2012. During spring 2012 transaction, pre- and post-release aquatic habitat measurements were conducted on May 29, 2012 and May 31, 2012, respectively. During the summer 2012 transaction pre- and post-release aquatic habitat measurement were conducted on August 6, 2012 and August 8, 2012, respectively.

3.3.2. Shasta River Canyon

The Shasta River flows through a steep canyon prior to entering the Klamath River. Late fall streamflows through the canyon are typically low in magnitude, reducing the volume of pools in which fall-run Chinook salmon often hold prior to migrating upstream to spawn. In September 2012, the Shasta River Resource Conservation District (RCD) organized voluntary irrigation reductions throughout the Shasta River to help increase flows through the Shasta River Canyon. During this period the Shasta River RCD and The Nature Conservancy implemented pool volume monitoring protocols developed by Watercourse (Nichols, 2012) to quantify changes in the volume of a single pool (Hudson's Pool) located in the lower Shasta River Canyon associated with increased flows in the Shasta River from upstream sources.

4. Analysis methods

Aquatic habitat was monitored by project partners following draft protocols developed by Holmes et al. (2011) and Nichols (2012). Analytical methods for reducing data collected through use of these protocols are described herein.

4.1. Habitat Cross sections (2-dimensional habitat)

Using stream cross-section transect data provided by project partners, Watercourse calculated five (5) hydraulic parameters (wetted area, wetted width, mean depth, wetted perimeter and width:depth ratio) for each surveyed cross section during each measurement period. These hydraulic variables are considered surrogates for aquatic habitat conditions. Where cross-section transects were conducted across a sufficient range of measured streamflows, standard hydraulic rating methods (as described in Leopold and Maddock, 1953; Jowett, 1998; Gordon et al., 2004) were used to quantify relationships between flow and the aforementioned hydraulic variables. Such methods generally follow "at-a-station" hydraulic geometry techniques established by geomorphologists (Leopold and Maddock, 1953) to quantify temporal changes in channel form variables with variation in flow through a specific cross-section. While analytical techniques based on hydraulic geometry data are commonly used to develop minimum instream flows (e.g. Jowett, 1997; Gippel and Stewardson, 1998; Reinfelds et al., 2004), hydraulic geometry data can be more generally used to quantitatively define discharge-aquatic habitat relationships across a range of streamflow magnitudes. Using this empirical approach, hydraulic-streamflow rating curves were developed using power functions (see Dunne and Leopold, 1978) of the general form

$$y = aQ^b ,$$

where:

y = hydraulic variable;
Q = mean daily discharge;
"a" and "b" = empirically derived coefficients and exponents, respectively.

It should be noted that channel geometry can influence habitat-discharge relationships. For example, Gippel and Stewardson (1998) found that triangular channel geometries generally give a power relationship between wetted perimeter and discharge, while rectangular geometries generally produce a logarithmic relationship.

Short duration flow transactions (several days to weeks) typically do not enable the generation of habitat rating curves using hydraulic rating methods, largely due to an inability to measure habitat variables across a sufficient range of flows. In such circumstances (e.g. the Little Springs Creek flow transaction in the Shasta River Basin), the five aforementioned hydraulic variables were measured from transects surveyed immediately prior to and immediately following a known change in streamflow. From these data, instantaneous changes in habitat conditions following the measured change in streamflow were calculated.

4.2. Pool Volume (3-dimenisonal habitat)

Data from multiple stream cross-section transects surveyed along the length of a pool were used to calculate the change in pool volume over the duration of a transaction. Analytical procedures were largely derived from those presented by Hilton and Lisle (1993). During each survey period (i.e., unique streamflow), wetted area was calculated for each of five (5) surveyed cross-section transects. The average wetted area for each pair of adjacent cross sections was multiplied by the channel centerline distance between each pair to generate the volume for each of four pool segments. The summation of volumes from all four pool segments provided the total pool volume during each measuring period. Using hydraulic rating methods similar to those discussed in section 4.1 (i.e., using a power function), a streamflow-pool volume rating curve was developed.

5. Results

Aquatic habitat monitoring results from 2011 and 2012 transactions are presented herein. For each transaction, aquatic habitat transect survey locations and stream gages utilized to quantify flow volumes during the transaction are identified. Additionally, discharge magnitudes on each habitat transect survey date are provided. For longer term transactions conducted over several months (i.e., Patterson Creek, Scott River below SVID, and Sevenmile Creek), representative aquatic habitat rating curves are provided, and habitat changes associated with alterations in streamflow are quantified. For short-term transactions (i.e., Little Springs Creek), “snapshots” of aquatic habitat changes associated with discrete changes in flow are quantified and presented. The measured or predicted magnitude of change associated with each habitat metric is used to characterize the resulting effects of each water transaction, but does not speak to whether the changes to physical aquatic habitat elements translated into comparable benefits to fish. Additional analysis to develop the relationship between aquatic habitat metrics and habitat suitability for targeted fish species was not a task included in this project. Translating physical aquatic habitat into the context of fish needs (e.g., pool volumes vs. holding habitat) would be a useful next step in the process of developing a flow transaction market to address environmental needs by identifying appropriate metrics and measures of success.

5.1. Scott River Basin

As previously discussed, two flow transactions were conducted in the Scott River Basin. Both transactions (Patterson Creek and the Scott River below SVID) were multi-month transactions, allowing for the development of aquatic habitat rating curves and conceptual analyses of habitat changes associated with water leased as part of each flow transaction. The results of the Scott River basin transactions are presented below.

5.1.1. Patterson Creek

Siskiyou Resource Conservation District (RCD) personnel generally surveyed 13 habitat transects (Figure 1) on each of five days between July 6, 2011 and September 19, 2011 (Table 1). For unspecified reasons, several habitat transects were only surveyed on four dates. Based on streamflow records generated by the Siskiyou RCD, mean daily discharge above the point of diversion ranged from 30.3 ft^3/s on July 6 to 1.0 ft^3/s on September 19. Mean daily discharge for each habitat transect measurement date is presented in Table 1. Flow measured at Stream gage #1 was used to develop habitat rating curves for transect A, as this transect was located above the fish bypass (Figure 1). Discharge data from Stream gage #2 (ranging from 18.3 ft^3/s on July 6 to 1.1 ft^3/s on September 19) represent flow remaining in Patterson Creek after water was diverted, and thus were used to develop habitat rating curves for transects B through K.

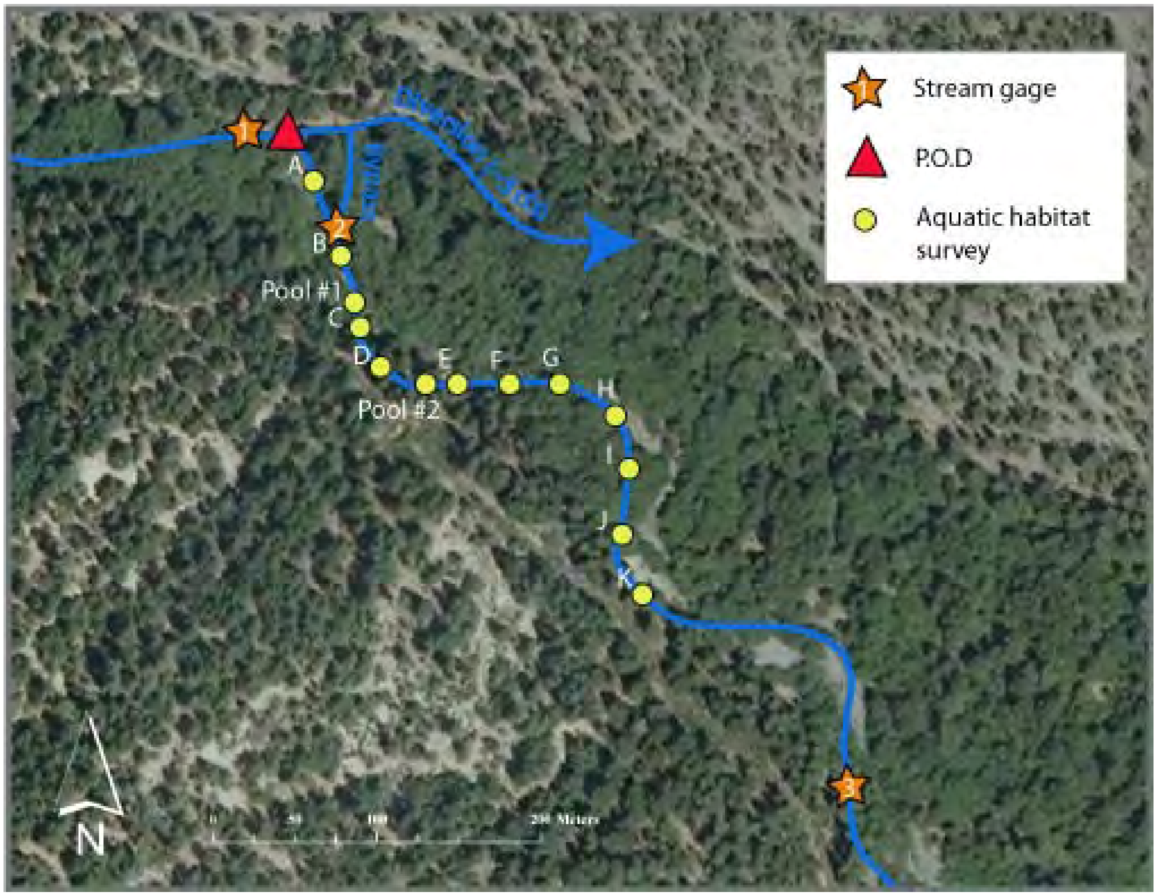

Figure 1. Patterson Creek aquatic habitat transect, stream gage and P.O.D. locations. Flow direction is generally to the southeast.

Table 1. Mean daily discharge on Patterson Creek aquatic habitat transect survey dates.

	Mean daily discharge (ft^3/s)		
Transect survey date	**Stream gage #1**	**Stream gage #2**	**Stream gage #3**
7/6/2011	30.3	18.3	17.7
7/11/2011	17.6	13.9	14.2
7/27/2011	5.9	5.4	5.7
8/24/2011	1.8	1.7	1.3
9/19/2011	1.0	1.1	0.1

5.1.1.1. Habitat Rating Curves

Rating curves relating flow for all five hydraulic variables (see Section 4) were developed from each habitat transect surveyed along Patterson Creek. Based on field reconnaissance (June 26, 2011), habitat transects were surveyed across many different geomorphic channel features (i.e., physical habitat types), including riffles, pools, mid-channel bars and islands. Based on conversations with the Siskiyou RCD, quantifying changes to aquatic habitat conditions associated with changing streamflows across riffles and pools was of primary concern based on ecological objectives. As such, only rating curves representative of a riffle habitat (transect "I") (Figure 2-Figure 6) and pool habitat (Pool #2) are presented (Figure 7-Figure 11).

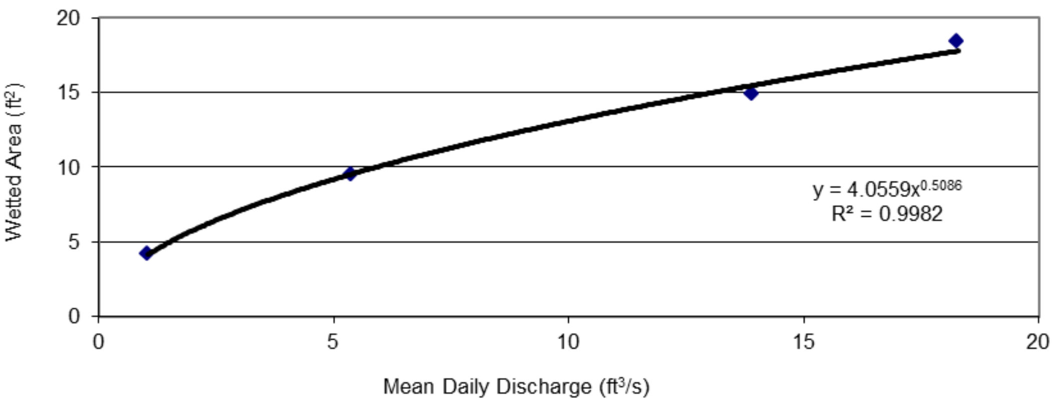

Figure 2. Aquatic habitat transect "I" wetted area – mean daily discharge rating curve.

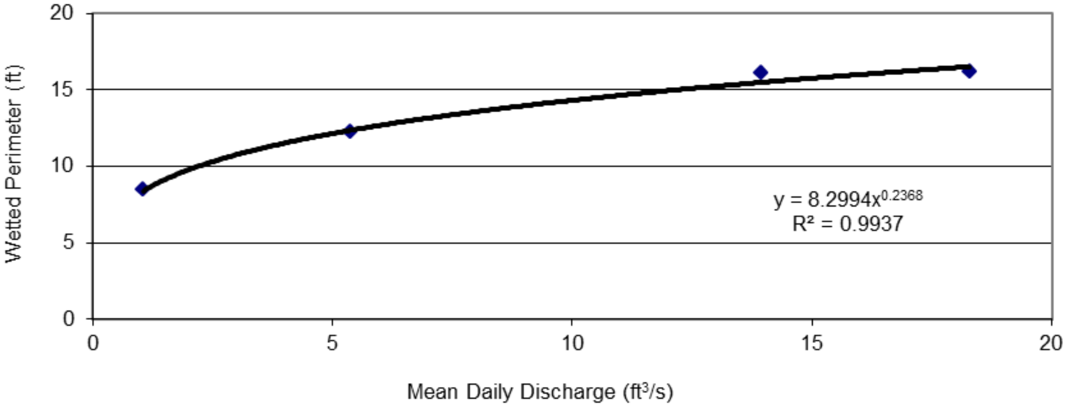

Figure 3. Aquatic habitat transect "I" wetted perimeter – mean daily discharge rating curve.

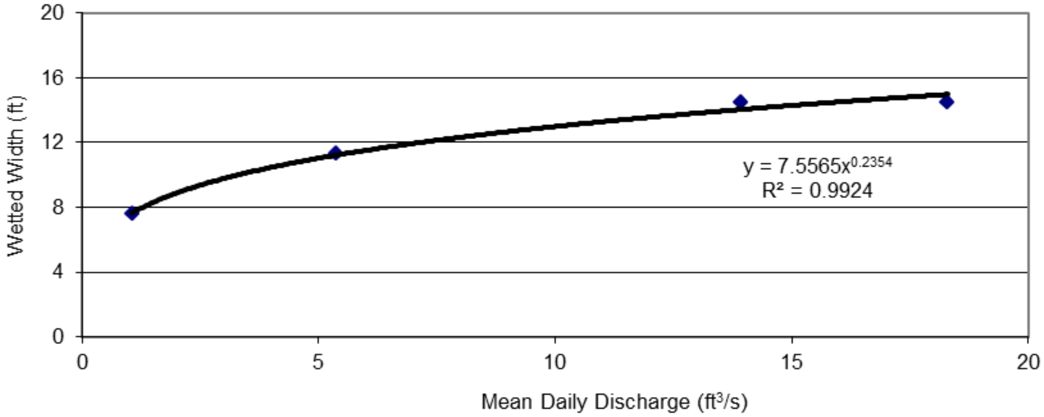

Figure 4. Aquatic habitat transect "I" wetted width – mean daily discharge rating curve.

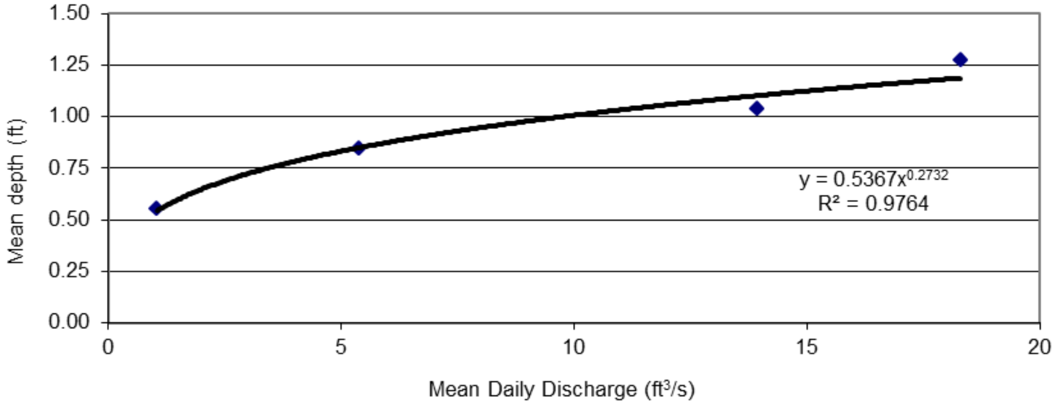

Figure 5. Aquatic habitat transect "I" mean depth – mean daily discharge rating curve.

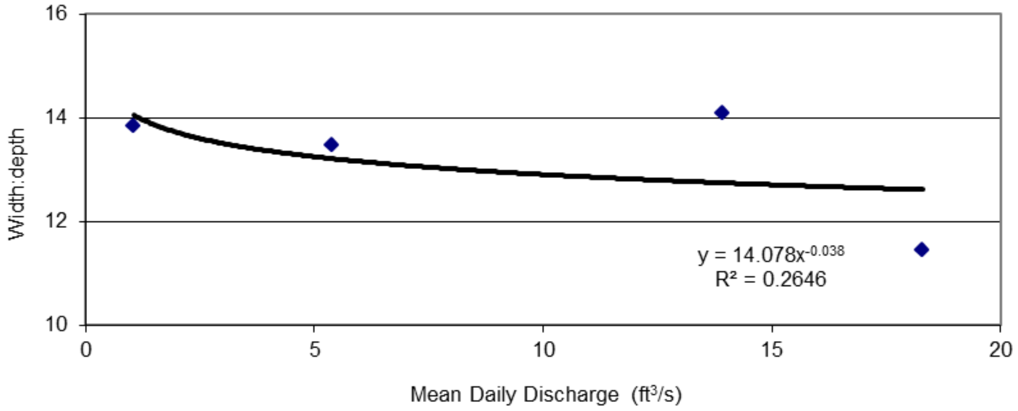

Figure 6. Aquatic habitat transect "I" width:depth – mean daily discharge rating curve.

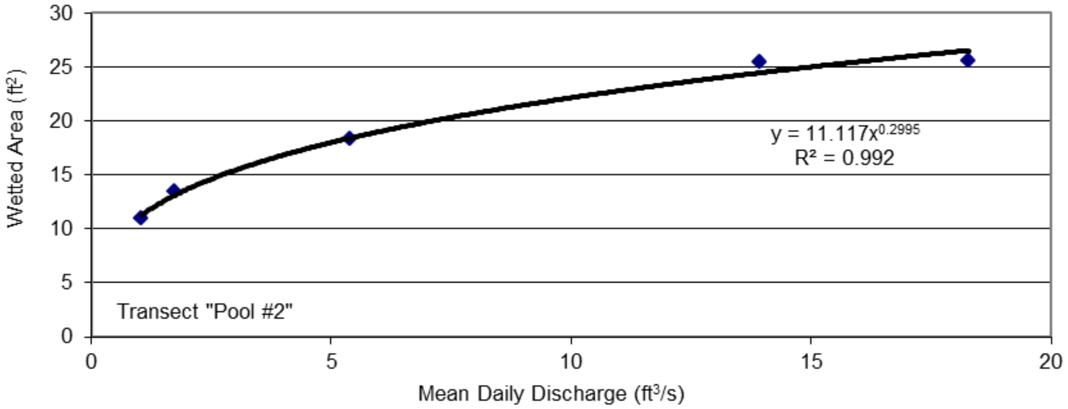

Figure 7. Aquatic habitat transect "Pool #2" wetted area – mean daily discharge rating curve.

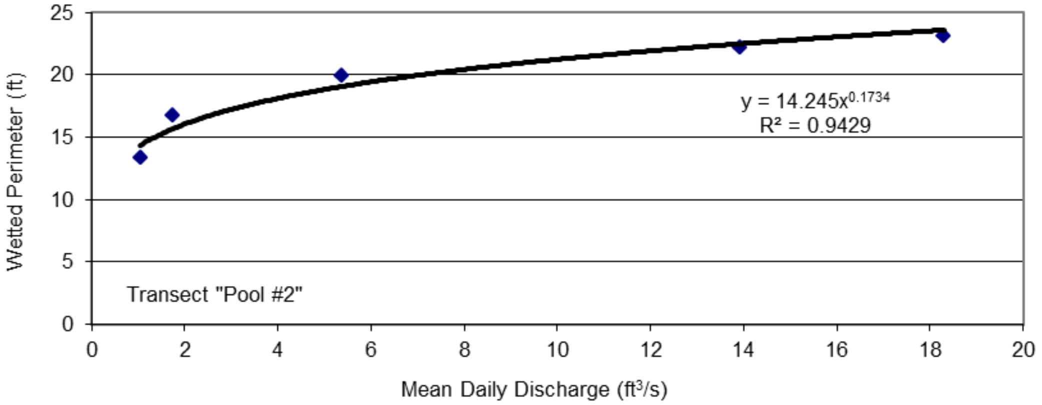

Figure 8. Aquatic habitat transect "Pool #2" wetted perimeter – mean daily discharge rating curve.

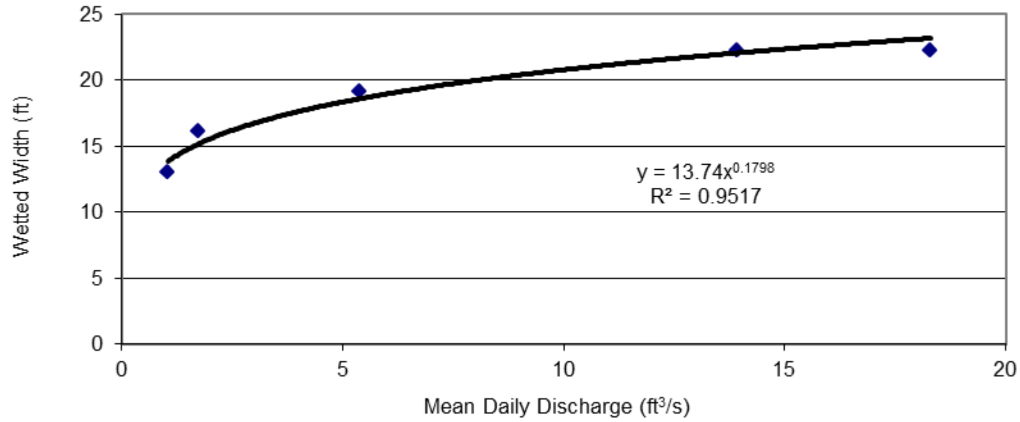

Figure 9. Aquatic habitat transect "Pool #2" wetted width – mean daily discharge rating curve.

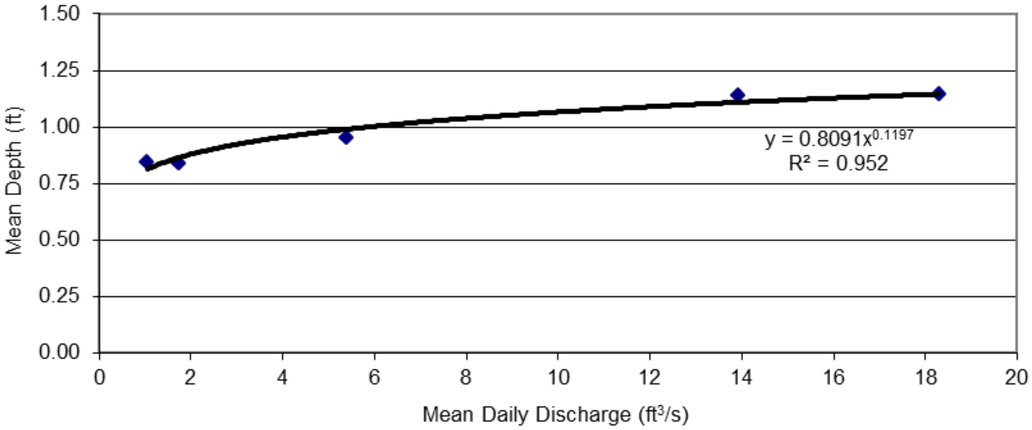

Figure 10. Aquatic habitat transect "Pool #2" mean depth – mean daily discharge rating curve.

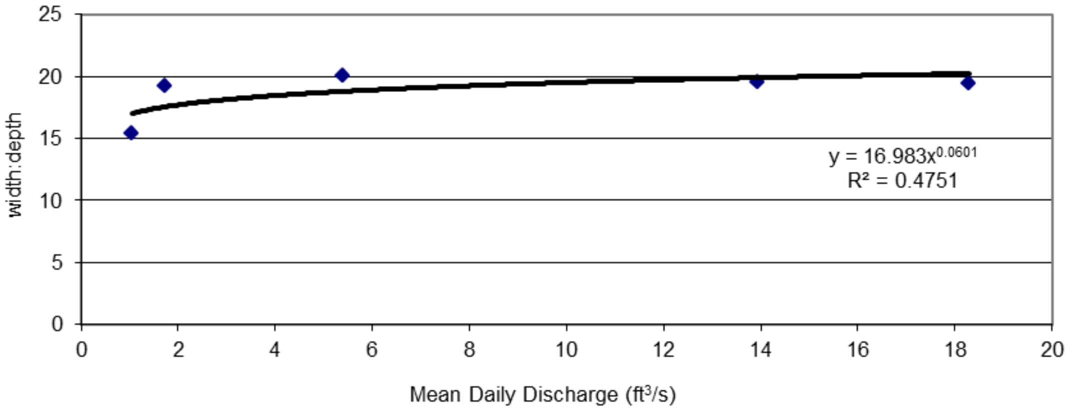

Figure 11. Aquatic habitat transect "Pool #2" width:depth – mean daily discharge rating curve.

Coefficients of determination (R^2) derived from power law functions fit to discharge-habitat relationships (Figure 2-Figure 5, Figure 7-Figure 10) suggest that aquatic habitat monitoring methodologies were sufficient to develop robust habitat rating curves for the following hydraulic parameters in pools and riffles in Patterson Creek: wetted area, wetted perimeter, wetted width and mean depth. The predictive power of width:depth – discharge rating curves was generally poor (Figure 6 and Figure 11), reflecting complex changes in this habitat variable with discharge in Patterson Creek. Many factors may have led to the poor quantification of W:D ratio, including complex channel cross-section morphologies and potential difficulty identifying channel edges due to cobble substrates. Further, measurement errors can be compounded when calculating W:D ratios from multiple other habitat metrics (i.e. wetted width and mean depth). Ultimately, W:D ratio may not be an appropriate habitat metric to use in evaluating habitat changes associated with flow transactions in Patterson Creek. Generally, habitat rating curves were less reliable at habitat transects exhibiting complex channel forms (e.g. mid-channel bars).

Previously, the Siskiyou RCD (Yokel, 2008 ; Yokel, 2009) developed discharge-pool volume and discharge-glide volume rating curves for pool and glide habitats identified in Patterson Creek. These metrics can be used to quantify the benefit of a flow transactions conducted specifically to increase the volume of pool and glide habitats. However, the draft field protocols (Holmes et al., 2011) developed for the 2011 field season were not intended to address such focused habitat objectives, but rather to evaluate whether the monitoring protocols were sufficient to develop discharge-habitat relationships for a range of habitat types across the range of flows observed during the Patterson Creek transaction. Furthermore, habitat transects were surveyed across two pool habitats (Pool #1 and Pool #2) specifically targeted by the Siskiyou RCD. However, quantifying the relative merits of using pool volume versus wetted area, wetted perimeter or mean depth in these two pool habitats is beyond the scope of this monitoring effort (i.e., no pool volume data was collected). If such an evaluation is desired, future monitoring efforts could develop and compare pool volume-discharge relationships to wetted area/wetted perimeter/mean depth-discharge relationships developed from a single transect across each pool monitored.

5.1.1.2. Habitat Changes Associated with Flow Transaction

Rating curves developed for habitat transects surveyed in Patterson Creek allow for quantitative predictions of habitat changes associated with changes in streamflow. These rating curves can be used to quantitatively evaluate changes in habitat variables associated with leased water over the range of flows observed during the transaction period. During the 2011 Patterson Creek flow transaction, the amount of water available for diversion declined until baseflow (~0.2 ft^3/s) was reached in the late summer. Consequently, quantities of water leased for in-stream dedication varied between 5.0 ft^3/s at the start of the transaction on July 7, 2011 (when the ditch headgate was closed) and 0.2 ft^3/s by late August (Yokel, 2012).

A conceptual evaluation of habitat changes associated with a 5 ft^3/s in-stream dedication is presented below. This conceptual evaluation assumes that in the absence of an instream dedication (i.e., transaction), up to the full quantity of the water right would be diverted. For example, if measured flows at the P.O.D. were 10 ft^3/s, then 5 ft^3/s would be diverted and 5 ft^3/s would remain instream. Likewise, if measured flow at the P.O.D. were 3 ft^3/s, then 3ft^3/s would be diverted and 0 ft^3/s would remain instream (i.e., the stream would be left "dry"). This oversimplifies the complexities of existing irrigation infrastructure capabilities and downstream water rights considerations. However, such simplification is needed to quantitatively compare aquatic habitat conditions observed during the flow transaction to hypothetical habitat conditions resulting from the potential diversion of the leased water right. A more refined record of the undiverted flow (i.e., daily average potential diversion volume) could improve understanding of the effect of the transaction.

Figure 12 through Figure 15 illustrate the percentage increase of wetted area (Figure 12 and Figure 13) and wetted perimeter (Figure 14 and Figure 15) associated with a 5 ft^3/s increase to base flows. Here, "base flows" are considered the hypothetical flow volume remaining below the P.O.D. if the entire 5 ft^3/s were diverted. Under this conceptual scenario, a "base flow" of 5 ft^3/s indicates flows above the P.O.D. are 10 ft^3/s, but only 5 ft^3/s remains instream below the P.O.D. following diversion. This conceptual exercise does not attempt to quantify aquatic habitat changes when measured flows above the P.O.D. are less than 5 ft^3/s. At flows below 5 ft^3/s, the instream dedication prevents the entire streamflow volume from being diverted. And since "zero-flow" aquatic habitat conditions are not known (e.g. pools can retain water even without measured through-flow), the quantified benefit of the dedication would approach infinity Figure 12 and Figure 14 present aquatic habitat change across base flows ranging from 5 ft^3/s to 30 ft^3/s in 5 ft^3/s increments. Percent change in wetted area for the riffle transect ranged from over 40 % for the 5 ft^3/s base flow condition to less than 10 % at the 30 ft^3/s base flow condition. For a pool transect, benefits ranged from over 20 % to approximately 5 % over the same range of flows. Wetted perimeter increases were less, but showed a similar trend.

Figure 13 and Figure 15 similarly illustrate the percentage increase of wetted area (Figure 13) and wetted perimeter (Figure 15) associated with a 5 ft^3/s increase to base flows over the range of flows observed during the transaction (beginning July 7). In this case, "base flows" of 5 ft^3/s correspond to a measured 10 ft^3/s flow below the P.O.D. during the 2011 transaction minus the hypothetical 5 ft^3/s diversion. For example, mean daily discharge through the protected reach on the first day of the transaction (July 7) was 20.37 ft^3/s. Hypothetical "base" flows on this date would have been 15.37 ft^3/s if 5 ft^3/s were diverted. Consequently, Figure 13 and Figure 15 can be used to evaluate the benefit of the 5 ft^3/s dedication on July 7, and each subsequent day of the transaction period. Similar conceptual analyses can be completed for any quantity of flow leased for in-stream use, which can help identify effective flow transactions.

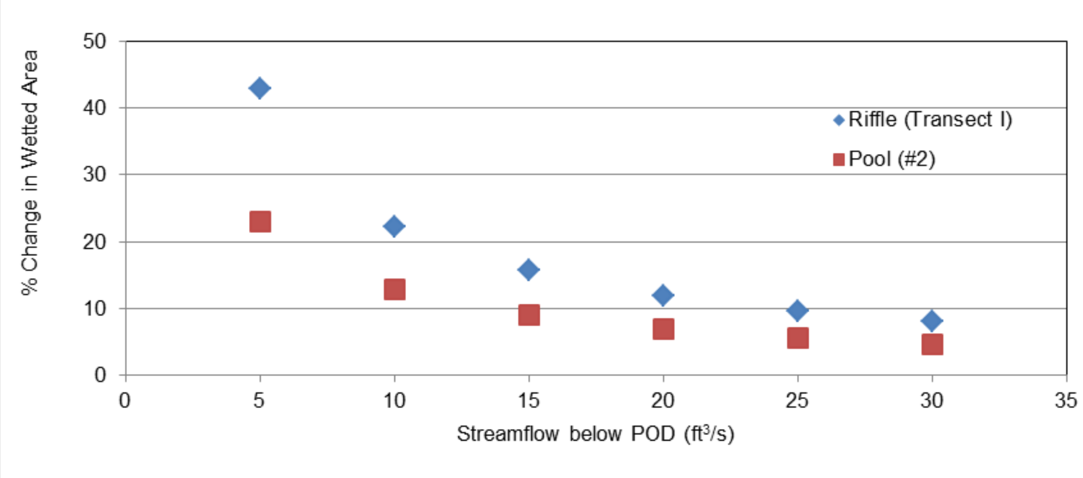

Figure 12. Percent increase in wetted area associated with a 5 ft^3/s increase in flow for base flows of 5 ft^3/s to 30 ft^3/s in 5 ft^3/s increments (x-axis)

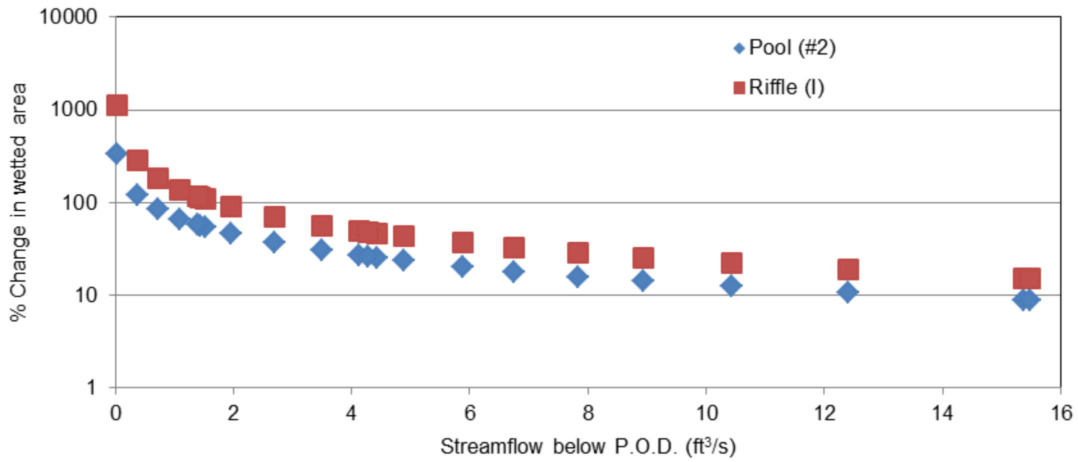

Figure 13. Percent increase in wetted area associated with a 5 ft^3/s increase in flow for base flows of 0.04 ft^3/s to 15.4 ft^3/s. Base flows represent the range of mean daily discharges observed in Patterson Creek from July 7 to July 28 minus 5 ft^3/s. From July 28 to the end of the transaction, flows below the P.O.D. were less than 5 ft^3/s, and thus the flow transaction hypothetically prevented the stream from running dry.

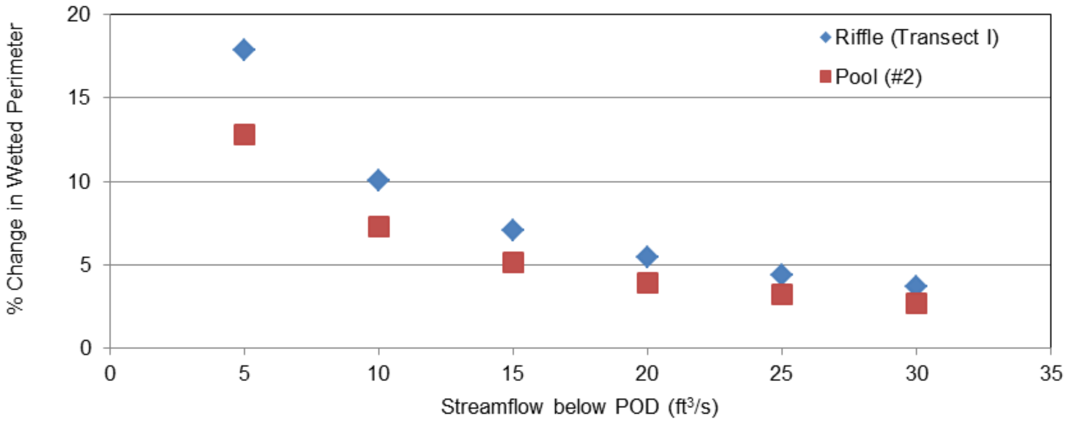

Figure 14. Percent increase in wetted perimeter associated with a 5 ft^3/s increase in flow for base flows of 5 ft^3/s to 30 ft^3/s in 5 ft^3/s increments (x-axis)

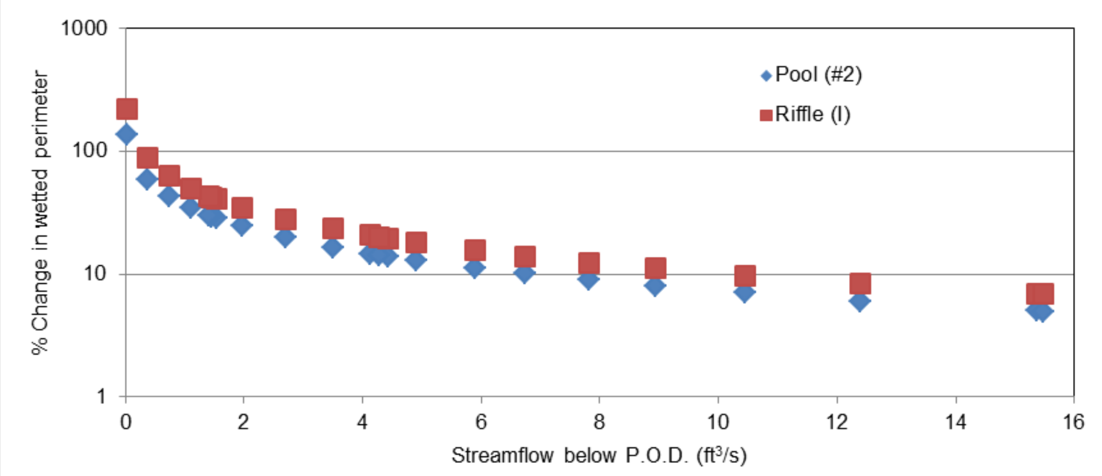

Figure 15. Percent increase in wetted perimeter associated with a 5 ft^3/s increase in flow for base flows of 0.04 ft^3/s to 15.4 ft^3/s. Base flows represent the range of mean daily discharges observed in Patterson Creek from July 7 to July 28 minus 5 ft^3/s. From July 28 to the end of the transaction, flows below the P.O.D. were less than 5 ft^3/s, and thus the flow transaction hypothetically prevented the stream from running dry.

The relative “benefit” of a 5 ft^3/s dedication was non-linear, with increasing benefit as base flows decreased. The relative benefit increased (Figure 13 and Figure 15) as flows above the P.O.D. approached 5 ft^3/s. Below flows of 5 ft^3/s, the entire volume of Patterson Creek could be diverted. At these flow magnitudes, habitat benefits associated with this flow transaction would approach infinity. Furthermore, habitat “benefit” was greater in the riffle habitat (Transect “I”) than in the pool habitat (transect “Pool #2). It has been noted by the SRWT (2012b) that results from Pool #2 may be influenced by accretion/depletion via hyporheic flows through the adjacent floodplain. However, empirically derived exponents for both pool habitats surveyed by the Siskiyou RCD (Pool# 1 and Pool #2) are relatively similar (0.36 and 0.30) suggesting that both responded similarly to changes in flow associated with the transaction. The greater responsiveness of riffle habitats (relative to pool habitats) to flow contributions (particularly at low flow) is well known (Gordon et al., 2004), and is principally a function of relatively complex relationships between channel geometry and flow velocities. Additionally, empirically-derived relationships illustrate that the quantity of habitat benefit associated with an increase in flow across all types of habitat is not proportional to the volume of the flow increase. This is well known hydraulic phenomenon supported by the Manning's equation and illustrated by decades of hydraulic geometry research (beginning with Leopold and Maddock, 1953) that have empirically derived non-linear relationships between hydraulic parameters (e.g. width, depth) and discharge.

5.1.2. Scott River below SVID (2011)

Siskiyou Resource Conservation District (RCD) personnel surveyed seven (7) aquatic habitat transects (Figure 16) on each of four days between October 12, 2011 (3 days before the lease began) and December 4, 2011 (7 days after the lease ended) (Table 2). Habitat transects were specifically located on riffle crests to assess the effect of leased water on adult salmon upstream passage at these locations (due to the location of salmon redds across Transect "B", only two habitat transects were conducted at this location during the transaction period). Due to equipment failure (the method of failure was not provided to Watercourse by the Siskiyou RCD), continuous streamflow records for locations either immediately upstream or downstream from the SVID point of diversion (P.O.D) (Figure 16) were not available (no data from the failed stream gauge was provided to Watercourse). As such, mean daily discharge data provided by the Siskiyou RCD for a stream gage located approximately 3.3 miles downstream from the P.O.D. (identified as Scott River "above Etna" gage) (Yokel, 2012) were used to develop habitat rating curves for each transect. Mean daily discharge in the Scott River "above Etna" during the transaction period ranged from 18.0 to 107.4 ft^3/s (Yokel, 2012). Mean daily discharge measured on each habitat transect measurement date is presented in Table 2. Streamflow records were not provided for the December 4, 2011 measurement date, and thus habitat rating curves were developed from aquatic habitat and streamflow data from only three measurement dates.

To help quantify the immediate effects of the transaction on flow volumes in the Scott River below SVID, Siskiyou RCD personnel measured discharge below the SVID P.O.D. on October 15 following the release of water instream. This measurement quantified flows below the P.O.D. at 50.27 ft^3/s. Further, staff gauge monitoring in the SVID irrigation diversion ditch by the Siskiyou RCD indicate diversion quantities decreased from 17.17 ft^3/s to 4.53 ft^3/s on October 15, thus quantifying the initial dedication at 12.64 ft^3/s. Additional ditch staff spot measurements on October 18, 2011 and November 11, 2011 quantified flow in the irrigation ditch as 5.7 ft^3/s and 1.01 ft^3/s, respectively. These measurements can be used to quantify the volume of water left instream on those dates. However, continuous volumes of water diverted by the SVID during the course of the transaction were not quantified.

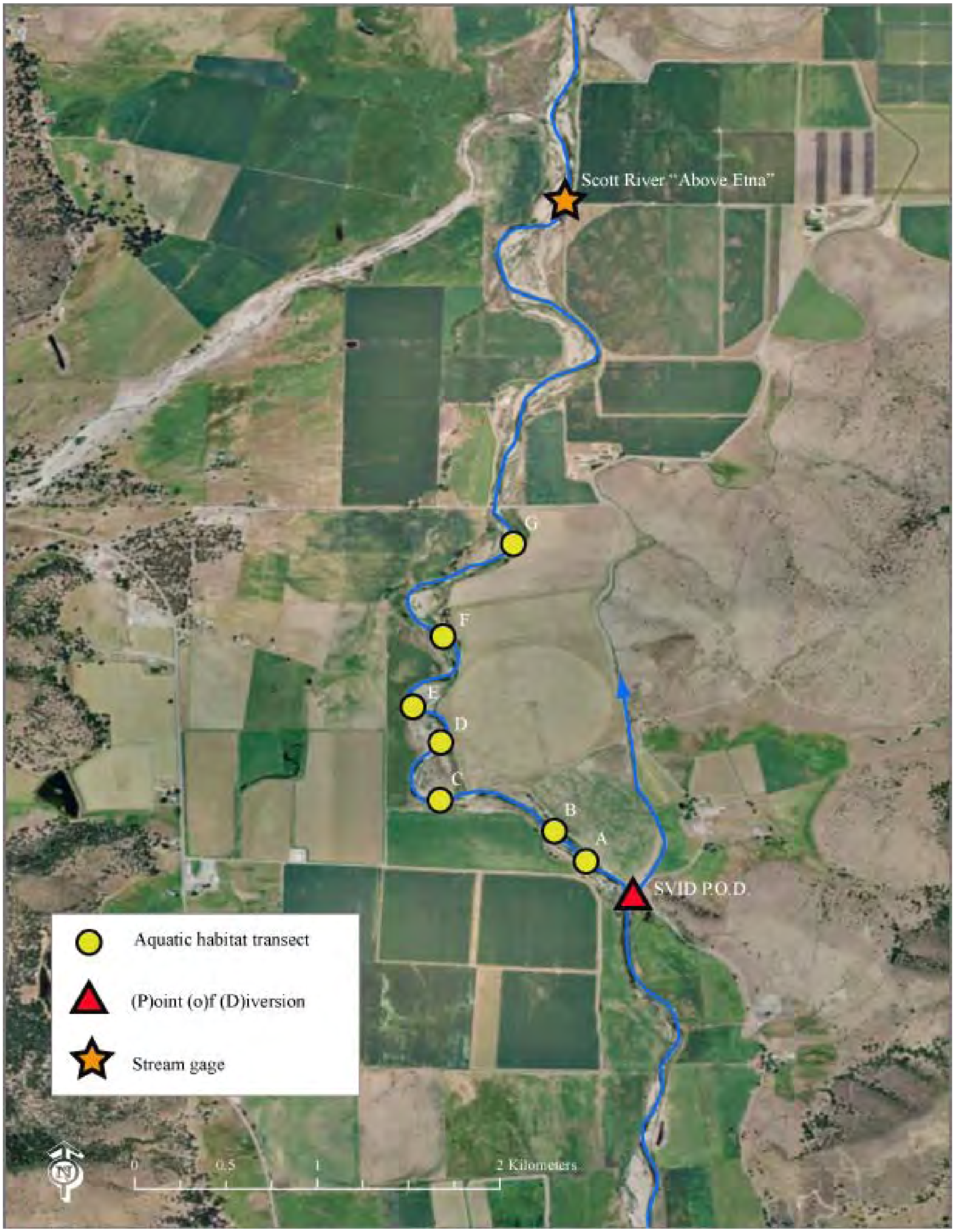

Figure 16. Scott River below Scott Valley Irrigation District (SVID) diversion aquatic habitat transect, stream gauge and P.O.D. locations. Flow direction is generally to the north.

Table 2. Mean daily discharge data on aquatic habitat transect survey dates.

Transect survey date	Mean daily discharge (ft^3/s) in Scott River "above Etna"
10/12/2011	95.2
10/18/2011	50.4
11/11/2011	47.2
12/4/2011	No measurement data

5.1.2.1. Habitat Rating Curves

Rating curves were developed for all five hydraulic variables (see Section 4) calculated from each habitat transect surveyed along the Scott River below SVID. However, due to 1) the small set (i.e., three) of useable habitat-discharge relationships; and 2) inability to measure habitat variables across a sufficient range of flows observed during the transaction (see Table 2; 2 of 3 transect survey dates exhibited streamflows between 47 and 51 ft^3/s), statistical validity of the developed rating curves is uncertain. Habitat-discharge relationships for a representative riffle transect (“transect C”) are provided in Figure 17 through Figure 21.

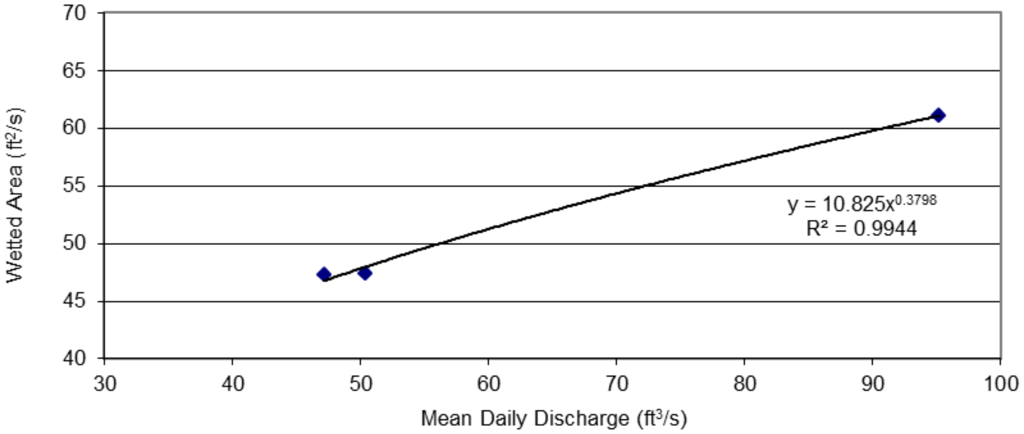

Figure 17. Aquatic habitat transect “C” wetted area – mean daily discharge rating curve.

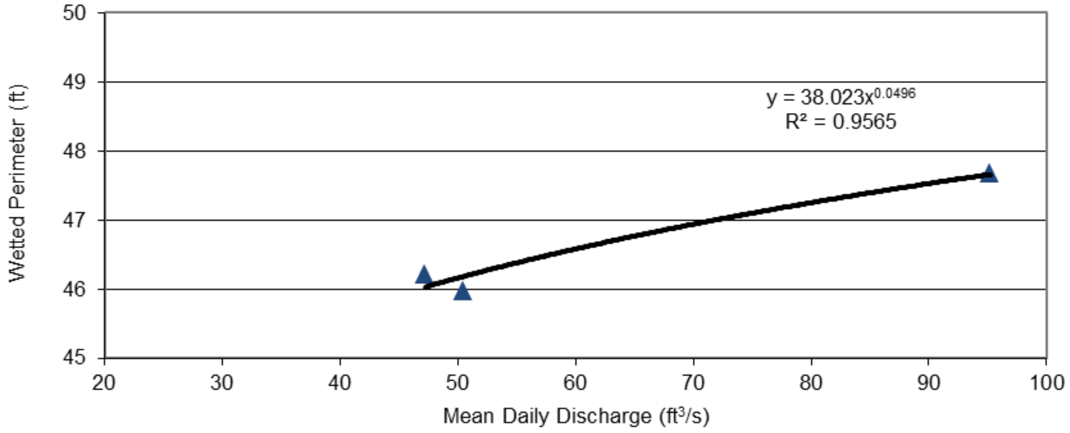

Figure 18. Aquatic habitat transect “C” wetted perimeter – mean daily discharge rating curve.

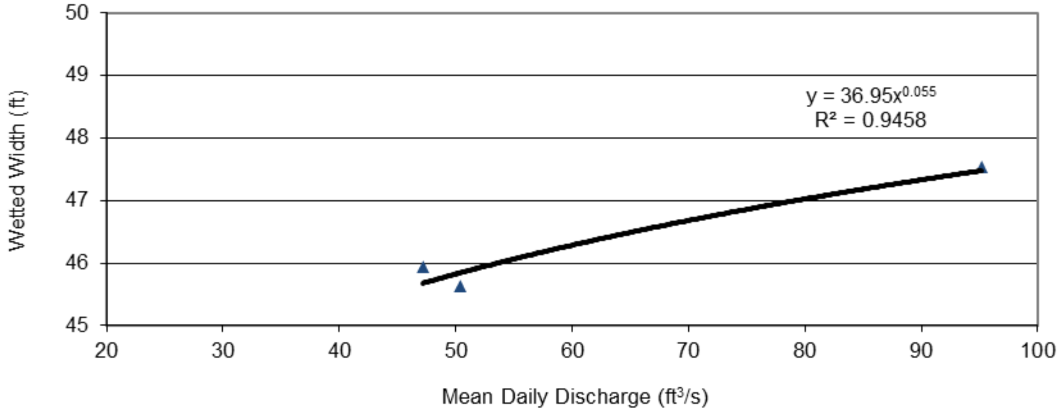

Figure 19. Aquatic habitat transect “C” wetted width – mean daily discharge rating curve.

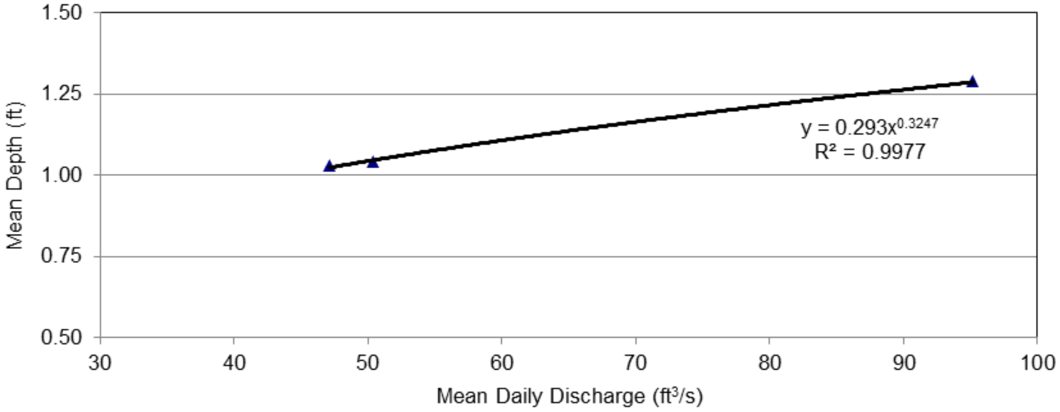

Figure 20. Aquatic habitat transect “C” mean depth – mean daily discharge rating curve.

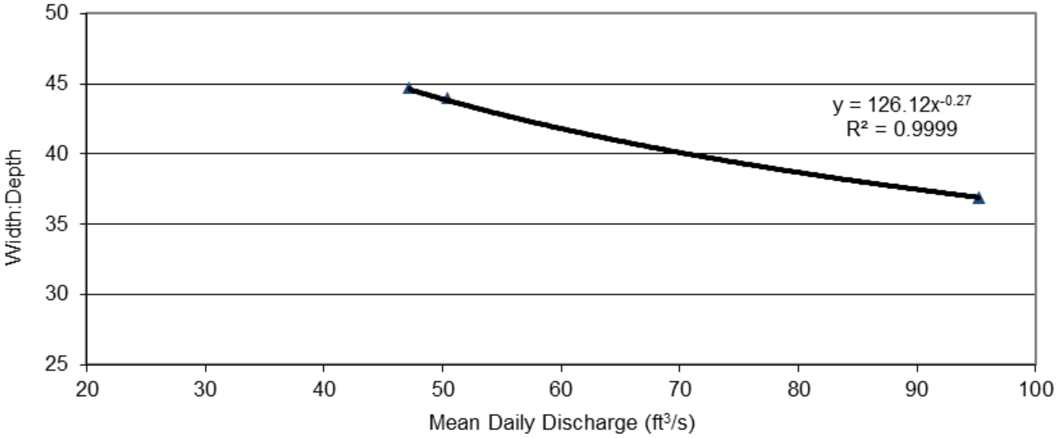

Figure 21. Aquatic habitat transect "C" width:depth – mean daily discharge rating curve.

Coefficients of determination (R^2) derived from power law functions fit to discharge-habitat relationships (see Figure 17 through Figure 20) suggest aquatic habitat monitoring methodologies were sufficient to develop habitat rating curves for wetted area, mean depth, wetted width and wetted perimeter. While the width-depth ratio-discharge relationship at Transect C (Figure 21) was robust, width:depth-discharge relationships were poor for several of the surveyed transects. Habitat-discharge data from a wider range of flows would be needed to test the statistical validity of the power law relationships presented above.

5.1.2.2. Habitat Changes Associated with Flow Transaction:

Hydraulic rating curves developed for habitat transects surveyed in the Scott River can be used to predict habitat changes associated with changes in streamflow. The rating curves can be used to quantitatively evaluate changes in habitat variables associated with leased water over the range of flows observed during the transaction period. During the 2011 Scott River flow transaction, approximately 8 ft^3/s was leased for in-stream use (Yokel, 2012). Initial measurements of water left in stream suggest that the volume of leased water may have approached 13 ft^3/s. However, due to the lack of watermaster service or ditch monitoring by the Siskiyou RCD, the amount of the dedication relative to the amount that could be potentially diverted was not quantified. As such, the established habitat rating curves could not be used to calculate habitat benefits associated with the actual leased water. However, similarly to the Patterson Creek flow transaction, the SRWT provided information regarding the contracted instream dedication flow volume, which was used to analyze the habitat benefits associated with the flow transaction.

In the absence of a continuous data set documenting the quantity of leased water each day over the course of the transaction, we present a conceptual evaluation of habitat changes associated with a seasonally-invariant 8 ft^3/s in-stream dedication. Figure 22 illustrates the percent increases of wetted area and mean depth associated with an 8 ft^3/s increase to flows ranging from 30 ft^3/s to 80 ft^3/s. As expected, the relative "benefit" of the dedication was non-linear: benefit increased as flows decreased. Additionally, habitat benefit associated with an increase in flow was not proportional to the volume of the flow increase, for reasons explained in Section 5.1.1.2 of this report. Conceptual analyses can be completed for any quantity of flow leased for in-stream use (within the range of streamflows used to build the habitat rating curves). Since the primary objective of the flow transaction was upstream adult salmon passage over riffles, Figure 23 provides predictions of the mean depth across a riffle located at transect "C".

Quantifying the "immediate" benefit of the flow transaction (i.e., change in habitat conditions prior to the transaction on October 14 and following the transaction on October 15) is of interest to project partners. However, such a "snap shot" analysis demands that streamflows above the diversion are stable prior to and following the transaction date, allowing pre- and post-transaction habitat measurement to be conducted on dates exhibiting similar streamflows. Hydrologic conditions in the Scott River immediately prior to the initiation of the transaction were not stable. Mean flows measured at the Scott River "above Etna" during the pre-transaction habitat survey date on October 12 were 95.2 ft^3/s, while flows measured during the post-transaction habitat survey date on October 18 were 50.4 ft^3/s. Such hydrologic instability prohibits the generation of a "snap shot" quantification of the habitat benefit of the flow transaction. In such instances, habitat rating curves are needed to quantify aquatic habitat benefits associated with the range of flows observed during the transaction.

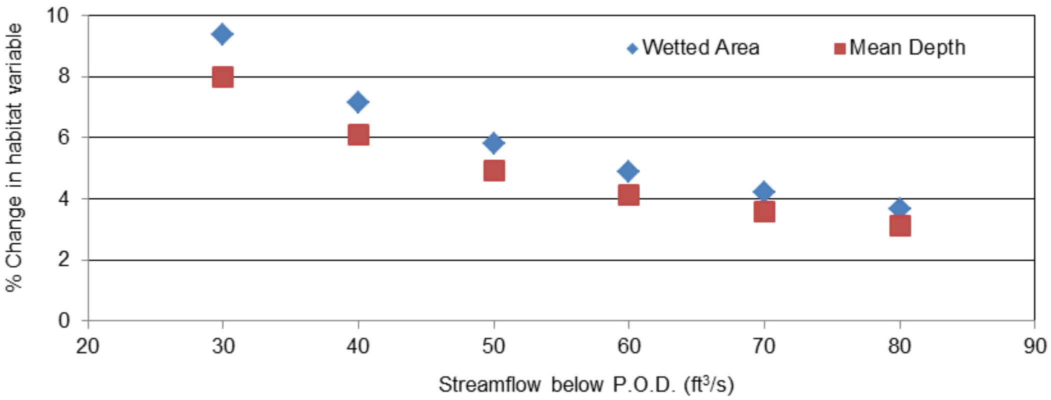

Figure 22. Percent increase in habitat (wetted area and mean depth) at riffle transect (Transect C) associated with an 8 ft^3/s increase in flow for base flows of 30 ft^3/s to 80 ft^3/s in 10 ft^3/s increments (x-axis).

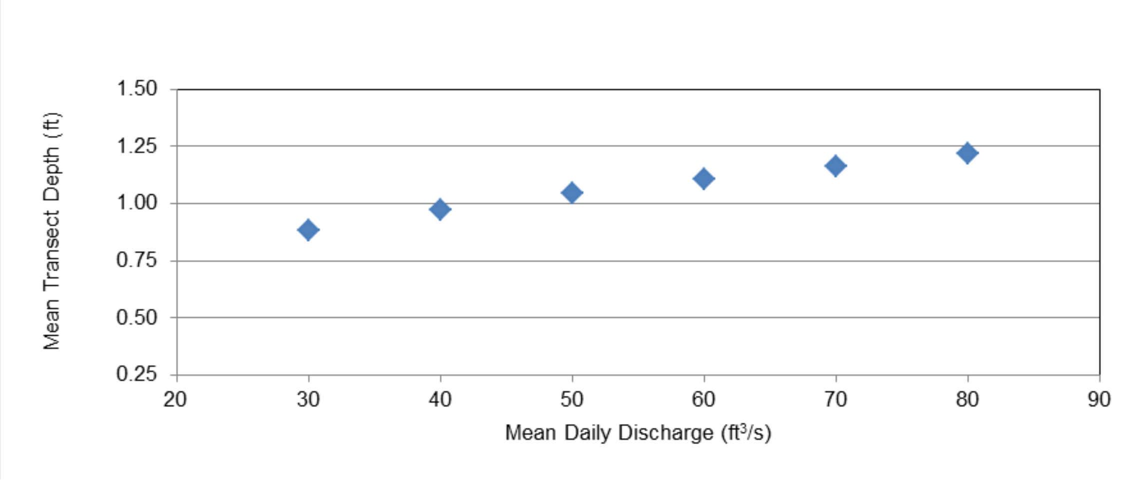

Figure 23. Predicted changes in mean riffle depth at Transect "C" with increased streamflows for base flows of 30 ft^3/s to 80 ft^3/s in 10 ft^3/s increments (x-axis). If known, critical riffle depths could be presented with this data set to help evaluate the benefit of the transaction.

5.1.3. Scott River below SVID (2012)

Scott River Water Trust personnel surveyed five (5) aquatic habitat transects (Figure 24) on each of four days between September 12, 2012 (pre-lease) and November 13, 2012 (post-lease) (Table 3). Similar to the 2011 transaction, habitat transects were specifically located on riffle crests or shallow runs (SRWT, 2012a). Mean daily discharge data from flow gaging station F1 were used to develop habitat rating curves transects A, B and C. Mean daily discharge data from flow gaging station F2 were used to develop habitat rating curves transects D and E. Mean daily discharge in the Scott River at Gage F2 during the transaction period ranged from 5.8 ft^3/s to 49.3 ft^3/s. Mean daily discharge measured on each habitat transect measurement date is presented in Table 2. River stage records were not available for the September 12, 2012 aquatic habitat transect survey date. Consequently, a streamflow measurement performed at gage F2 on that date is used in replacement of a calculated mean daily discharge.

Figure 24. Scott River below Scott Valley Irrigation District (SVID) diversion aquatic habitat transects (A to E) surveyed in 2012, stream gauges (F1 and F2) and P.O.D. locations. Flow direction is generally to the north. Figure provided by Scott River Water Trust.

Table 3. Mean daily discharge data on aquatic habitat transect survey dates.

	Mean daily discharge (ft^3/s) in Scott River	
Transect Survey Date	**Stream gage F1**	**Stream gage F2**
9/12/2012	1.69	NA
10/1/2012	4.38	8.01
10/23/2012	13.63	18.76
11/13/2012	24.56	29.20

5.1.3.1. Habitat Rating Curves

Transaction objectives and 2011 aquatic habitat monitoring results (see Section 5.1.2.1) identified wetted area and mean depth as principal habitat metrics for the Scott River below SVID. As such, rating curves were developed for wetted area and mean depth (see Section 4) calculated from each habitat transect surveyed along the Scott River below SVID. Habitat-discharge relationships for a representative riffle transect ("transect E") are provided in Figure 25 and Figure 26.

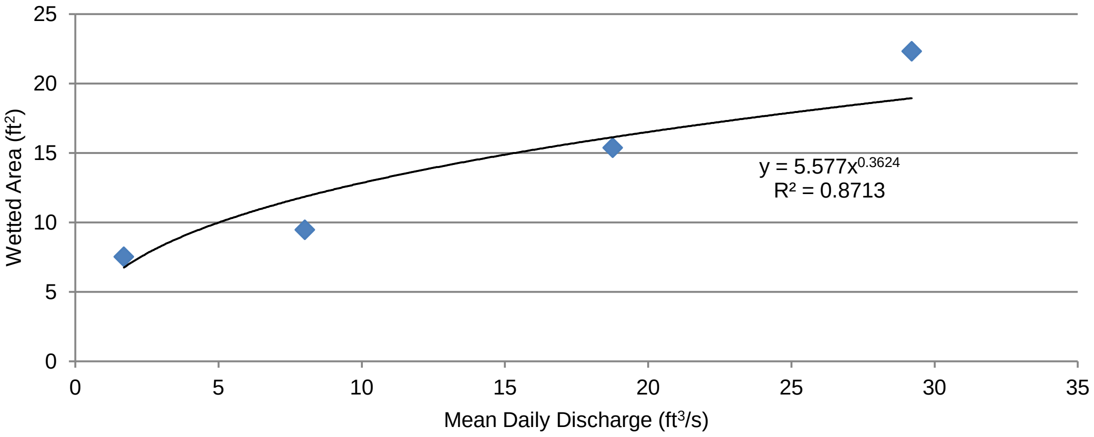

Figure 25. Aquatic habitat transect "E" wetted area – mean daily discharge rating curve.

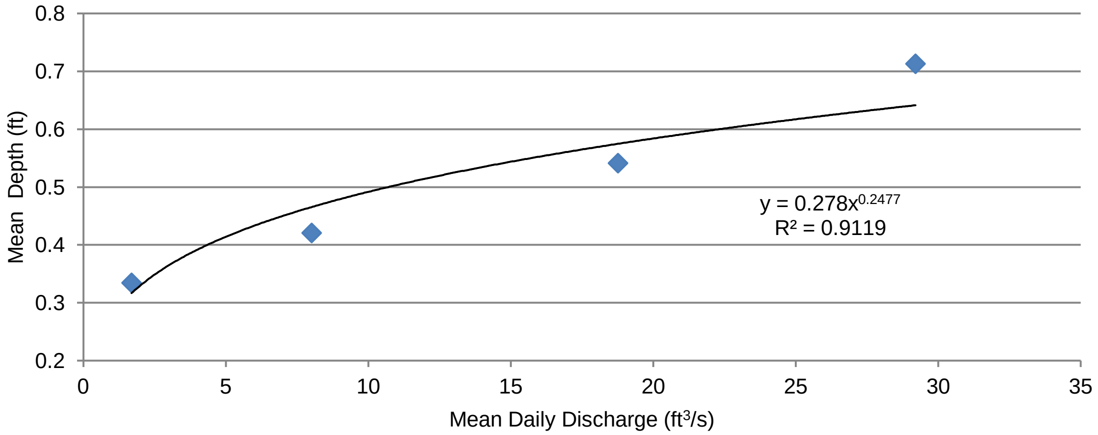

Figure 26. Aquatic habitat transect "E" mean depth – mean daily discharge rating curve.

The morphology of transects surveyed across shallow riffles and runs in the Scott River below SVID were altered by spawning salmon over the course of the 2012 transaction. Generally, spawning activities across three of the five surveyed transects (A, C and D) generated shallower channel depths and smaller cross-sectional wetted areas over the course of the transaction (SRWT, 2012a). Wetted area and mean depth habitat rating curves for Transect A are provided below to demonstrate this effect (Figure 27 and Figure 28). Notice that during a flow of 13.63 ft^3/s on October 23, 2012, wetted area and mean depth at Transect A were 23.8 ft^2 and 0.48 ft, respectively. However, for flows of 24.56 ft^3/s on November 13, 2012, wetted area and mean depth at Transect A were 21.1 ft^2 and 0.41 ft., respectively. Redd construction across this transect between October 23 and November 13, 2012 reduced wetted cross area by approximately 11%, even though mean daily discharge increased by approximately 80%.

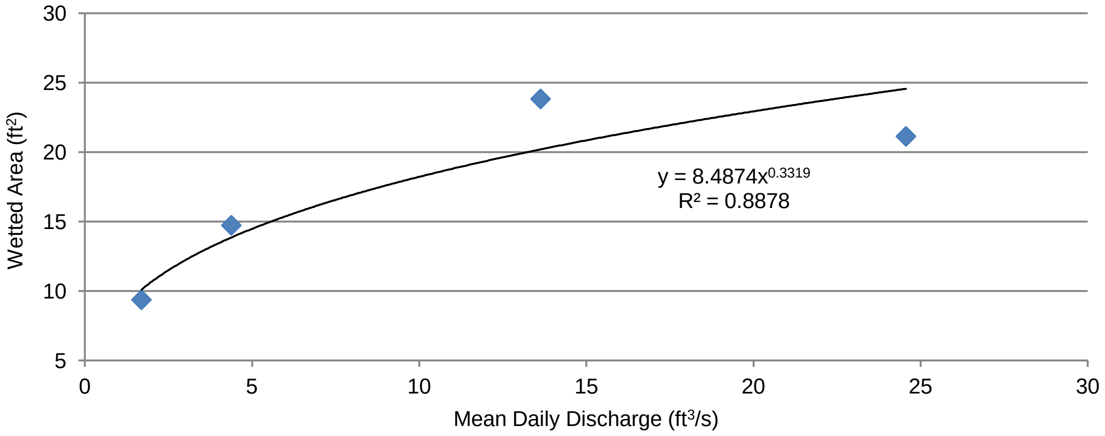

Figure 27. Aquatic habitat transect "A" wetted area – mean daily discharge rating curve.

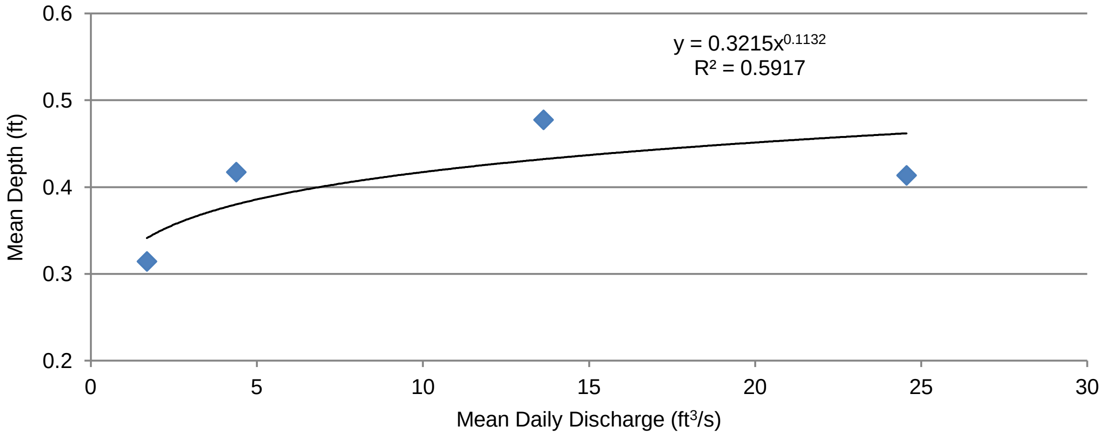

Figure 28. Aquatic habitat transect "E" mean depth – mean daily discharge rating curve.

Coefficients of determination (R^2) derived from power law functions fit to discharge-habitat relationships for transects unaffected by spawning salmon (see Figure 25, Figure 26) suggest aquatic habitat monitoring methodologies continued to be sufficient to develop habitat rating curves for wetted area and mean depth in the Scott River below SVID. Importantly, 2012 habitat-discharge rating curves were successfully generated over a wider range of flows than those observed in 2011, helping confirm the statistical validity of the power law relationships presented for the 2011 and 2012 Scott River transactions. However, habitat-discharge relationships are quite poor for survey transects where the channel bed has been altered over the course of a transaction.

5.1.3.2. Habitat Changes Associated with Flow Transaction:

Hydraulic rating curves were used to quantitatively evaluate changes in habitat variables associated with leased water over the range of flows observed during the transaction period. During the 2012 Scott River flow transaction, up to approximately 12 ft^3/s of water was leased for in-stream use, depending on flow magnitudes in the Scott River above the P.O.D. For flows below 12 ft^3/s, the entire flow of the river was leased. For flows above 12 ft^3/s, the entire 12 ft^3/s SVID water right was leased. Below, we present a conceptual evaluation of habitat changes associated with an in-stream dedication of 12 ft^3/s. Figure 29 illustrates the percentage increases of wetted area and mean depth associated with a 12 ft^3/s increase to hypothetical base flows ranging from 1 ft^3/s to 18 ft^3/s through Transect "E". The relative "benefit" of the dedication was non-linear: benefit increased as flows decreased. Since the a primary objective of the flow transaction was upstream adult salmon passage over riffles, Figure 30 provides predictions of mean depths across the riffle located at transect "E".

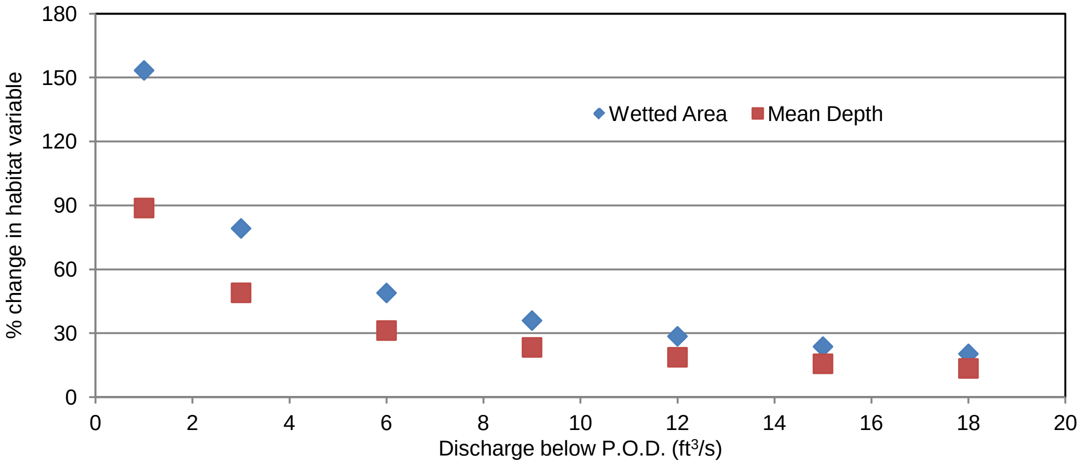

Figure 29. Percent increase in habitat (wetted area and mean depth) at a riffle transect (Transect E) associated with an 12 ft^3/s increase in flow for base flows of 1 to 18 ft^3/s in 3 ft^3/s increments (x-axis).

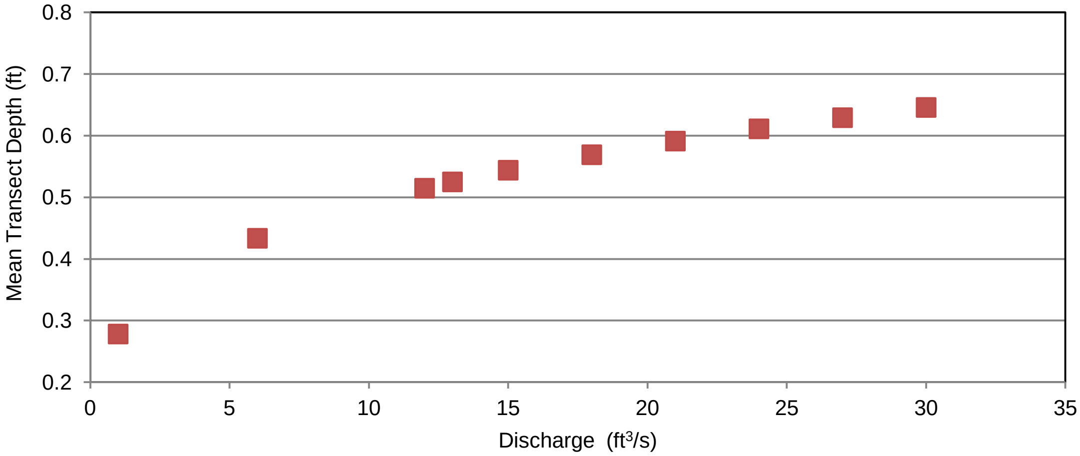

Figure 30. Predicted changes in mean riffle depth at Transect "E" with increased streamflows for base flows of 1 ft^3/s to in varying flow increments (x-axis). If known, critical riffle depths could be presented with this data set to help evaluate the benefit of the transaction.

Streamflow through Transect "E" did not reach 12 ft^3/s until October 16, 2012. Thus for the first 16 days of the transaction, 100% of the flow in Scott River below SVID was water leased for the instream flow dedication. Leaving this flow instream allowed the maintenance of minimum flow depths (see Figure 30). Flow volumes through Transect "E" during this 16-day period ranged from 8.01 ft^3/s to 11.98 ft^3/s, allowing the maintenance of flow depths ranging from 0.47 ft to 0.51 ft. Without leasing water from SVID, flow depths through Transect E could be reduced to less than 0.3 ft (see Figure 30) depending on the quantity of water diverted at the P.O.D.

5.1.4. French Creek (2012)

Scott River Water Trust (SRWT) personnel generally surveyed 11 habitat transects (Figure 31) on each of four days between July 13, 2012 and August 29, 2012 (Table 4). For reasons specified in the transaction field notes (SRWT, 2012a), two habitat transects (transects L and M) were only surveyed on three dates. Continuous streamflow records were generated by the SRWT for two gages (FA and FG). Mean daily discharge at gage FA (immediately below the P.O.D.) ranged from 7.51 ft^3/s on July 13, 2012 to 0.62 ft^3/s on September 23, 2012. Mean daily discharge at gage FG ranged from 5.85 ft^3/s on July 14, 2012 to 0.18 ft^3/s on September 25, 2012. Mean daily discharge for each habitat transect measurement date is presented in Table 1.

Over the course of the transaction period, several unanticipated changes in flow volumes and return locations of diverted water occurred (see SRWT, 2012a) throughout the channel reach monitored for aquatic habitat. For example, following the initial (i.e., pre-transaction) habitat surveys, all of the water diverted at the P.O.D. was returned to French Creek at a location between transects B and C. As such, only aquatic habitat monitoring data from transects A, B and L can be quantitatively related to streamflow measured at gage FA. Flows through transects C, D, E, F1 and F2 do not appear to be accurately quantified by gage FA. Discharge data from gage FG measures flow through transects G, H and M, and thus were used to develop habitat rating curves for these transects. Due to the development of multiple channels, potential flow losses through alluvial features, and vegetation growth immediately upstream from gage FG, this gage cannot be used to develop habitat rating curves for transects C, D, E, F1 and F2. However, the complications that resulted from these channel changes illustrated the value of surveying 11 cross-sections, as the analysis could still be completed using data collected for the remaining aquatic habitat monitoring sites. Herein, only habitat rating curves from transects A, B, L, G, H and M will be discussed.

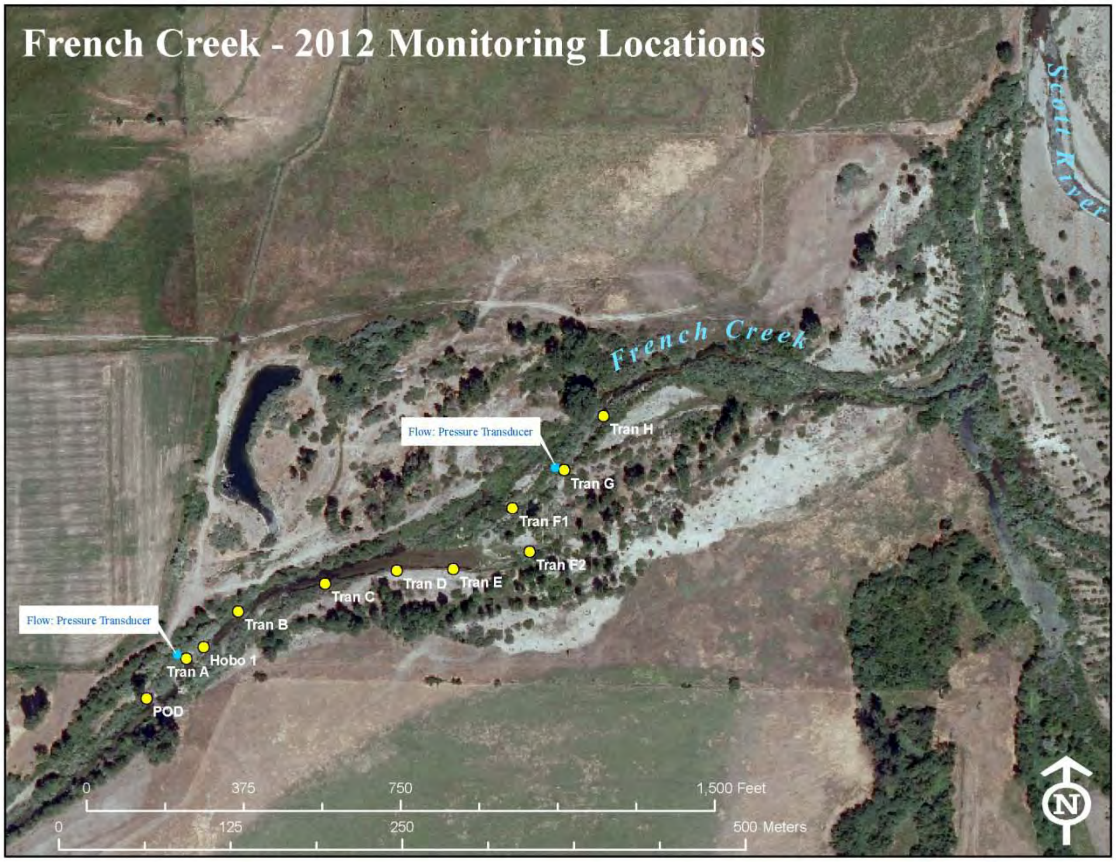

Figure 31. French Creek aquatic habitat transects (A to M) surveyed in 2012, stream gauges (FA and FG) and P.O.D. locations. Flow direction is generally to the east. While not identified on map, Transect L is located between the P.O.D. and Transect A, while Transect M is located approximately 100m downstream from Transect H. Figure provided by Scott River Water Trust.

Table 4. Mean daily discharge data on aquatic habitat transect survey dates.

	Mean daily discharge (ft^3/s) in French Creek	
Transect Survey Date	**Stream gage FA**	**Stream gage FG**
7/13/2012	7.51	4.47
7/18/2012	5.64	4.15
8/1/2012	2.62	0.89
8/29/2012	1.19	0.34

5.1.4.1. Habitat Rating Curves

Rating curves relating flow with all five hydraulic variables (see Section 4) were developed from each habitat transect surveyed along French Creek. Based on available photographs, habitat transects were surveyed across many different geomorphic channel features (i.e., physical habitat types), including riffles, runs, pools, bars and islands. Herein, rating curves for a representative riffle/run habitat (transect “A”) are presented (Figure 32 through Figure 36).

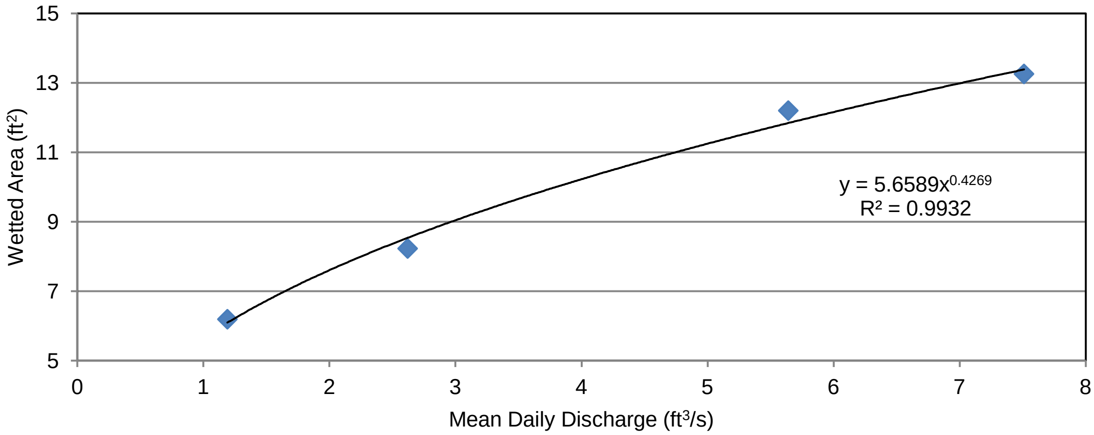

Figure 32. Aquatic habitat transect "A" wetted area – mean daily discharge rating curve.

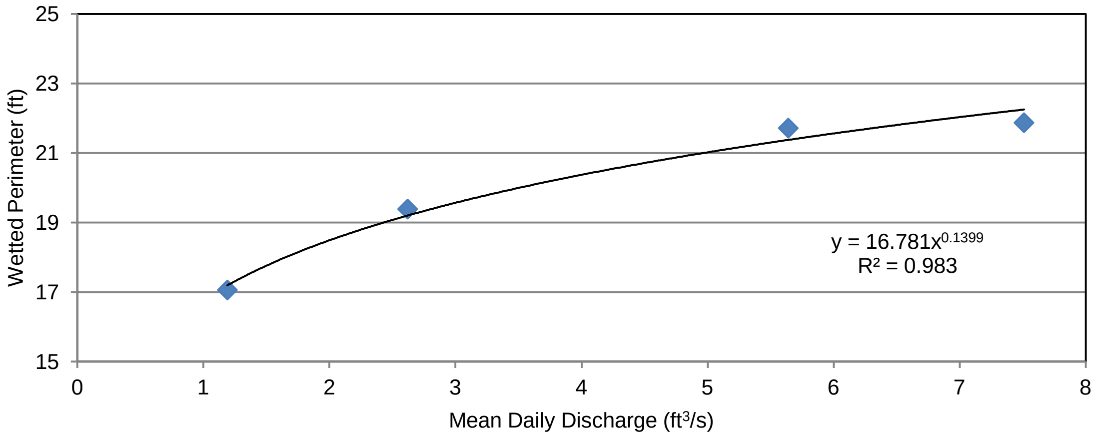

Figure 33. Aquatic habitat transect "A" wetted perimeter – mean daily discharge rating curve.

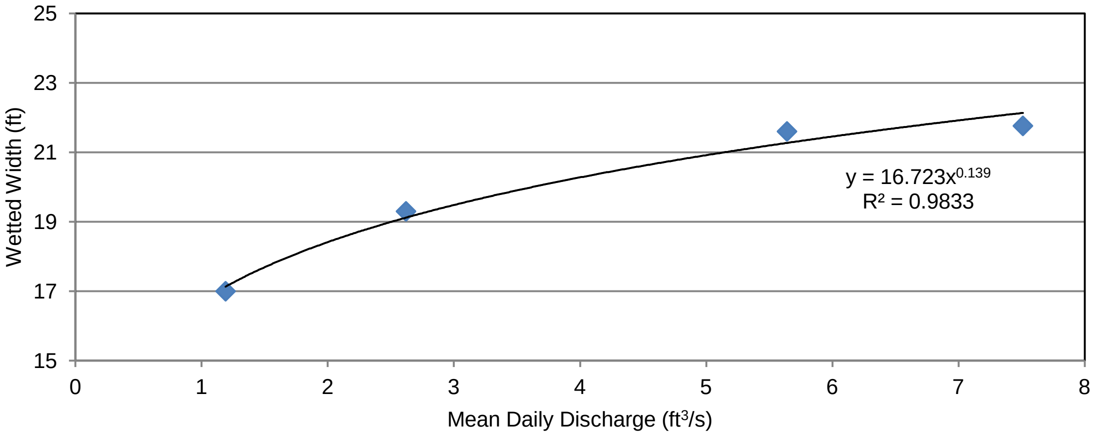

Figure 34. Aquatic habitat transect "A" wetted width – mean daily discharge rating curve.

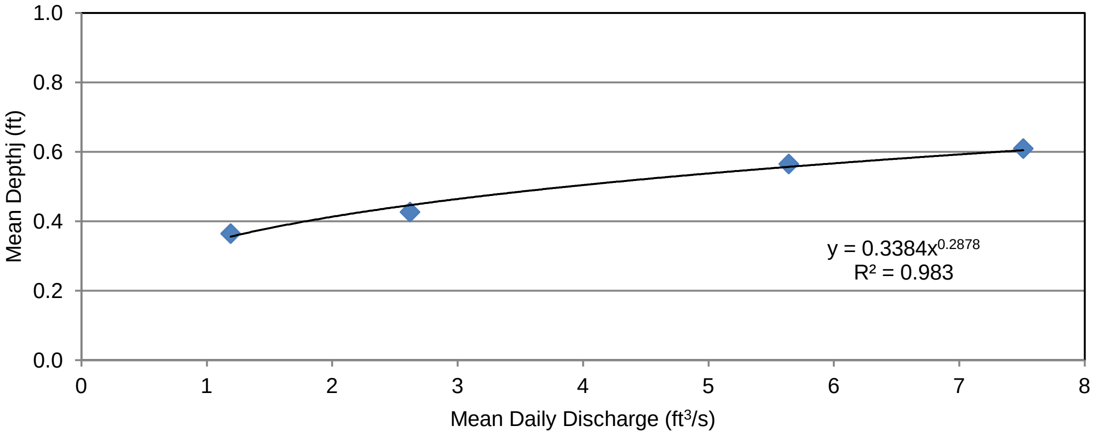

Figure 35. Aquatic habitat transect "A" mean depth – mean daily discharge rating curve.

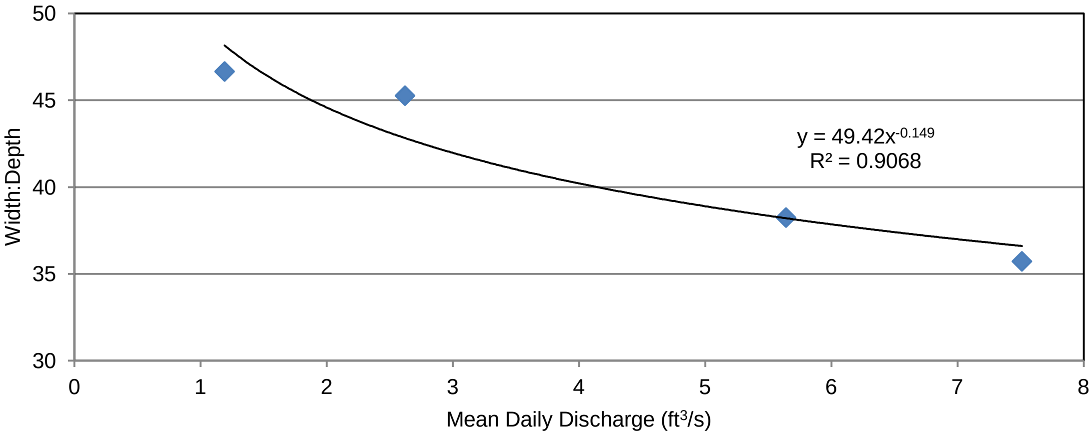

Figure 36. Aquatic habitat transect "A" width-depth – mean daily discharge rating curve.

Coefficients of determination (R^2) derived from power law functions fit to discharge-habitat relationships (e.g. Figure 32 through Figure 36) suggest aquatic habitat monitoring methodologies were sufficient to develop robust habitat rating curves for all five hydraulic parameters in French Creek: wetted area, wetted perimeter, wetted width and mean depth. Similarly robust coefficients of determination were derived for French Creek pool habitats (e.g. Transect M). Interestingly, habitat-discharge relationships were not able to be developed for transects C, D, E, F1, and F2. This is likely due to a combination of poor quantification of flow through these transects (losing reach and changing inflows due to water management) and instream vegetation growth over the course of the transaction (SRWT, 2012a).

5.1.4.2. Habitat Changes Associated with Flow Transaction:

Rating curves developed for selected habitat transects surveyed in French Creek were used to quantitatively evaluate changes in habitat variables associated with leasing 0.76 ft^3/s over the range of flows observed during the transaction period. During the 2012 transaction period, late summer baseflows (minimum if 0.62 ft^3/s) were rarely less than the transacted flow volume. As such, the quantities of water leased for in-stream dedication remained relatively constant, varying only between 0.62 ft^3/s and 0.76 ft^3/s.

Herein, we present a conceptual evaluation of habitat changes associated with the 0.76 ft^3/s transaction. This conceptual evaluation assumes that in the absence of an instream dedication (i.e., transaction), up to the full quantity of the water right would be diverted. For example, if measured flows at the P.O.D. were 10 ft^3/s, then 0.76 ft^3/s would be diverted and 9.24 ft^3/s would remain instream. Likewise, if measured flows at the P.O.D. were 0.62 ft^3/s, then 0.62 ft^3/s would be diverted and 0 ft^3/s would remain instream (i.e., the stream would be left "dry"). This simplification is needed to quantitatively compare aquatic habitat conditions observed during the flow transaction to hypothetical habitat conditions resulting from the potential diversion of the leased water right.

Figure 37 illustrates the percentage increase of wetted area associated with a 0.76 ft^3/s increase to base flows through aquatic habitat transect "A". Here, "base flows" are considered the hypothetical flow volume remaining below the P.O.D. if the entire 0.76

ft^3/s were diverted. Under this conceptual scenario, a “base flow” of 5 ft^3/s indicates flows above the P.O.D. are 5.76 ft^3/s, but only 5 ft^3/s remains instream below the P.O.D. following diversion. This conceptual exercise does not attempt to quantify aquatic habitat changes when measured flows above the P.O.D. are less than 1 ft^3/s due to unknown “zero-flow” conditions. Percent change in wetted area following 0.76 ft^3/s addition of flow through transect “A” ranged from over 28 % for the 1 ft^3/s base flow condition to less than 5 % at the 8 ft^3/s base flow condition.

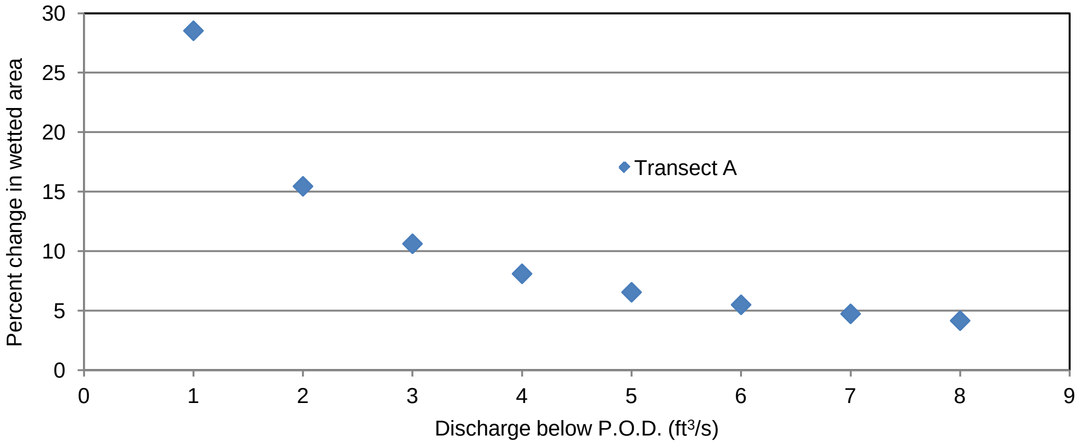

Figure 37. Predicted changes in wetted area at Transect “A” with increased streamflows for base flows of 1 ft^3/s to 8 ft^3/s in 1 ft^3/s increments (x-axis).

5.2. Sevenmile Basin

A multi-month transaction was initiated by the Klamath Basin Rangeland Trust (KBRT) in Sevenmile Creek below Blue Springs. Aquatic habitat data provided by KBRT, via Graham Matthews & Associates (GMA), allowed for the development of aquatic habitat rating curves and conceptual analyses of habitat changes in Sevenmile Creek associated with water leased as part of each flow transaction. The results from the Sevenmile Creek transaction are present below.

5.2.1. Sevenmile Creek

Graham Matthews & Associates (GMA) personnel surveyed 12 habitat transects (Figure 38) during four multi-day measurement periods between August 4, 2011 and November 1, 2011 (Table 5). Streamflow was continuously monitored by GMA during the period of the transaction at a location immediately upstream from XS 1 in Figure 38. Based on these streamflow records, mean daily discharge through the protected reach ranged from 46.7 ft^3/s on June 23, 2011 to 6.08 ft^3/s on August 11, 2011. The range of mean daily discharge for each habitat transect measurement period is presented in Table 5. This flow record was used to develop habitat rating curves for each surveyed transect. Additional streamflow monitoring locations were not maintained my GMA, thus neither the transacted volume of water or potential flow gains/losses through the protected reach were quantified.

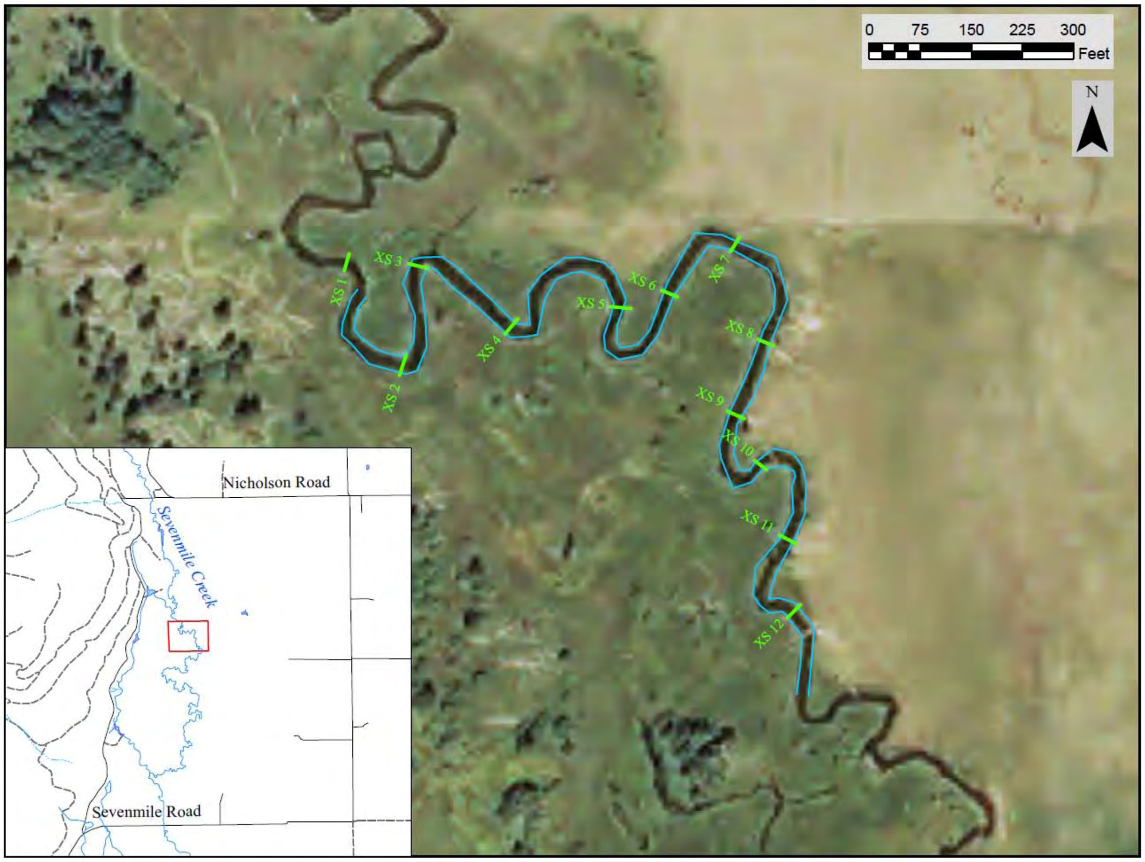

Figure 38. Sevenmile Creek below Blue Springs aquatic habitat transect locations (XS1 = XSA; XS3 = XSC). Flow direction is to the southeast. Figure provided by GMA (2012).

Table 5. Mean daily discharge data on aquatic habitat survey dates

Transect survey date(s)	Mean daily discharge (ft^3/s) in Sevenmile Creek
8/3/2011 - 8/5/2011	15.3 - 15.4
8/11/2011 - 8/12/2011	6.08 - 6.19
8/24/2011 - 8/26/2011	23.7 - 23.9
10/31/2011 - 11/2/2011	34 - 34.8

5.2.1.1. Habitat Rating Curves

Rating curves were developed for all five hydraulic variables (see Section 4) calculated from each habitat transect surveyed along Sevenmile Creek. Using available data, wetted area-discharge, mean depth-discharge and wetted perimeter-discharge relationships proved to be the most robust across all transects (Figure 39 through Figure 42). W:D-discharge relationships varied in predictive capacity, while wetted width-discharge relationships were generally poor (Figure 43). Rating curves developed for a representative survey transect (“C”) (this transect is identified as XS 3 in Figure 38) are provided in Figure 39 through Figure 43.

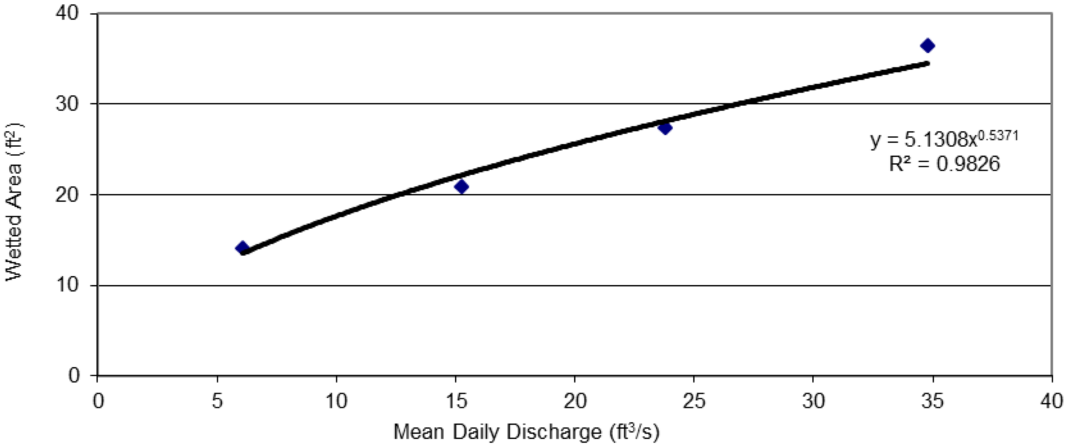

Figure 39. Aquatic habitat transect "C" wetted area – mean daily discharge rating curve.

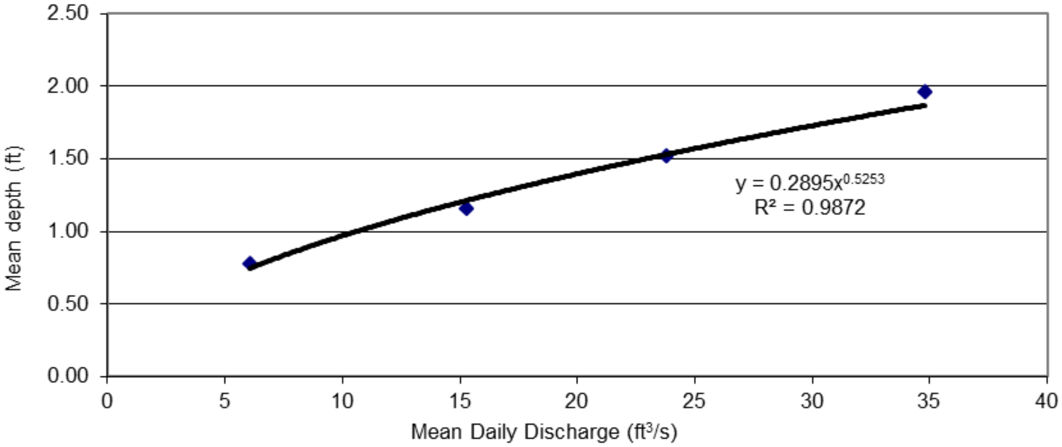

Figure 40. Aquatic habitat transect "C" mean depth – mean daily discharge rating curve.

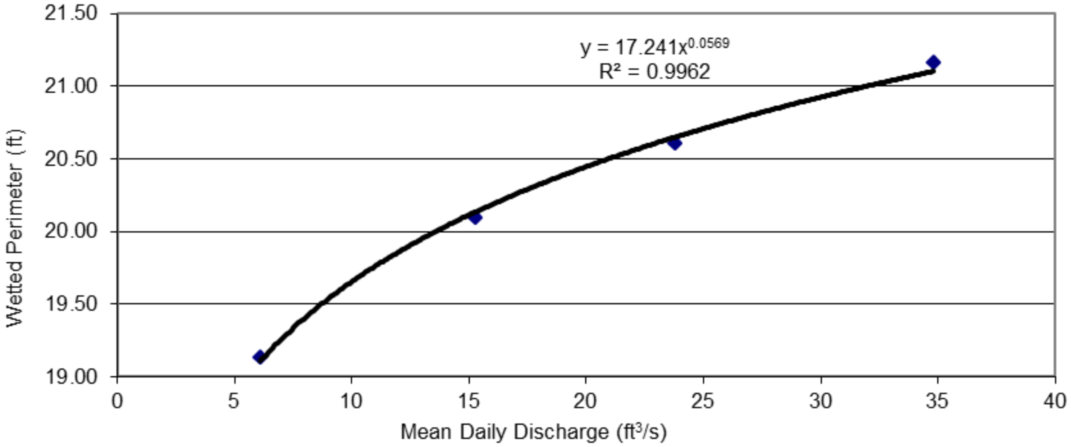

Figure 41. Aquatic habitat transect "C" wetted perimeter – mean daily discharge rating curve.

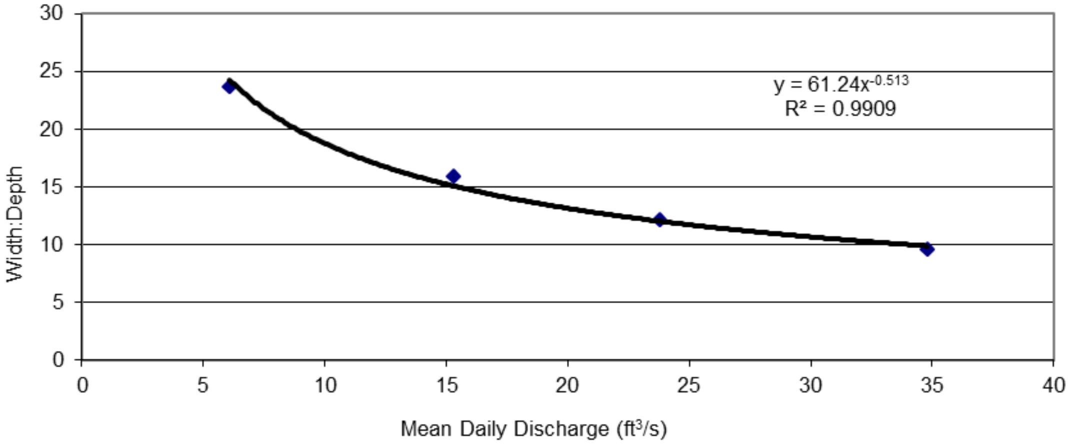

Figure 42. Aquatic habitat transect "C" width:depth – mean daily discharge rating curve.

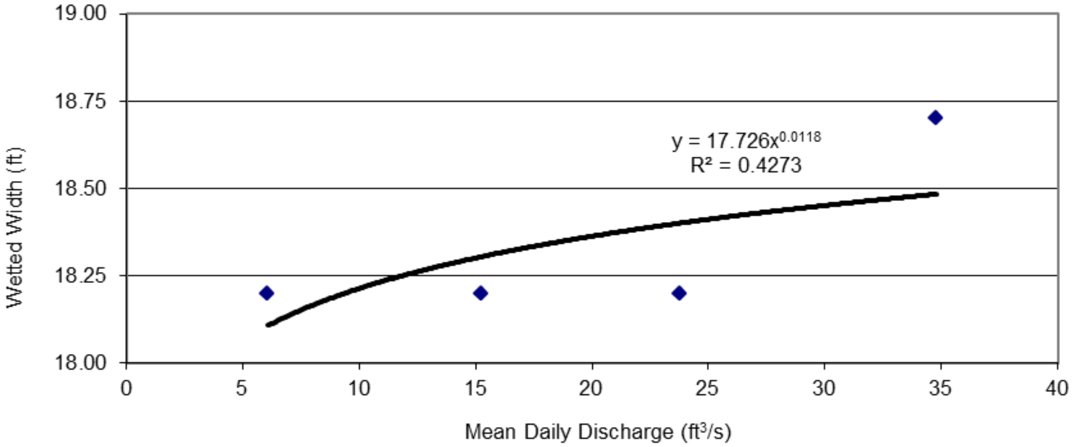

Figure 43. Aquatic habitat transect "C" wetted width – mean daily discharge rating curve.

Coefficients of determination (R^2) derived from power law functions fit to discharge-habitat relationships (Figure 39 through Figure 43) suggest aquatic habitat monitoring methodologies were sufficient to develop habitat rating curves for each surveyed transect. Predictive power of wetted-area, mean-depth, wetted perimeter and width-depth-discharge relationships were generally good. However, the predictive capacity of wetted width – discharge rating curves was generally poor, reflecting the rectangular channel geometries of Sevenmile Creek. Generally, wetted widths of rectangular channels change very little with discharge. This suggests wetted width is not an appropriate habitat metric to use in evaluating habitat changes associated with flow transactions in water bodies with rectangular channel geometries, such as Sevenmile Creek.

5.2.1.2. Habitat Changes Associated with Flow Transaction

Rating curves developed for habitat transects surveyed in Sevenmile Creek allow for quantitative predictions of habitat changes associated with changes in streamflow. These rating curves can be used to quantitatively evaluate changes in habitat variables associated with leased water over the range of flows observed during the transaction period. During the 2011 Sevenmile Creek flow transaction, the amount of water available for diversion from Blue Springs was unknown. Furthermore, quantities of water “leased” for in-stream dedication were also unknown. As such, the established habitat rating curves could not be used to calculate habitat benefits associated with the actual amount of leased water at different temporal periods of the flow transaction.

In the absence of data documenting the quantity of leased water relative to the volume that could be diverted, we present a conceptual evaluation of habitat changes associated with a seasonally-invariant 5 ft^3/s in-stream dedication (correspondence with KBRT suggest transacted flow volumes from Blue Springs were likely between 5 and 10 ft^3/s). Figure 44 through Figure 46, illustrate the percentage increase of wetted area, mean depth and wetted perimeter associated with a 5 ft^3/s increase to base flows ranging from 5 ft^3/s to 30 ft^3/s. Percent change in wetted area and mean depth for transect C (representative of rectangular channel geometries throughout Sevenmile Creek) ranged from over 40 percent for the 5 ft^3/s base flow conditions to less than 10 % at the 30 ft^3/s base flow condition (Figure 44 and Figure 45). Given the rectangular channel geometry of Sevenmile Creek (i.e., largely unchanging wetted width with change in flow), wetted area and mean depth were expected to respond similarly to changes in flows. Changes in wetted perimeter with flow were much less, ranging from approximately 1 to 4 % (Figure 46). This smaller percent change relative to wetted area and mean depth can be explained by the wide, shallow and rectangular channel geometries of Sevenmile Creek. As expected, the relative “benefit” of a 5 ft^3/s dedication was non-linear, with increasing benefit as base flows decreased.

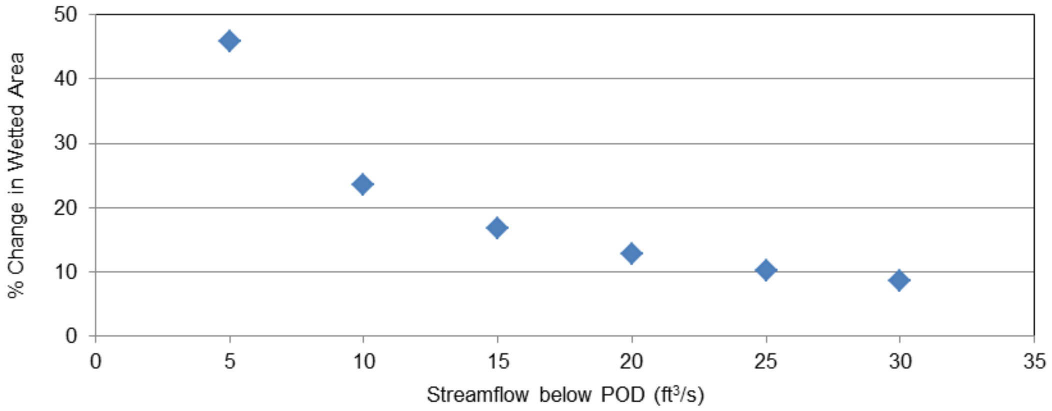

Figure 44. Percent increase in habitat (wetted area) at Transect C associated with an 5 ft^3/s increase in flow for base flows of 5 to 30 ft^3/s in 5 ft^3/s increments (x-axis).

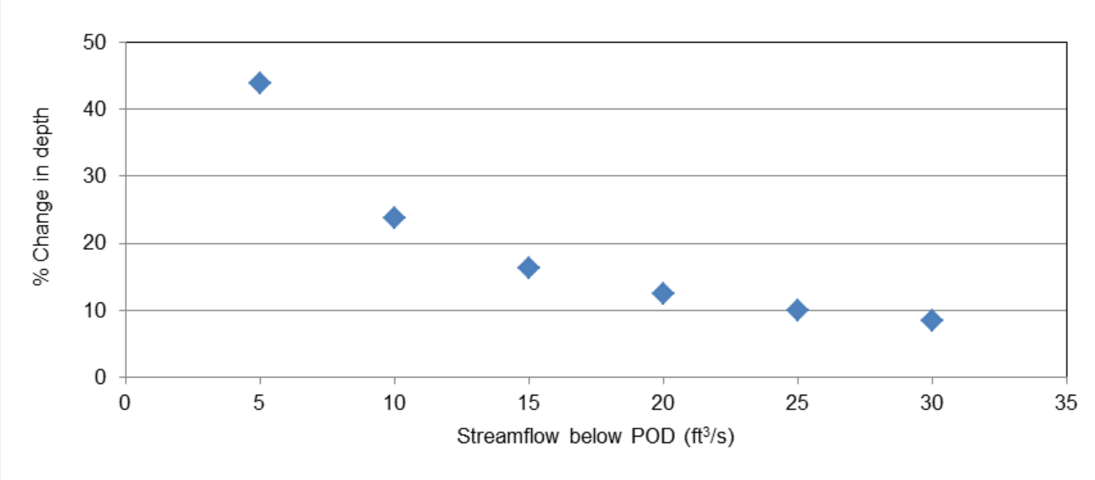

Figure 45. Percent increase in habitat (mean depth) at Transect C associated with an 5 ft^3/s increase in flow for base flows of 5 to 30 ft^3/s in 5 ft^3/s increments (x-axis).

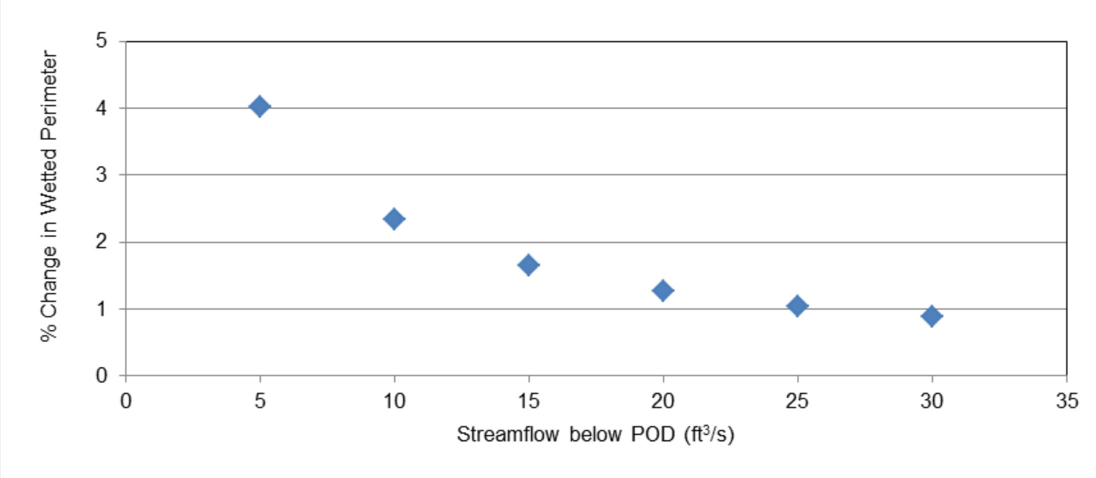

Figure 46. Percent increase in habitat (wetted perimeter) at Transect C associated with an 5 ft^3/s increase in flow for base flows of 5 to 30 ft^3/s in 5 ft^3/s increments (x-axis).

5.3. Shasta River Basin

Multiple flow transactions were conducted in the Shasta River Basin during 2011 and 2012. Three short-duration transactions (~2-3 days) were conducted in Little Springs Creek and Big Spring Creek, providing the opportunity to examine habitat monitoring protocols in a relatively stable hydrologic setting (the spring-fed Big Springs Creek). A single longer-duration (~ 1 month) transaction was initiated in September 2012, during which pool volume changes in the lower Shasta River Canyon were monitored.

5.3.1. Little Springs Creek (2011)

Watercourse Engineering, Inc. (Watercourse) personnel surveyed eleven (11) habitat transects (Figure 47) on each of two days: September 27, 2011 and September 28, 2011 (Table 1). Calculated discharge in Big Springs Creek above the point of diversion (as measured at the "waterwheel streamflow gage" in Figure 47) ranged from 65 to 75 ft^3/s on September 27 and 71 to 75 ft^3/s on September 28. This variability reflects upstream water management (i.e., irrigation withdrawals) during the transaction period. A discharge hydrograph for Big Springs Creek above Little Springs Creek during the transaction period is presented in Figure 48. Aquatic habitat transects surveyed on September 27 were surveyed on the ascending limb of the Big Springs Creek hydrograph (Figure 48). Aquatic habitat surveys conducted on September 28 were performed with considerably more stable flows in Big Springs Creek.

Figure 47. Little Springs Creek flowing northwestward into Big Springs Creek. Aquatic habitat transect and stream gauge locations associated with the transaction are identified. Flow direction in Big Springs Creek is to the west.

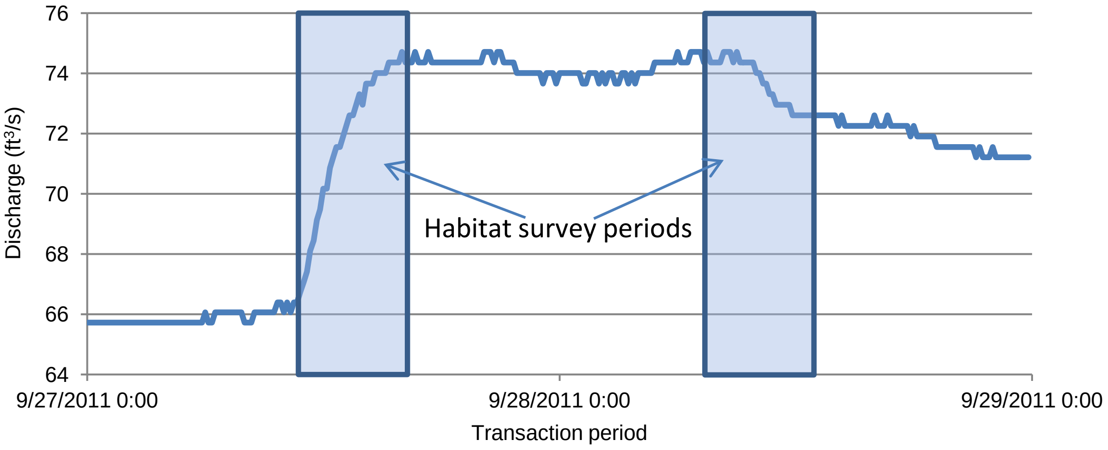

Figure 48. Big Springs Creek streamflow hydrograph (above Little Springs Creek) during transaction period (September 27-28, 2011).

Due to the short duration of the flow transaction, streamflows in Little Springs Creek were assessed through point measurements at the mouth of Little Springs Creek (see Figure 47). On September 27, no flows were observed in Little Springs Creek, as all of the streamflow was used to irrigate adjacent pastures. During this period, flows measured in Big Springs Creek (~66 ft^3/s to 74 ft^3/s; see Figure 48) represented flows through the protected stream reach below Little Springs Creek. On September 28, the measured discharge in Little Springs Creek was 13.5 ft^3/s. This measurement quantified inflows from Little Springs Creek into Big Springs Creek during the transaction. Subsequent analysis of river stage data in Little Springs Creek and Big Springs Creek downstream from Little Springs Creek indicates the transacted volume decreased over the day of September 28, as water impounded behind small dams along Little Springs Creek slowly drained. For the purposes of this assessment, the transacted volume of water is assumed to be stable at approximately 13 ft^3/s. Previous studies (Jeffres et al., 2009) have shown that flows in the spring-fed Little Springs Creek stabilize at approximately 8 ft^3/s, thus the results presented here potentially over-estimate the effects of Little Springs Creek on Big Springs Creek during the transaction period. Estimated flows through the protected reach on September 28 were approximately 86 ft^3/s (= 73 ft^3/s + 13 ft^3/s).

5.3.1.1. Habitat Changes Associated with Flow Transaction

Due to the short temporal period of the flow transaction, standard hydraulic rating methods were not used to establish whether the aquatic habitat variables could be adequately related to changes in flow. Instead, percent change in aquatic habitat variables (wetted area, mean depth, wetted width, width-to-depth ratio and wetted perimeter) were calculated to relate changes in habitat variables with changes in streamflow. Because streamflows in Big Springs Creek gradually increased during September 27, percent change in habitat variables between September 27 and 28 cannot accurately capture (within several ft^3/s) changes in habitat variables with a 13 ft^3/s contribution from Little Springs Creek. However, this data can be used to specify: 1) the directionality of the habitat flow relationship; and 2) the general responsiveness of hydraulic variables with changes in flow. With an approximately 13 ft^3/s increase in flows in Big Springs Creek, predictable increases in wetted area, mean flow depth and wetted perimeter were identified, as were decreases in W:D ratio (Table 6). Due to the rectangular channel cross-section geometry of Big Springs Creek, a consistent directional relationship between wetted width and flow could not be identified. Further, due to the wide, shallow and rectangular channel geometry of Big Springs Creek, wetted area and mean depth proved to be the most responsive hydraulic variable to changes in flow, showing changes ranging from approximately 10-20% across all survey transects.

Table 6. Percent Change in hydraulic variables at aquatic habitat transect "G", associated with ~13 ft^3/s flow contributions from Little Springs Creek to Big Springs Creek.

Hydraulic variable	Date		Percent Change
	9/27/2011	9/28/2011	
Wetted Area	11.86	13.22	11.46
Wetted Width	19.84	20.36	2.61
Mean Depth	0.60	0.65	8.62
Wetted Perimeter	19.86	20.32	2.34
W:D	33.19	31.35	-5.54

5.3.2. Little Springs Creek (2012)

Watercourse personnel surveyed the same eleven (11) Big Springs Creek habitat transects (Figure 47) during two separate flow transactions conducted in May and August 2012, respectively. During the May 2012 transaction, habitat transects were surveyed on each of two days: May 29 and 31. During the August 2012 transaction, habitat transects were surveyed on August 6 and 8. For each transaction, the initial aquatic habitat measurements were intended to document conditions without Little Springs Creek inflow, while the subsequent measurements were intended to quantify habitat changes associated with providing the entire flow of Little Springs Creek to the stable flow of Big Springs Creek. The two periods were selected to examine the effects of the transaction during distinct periods of vegetation growth and water temperature patterns in Big Springs Creek.

During the May 2012 transaction, discharge through the protected reach varied dramatically, particularly during the initial May 29 aquatic habitat survey period. The observed flow variations were caused by multiple factors. First, discharge in Big Springs Creek above the point of diversion (as measured at the "waterwheel streamflow gage" in Figure 46) decreased from 68 ft^3/s to 55 ft^3/s during the period of the May 29 aquatic habitat surveys. This variability reflected unplanned upstream water management (i.e., irrigation withdrawals) during this period. Second, concomitant with the observed reductions in flows in Big Springs Creek during the initial May 29 aquatic habitat surveys, flow magnitudes in Little Springs Creek ranged from approximately 1 ft^3/s to 6 ft^3/s (although they were anticipated to be 0-1 ft^3/s), again due to anticipated irrigation water management. As such, aquatic habitat transects surveyed on May 29 were surveyed along a fluctuating hydrograph. Flow magnitudes through the protected reach during the May 31 aquatic habitat surveys were much more stable, ranging from 64 ft^3/s to 65 ft^3/s. A discharge hydrograph for Big Springs Creek below Little Springs Creek (composite hydrograph summing flow data from the Big Springs Creek "waterwheel" gage and the Little Springs Creek gage) during the transaction period is presented in Figure 49.

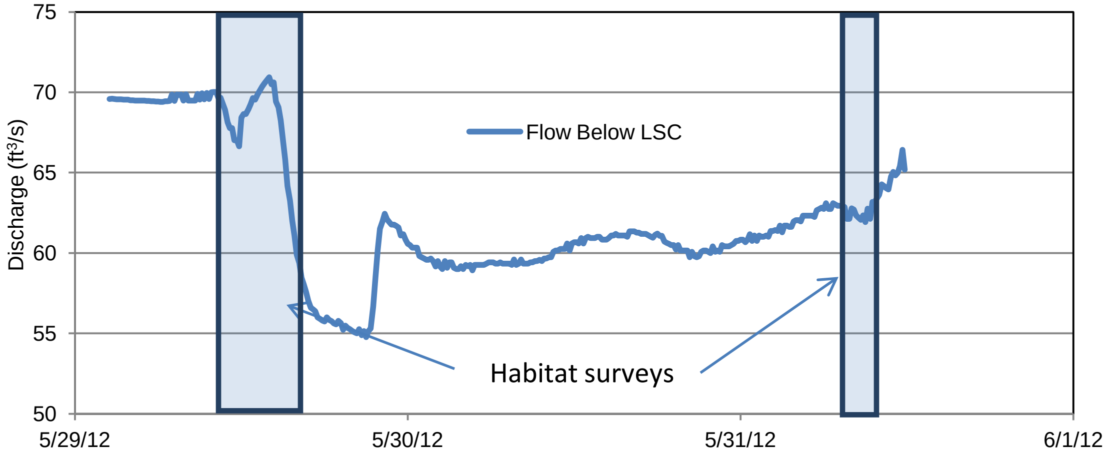

Figure 49. Big Springs Creek streamflow hydrograph (below Little Springs Creek) during transaction period (May 29-31, 2012).

During the August 2012 transaction, discharge in Big Springs Creek above the point of diversion (as measured at the "waterwheel streamflow gage" in Figure 47) once again varied over the duration of the transaction. On August 6, flow magnitudes in Big Springs Creek were stable at approximately 60 ft^3/s. However, Big Springs Creek flow magnitudes dropped to approximately 56 ft^3/s on August 8 due to upstream water management (i.e., irrigation withdrawals) during the transaction period. Zero-flow conditions existed in Little Springs Creek on August 6, while August 8 flow magnitudes remained stable at approximately 6 ft^3/s. A discharge hydrograph for Big Springs Creek below Little Springs Creek (composite hydrograph summing flow data from the Big Springs Creek "waterwheel" gage and the Little Springs Creek gage) during the transaction period is presented in Figure 50. Flows through the protected reach on August 6 and August 8 were approximately 60 ft^3/s and 56 ft^3/s, respectively.

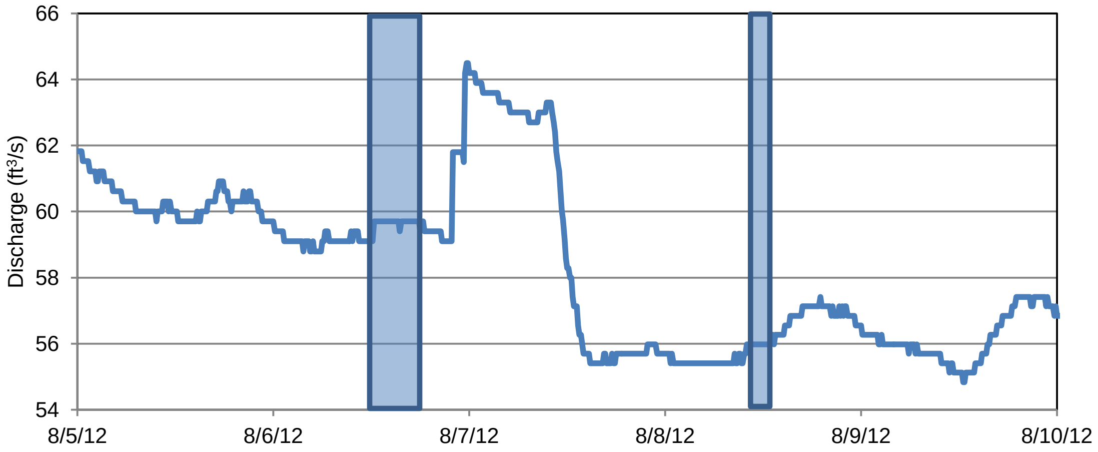

Figure 50. Big Springs Creek streamflow hydrograph (below Little Springs Creek) during transaction period (May 29-31, 2012).

5.3.2.1. Habitat Changes Associated with Flow Transaction

Similar to the 2011 Little Springs Creek flow transaction, the short temporal periods of the May and August 2012 transactions prevented the use of standard hydraulic rating methods to establish whether the aquatic habitat variables could be adequately related to changes in flow. Instead, percent change in four aquatic habitat variables (wetted area, mean depth, wetted width and width-to-depth ratio) was calculated to relate changes in habitat variables with changes in streamflow.

Because streamflows through the protected reach during the May 2012 transaction varied so much (due to rapidly changing flows in both Big Springs Creek and Little Springs Creek on May 29), identifying streamflows through each habitat transect at the time each survey was conducted proved problematic. As such, changes in habitat variables between May 29 and May 31 were not able to accurately capture changes in habitat variables associated with flow contributions from Little Springs Creek. For example, calculated flows through Transect G showed an approximately 9% reduction in streamflow between the May 29 and May 31 aquatic habitat surveys. However, over the same temporal period, measured hydraulic variables exhibited increases in wetted area, wetted width, mean depth; and decreases in width:depth ratio (Table 7). Such responses in habitat variable would be expected if streamflows had increased between May 29 and May 31. Ultimately, rapidly changing streamflows in both Big Springs Creek and Little Springs creek made quantifying flows through each habitat transect difficult. As such, even quantifying directionality of change (i.e., whether the change was positive or negative) was limited.

Table 7. Percent Change in hydraulic variables at aquatic habitat transect "G" during the May 2012 flow transaction

Hydraulic Variable	Date		Percent Change
	5/29/2012	5/31/2012	
Wetted Area	7.51	8.00	6.53
Wetted Width	19.48	19.51	0.15
Mean Depth	0.39	0.41	6.37
W:D	50.50	47.55	-5.85

Largely stable streamflows during the August 2012 aquatic habitat measurement periods (see Figure 50) allow assessment of habitat changes with flow. The approximately 4 ft^3/s reduction in flow through the protected reach was expected to produce small changes in aquatic habitat conditions, namely decreases in wetted area and mean depth, increases in W:D, and minimal change in wetted width. However, average changes in wetted area across all transects were +3%, while changes in mean depth and wetted width averaged +3.2% and -0.18%, respectively. Changes in aquatic habitat variables measured at transect G are provided in Table 8.

Table 8. Percent change in hydraulic variables at aquatic habitat transect "G" during the August 2012 flow transaction

Hydraulic Variable	Date		Percent Change
	8/6/2012	8/8/2012	
Wetted Area (m^2)	9.58	9.87	2.98
Wetted Width (m)	19.64	19.39	-1.29
Mean Depth (m)	0.49	0.51	4.33
W:D	40.27	38.11	-5.39

Aquatic habitat data from the August 2012 transaction suggest the measurement methodologies deployed were not suitable for quantifying flow-habitat relationships. However, this is may be the result of poorly quantified flow through the protected reach. While not rated for streamflow, a stream gage ("lowest x-ing") located within the protected reach (Figure 51) exhibited a negligible change in river stage (mean = -0.29%) between the two aquatic habitat measurement periods, suggesting flows through the protected reach during each measurement period were quite similar. This helps explain the small changes in aquatic habitat variables measured over the course to the transaction. It is likely that unquantified agricultural return flow between the "waterwheel" stream gage and the protected reach resulted in the underestimation of streamflow through the protected reach during the August 8 aquatic habitat measurement period.

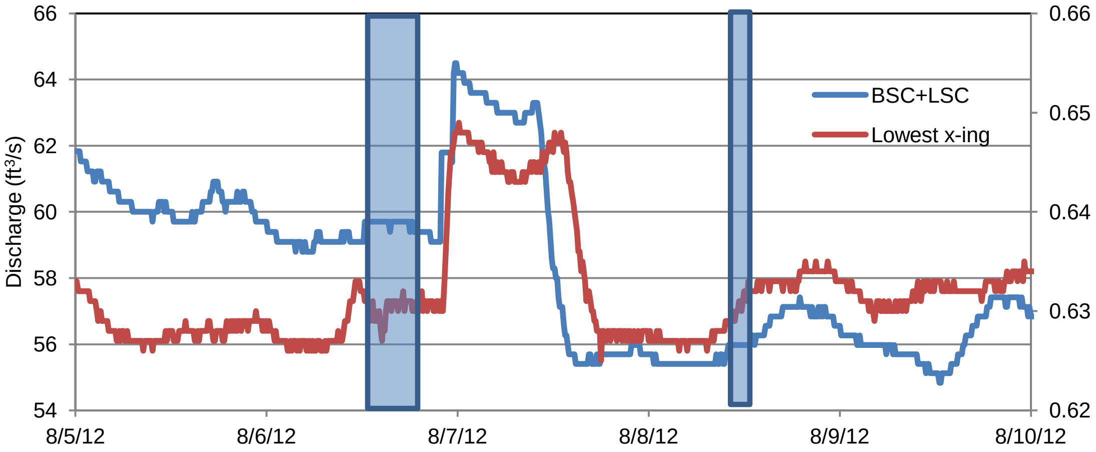

Figure 51. Big Springs Creek streamflow hydrograph (below Little Springs Creek) and measured river stage (lowest x-ing) during transaction period (August 6-8, 2012).

The May and August 2012 transactions were conducted in an attempt to identify “snap-shot” aquatic habitat changes in Big Springs Creek associated with flow contributions from Little Springs Creek. However, changing flow magnitudes in Big Springs Creek above Little Springs Creek during the course of both transactions precluded the quantification of habitat changes resulting from Little Springs Creek flow contributions. Furthermore, changing flow volumes in Big Springs Creek during the aquatic habitat measurements (due to upstream water management or unquantified agricultural return flows) precluded consistent identification of even the directionality of discharge-habitat relationships through the protected reach.

5.3.3. Shasta River Canyon (2012)

The Nature Conservancy – California (TNC) personnel employed pool volume survey protocols (Nichols, 2012) to measure changes in the volume of Hudson’s Pool in the Shasta River Canyon (Figure 52) over the period of September 4, 2012 through October 9, 2012. During each of four habitat measurement dates (Table 9), five cross-sections were surveyed along the length of Hudson’s Pool. Pool volumes calculated from each series of cross-section transect surveys were quantitatively related to mean daily discharge data available from USGS streamflow gage 11517500 (Table 9), located less than 1 km downstream from Hudson’s Pool.

Figure 52. Surveyed transects along "Hudson's Pool" in the Shasta River Canyon

Table 9. Mean daily discharge data on aquatic habitat survey dates

Pool volume measurement date	Mean daily discharge (ft^3/s)
9/4/2012	49.9
9/14/2012	54
9/25/2012	71.1
10/9/2012	113.3

5.3.3.1. *Habitat Rating Curve*

A pool volume-discharge rating curve was developed for Hudson's pool following standard hydraulic rating methods. The coefficient of determination (R^2) derived from a fitted power law function (Figure 53) suggests the pool volume monitoring methodologies were sufficient to develop a robust rating curve for pools in the Shasta River Canyon.

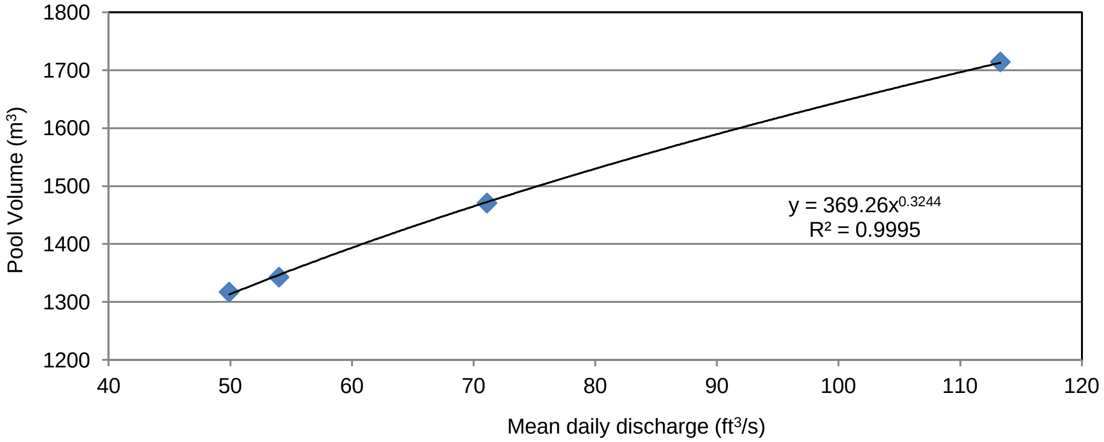

Figure 53. Hudson's Pool Volume – mean daily discharge rating curve.

5.3.3.2. *Pool volume changes associated with the flow transaction*

The Shasta River Resource Conservation District (RCD) organized voluntary irrigation reductions throughout the Shasta River to help increase flows through the Shasta River Canyon during September 2012. While the exact volumes of flow increases negotiated by the RCD cannot be ascertained due to the large numbers of irrigation diversion and return flows throughout the Shasta River, it is known that between September 4 and September 30, 2012, flow magnitudes through Hudson's Pool ranged from 30.2 ft^3/s to 71.1 ft^3/s. However, flow magnitudes during the three aquatic habitat measurements periods in September 2012 (see Table 9) only varied from 49.9 ft^3/s to 71.1 ft^3/s. As such, estimates of pool volume changes associated with the September period of the flow transaction can only be quantified across the more limited range of measured flows. Over this range, the discharge-pool volume relationship was nearly linear, resulting in pool volume increases of between 6 and 9 m^3 for each cubic foot of streamflow gained. It is anticipated that if pool volume measurements were available for the lower flows measured during the transaction period (e.g. 30.2 ft^3/s), the pool volume-discharge relationship would deviate from the approximately linear relationship shown in Figure 53, with a much steeper beginning of the fitted power function.

6. Potential metrics

Aquatic habitat monitoring methodologies utilized during the 2011 and 2012 flow transactions and described in Holmes, et al. (2011) and Nichols (2012) allowed for the quantification of six hydraulic variables (wetted area, wetted width, wetted perimeter, mean depth, width:depth ratio and pool volume), depending on the measurement protocols utilized. For each surveyed aquatic habitat transect, wetted area, wetted width, wetted perimeter, mean depth and width:depth ratio were calculated. These variables are commonly utilized as surrogates for aquatic habitat conditions (Gordon et al., 2004). As such, quantification of these transect-based hydraulic variables across a range of flow allows for an assessment of changes to aquatic habitat associated with changes in streamflow quantities.

Data gathered during both field seasons indicate that both the general applicability of specific hydraulic variables, as well as the magnitude of hydraulic variable responsiveness to alterations in streamflow, is largely controlled by channel geometry. A summary of these metrics and their applicability is presented below.

1) *Wetted Area*: Discharge-wetted area relationships were statistically robust across most channel geometries surveyed. Only in transects surveyed across complex channel forms (e.g., mid-channel bars in Patterson Creek) was this relationship compromised. Further, wetted area generally proved more responsive (e.g., greater magnitude of change) to changes in streamflow than other hydraulic variables.

2) *Wetted width*: Discharge-wetted width relationships were statistically robust for the trapezoidal channel geometries of Patterson Creek, French Creek, and the Scott River. However, statistical relationships between wetted width and discharge could not be generated in channels with largely rectangular geometries (e.g., Sevenmile Creek and Big Springs Creek). Wetted width generally proved much less responsive (e.g., smaller magnitude of change) to changes in streamflow relative to wetted area or mean depth.

3) *Wetted perimeter*: Discharge-wetted perimeter relationships were generally statistically robust across most channel geometries surveyed. Only in transects surveyed across complex channel forms (e.g., mid-channel bars in Patterson Creek) was this relationship compromised. Further, wetted perimeter generally proved more responsive to changes in streamflow in trapezoidal or triangular channel geometries versus rectangular geometries.

4) *Mean Depth*: Discharge-mean depth relationships were statistically robust across most channel geometries surveyed. Mean depth-discharge relationships in rectangular channels largely mimicked wetted area-discharge relationships. However, in channels with trapezoidal or triangular channel geometries, mean depth-discharge relationships were less responsive to changes in streamflow relative to observed wetted area-discharge relationships.

5) *Width:Depth:* Discharge-width:depth relationships were poor for most surveyed transects (and particularly those surveyed in Patterson Creek and Scott River). However statistical relationships between width:depth and discharge were successfully developed in Sevenmile Creek, while the directionality of this relationship was consistent in Big Springs Creek during

the 2011 transaction period – suggesting potential applicability of this habitat metric in rectangular channels.

Conversations with project partners following the 2011 transactions suggested pool volume may play a critical role for anadromous fish (and particularly coho salmon) in small tributary streams where pools may form the principal over-summering habitat (Moyle, 2002). Pools, particularly those with sufficient depth and cover, can be suitable habitats. As pool volume increases, increases in depth and potential increases in cover can yield benefits that may be important for some stream transactions. Consequently, developed pool volume measurement protocols were applied to the 2012 transaction in the lower Shasta River Canyon. Evaluation of the pool volume data indicated that robust statistical relationships between pool volume and streamflow could be developed using the established protocols.

7. Considerations and Recommendations

Aquatic habitat data collection and analysis from the 2011 and 2012 flow transactions identified considerations of the assessment methodologies presented in Holmes, et al, (2011) and Nichols (2012), as well as suggested some recommendations for on-going work. These considerations and recommendations include:

1) Short duration "snap-shot" transactions (e.g., Big Springs Creek) demand stable streamflows during the course of the transaction. Changing streamflows either above the P.O.D. or through the protected reach can prevent the quantitative evaluation of the aquatic habitat changes associated with a given flow transaction;

2) Streambed alterations (e.g., gravel movement by spawning salmon) over the course of a transaction can prevent the development of aquatic habitat-flow rating curves necessary to evaluate or forecast benefits of a flow transaction;

3) Complex channel morphologies (e.g., multi-channel streams) or changing bed roughness conditions (e.g., in-channel vegetation growth) can hinder or altogether prevent the development of statistically robust aquatic habitat-flow rating curves;

4) Large flow losses through alluvial features can prevent an accurate quantification of flow through surveyed aquatic habitat transects, particularly when upstream flow gauges are used to develop continuous streamflow records. If flow through individual transects is poorly quantified, accurate habitat-discharge relationships cannot be developed.

5) To help quantify the benefit of the flow transactions to targeted aquatic species, relationships should be developed between the physical aquatic habitat metrics and species needs.

8. Concluding Comment

Aquatic habitat monitoring protocols employed during 2011 and 2012 enabled the successful collection of field data necessary to develop quantitative relationships between streamflow and hydraulic variables acting as surrogates for aquatic habitat conditions. The general applicability and magnitude of responsiveness individual habitat metrics to changes in flow was largely determined by channel geometry. Further, where habitat data could be collected over a sufficient range of accurately quantified streamflows, hydraulic rating methods allowed successful quantitative predictions of habitat changes resulting from negotiated streamflow alterations.

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Appendix II

Development of Environmental Flow Calculator

Contents

Preface: Design Considerations

The purpose of the Instream Flow Crediting Protocol is to outline a process for developing and marketing credits representing ecological uplift generated by implementing instream flow restoration projects. This is no simple task given the intricacies of the systems involved. Watershed hydrology, like all natural systems, is exceedingly complex. Natural and human-caused variations influence watershed hydrology on multiple temporal and spatial scales, often simultaneously. At the same time, ecosystem credit trading requires standardized units of currency, and, where regulatory compliance is involved, a very high degree of certainty that predicted ecosystem benefits in fact occur.

This Instream Flow Crediting Protocol therefore takes a conservative approach to the exercise. Where uncertainties exist, they are highlighted and discussed in the narrative below and the accompanying attachments. More importantly, these same uncertainties are accounted for in every step of the crediting process through a variety of protocols that discount the number of credits awarded for any particular project. By discounting credits based on known uncertainty, regulators and observers can have a high degree of confidence that projects implemented under these protocols are providing significant ecological benefits equal to or greater than the number of credits that a given project generates.

Introduction: An Instream Flow Crediting Protocol (IFCP)

This document outlines a process to develop and market credits representing ecological benefit generated by implementing instream flow restoration projects. The IFCP closely mirrors protocols already established by Willamette Partnership for other credit types, such as stream temperature reductions resulting from riparian shade planting. The IFCP is meant to be appended to Willamette Partnership's General Crediting Protocol (GCP).

Overview of the Crediting Process

The IFCP does not provide a handbook for developing and implementing instream flow restoration projects. Rather, this document focuses on the process beginning when a project proponent has identified and developed a potential instream flow restoration project (project) to a point where it is ready to begin the crediting process. In general, this means that the proponent has identified a water right and come to preliminary agreement with the owner of the water right (through a signed Letter of Intent, or LOI) about the terms of a potential project.

The crediting process can be broken into five steps: project validation, credit calculation, project verification, credit registration and issuance, and credit tracking. The process is outlined on the following page in **FIGURE 1**. Because of the similarity of credit registration and issuance between the IFCP and other developed protocols, a description of that step is omitted from this document.

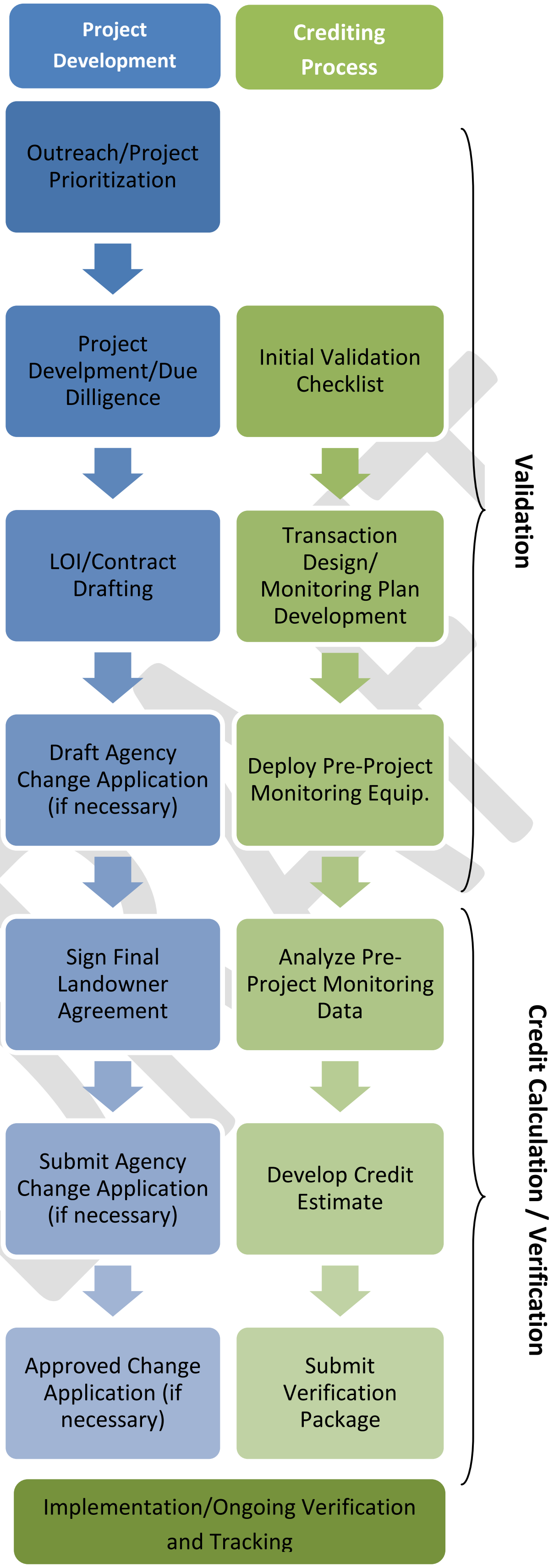

Figure 1: Crediting and flow project development process

Validation

The first step in the crediting process is determining whether a proposed project is a valid project for crediting. This section discusses guidelines that the Market Administrator will use in making validity determinations about projects submitted for crediting. Validation guidelines filter potential projects to ensure that only those projects meeting specific, high standards for quality and relevance progress through the crediting process and are submitted for verification and credit generation.

The validation process begins with the completion of an initial validation checklist (see APPENDIX A). This checklist is a broad filter meant to disqualify projects that obviously do not or cannot meet the standards required for crediting. In addition to the initial validation checklist, project proponents develop and submit full transaction designs (templates attached at APPENDIX B), stewardship plans (template attached at APPENDIX C), monitoring plans (templates attached at APPENDIX C), a proposed project budget, a signed letter of intent (LOI) by the landowner who will participate in the project, and, where necessary, a completed state agency water right change application. Other documentation may also be required under the GCP for all credit types; however, that documentation is not outlined in this document.

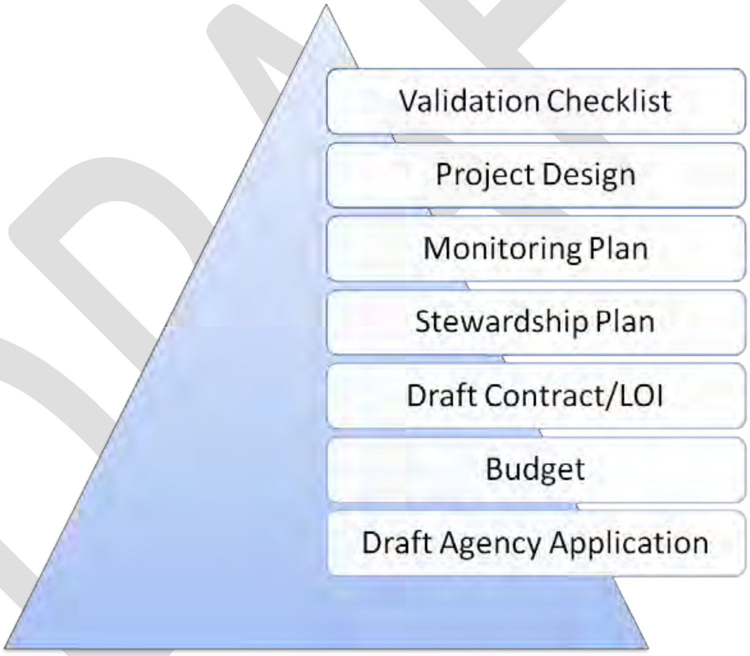

Figure 2: Validation documentation requirements

This package of materials allows the market administrator to determine whether a project meets the requirements of: 1) additionality, 2) suitability, and 3) sustainability. Specific elements of each of these requirements are more fully described below.

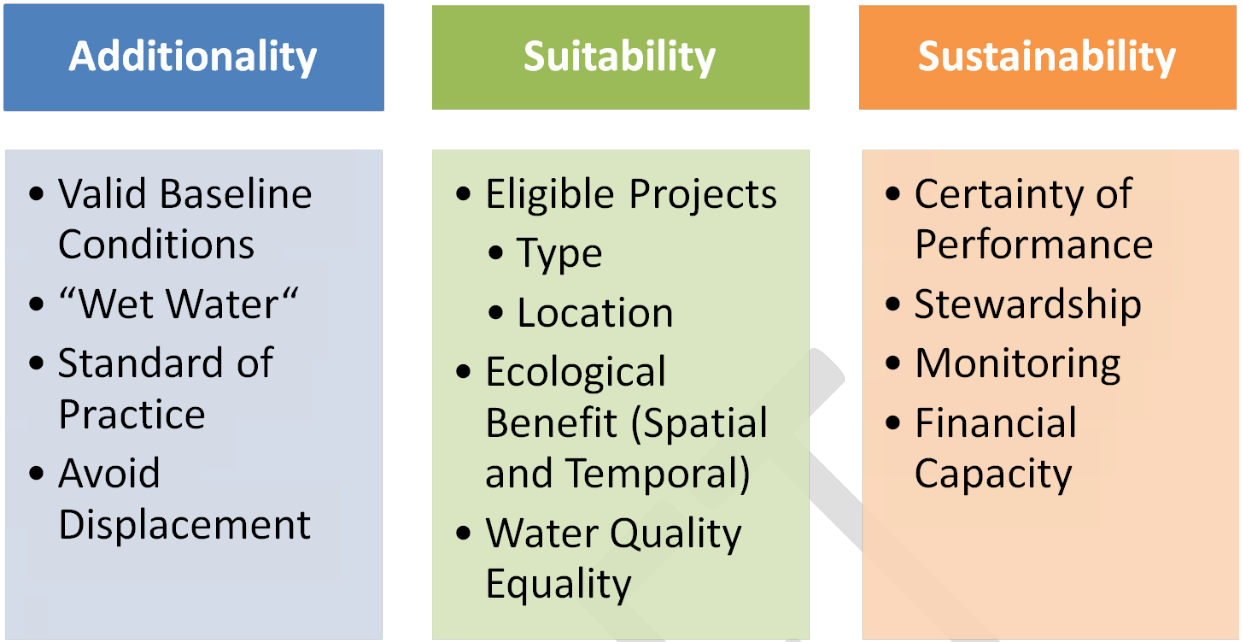

Figure 3: Validation criteria

Additionality

The first requirement of a valid and creditable flow transaction is that it contributes additional flow to a river reach. Showing additionality is a four part test that requires establishing 1) valid project baseline, 2) that the proposed transaction will result in "wet water" instream, 3) that the project meets a standard of practice above which actions are creditable, and 4) ensuring that the benefits of the project are not displaced. This test ensures that valid projects go above and beyond business-as-usual, past pre-existing obligations and standards of practice, and contribute to an increase in instream flow through a defined reach resulting in measureable ecological benefit. A simple way of expressing additionality is to say that, “but for this project, X amount of instream flow would not be present in an ecologically significant reach at an ecologically significant time.”

1) Establishing a Valid Project Baseline

Project proponents must establish baseline conditions that are conducive to measureable, enforceable instream flow restoration actions. The burden is on the proponent to demonstrate that instream flow through the reach affected by the proposed project can be increased by one or more actions including but not limited to the instream lease or transfer of existing and active irrigation or other consumptive use water rights, the release of stored water that would otherwise not be released in the same location or at the same time, or some other acceptable, enforceable mechanism to increase instream flow. It is important to note that for validation purposes, it is not necessary to develop a detailed hydrograph of the affected reach. Detailed hydrographic information is, however, vital for later steps in the crediting process.

2) Establishing that the Project will Result in Wet Water Instream

Valid credit generating transactions must result in “wet water” instream. Wet water means that the project results in a net increase, above pre-project flow conditions, of instream flow protected through a defined river reach either through state agency regulation of water rights or through an approved, enforceable contractual mechanism.

For validation purposes, projects must involve legally valid[1] (non-forfeited, non-abandoned) water rights under which a verifiable amount of water has been beneficially and regularly used in the past five years[2], and which will no longer be used consumptively during a relevant time period after the project is implemented, and/or the release and protection instream of stored water that would have previously been diverted or not released at an ecologically significant time and place.

In addition, the project proponent must demonstrate that the project water right(s) is/are not currently involved in any uncompleted state agency, or other, processes that would hinder transaction implementation.

3) Establishing that the Project Meets the Standard of Practice

The standard of practice for instream flow restoration projects requires that all credit generating projects are tied specifically to their relevant funder, permit, etc., and do not result from actions already planned or undertaken for another purpose. Flow transactions completed for existing regulatory obligations that would occur without the credit generating project (e.g., forest practice rules, ag water quality requirements, or municipal natural resource protections) or actions defined as business as usual, are not creditable because they do not fulfill the requirement of additionality.

Existing state instream water rights or minimum flows set for the relevant reach that are not in priority during a relevant time of the year are not considered existing regulatory obligations. However, any portion of a state instream water right met by existing senior water rights—whether by instream lease, instream transfer or other instream water rights agreements—should be acknowledged and not counted for crediting purposes unless they result from the project being proposed for credits.

4) Ensuring Against Displacement of Value

Ensuring against displacement of value from transacted flow requires a demonstration that the project and any resulting credits will not be used to secure other water rights or credits for another funder, permitee, etc., and/or that the transaction will not result in a detriment to the project water source and/or another water source. To further this goal, there is a rebuttable presumption of hydrologic connectivity between surface water and groundwater sources that must be overcome before credits can be issued for a project that proposes to use a source switch from surface to ground water to increase

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[1] The legal validity of a water right is distinct from project validity for the purposes of crediting. The specific contours of legal water right validity, however, can vary depending on the state in which the project is located and therefore reference to specific state law and regulation is the only way to determine legal water right validity.

[2] Five years is a standard time limit for Western states during which water must be beneficially used in order to avoid statutory forfeiture however specific reference must be made to state law and regulation where the project is implemented.

instream flows and/or for any transaction that results from pumping either artificially stored or native groundwater directly into a surface stream.

For transactions that involve trans-boundary movement of water—increasing flow in one stream with flow diverted from another stream – transaction proponents will need to overcome a presumption of harm to the stream from which the water is originally diverted. Finally, project proponents must demonstrate that the amount and quality of flow they are adding by implementing their proposed project is not detrimental to the target river reach or downstream reaches and/or receiving water bodies.

Suitability

Beyond additionality, the proposed transaction must also meet the validation requirement of suitability of. Suitability requires determining 1) project type eligibility, 2) project location eligibility, 3) spatial and temporal eligibility of the proposed project with regard to ecological objectives, and 4) restored water quality eligibility.

1) Eligible Actions

Instream flow restoration projects for credit generation are strictly limited to transactions with verifiable ecological uplift. Several factors go into determining whether a transaction meets this requirement, including the type of transaction proposed, and whether the location of the proposed transaction is conducive to increasing instream flow through water transaction projects.

Eligible transaction types

The following project types (either alone or in combination) are approved for use to create flow credits:

- Full-season instream leases
- Split-season instream leases
- Allocations of conserved water
- Time-limited transfers
- Permanent transfers
- Minimum flow agreements (in limited situations)
- Forbearance agreements (in limited situations)
- Point of Diversion (POD)changes (in limited situations)
- Source switches between hydrologically unconnected water sources
- Reservoir releases (in limited situations)
- Releases of water stored underground using Aquifer Storage and Recovery (in limited situations)

The market administrator may consider project types not on the list above, however the project proponent must demonstrate strict adherence to all other validation requirements.

2) Eligible transaction locations

Instream flow credit-generating projects must create ecological uplift by restoring instream flow through water transactions. Flow credits may only be established on streams/reaches with the following characteristics:

- Perennial flow
- Presence of federally and/or state-specific species of concern (i.e. fish or other species that are ESA-listed, native, or protected under another relevant state or federal law or regulation)
- Certificated, consumptive use water rights
- Without/below dams or other major fish passage barriers that act as complete fish passage barriers
- Annual minimum discharges not more than twenty (20) times greater than the transacted flow present in the reach.

3) Ecological Uplift Requirements

Suitable transactions must also align restored instream flow with relevant ecological objectives (temperature, sediment, fish passage, etc.) in both time and space. This requires demonstrating that the location and timing of the restored instream flow will satisfy identified credit objectives such as temperature reduction, and provide other ecological uplift (for example, increased habitat area for focal fish species). Determining the ecological suitability of a project requires establishing both spatial and temporal project prioritization.

Spatial prioritization

Project implementation should be prioritized based on how well projects meet crediting objectives (such as kilocalories per day, or total credits generated), and how much they contribute to addressing other identified ecological limiting factors in a defined stream/reach/watershed. For validation purposes, project proponents should demonstrate how the location of a proposed transaction addresses both the specific crediting objective and other ecological limiting factors. Consultation with relevant state and federal agencies and reference to publicly available plans and/or studies will help project proponents identify high priority locations to target project activity.

Temporal prioritization

Projects can only generate credits when credit objectives and other ecological objectives overlap with the time of use stipulated by the relevant water right. Making this determination requires reference to TMDLs and/or other applicable orders/plans/documents to establish whether restoration objectives can be addressed by projects during a time of year when flow transactions are feasible.

In order to convert project benefits into trading credits, validation must show that the proposed transaction will increase instream flow during a time period that is relevant to the permit or other regulatory obligation under which trading is authorized (refer to the **Procedural Manual for Temperature Credit Analysis** in APPENDIX D for a detailed description of this process).

4) Quality of Restored Flow

The final suitability requirement involves the quality of water restored instream by the project. Suitable projects must result in either the addition or non-diversion of water of equal or higher quality than what is naturally present in the receiving stream.

Sustainability

The final element of project validation ensures the sustainability of credit generating projects over the life of the credit. Sustainability can be broken into four components: 1)certainty of transaction performance for the life of the credit, 2) project stewardship, 3) project monitoring, and 4) financial sustainability.

1) Certainty of Instream Performance for the Life of the Credit

For validation purposes, project proponents must identify the legal mechanisms in place once the project is implemented that provide certainty the water will be instream for the life of the credit. Depending on the type of transaction involved in the project, some or all of the following will be required to guarantee certainty of performance:

- Legally enforceable landowner agreements
- State agency issued Final Orders approving proposed water right changes
- Contracts with relevant federal and/or private entities that own stored water
- Recordation of transaction details in county records
- Organizational succession plans guaranteeing ongoing performance should the project proponent cease to exist or lose necessary oversight capacity

2) Project Stewardship

In addition to legal certainty that water will be instream for the life of the credit, a similar degree of legal certainty of project performance must be outlined by in a stewardship plan designating a party to maintain specific project components. A stewardship plan (APPENDIX C) includes a description and schedule of any necessary maintenance for the life of the project.. Examples of maintenance activities for projects include, but are not limited to, maintaining any non-monitoring-related infrastructure installed to deliver project water instream, or conducting stewardship activities meant to comply with local land use regulations on project lands ,(i.e. weed and pest control).

Project stewardship is distinct from project monitoring because it does not involve measuring/tracking instream flow, but rather focuses on actions/infrastructure necessary to implement the flow transaction.

3) Project Monitoring

Credit generating projects must be closely monitored for the project duration. Project proponents must submit a detailed monitoring plan as part of the Validation documentation submission (see APPENDIX C, Monitoring Plan Template). Within the monitoring plan monitoring activities must be clearly designated and designed to achieve two primary goals: 1)ongoing compliance and regulatory enforcement certainty; and 2) ongoing documentation and tracking of credit objectives. A robust monitoring plan will ensure partner compliance with the terms of a project agreement and, where relevant, provide vital data to state agency personnel to assist in water right regulation activities within the watershed. Additionally, monitoring data will be used to measure and verify ecological uplift, as well as contribute to biological or hydrological assessments.

Figure 4: Example monitoring configuration

4) Financial certainty

The final element of Sustainability for the validation phase of a project is financial certainty. Project proponents must develop a project budget and demonstrate the ability to fund the proposed project, including any ongoing requirements for monitoring and stewardship. For increased certainty, proponents must demonstrate that an endowment exists to cover the cost of maintenance and monitoring for the life of the credit.

Validation Certification

The Market Administrator will review all documents submitted for validation and return a validity determination to the project proponent. If the submitted project is deemed valid for crediting purposes, the project proponent can proceed to the next steps in the crediting process. At this point, the project proponent should also proceed with necessary transaction steps to keep the project moving toward implementation. For most projects this will include completing a final, signed landowner agreement and submitting any relevant state agency water right change application(s), as well as deploying any necessary monitoring devices for model baseline data collection.

Credit Calculation

Once a project is validated by the market administrator, the next step is to calculate the amount/number of credits that will result from the project. Credit calculation for instream flow restoration projects requires at least one year of site-specific, pre-project monitoring data to set the modeling baseline for credit calculation. The process steps from validation to credit calculation are therefore: 1) receive notice of project validation; 2) deploy monitoring equipment (as described in attached APPENDIX C for pre-project monitoring); 3) collect monitoring data from one full irrigation season before planned implementation of the project; 4) develop modeling baseline; 5) calculate credits.

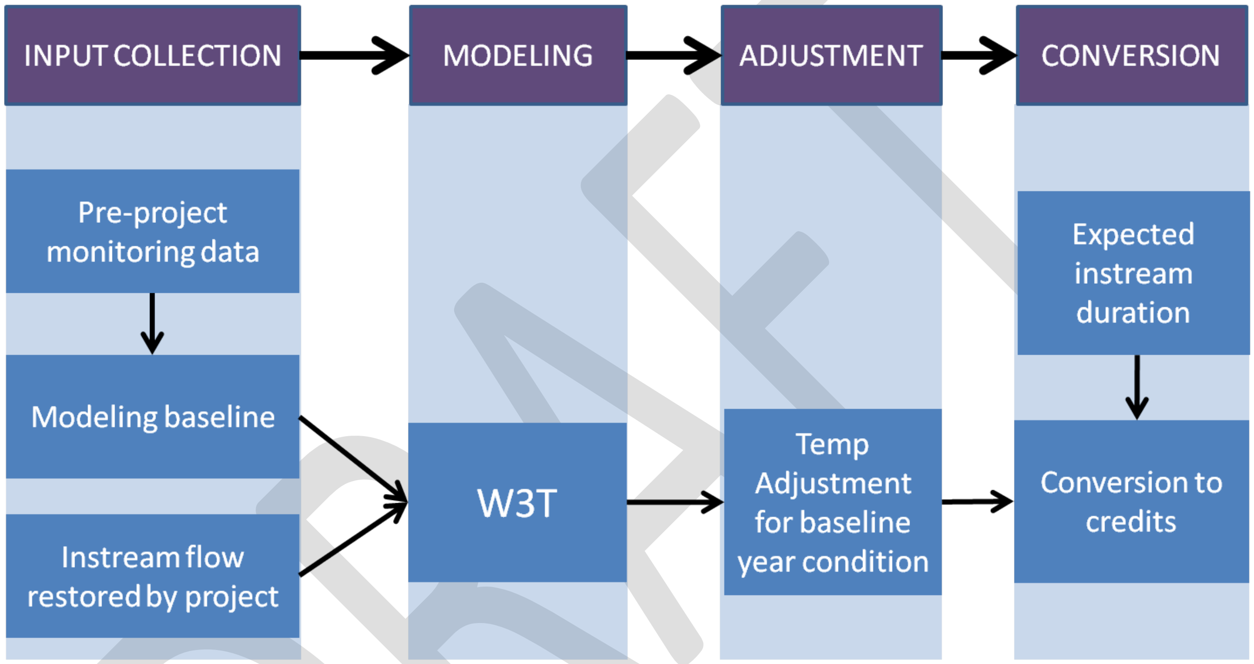


Figure 5: Temperature credit calculation example

Because credit calculation requires at least one year of site-specific, pre-project monitoring data, project developers should deploy necessary monitoring equipment as far in advance of project implementation as practicable. Though it is not necessary to deploy monitoring equipment in advance of validation, and in some instances, due to cost or access issues, may not be advisable, developing pre-project monitoring data at the soonest possible point in the process will accelerate credit calculation and subsequent crediting processes.

Credit calculation for flow transactions must account for several sources of variability unique to flow in river systems including 1) natural hydrographic variability, 2) water right reliability and regulation patterns, 3) hydrographic and water reliability data quality/presence, and 4) timing of transaction objectives. This variability is overcome by using a calculation framework that accounts for variation in the amount and timing of transacted flows by making conservative estimates of instream benefits (wet water instream) based on factors discussed below. This section discusses each of the sources of variability in turn. A comprehensive temperature credit calculation framework for flow transactions can be found in APPENDIX D.

1) Natural Hydrographic Variability

No two water years are exactly the same. Depending on snow fall and runoff timing, spring and summer rains, and other factors, every year's hydrograph is different. For credit calculation purposes, where data quality allows (data quality is discussed in more depth below), hydrographic variability can be accounted for using accepted statistical methodologies to develop what are called exceedance flow levels (expressed as percentages). For example, an 80% exceedance flow is the flow at a defined point and time or time period that will be met or exceeded in eight out of ten years (or 80% of the time) and a 50% exceedance flow level is the flow at a defined point and time or time period that will be met or exceeded in five out of ten years (or 50% of the time). Exceedance flows can be used to help calculate transacted water right reliability by determining whether a given water right seniority will be in priority at a given time of year under either or both the 80% and 50% exceedance scenarios.

In concert with 80% and 50% exceedance flow levels, hydrologic variability is further addressed using an assumption about the frequency of different water year types. "Dry" water years are assumed to occur four out of every ten years while "Typical" and/or "Wet" years are assumed to occur six out of every ten years (this factor is user adjustable, but the 4/6 split is the conservative recommendation for crediting purposes). Eighty percent exceedance flow levels are correlated with "Dry" water years and 50% exceedance flows are correlated with "Typical" and "Wet" water years. Combined with water right reliability data (discussed below), these correlations allow the calculation of overall expected reliability for a given water right. In other words, they allow for a conservative estimate of the average number of days a transacted water right will provide instream benefits in any given year, regardless of yearly variability.

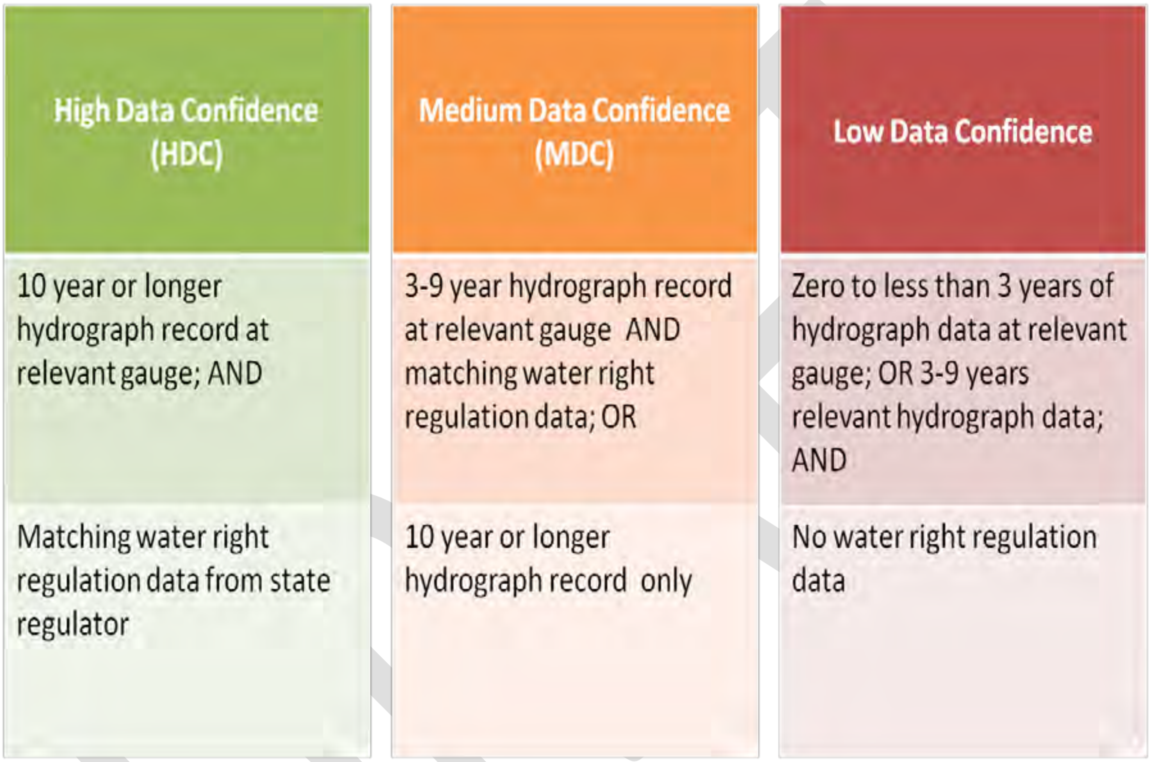
2) Water Right Reliability and Regulation Patterns

Western water law relies on a priority system to determine what water rights are entitled to continue diverting water during times of shortage. This "first in time, first in right" system has major implications for the calculation of temperature credits from projects. Depending on the transacted water right's seniority, it may or may not be in priority or available during low flow periods of the year when transaction objectives are likely to be focused. Carrying out this system of water right priority requires state employees to coordinate and enforce the system among and between water right holders. This is achieved by regulatory actions that include ordering out-of-priority junior water rights to shut off to allow water to flow to in-priority senior water rights.

3) Hydrographic and Water Right Reliability Data Presence and Quality

The ability to derive meaningful predictions from hydrographic and water reliability data to aid in credit calculations depends heavily on data presence and quality that vary from basin to basin. Data availability and quality, therefore, are major drivers in the calculation process. Credits are calculated in three different ways depending on whether the transaction takes place in a High Data Confidence scenario (HDC), a Medium Data Confidence scenario (MDC), or a Low Data Confidence scenario (LDC). Because high data confidence provides a better prediction of reliability, the formula used to calculate credits in these scenarios will produce more credits than the formula used to calculate credits in medium data confidence scenarios. Discounting credits based on the level of data confidence captures the risk/benefit trade-off inherent in each data scenario.

Because of the lack of data for developing credit estimates, Low Data Confidence scenarios will require credit issuance after deal implementation. The practical result will be that credits cannot be issued for projects in LDC scenarios until at least the end of the first irrigation season during which project flows are instream and observed conditions can be modeled.



High Data Confidence (HDC)	Medium Data Confidence (MDC)	Low Data Confidence
10 year or longer hydrograph record at relevant gauge; AND	3-9 year hydrograph record at relevant gauge AND matching water right regulation data; OR	Zero to less than 3 years of hydrograph data at relevant gauge; OR 3-9 years relevant hydrograph data; AND
Matching water right regulation data from state regulator	10 year or longer hydrograph record only	No water right regulation data

Figure 6: Data confidence

High Data Confidence Scenarios (HDC)

High Data Confidence scenarios involve projects on stream reaches where a spatially relevant gauge (define?) has a ten year or longer hydrographic record AND the relevant state water regulator has a corresponding record of water right regulation by priority. HDC scenarios allow for both an 80% and a 50% exceedance flow to be developed and correlated to documented water right regulation patterns based on seniority. In turn, HDC scenarios allow for accurate predictions of the number of days a water right with a given seniority will be instream during the relevant time period.

Medium Data Confidence Scenarios (MDC)

Medium Data Confidence means either of two scenarios: 1) a spatially relevant gauge with less than a ten-year, but greater than a three-year hydrographic (i.e. 3-9 year) record exists AND the relevant state water regulator has a corresponding record of water right regulation by priority; or 2) a spatially relevant gauge with a ten-year or longer hydrographic record exists BUT little or no records of water right regulation by priority exist. Where little to no record of water right regulation by priority exists, water right regulation patterns can be predicted based on paper water rights and hydrographic data. In all MDC scenarios, only an 80% exceedance will be developed and analyzed. Basing credit calculation on an 80% exceedance flow provides a significant buffer to overcome the uncertainty associated with having only medium confidence in available data.

Low Data Confidence Scenarios (LDC)

Finally, if less than three years of hydrographic records exist--a "Low Data Confidence" scenario (LDC)--credits will be discounted by 50% for the first three years of project implementation and credit calculation will only be allowed after the first year of project implementation.

4) Timing of Project Objectives

Depending on the specifics of the relevant TMDL or other restoration driver, project objectives will often be targeted at specific periods during the year. For instream flow restoration projects, the precise timing of objectives is vital to the calculation process. Project objectives therefore will dictate the precise time period during which instream benefits from projects can count toward credit generation. This analysis informs both the water right reliability and hydrographic analysis above by defining the period during which those analyses should be performed.

Using both the hydrographic and water right reliability analyses explained above and discussed in more detail in Appendix D, estimates of water right reliability can be documented in terms of the number of days a given water right is predicted to be in priority during the during the applicable season (based on transaction objectives) under either the 80% and 50% exceedance flows for HDC scenarios, or only the 80% exceedance for MDC scenarios.

Calculating Temperature Credits from Flow Transactions Using the Water Temperature Transaction Tool (W3T)

The Water Temperature Transaction Tool (W3T) uses a combination of river and landscape characteristics to estimate the hourly heat loss or gain experienced by a defined river reach, from which it predicts temperature changes in that reach. The models uses three parameters: 1) physical channel characteristics such as river depth, width, length, gradient, and bed roughness; 2) topographical and vegetation features such as surrounding zones of vegetation that provide shade and inhibit solar radiation; and 3) meteorological conditions affecting heat transfer at the air-water interface such as air temperature, humidity, and cloudiness.

To run the model, project developers import measured inflow water temperatures and discharge for a defined reach. As water travels downstream from the top to the bottom of the reach, W3T estimates incoming solar radiation and atmospheric heat exchange, incorporating tributary inputs and meteorological information to calculate a net change in temperature. A detailed discussion of the model and how to use it are included in the ***W3T User's Guide*** in Appendix D.

Once the project developer has pre-project monitoring data in hand and an estimate of the number of days the project will protect flow instream during the relevant time period for credit generation, collected data (a list of model inputs is discussed in the ***W3T User's Guide*** in Appendix D) can be entered into the W3T interface to model the extent of temperature reduction resulting from the project expressed as kilocalories/day).

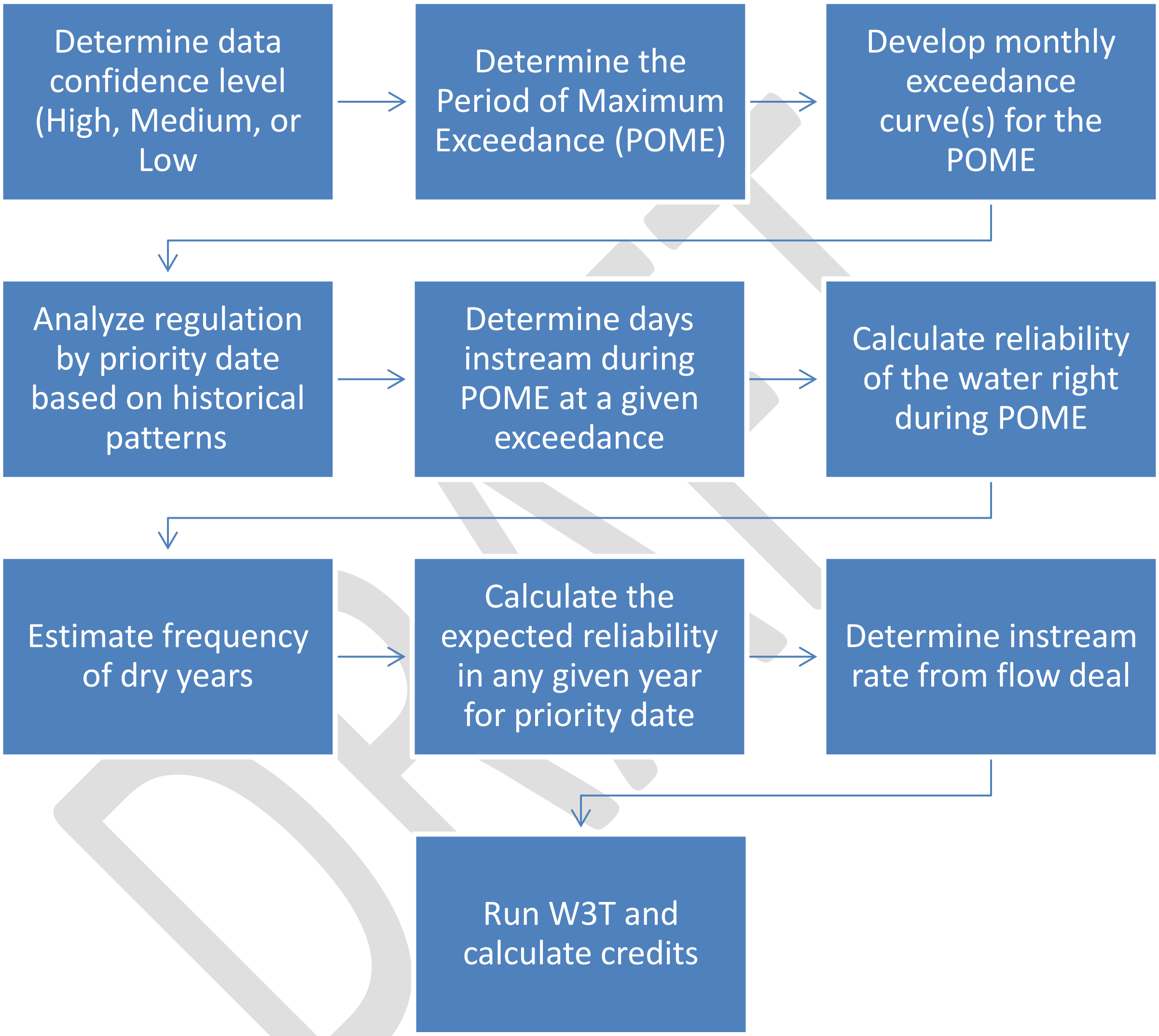


Figure 7: Temperature credit calculation process

Verification

Once a credit estimate for a valid project has been developed, the project developer submits documents to the Market Administrator for project Verification. The Market Administrator selects a verifier from a pre-qualified pool of contractors and provides them with the documentation for verification. Verifiers follow a set of guidelines (see attached APPENDIX B) adopted by the Market Administrator to review submitted projects. Verification involves the following general steps (described in more detail in the following sections): 1) the project developer receives and submits confirmation from the state agency that all necessary water right changes have been approved (for projects that do not require state agency action, this step is omitted); 2) the project developer makes any necessary changes to the transaction design, monitoring plan, and/or credit calculation worksheet to accurately reflect the final state agency approval of the project; and 3), the project developer clearly notes these changes so the verifier can compare them with the initial project design that was validated.

Figure 8: Verification documentation requirements

Verification by Project Type

Projects will generally fall into one of two categories: those that require a state administrative process to officially change water right(s), and those that do not require a state administrative action and only require a contractual agreement between the project developer and the landowner.

Verification of Projects Requiring State Agency Action

During the validation process, the project developer submits a draft state agency change application and a Transaction Design document to be reviewed by the Market Administrator. However, state agency processes can often result in final approvals that vary slightly from predicted outcomes originally delineated in the change application and Transaction Design. State agency approval is the final word on how much, when, and where water will be protected instream. Therefore, if any variance occurs between the original transaction design and the final agency approval, the project developer must make pertinent modifications to the Transaction Design, Monitoring Plan, and also, under HDC and MDC scenarios, recalculate credit estimates to reflect these changes. Verifiers will be trained to carefully analyze relevant sections of the Transaction Design, Monitoring Plan and Credit Calculation documentation for accordance with final state agency approvals.

Verification of Projects with no State Agency Action

In specific circumstances, instream flow restoration can be achieved without the need for state agency approved water right changes. For example, where only one irrigation diversion exists on a target tributary, credit generating instream flow restoration may be achieved through a contract between the landowner and the project developer under which the landowner agrees to not divert during some or all of the irrigation season. For these projects, verification will involve an analysis by the Verifier of the final signed contract to make sure it accomplishes the same instream flow restoration proposed in the draft contract submitted for validation. Because such transactions rely solely on contracts without the support of state agency regulation, verification of the enforceability, workability, and legal soundness of the contracts involved is vital (this analysis is performed according to verification guidelines attached in Appendix B). Project developers will also submit a credit calculation based on the final parameters of the signed landowner agreement for verification.

Verification Report Submission

Once successful verification is complete, the Verifier submits a **Verification Report** containing a summary of verification activities, an opinion on the credit estimates, and a log of activities and findings to the Market Administrator, initiating the final credit certification process.[3]

Final Flow Credit Certification

The Project Developer, Market Administrator, and, where necessary, the regulatory agencies perform a final review of the verified credit estimates and all project documentation. Where the credits are to be issued for compliance, agency certification is usually required before issuance of credits.

Ongoing Verification and Credit Tracking

Ongoing verification occurs in five-year cycles. The full verification process typically occurs in the year of project approval (year zero), and every fifth year thereafter. Requirements for fifth year verification are outlined in TABLE X below. During interim years, the Project Developer is responsible for submitting annual monitoring reports.

YEAR 0 ACTIVITIES		
Review Documentation of Eligibility	- Confirm ownership and stewardship - Confirm minimum quality stds - Confirm Additionality	
Verify Credit Estimate Submitted to Market Administrator	- Review supporting documentation - Confirm Completion of appropriate implementation steps - Conduct site visit Submit verification report including credit estimate	
YEAR 1-4 (OFF-YEARS)	**COMPLIANCE-GRADE VERIFICATION**	**VOLUNTARY CREDIT VERIFICATION**
Verifiers review Annual Monitoring Reports (submitted by Project	- Review annual monitoring reports	Collect annual monitoring reports

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[3] GCP, Page 27.

Developer)	- Conduct site visits if needed	
YEAR 5 (5-YEAR CYCLE)	**COMPLIANCE-GRADE VERIFICATION**	**VOLUNTARY CREDIT VERIFICATION**
Full verification of project performance	- Review supporting documentation - Evaluate project based on performance criteria - Conduct site visit	- Review monitoring reports - Conduct site visit if needed

Figure 9: Ongoing verification/tracking activities

Additional Crediting Steps Not Covered in the IFCP

The IFCP outlines the crediting process steps that are unique to instream flow restoration projects including: project validation, credit calculation, project verification, and credit tracking. There are additional steps required for full crediting under the General Crediting Protocol. However, these steps are identical whether the project developed for crediting is an instream flow restoration project or another project type.

Appendix III

Transaction Verification Protocol

Deliverable 3

Please refer to the *Instream Flow Crediting Protocol v 2.3* in **Appendix II** for information related to this deliverable.

Appendix IV
Monitoring Verification Protocol

WATER TRANSACTION MONITORING PROTOCOLS:
GATHERING INFORMATION TO ASSESS
INSTREAM FLOW TRANSACTIONS

DECEMBER, 2013

VERSION 4.0

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List of Acronyms and Abbreviations

AIP	Aquatic Inventories Project
AREMP	Aquatic and Riparian Effectiveness Monitoring Program
CDFG	California Department of Fish and Game
cfs	cubic feet per second
CIG	Conservation Innovation Grant
cms	cubic meters per second
D.O.	dissolved oxygen
DWR	State of California Department of Water Resources
EMAP	Environmental Monitoring Assessment Program
GPS	Global Positioning System
LBP	left bank pin
LEW	left edge of water
NFWF	National Fish and Wildlife Foundation
NRCS	Natural Resource Conservation Service
ODFW	Oregon Department of Fish and Game
PDA	personal data assistant
POD	point of diversion
Q	stream discharge
RBP	right bank pin
REW	right edge of water
RTK	real-time kinematic
SOP	standard operating procedure
SWAMP	Surface Water Ambient Monitoring Program
Tw	water temperature
USEPA	United States Environmental Protection Agency
USFS	United States Forest Service
USGS	United States Geologic Survey

Executive Summary

Monitoring programs are generally designed to provide information about on-the-ground conditions at specified locations to help assess a specific objective. A stream flow monitoring program designed to assess the effects of an instream flow transaction (or water transaction) should provide more information: in addition to quantifying the actual on-the-ground stream flow responses, it should support an analysis of what conditions may have been if the water transaction had never occurred. To make this assessment, targeted data collection and specific tools may be applied to better quantify stream conditions with and without the flow transaction. These protocols were developed to guide monitoring activities in a range of hydrologic settings to support the analysis of instream flow transactions.

The instream flow monitoring protocol described in this document identifies the assessment tools, data needs, and monitoring programs necessary to examine three potential transaction objectives: streamflows (discharge), water temperature, and aquatic habitat. Generally, all instream flow transactions involve streamflow objectives, specifically focused on the quantification of water rights and their associated flow rates or volumes. Instream flow transactions may also have water temperature and/or aquatic habitat objectives. Depending on the objective, one or more tools may be applied to assess the environmental response of the water transaction. These tools may include a stream-discharge rating curve, the Water Temperature Transaction Tool (W3T), or an aquatic habitat rating curve. The data needs to apply these tools and assess the environmental response of an instream flow transaction guide the design of the monitoring program.

The stream flow monitoring methods described in this document can provide information that quantifies the effects of those transactions to the flow transaction project stakeholders. These assessments may occur prior to the implementation of a flow transaction to determine whether the transaction is an effective action to meet pre-determined objectives, or after the transaction has been implemented to confirm, or validate, its effects. Each phase (i.e., pre-transaction assessments or validation), has similar data needs; however, depending on available data and resources, the monitoring strategies may vary. Monitoring strategies that rely on limited or regional (rather than local) data or estimates may increase the amount of uncertainty in the assessment. For pre-transaction assessments, a higher level of uncertainty is acceptable as the purpose is to estimate a transaction’s environmental potential. However, when evaluating an actual transaction, less uncertainty is desirable so as to accurately quantify its actual environmental effect.

Fundamentally, the process of evaluating instream flow transactions requires experienced professional judgment. Identifying potential instream flow transactions; designing, implementing, and maintaining a monitoring program; and applying the data to evaluate their effects are all phases in the evaluation process that benefit from extensive background knowledge and training in the scientific methods that have been developed to examine flow, water temperature, and aquatic habitat characteristics. It should also be noted that those interested in conducting or attempting to implement a water transaction should additionally have or seek expertise with a strong background and/or understanding of state water laws, water right management, and the surface water management conditions of the targeted stream reach. While implementing these monitoring protocols and analysis methods can help inform managers and other policy-level stakeholders, the analysis process is designed for scientists, researchers, and other technical professionals with a strong background in stream flow monitoring and data analysis. These protocols can help guide experienced technical professionals through the process of gathering data to better evaluate and communicate actual stream flow response from an instream flow transaction.

Water Transaction Monitoring Protocols

1. Introduction

Water transactions are increasingly used in water management strategies to help balance competing demands of limited water resources across the western United States. A water transaction describes an agreement between two parties to transfer a specific water volume to the buyer from the seller, and provide a mechanism to apply water to alternative uses (e.g., instream environmental flows) in otherwise restrictive water right or regulatory frameworks. Water transaction programs, such as the Columbia Basin Water Transactions Program, have demonstrated how incentive-based approaches can successfully bring water resource use into balance with the natural ecosystem while preserving existing water rights. However, while the concept and potential of water transactions are becoming more widely understood, in practice, the actual benefit of these water transactions has at times been poorly quantified. By clearly quantifying the benefit of these water transactions, potential opportunities can be identified to successfully navigate through complex water resources challenges.

To address this need, The National Fish and Wildlife Foundation (NFWF) partnered with the Natural Resource Conservation Service (NRCS) through a Conservation Innovation Grant (CIG) to develop a standardized and targeted methodology to help quantify and evaluate the environmental effects of instream flow transactions. Over a three-year period from 2011-2013, NFWF collaborated with a range of water users and stakeholders throughout northern California and Oregon to study experimental transactions for the purpose of developing monitoring protocols to support emerging water markets. These monitoring protocols focus on three stream characteristics, and describe how to assess the effect of a water transaction using data collected through a monitoring program that is designed specifically to monitor the effectiveness of water transactions.

This water transaction monitoring protocol handbook begins by presenting some background information about water transactions, examples of environmental objectives, and a conceptual description of their general spatial and temporal scale – that is, how the stream reach affected by the transaction is defined, and the potential period when a transaction can occur. Next, an overview is presented of how a monitoring program that is designed for a transaction differs from more typical monitoring programs that are designed to monitor general stream conditions. Then, each stream characteristic is identified that can be used to evaluate a water transaction using these protocols. For each characteristic, an assessment tool, the tool's data needs, and monitoring approaches to address those data needs are identified. Finally, a summary is presented of how these protocols can be used to quantify the effects of a water transaction. Appendices with example monitoring methodologies, equipment, and datasheets for each stream characteristic are also included. With these protocols, experienced technical professionals can develop monitoring programs that provided the data needed to assess the effect of those transactions.

2. Water transactions

There are several components of water transactions that are helpful to understand before examining potential assessment tools and monitoring programs. Understanding potential water transaction objectives helps identify important elements of the monitoring program to assess the effect of the water transaction. Similarly, a conceptual understanding of a water transaction’s general spatial and temporal scale helps identify the spatial and temporal scale of the associated monitoring program. By defining potential objectives, as well as spatial and temporal characteristics of a transaction, the framework is established to illustrate the differences between monitoring programs that are designed to assess general stream conditions and those that are designed to evaluate the effects associated with the water transaction.

2.1. Objectives

Water transactions generally meet one or more objectives. These objectives include changes to existing:

- **fish passage –** enhanced flow may target critical riffles, enhance dewatered stream systems for migratory fish movements, or cue a migratory response for particular fish species.

- **fish oversummering / rearing habitat –** added flow would provide enhanced flow depth and area, maintain desirable water temperature, enhance pool volumes, extend habitat and/or prolong flow rates during the summer period for all aquatic/fishery life stages.

- **channel geomorphic maintenance –** supplementing or re-creating high flow conditions, typically during a run-off event with the intent of changing or maintaining functional geomorphic processes and/or enhancement of stream substrate conditions for aquatic species.

- **fish over-wintering –** enhancing stream flow during critical winter periods to provide available and/or adequate conditions for winter fishery needs.

- **water quality –** enhanced flow may improve water temperature, improve biological components, or reduce nutrient inputs into the stream system.

Depending on the objective of the flow transaction, one or more physical characteristics may need to be monitored. The specific protocol(s) implemented for a water transaction will depend on the transaction’s objective, and will be determined by the project partners or implementing organization on an individual basis.

2.2. Spatial and temporal scale

The area affected by the water transaction is generally referred to as the “beneficial” or “protected” reach. For purposes of this document, the term “beneficial reach” refers to the stream reach in which instream flows are augmented via water transactions to provide environmental benefits. Specifically, the beneficial reach is a defined stream reach for a specific water right, which begins at its associated point of diversion (POD), and extends downstream to an identified location where the flow could be legally diverted or the effects of the additional water (e.g., on discharge volumes, water temperature, or physical habitat characteristics) are no longer measureable, generally whichever occurs first (Figure 1). Since this document focuses on surface water transactions, diversions will similarly be limited to surface water use only, excluding groundwater transactions or groundwater pumps. The most common example of a POD in water transactions is a diversion ditch with a constructed headgate diversion structure (Figure 2); however, dams, pumps, and other water management infrastructure can at times function as a POD.

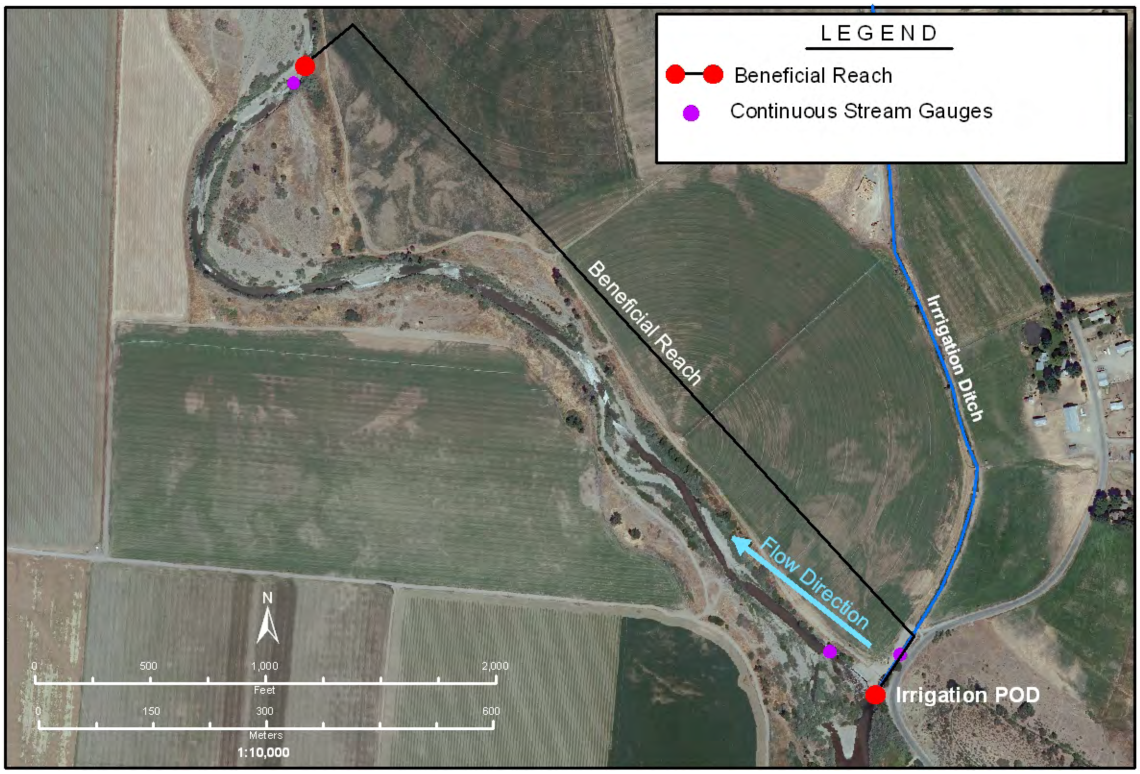

Figure 1. An example of a beneficial reach for a flow transaction.

Figure 2. An example of a POD. Pictured is an irrigation headgate with a continuous stage recorder located directly downstream.

The extent of a beneficial reach varies for multiple reasons. The legal elements of an associated water right, such as its priority date, diversion location, flow rate, and place and period of use, primarily determine when and where water may be put instream during a transaction to enhance a beneficial reach. Secondary considerations are within the design of the water transaction itself. Water transactions may be as simple as leasing one water right for one environmental objective in a targeted beneficial reach, which would require basic compliance flow monitoring at the POD location in addition to the environmental monitoring of the beneficial reach; or a water transaction may be much more complex with multiple lease agreements with multiple water right holders for multiple environmental objectives, requiring monitoring of multiple POD locations as well as various types of environmental monitoring of the targeted beneficial reach attempting to measure response. Identifying these objectives before the water transaction, then designing a plan or road map for project success, will further assist managers with determining the various costs necessary to implement a successful water transaction as well as how to best allocate limited project resources.

The timeline, or temporal scale, of a water transaction is firmly limited to when the water right holder may utilize the water right for its recognized beneficial use, referred to as the "period of use." In the western U.S., this period tends to reflect the growing season for agriculture, especially for "irrigation use" water rights. This generally occurs from April through October. However, most streams tend not to be flow limited or in need of enhancement until later in the summer season. Therefore, water transaction monitoring can occur over a period of months, weeks, or less, depending on when the instream flow enhancement is needed. Ultimately, water transactions may occur throughout the period of use, or for a portion of the potential diversion period. By specifying the water transaction objective, opportunities may then be identified to balance water use and instream flow needs in a way that benefits both.

2.3. Monitoring

There are some key differences between monitoring plans that are developed for assessing general stream conditions versus assessing the effects of a water transaction. General monitoring programs can evaluate spatial and temporal trends in flow, habitat quality or water quality. However, transaction monitoring is used to evaluate changes in flow, aquatic habitat or water quality associated with a specific transaction. The timing and goals of the transaction determine monitoring parameters.

Three stream features may be targeted by water transactions: flow, water temperature, and physical aquatic habitat. Analytical approaches have been developed to assess the effects of a transaction on each characteristic. These approaches generally include the application of tools that provide information about the relationship between streamflow and another characteristic, such as water temperature or physical aquatic habitat elements (e.g., width, depth, wetted area, etc.). Transaction monitoring programs provide the data needed to apply these assessment tools and quantify the effects of individual transactions. The following sections identify how each of the three stream features may be assessed during a water transaction and what components are recommended for their associated monitoring programs. For each feature, the assessment tool used to quantify the effect of a transaction is identified, including each tool's data needs and how it can be applied to evaluate instream flow transactions. Based on the data needs identified for each tool, various monitoring approaches are presented to illustrate how each parameter can be quantified using a range of potential data sources. Specific information is provided in the appendices.

Ultimately, the monitoring program that is designed and implemented for a transaction will depend on the objectives of the transaction. By identifying the transaction objective, limited resources can be effectively directed to monitoring activities that support the evaluation of the transaction, and limits the collection of extraneous data. Also, the elements that are included in a monitoring program to assess a transaction will be identified by project partners or the implementing organization on a case-by-case basis. Experienced technical professionals can refer to the appendices for examples of monitoring methodologies, equipment, and documentation; however, the final determination of monitoring approaches should be informed by on-the-ground knowledge of the transaction area, and should consider available resources.

3. Flow

Flow (or discharge) monitoring is a critical component of a water transaction monitoring program and should be implemented for all transactions to ensure protections of project water rights and project investments. Accurately accounting for contracted water rights and/or flow then provides the basis for quantifying relationships between flow magnitudes and other stream characteristics (e.g., water temperature, aquatic habitat). It also provides a method with which to document the events of the transaction (e.g., the time when diversions cease and the contracted flow is left instream). To make this assessment, detailed flow records over the period of the transaction are recommended. A monitoring approach that provides data to develop rating curves and time series flow records can provide a robust foundation for a transaction assessment.

In this section, an overview of the assessment tool used to develop flow records is presented, including its data needs and how it can be applied to a water transaction assessment. Then, the recommended monitoring approach is described to illustrate a comprehensive program to quantify flow during a water transaction. In some situations, limited resources may preclude the implementation of the recommended monitoring approach. To illustrate how to address those situations, examples of transaction analyses are presented in which alternative approaches were used to quantify flow at critical locations were made. By understanding the assessment goals, transaction stakeholders can decide how to best allocate limited resources to target high-value monitoring objectives.

3.1. Assessment tool: Discharge rating curves

Because water transactions generally occur over extended periods such as weeks or months, flow volumes typically change in response to daily and seasonal meteorological and hydrologic conditions. As the natural hydrograph fluctuates and instream flows change, so do the potential effects of a water transaction by influencing the allowable diversion rates of active water rights. To examine how the effect of a water transaction might change during the transaction period, detailed discharge records are important. However, allocating resources to manually take sub-daily flow measurements is often impractical. Instead, rating curves are used to develop a relationship between two parameters. For flow monitoring, rating curves typically relate stream stage to discharge. Automated monitoring of stream stage, combined with periodic manual measurements of discharge, is an inexpensive and efficient approach to developing detailed time series flow records, improving the transaction analysis and project assessment.

In some cases, discharge records may be available from alternative sources and rating curves may not be necessary. If the transaction is taking place in a reach where a rated monitoring station has already been established, then the discharge record from that station may be used in lieu of developing a separate rating curve. Also, other approaches may be used to develop discharge records, such as implementing equipment that automatically calculates discharge based on channel geometry (e.g., sonar devices installed in culverts). Ultimately the final method should be identified based upon monitoring needs, project costs, and transaction stakeholders. However, for the purposes of this document, developing a rating curve using time series stage data and periodic discharge measurements suits a broad range of potential transaction groups, making it the most appropriate approach for this application.

3.1.1. Data needs

The data needs to develop rating curves are relatively minimal (Table 1). Rating curves are developed using stream stage data at a specified monitoring location and discharge measurements taken over a range of flow volumes. To confidently apply rating curves to a wide range of flows, gathering discharge measurements at varying stage heights over the course of the transaction is recommended (i.e. ranging from peak flows to minimum flows). Additional details describing rating curves and their data needs can be found in Rantz et al. (1982b).

Table 1. A summary of the parameters needed to develop rating curves to assess stream flows associated with a transaction.

Category	Parameter(s)	Potential source
Discharge	Stage Channel depth Channel width Velocity	Field measurements Existing stations Stage recorder

Robust rating curves include at least five measurements taken over the course of the water transaction, at a range of flow conditions (Figure 3). The rating curve illustrated in Figure 3 was developed using multiple measurements taken over a range of flows, mostly between 0 ft^3/s and 150 ft^3/s. A power function is used to define the curve, and the R2 value indicates how well the function fits the pattern of measured flows (R^2 values of approximately 0.9 or greater are desirable; R^2 values lower than 0.8 are considered weak and associated rating curves should be applied conservatively). Within this range, the curve can be confidently applied; however, the single measurement taken at 300 ft^3/s indicates that the curve should be applied with caution above 150 ft^3/s. While the fitted curve illustrated on the figure extends beyond 300 ft^3/s, the lack of data indicates that applying the curve for higher flows is not recommended. However, it should be noted that rating curves with power functions are best for low to moderate flow conditions contained within a single channel, and are not ideal for rating flows during periods of overbank flooding.   Because most flow transactions are necessary due to "flow limiting" conditions, this approach was deemed more practical and acceptable for flow transaction monitoring.

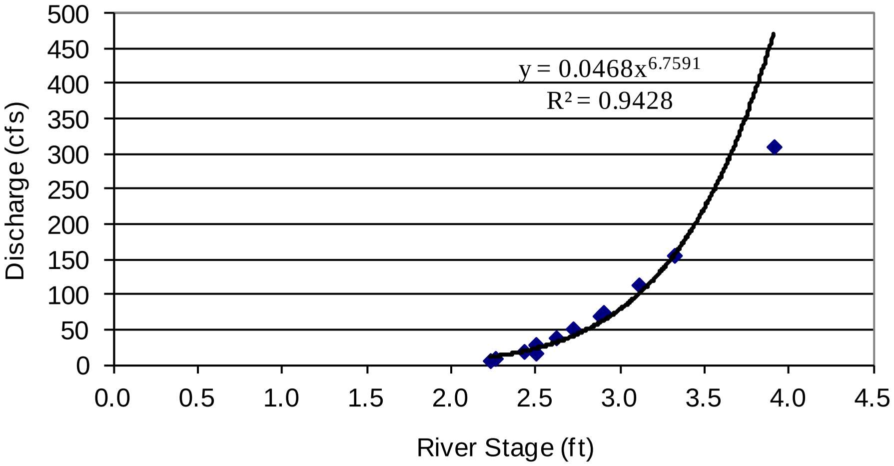

Figure 3. An example of a rating curve relating stream stage to discharge.

3.1.2. Application

Once instruments have been installed and the flow measurement data has been collected, the rating curve can be developed and applied to a time series stage dataset to develop a time series flow record. Care should be taken to apply the rating curve to the appropriate range of stage data. An examination of the rating curve and the points used to develop the curve can indicate where more conservative applications are warranted, as illustrated by the example in the previous section.

Developing a time series flow record allows transaction stakeholders to examine the continuous stream conditions and the effects of a transaction over a range of flows using a modest amount of monitoring resources. Applying the rating curve in this manner can provide valuable insight to the transaction, such as whether the transaction had a diminishing effect as flow volumes decreased, or whether there was a critical threshold at which the transaction provided high value. Such findings can help maximize opportunities for water users and project managers by identifying high value flow objectives for instream conditions.

3.2. Monitoring

A monitoring program that is designed to consider the objectives of a water transaction can provide valuable information with which to evaluate the transaction. Examining a project's targeted beneficial reach for existing monitoring equipment is strongly recommended to efficiently allocate resources. However, in the absence of existing monitoring equipment, several key locations should be considered for flow monitoring as part of a water transaction. Conducting a pre-project site visit is again strongly encouraged to help determine project needs and requirements prior to implementing these monitoring protocols.

To best quantify and track surface water flows during a flow transactional project, a minimum of two locations should be selected and gaged for flow monitoring:

1. The upstream boundary of the beneficial reach (located at, or within 100ft downstream of the POD)

2. The POD at which the water right is diverted from the stream (e.g. headgate, dam outlet gates, or pump diversion), and

For most water right flow transactions, the primary area of flow monitoring will be in the stream channel at or near the POD location of the water right (Figure 4). Monitoring stream flow at this location helps quantify the flow contributed by associated water rights within the beneficial reach at a specific place and time. The absence streamflow records at the upstream boundary of the beneficial reach creates considerable uncertainty and results in a relatively weak evaluation of the transaction. The POD site is the legal location where water right is diverted from its water source (e.g. stream), and may already be monitored for quantification and appropriation compliance by a water agency, however, without this diversion record, and measurement records for stream flows at the POD, no evaluation or understanding of the water transaction can be determined. For transactions in which a portion of the water right is contributed to instream flows (while the remaining portion is still diverted), automated monitoring of the POD is recommended. While transactions in which the entire water right is leased to augment instream flows, visual confirmation that no diversions are occurring at the POD is sufficient. Finally, if resources permit, an additional monitoring site is recommended at the downstream boundary of the beneficial reach, which may provide valuable information about potential gains or losses in the transaction's project area. In the absence of other streamflow data, assumptions about the water rights volume and gains/losses through the protected reach can be made to evaluate the transaction. If additional inflows or outflows of surface water occur anywhere in the flow transactional project's targeted beneficial reach, these locations should also be monitored for flow discharge with continuous flow gaging instrument.

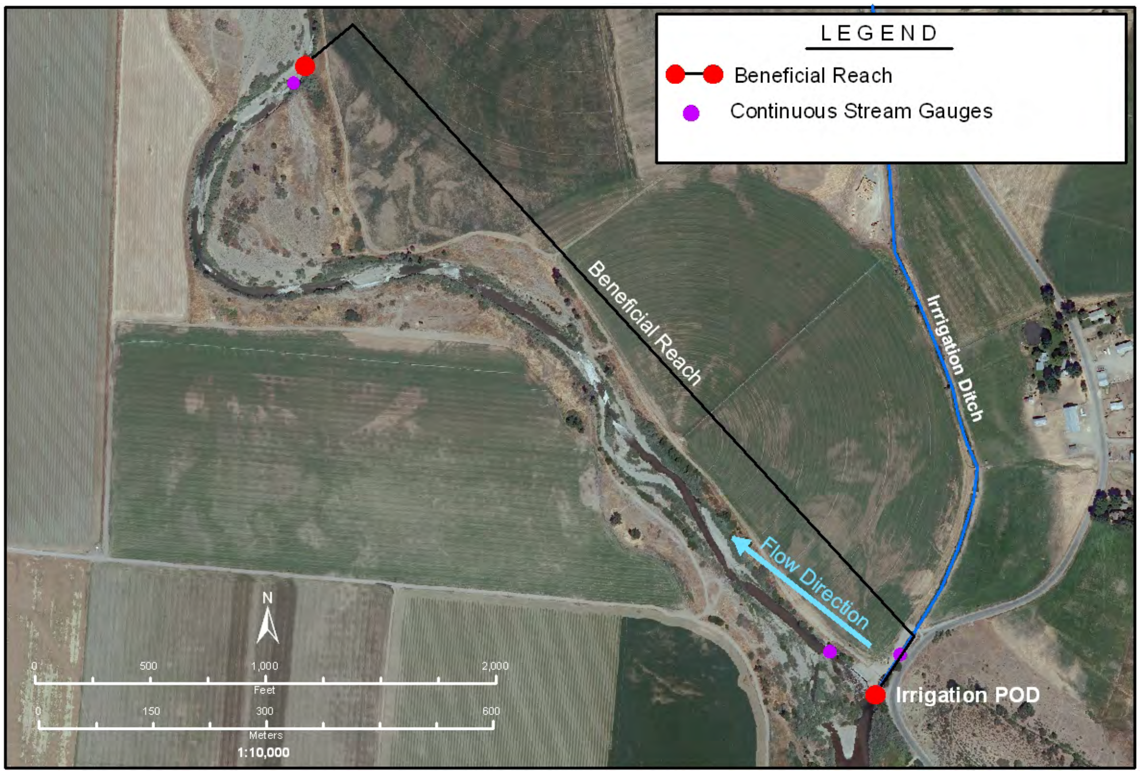

Figure 4. An example of a beneficial reach for a flow transaction.

3.3. Summary

Flow monitoring is important to quantifying, documenting, and administering a water transaction. Several methods can be used to evaluate streamflows; however, developing rating curves to create time series flow records is an approach that is widely used throughout the scientific community, requires relatively modest resources to implement, and is suitable for a broad range of basins. In the absence of existing rated flow monitoring sites, monitoring streamflows using rating curves is recommended. By monitoring key sites, including the upstream boundary of the beneficial reach, the POD, and the downstream boundary of the beneficial reach, stakeholders can quantify the hydrologic conditions during the transaction with minimal uncertainty. In the event that limited resources prevent the implementation of the recommended monitoring design, alternative approaches may be used. These alternatives should be identified in cooperation with all transaction stakeholders and clearly documented.

4. Water temperature

Addressing water temperature conditions is often a primary objective of flow transactions. However, determining the effect of a transaction on water temperatures requires more information than simply monitoring water temperature conditions in the beneficial reach during the transaction period. To evaluate the benefit of a transaction effectively, water temperature conditions during the transaction must be compared to conditions that would have occurred without the transaction. To make this comparison, the Water Temperature Transaction Tool (W3T) can be used to simulate water temperature conditions in the beneficial reach for a range of flows. With a modest amount of data, this tool can be used to evaluate the potential benefit of a transaction before the transaction has been implemented. To evaluate a completed transaction, a more robust data set is required. The results of those simulations can help evaluate whether a transaction is an effective action to address a specific water temperature objective with various hydrologic scenarios. A monitoring program that supports the application of W3T can provide the information needed to effectively characterize the water temperature benefit of a flow transaction prior to or following its implementation.

In this chapter, an overview of the W3T and its role in evaluating flow transactions will be provided. Then, the data needs to implement and apply W3T will be identified. Once the data needs to evaluate the water temperature benefit of a flow transaction have been identified, examples of monitoring programs will be presented that demonstrate the process of assessing the water temperature benefits of a flow transaction. While the recommended monitoring programs all include the same monitoring elements, the resolution of the data needed to quantify those elements varies depending on whether a transaction is being pre-screened at a regional level (i.e., assessed prior to implementation to determine its potential effects) or validated on-the-ground (i.e., evaluated after the transaction has been implemented to evaluate its actual benefit). Examples of data used to pre-screen or validate transactions are provided to help identify potential approaches, limitations, or considerations that may apply to other flow transactions.

4.1. Assessment tool: W3T

The Water Temperature Transaction Tool (W3T) is a spreadsheet model that was developed to assess the water temperature benefit of a flow transaction by simulating water temperature conditions given various instream flow management strategies. A user’s guide (Watercourse 2013) detailing its background, technical development, and operating instructions was developed separately from this document. To operate, this tool requires some data describing channel geometry, meteorology, shading, flow, and water temperature. While traditional monitoring programs can inform water users about the water temperatures during a flow transaction, they generally do not provide enough information to demonstrate how the transaction changed water temperatures from baseline conditions – that is, what water temperatures would have been if the transaction had not occurred. Without this information, the effectiveness of a transaction cannot be assessed, creating uncertainty about the value of the investment. Because water is valuable to many users, including agricultural or environmental uses, a clear understanding of the benefits associated with a specific transaction is critical to ensure that limited resources are managed effectively.

4.1.1. Data needs

To operate W3T, field data and other information must be provided. Data sources depend on the user's objective. W3T can be used to "pre-screen" transactions to estimate whether the transaction has potential to be effective. For pre-screening applications, historical data or estimates based on aerial photographs, maps, flow records or comparable features in similar stream systems may be a sufficient starting point. W3T can also be used to validate a transaction; that is, data collected during the transaction can be used in W3T to confirm that the transaction provided the desired effect. For validation, a higher level of data collection is required, and the transaction monitoring program should be designed with that consideration. A summary of the data needs and potential sources, depending on whether the transaction is being pre-screened or validated, is provided in Table 2.

Table 2. A summary of the data needs and potential data sources for the W3T model.

Category	Parameter(s)	Recommended potential sources	
		Pre-Screening	Validation
Meteorology	Air temperature Wet bulb or dew point temperature (calculated) Wind speed Relative humidity	Weather station (regional)	Weather station (local) GPS
Geometry	Planform (x-y description) Elevation Channel gradient Channel cross-section Channel roughness	Google Earth Proxy Literature values	Field surveys GIS
Flow	Boundary conditions (in) Upstream inflow Tributary, return flows, and discharges Seeps/springs etc. Boundary conditions (out) Diversions Losses Validation Downstream flows at end of protected reach	Modeled flows Watershed models Rainfall models Other models Estimates Watershed area Minimum flow Field observations Existing flow gages	Field observations Existing flow gages Spot measurements Stage recorder and rated section
Water Temperature	Boundary conditions (in) Upstream inflow Tributary, return flows and discharges Seeps/springs etc. Validation data Downstream temperature at end of protected reach	Modeled temperatures Various models Estimates Equilibrium Nearby systems Field observations Spot measurements FLIR/TIR	Field observations Existing loggers Deployed loggers
Shade	Left bank and right bank vegetation assemblage types and density (see Shade-a-lator requirements)	Google Earth Proxy/estimate Literature	Field surveys GIS/Lidar

4.1.2. Application

During the pre-screening phase, a potential transaction is evaluated to estimate its effect on water temperature. Ideally, this phase would occur after the transaction area (or beneficial reach) had been characterized using data from a baseline assessment program; that is, previous studies had been completed that identified the beneficial reach as an area where a water temperature impairment (e.g., elevated water temperatures) occurred, and some effort had been made to characterize different elements that can affect the heat budget in that reach, including geometry, vegetation (aquatic and riparian), and various inflows and outflows. In reality, though, available data is often limited, or was collected for a different study objective and does not necessarily provide optimal information that can be used to pre-screen a flow transaction. While limited data increases the uncertainty of a pre-screening assessment, it does not preclude the assessment. Specific categories of data are required to pre-screen a transaction, but a broad range of sources, including estimates made using regional monitoring stations, aerial photos, or proxy systems, may be utilized and deemed appropriate for this level of analysis.

During the validation phase, a completed water transaction is assessed to quantify the effect on stream temperatures. This validation requires more information than would be needed to assess stream conditions during the transaction; the objective is to evaluate the effectiveness of the transaction as a strategy to address water temperature objectives in a particular location and during a specific period. In this way, resources can be allocated to effective water management activities, while less valuable activities can be phased out of broader management strategies.

While the same types of data are needed to use W3T, the data sources and collection methods are designed to provide a higher resolution of information that can be used to evaluate specific transactions. In this section, monitoring recommendations to help evaluate flow transactions are presented for each parameter in W3T. In some cases, limited resources may preclude monitoring of each element to a high level of detail. Depending on the amount and type of data available, some transactions can still be evaluated for water temperature even if the monitoring program was not specifically designed for validation.

4.2. Monitoring

For flow transactions that are designed to address water temperature objectives, the scope of a monitoring program varies depending on whether transaction is in the pre-screening or validation phase, as well as available resources. During the pre-screening phase, a potential transaction is evaluated to determine whether its implementation may warrant the time and resources to implement, monitor, and administer the transaction given its potential effect on water temperatures. Because the benefit of the transaction is unknown, balancing the resources needed to collect preliminary data to evaluate the transaction and the desire not to overinvest in a potentially less effective transaction is critical. Once a transaction has been implemented, though, collecting a robust dataset is critical to determining the benefit of the transaction with a narrow range of uncertainty. Thus, a more robust monitoring program is recommended for implemented transactions to gather the more-refined dataset.

To illustrate how a monitoring program could be designed for the pre-screening or validation phase of a flow transaction, a conceptual design of each is presented, followed by examples based on experimental flow transactions that were proposed or implemented to address water temperature. In each example, the available data is identified as well as areas where alternative approaches were developed to estimate unknown parameters.

4.2.1. Meteorology

Meteorology describes the daily weather conditions that affect the daily and seasonal heat budget, and is characterized by a wide range of elements. Some of these elements, like solar radiation, are calculated by W3T. However, information describing other elements is necessary to operate the tool. These elements include:

- Air temperature
- Wet bulb or dew point temperature
- Wind speed
- Relative humidity

Air temperature, wind speed, and relative humidity are commonly monitored at meteorological stations. Wet bulb or dew point temperatures can be calculated. During the pre-screening process, a flow transaction can be evaluated using data collected from regional meteorological stations. While stations located near the beneficial reach are preferred, others located within the basin are acceptable sources of meteorological data. Differences between the location of the beneficial reach and the meteorological station, such as elevation and the distance from each other, should be noted to document potential sources of uncertainty in the results.

Because meteorological conditions can strongly influence the daily and seasonal heat budget of a stream, data collected near the stream site can provide insight to microclimate influences that may not be captured by regional meteorological stations. For example, local differences in air temperature can result in statistically significant differences in simulated water temperatures (Willis and Deas 2010). If the monitoring objective were to generally characterize meteorological conditions during a specified period, then regional meteorological data may be sufficient. However, to evaluate a flow transaction, small differences in simulated water temperatures may be important, particularly if the potential temperature reductions are small (i.e., < 1°C) and occur near important thresholds for aquatic ecosystems. Therefore, to accurately validate the effect of a flow transaction on water temperatures, collecting meteorological data near the protected reach is preferred where possible.

4.2.2. Geometry

Geometry describes the direction, shape, gradient, and elevation of the stream channel, all of which are critical to determining heating and cooling trends. The data needed to describe stream geometry includes:

- planform description (x-y coordinates)
- elevation
- channel gradient
- channel cross-section (wetted width, side slope)
- channel roughness

While some or all of this data may be available from previous characterizations, much of this information can be estimated from aerial photographs or publically available resources like Google Earth to pre-screen transactions. The planform description provides a general description of the direction of flow; for example, north to south, east to west, etc. This can be easily determined from aerial photography or a map. Elevation and channel gradient can also be estimated from Google Earth or topographic maps. By calculating the difference in elevation at different points in the stream, the channel gradient can be estimated. Channel cross-section information can also be estimated using aerial photography, though this method can be imprecise. W3T considers the wetted width in the channel given a specified flow, rather than the full channel width (which may not be fully wetted at low flows). Side slopes and channel roughness can be estimated from literature values.

To validate the effects of a transaction, geometry data collected in the protected reach is desirable. Width and depth data can be collected concurrently with flow measurements to provide a coarse description of channel cross-sections. Cross-section surveys taken at several locations throughout the protected reach using equipment such as real-time kinematic (RTK) survey equipment would provide high-resolution data, reducing one potential source of uncertainty in the transaction analysis. However, depending on available resources, alternative approaches may be sufficient.

4.2.3. Flow

Quantifying flow in the beneficial reach is highly important to accurately assess the effects of a flow transaction. During the pre-screening phase, flow rates may be estimated when little or no data is available to characterize the water transaction project area. Models, minimum flow estimates, or existing flow gages may be potential sources of information to help guide or refine pre-screening analyses. However, when validating an implemented transaction, each inflow and outflow in the beneficial reach should be identified, including the upstream and downstream boundaries of the reach, tributaries, diversions, return flows, and other flow sources or losses (Table 2). A detailed description of flow monitoring is presented in section 3. While the recommended monitoring array identifies three locations (e.g., top of beneficial reach, bottom of beneficial reach, and POD), some transactions can be quantified by monitoring discharge using alternative approaches. In some cases, fewer monitoring locations are acceptable to monitor flow during a transaction. However, for other transactions, following the recommended flow monitoring guidelines provides a robust foundation on which to assess flow transactions.

4.2.4. Water temperature

Water temperature data is important for making an accurate assessment of a potential or actual instream flow transaction. An analysis of existing water temperature data can indicate whether the transaction is addressing water temperature conditions near a critical threshold (i.e., such as reducing elevated water temperature near the threshold between sub-optimal to optimal, or detrimental to sub-optimal), and can also indicate how much of an effect is necessary for the transaction to be effective. This information provides the criteria for evaluating the effectiveness of a transaction.

Several data sources can be used to characterize water temperature conditions in the protected reach. Ideally, sub-daily (e.g., hourly or half-hourly) water temperature data is recommended as W3T evaluates sub-daily changes to water temperature through the protected reach. Important monitoring locations include the upstream and downstream boundary of the protected reach, tributary inflows, point of return flows, and other inflow/accretion locations. A conceptual example of water temperature monitoring locations in the protected reach is provided in Figure 5. To assess potential transactions, other sources of data may be used, including modeled water temperatures, estimates, or spot measurements. However, to assess an implemented transaction, water temperature data gathered at the recommended locations in the protected reach is important to completing an accurate assessment.

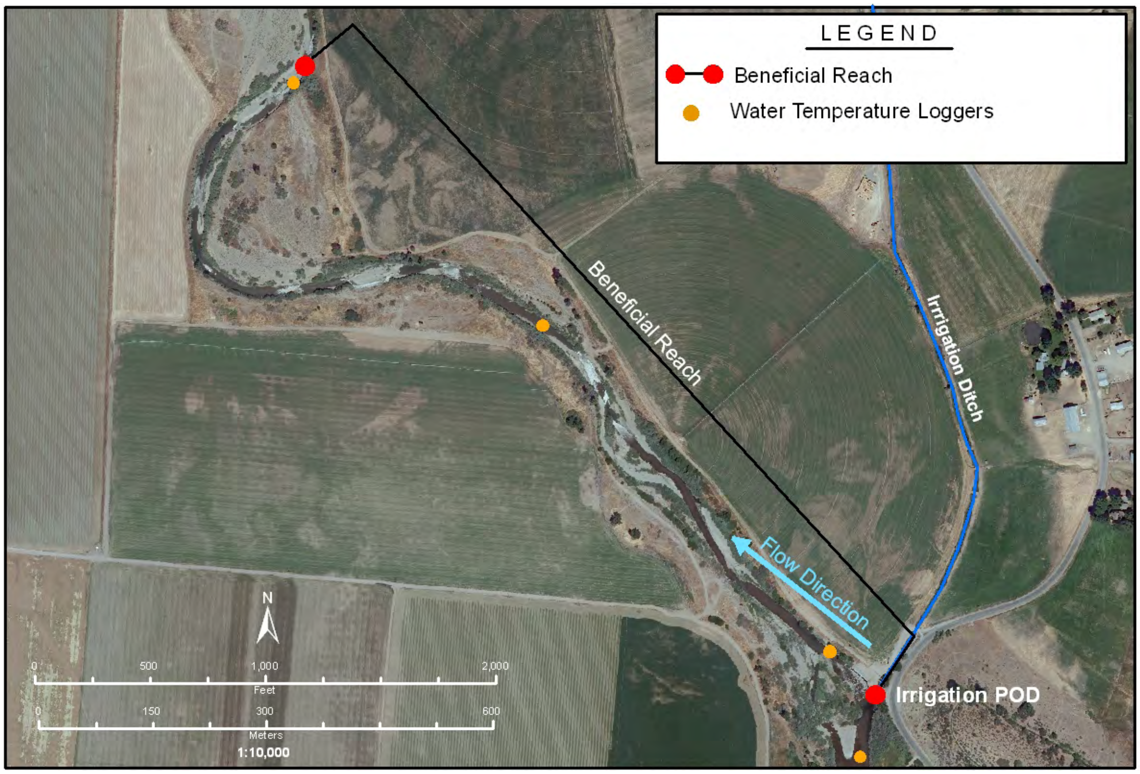

Figure 5. An example of a water temperature monitoring array.

4.2.5. Shade

Shade is the last parameter in W3T, and is quantified by the riparian vegetation (or land cover) features in the beneficial reach. Unlike the other parameters, which require measured data, a simple conceptual description of shade features is needed to assess a potential or implemented transaction. Once a vegetation or land cover type has been selected, W3T calculates the shade (i.e. solar radiation reduction) based on height and density features that are predefined in W3T. As such, the monitoring needs to quantify shade are minimal. Estimates of riparian vegetation or land cover can be made using images from Google Earth or proxy stream systems. Field surveys can provide more precise inventories of riparian vegetation and may indicate any potential discrepancies between observed conditions and W3T assumptions. For example, a field survey may indicate that a vegetation type has a difference density or height than the ones defined in W3T. This information allows users to identify potential sources of uncertainty.

4.3. Summary

The purpose of transaction monitoring is to provide information to evaluate the effects of the transaction. To evaluate transactions with water temperature objectives, W3T can be used to assess potential or implemented transactions. Thus, monitoring programs for these transactions are designed to collect data needed to apply W3T, and extend beyond monitoring water temperature and instream flow conditions. Meteorology, geometry, and shade data or estimates are also needed to assess the effects of a transaction on water temperatures. Potential sources for this information range from field measurements to estimates based on aerial photography, literature values, proxy watersheds, model results, and others. Limited resources may preclude extensive monitoring of the transaction; however, uncertainty of the results increases with the number of estimates/assumptions. For transactions that are being pre-screened to estimate their potential effectiveness, but have not been implemented, results with a wider range of uncertainty can still yield valuable insight. However, for analyses that focus on verifying implemented transactions, less uncertainty is desirable to accurately quantify the actual effect of the transaction. Experienced professional judgment plays a large role in an analysis of instream flow transactions to determine which assumptions are acceptable for pre-screening or verification objectives.

5. Aquatic habitat

Some water transactions have specific aquatic habitat objectives such as increasing available physical habitat for fish passage and/or rearing. To assess the effect of transactions with aquatic habitat objectives, rating curves are developed to relate aquatic habitat physical parameters to stream flows at selected channel cross-section locations. These rating curves can then be applied to determine how much physical aquatic habitat was gained with the addition of the contracted water volume. An overview of aquatic habitat rating curves, their data needs, and application is presented in this section, followed by a description of the monitoring activities that support the development of aquatic habitat rating curves.

5.1. Assessment tool: Aquatic habitat rating curves

Aquatic habitat rating curves represent relationships between flows and specified physical aquatic habitat parameters. Based on water transaction experiments, two parameters were identified that provided valuable insight to the effect of a water transaction when related to flow: wetted area and pool volume (Nichols et al. 2013). The analysis approach and methodologies provided in this document can be adapted to use other parameters. The parameter that is selected to support the analysis of a water transaction should be identified by experienced technical professionals in collaboration with transaction stakeholders.

5.1.1. Data needs

The data needs to support the development and application of aquatic habitat rating curves focus on a few key parameters that characterize cross-section topography and the wetted channel. Stream flow, wetted channel width, average channel depth, and depending on transaction, pool length, are all used to characterize the effects of a water transaction (Table 3). Stream flow data is required for all aquatic habitat rating curves as it provides the basis to evaluate changes in habitat parameters due to changes in stream flow. Wetted width and average depth data are also required to assess the effects of a transaction, and are used to characterize wetted area. For transaction in which habitat volumes are of interest (e.g., transactions that are designed to increase the amount of available pool volume habitat), additional data describing the length of the specified habitat reach is also required.

Table 3. A summary of the parameters need to assess the effect of water transactions on aquatic habitat.

Category	Parameter(s)	Potential source
Discharge	Channel depth Channel width Velocity	Field measurements Existing stations Stage recorder
Aquatic habitat	Channel depth Channel width Reach length	Field measurements

5.1.2. Application

The primary hydrologic variable that is used to assess aquatic habitat is wetted area. While other aquatic habitat parameters, such as wetted perimeter, also quantify aquatic habitat, the results of experimental water transactions illustrated that related stream flow to wetted area (or pool volumes) provided a robust assessment of water transactions in a broad range of hydrologic settings (Nichols et al, 2013). By applying standard hydrologic rating methods (Leopold and Maddock, 1953), the relationship between stream flow and aquatic habitat conditions can be evaluated. These analytical techniques are based on hydraulic geometry data, and are commonly used to identify desired instream flows (e.g. Jowett, 1997; Gippel and Stewardson, 1998; Reinfelds et al., 2004). Using this empirical approach, hydraulic-streamflow rating curves are developed using power functions (see Dunne and Leopold, 1978) of the general form

$$y = aQ^b ,$$

where:

y = hydraulic variable;
Q = mean daily discharge;

"a" and "b" = empirically derived coefficients and exponents, respectively.

An example of an aquatic habitat rating curve is presented in Figure 6.

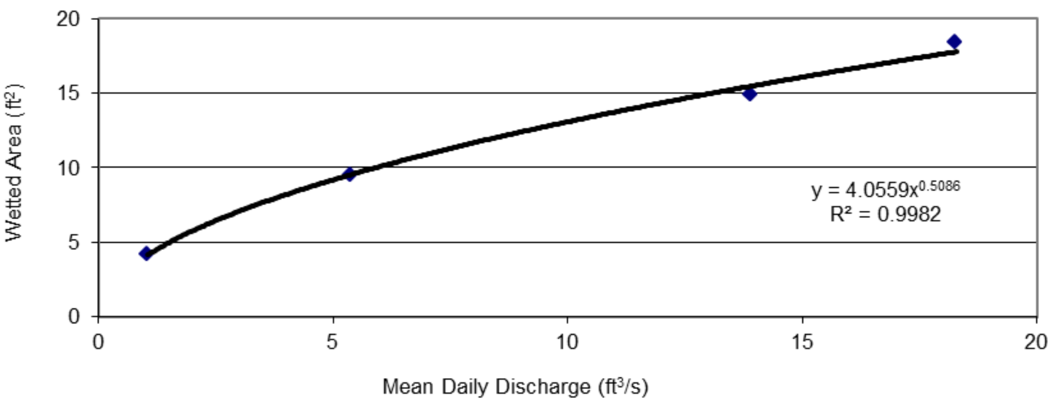

Figure 6. An example of an aquatic habitat rating curve, where the wetted area of the monitoring location is related to mean daily discharge.

Analytical procedures to examine the relationship between pool volumes and stream flow are largely derived from those presented by Hilton and Lisle (1993). During each survey period (i.e., unique streamflow), wetted area is calculated for each surveyed cross-section transects (details describing monitoring approaches and methodologies are included in section 5.2 and Appendix A). The average wetted area for the upstream and downstream cross-section of the targeted pool is multiplied by the channel centerline distance between each pair to calculate the pool volume. Using hydraulic rating methods similar to those previously discussed, a streamflow-pool volume rating curve can be developed.

Once the curves have been developed, changes in aquatic habitat that are associated with transaction flows can be evaluated. This assessment can be made at a specific location (e.g., a reach where aquatic habitat limitations have been identified, such as a generally dewatered reach), or examine the general change across a habitat type use one or more representative monitoring locations (e.g., pools, riffles, etc.). To evaluate the general effect of the transaction across all habitat types, rating curves should be developed for each cross-section included in a randomized set of aquatic habitat monitoring locations. Additional guidance regarding the number and types of cross-sections that should be monitored to evaluate aquatic habitat is provided in Appendix A.

It should be noted that the location and duration of a transaction can affect the application of aquatic habitat rating curves. Channel geometry may affect the strength of the rating curve, suggesting that alternative approaches may better characterize the relationship between stream flow and aquatic habitat in some systems, particularly if alternative parameters (e.g., wetted perimeter) are selected to characterize aquatic habitat (Gippel and Stewardson, 1998). Also, short duration flow transactions (several days to weeks) typically do not enable the generation of habitat rating curves using hydraulic rating methods, largely due to an inability to measure habitat variables across a sufficient range of flows. Results from experiments performed to develop these protocols indicated that power relationships between discharge and wetted area could be applied across a broad range of stream systems as they are least sensitive to geometry and because water transactions generally occur over a period of weeks or months. However, alternative relationships may be developed given specific transaction objectives; in such cases, experienced technical professionals should identify and document the reasoning and methodologies used for the alternative approach in collaboration with transaction stakeholders.

5.2. Monitoring

To support a robust analysis of the effect of a water transaction on aquatic habitat, field data should be gathered to develop the aquatic habitat rating curve. Alternative methods can be used to develop flow records and have been described in detail in previous sections; however, flow through each cross-section should be well-characterized. Aquatic habitat data is gathered via manual field surveys. Details describing methodologies, documentation, and data sheets are included in Appendix A. Because aquatic habitat changes focus on the wetted dimensions of the channel (as opposed to the dimensions of the general channel shape), and because accurate relationships between aquatic habitat and discharge are critical to any evaluation of a transaction, alternative methods to develop the rating curve are generally unsuitable for this type of analysis.

Generally, 11 cross-section sites are recommended as per U.S. Environmental Protection Agency’s Environmental Monitoring Assessment Program (EMAP) (). However, available resources may limit the number of field visits that can be completed to conduct the aquatic habitat surveys. At least five cross-sections are recommended to develop aquatic habitat rating curve. When fewer cross-section surveys occur, site visits may be timed so that the surveys occur over a range of streamflow conditions. The data collected over the range of conditions supported the development of rating curves that related wetted area to discharge at multiple habitat types, including riffles (Figure 6) and pools (Figure 8). Using these curves, the water transaction may be evaluated for individual monitoring locations, and the general effect may be characterized through the beneficial reach.

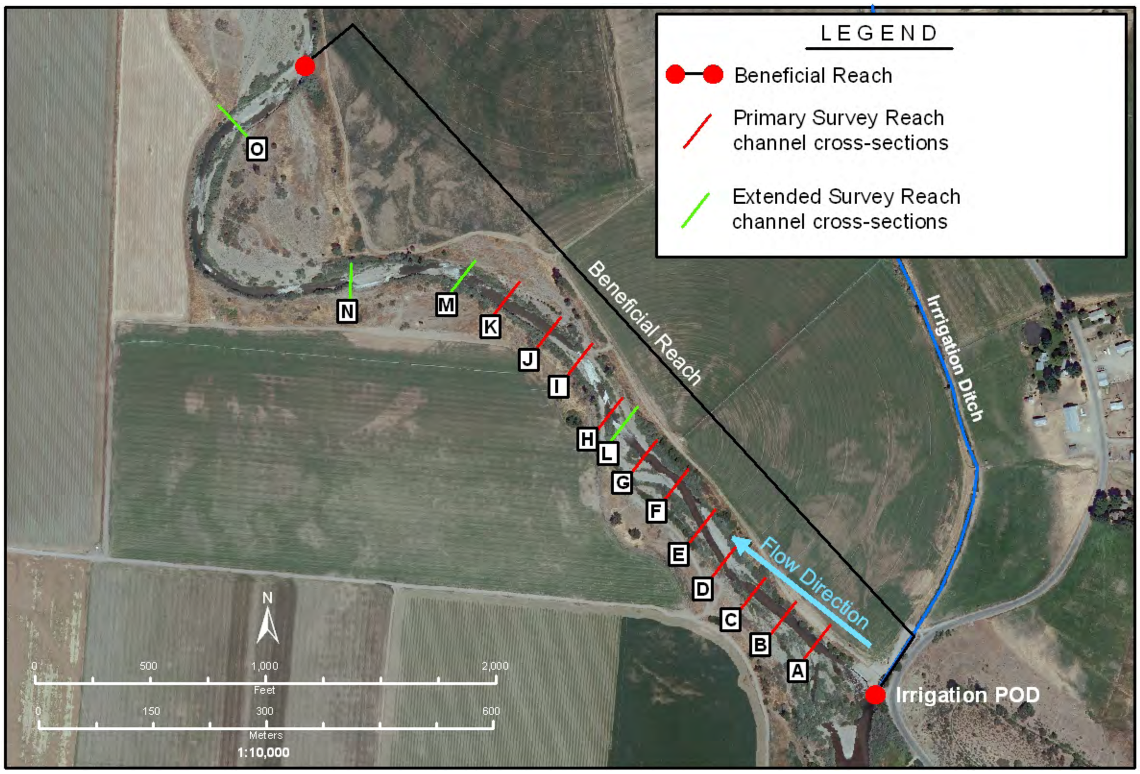

Figure 7. An example of an aquatic habitat monitoring array.

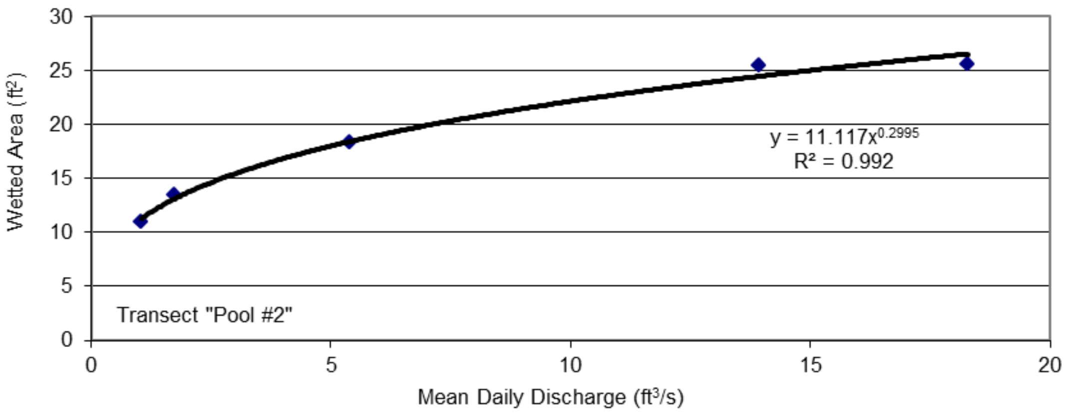

Figure 8. A rating curve that was developed with the minimum recommended survey events to examine the relationship between discharge and wetted area for a pool located in Patterson Creek.

5.3. Summary

Water transactions that are designed to address physical aquatic habitat objectives can be evaluated by examining the relationship between stream flows and a specified parameter, such as wetted area. This relationship is quantified using a rating curve. Aquatic habitat rating curves that have been developed for relatively stable cross-sections can be used to assess completed transactions as well as estimate potential benefits of future transactions. Generally, relationships between discharge and wetted area of pool volumes provide a robust assessment of the effects of a flow transaction. Consideration of the transaction objective as well as local channel features can help identify appropriate alternative aquatic habitat parameters.

Monitoring activities to support the development of aquatic habitat rating curves can be completed with relatively low-tech field sampling methods; however, no alternative approaches have been identified that provide a suitable level of certainty to support water transaction analyses for this objective. Gathering data over a range of flows improves the resolution of the rating curve. Similarly to discharge rating curves, aquatic habitat rating curves are generally applicable to transactions that occur within the range of flow volumes for with physical habitat parameters were monitored. Applying these rating curves outside of the monitored flow range should be done with caution.

6. Summary

Water transactions introduce a flexible mechanism with which to address instream flow objectives while working within current water right frameworks. Tools have been developed to assess the effect of water transactions on instream flows, water temperatures, and physical aquatic habitat. By using these tools to quantify the effects of a transaction, proponents of instream flows can demonstrate to water right holders the value of leasing their water, and water right holders can assess the value of their respective water rights for specific transaction objectives. Such quantifications could provide valuable insight to water users who are affected by regulatory objectives for instream conditions.

The monitoring programs for transactions with instream flows, water temperature, or aquatic habitat objectives are designed to collect data that supports the analysis of the transaction. As such, these programs include elements that go beyond a general characterization of on-the-ground conditions. For some assessments, alternative approaches may be used to quantify each parameter; for others, such as aquatic habitat assessments, direct field measurements are the only recommended approach to gather the appropriate monitoring data. As with any assessment, trade-offs between available resources and desired accuracy in the results should be considered when alternative approaches are implemented. Details describing example monitoring methodologies, transaction documentation, and data sheets are provided in Appendix A.

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Appendices

Appendix A. Monitoring methodologies, documentation, and data sheets

The monitoring methodologies recommended in these protocols generally reflect common industry practices. An overview of those methods is provided for stream flow, water temperature, and aquatic habitat assessments to illustrate the general approaches that may be taken to gather the appropriate field data. Local considerations may indicate that certain aspects of these methods should be adapted; the final monitoring methodology should be determined by experienced technical professionals.

Documentation of monitoring activities and data organization is important to ensuring an accurate assessment of instream flow transactions. Generally, items that should be documented include:

1. A monitoring plan, developed prior to implementation of monitoring activities, that details the instream flow transaction and its objective(s), monitoring elements, locations, methodologies, and periods;
2. A map or aerial photo of the monitoring area, on which the protected reach and monitoring site(s) of each parameter are identified;
3. Electronic databases of all data collected for each parameter; and
4. Photopoints (upstream and downstream) of all monitoring locations.

Additional documentation may be required by the administering body overseeing the water transaction. For example, the Columbia Basin Water Transaction Program provides a checklist to transaction stakeholders in which participants provide details of the transaction, including the transaction flow rate, volume, period, objective, costs, and other information. Also, local, state, or federal agencies that are responsible for managing aquatic resources in the transaction basin may request information to ensure that the transaction complies with aquatic resource management policies. Potential water transaction participants should coordinate with relevant groups and agencies to ensure that the relevant documentation is completed for each transaction. Sample datasheets are provided in this appendix.

A.1. Flow

Flow monitoring is required for any flow transaction, regardless of the transaction objective. Flow monitoring allows transaction participants to confirm the quantity and timing of flow transactions. Due to the critical nature of flow monitoring data, selecting appropriate flow monitoring equipment (i.e. flow current meters, stage recorders, and staff gauges) is important. Flow monitoring equipment selection will depend on both the hydrologic conditions and available resources in the potential transaction location. As such, no specific brand or model of flow monitoring equipment are recommended. To illustrate the different characteristics of flow monitoring equipment, an overview of several flow current meters, pressure transducers, and staff gauges are presented.

A.1.1. Objective

The objective of the discharge monitoring is to monitor instream flow conditions prior to, during, and following the initiation of a flow transaction. The monitoring effort will determine whether the augmented flow volume can be detected throughout the beneficial reach using the protocols defined in this program[1].

A.1.2. Site selection

Site selection for flow monitoring is discussed in detail in section 2.3. Continuous stream gauging should be done at site locations where hydraulic conditions are as uniform as possible, with straight glide-like conditions, free of obstacles which otherwise might alter or influence stream velocity at the surface or sub-surface (Rantz et al. 1982). It is also suggested that during low flow periods, gauging sites be selected with a downstream stage control. Establishing stream cross-section discharge measurement locations using stakes, flagging and GPS coordinates from a local surveyed benchmark is recommended for long-term stream discharge or flow transaction monitoring in order to replicate consistent monitoring techniques and adequately monitor temporal flow changes.

A.1.3. Sampling schedule

Periodic discharge measurements will be taken at established channel cross-section locations. Water depths and corresponding flow velocities will be collected to enable the periodic calculation of discharge at each established discharge measurement cross-section. These measurements will be used, along with time series stage data obtained at continuous stream gauging locations, to develop discharge rating curves, which can be applied to develop time series flow records. Stage data will be gathered on a sub-hourly interval. No less than five discharge measurements per site, taken over a range of discharge volumes, should be collected during the entire flow transaction to establish strong discharge-stage relationships.

A.1.4. Equipment

Equipment needed to complete discharge monitoring on stream reaches includes:

- a flow current meter,

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[1] These results will be analyzed for changes that go beyond background noise and natural variability. The results of these changes will also be examined for their applicability to future phases in this pilot effort.

- a USGS top setting wading rod,
- continuous stage recorders (Appendix B)
- measuring tape,
- GPS unit,
- stakes,
- camera,
- staff gauges, and
- field notebook.

A brief overview of the different types of available current meters, stage recorders, and staff gauges are presented in Appendix B. Equipment selection will depend on available resources and the study basin's hydrologic characteristics.

A.1.5. Calibration

Calibration and maintenance of flow metering and stream gauging equipment should be conducted prior to initiating the project monitoring, then periodically throughout the field season, and according to equipment instructional or operational manuals and recorded in field notebooks or equipment log books. It is also suggested that a staff gauge be installed with stage recorders to assist with calibration and rating curve development. Information such as date/time of calibration, equipment serial number, and the field technician responsible for calibration should be recorded.

A.1.6. Monitoring methodology

Stream discharge is measured as the volume of water that passes through an identified stream cross-section per a specified unit of time, and is expressed as cubic feet per second (cfs) or cubic meters per second (cms) Stream discharge (Q) measurements will be conducted per U.S. Geological Survey (USGS) protocols and methods whenever possible (Rantz, et al. 1982). If measurements are taken outside of the USGS protocol due to site complications, then documentation and a thorough explanation should accompany the data. and field notebooks. Stream gauging equipment and methods will be determined by site cross-section depth and estimated stream discharge at the time of gauging, per the USGS protocols for equipment and such site conditions.

When using the velocity area method, the surveyed cross-section should be divided up with a minimum of twenty sub-sections (ideally 20-30 sub-sections), with no greater than 10% of the volume of water being gauged per any one sub-section. At each of these identified sub-sections, velocity measurements should be averaged over a 40-second period per sub-section.

When using a standard portable flow meter, if the stream cross-section depths are less than approximately 0.8 m (2.5 ft), the sixth-tenths- depth (0.6) point velocity-area measurements typically would be used. This method measures stream velocity at 60% of the stream depth at one point (for 40 seconds) using a USGS top setting wading rod at each sub-section within the stream cross-section (minimum 20 sub-sections).

If the stream's vertical cross-section depths were greater than approximately 0.8 m (2.5 ft.), a two-point method would be recommended, which requires velocity measurements at 20% and 80% stream profile depths then averaging the two for mean velocity.[2]

All flow meters and stage recorders should be used according to their operational manuals and relevant USGS protocols and recommendations. Discharge measurement data collection should always be recorded in field notebooks and in addition to appropriate handheld computer equipment such as computer laptops or personal digital assistant (PDA) using the standardized USGS data sheets if so chosen. Information typically recorded includes:

- site name / location
- date /
- starting time / end time
- field technician
- flow current meter (serial number/ or ID)
- stream condition
- weather conditions
- gauge heights (before measurement and after measurements)
- edge of water for measurement (left edge of water (LEW), or right edge of water (REW), when looking downstream)

Other relevant information, remarks about site or conditions should be noted. An example of a discharge data sheet is provided in Appendix A.

*Note: For low flow discharge monitoring (i.e. less than 2 cfs), it is suggested that entities utilize a portable flume or weir to attain the desired accuracy for flow rate/volume accounting. Portable flow current meters tend to increase in error in depths less than 2" (dependent upon the meter type) and flows less than 2 cfs often display these shallow depths making discharge gauging more challenging and increase of error more likely.

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[2] If using a pygmy current meter or an Acoustic Doppler Velocimeter (ADV), the two-point method is sometimes recommended for depths greater than 1.5 ft.

Attention and care to site location is extremely important when flow gauging small stream systems. Portable flumes and weirs set up instream temporarily confine flows through their fixed throat width areas of the device to quantify flow rate. Attention to fragile stream environments should be incorporated when assessing streamflow and care not to "dam" the small streamflow when installing the portable flumes and/or weirs should be observed.

A.1.7. Photo-point monitoring

Photo-point monitoring should also be incorporated to provide a visual context for monitoring data gathered during the flow transactional monitoring period. When gauging stream discharge, a photo should be taken looking upstream from the center of every cross-section. While all photos should be taken during a single sampling event, photo-points do not have to be repopulated during every sampling event. The camera used, time, date, picture number, stream location, and any other relevant information should be recorded in field note-books at the time of documentation. Holding up signs with date and location in the corner of the photo field is helpful for quick identification (include photo example; OWEB 2007).

A.1.8. Discharge protocol documentation

To evaluate and quantify the effect of the flow transaction on instream flow volume, several pieces of information should be documented. These include:

- A monitoring plan, developed prior to the implementation of monitoring activities, that details monitoring locations, stream features, methodologies, and periods,

- A map or aerial photo of the monitoring area, with relevant irrigation infrastructure, relevant stream attributes, hydrography data, with each monitoring site indicated, (e.g. Flow, Temperature and/or Habitat Cross-sections),

- A photo of each monitoring location, and

- Stage and discharge records for the monitoring period for each monitoring site, including spot measurements, rating curves, and time-series stage and discharge data.

A.1.9. Data sheet

DISCHARGE MEASUREMENT NOTES

NFWF CIG Field Monitoring

River ______________________ **Station ID** ______________________

Date ______________________ **Time** ______________________

Begin *End*

Method ______________________ **Gauge Height** ______________________

Location ____

Sampler ____

****Remember to note REW and LEW from tape measure**

Distance from initial point UNITS:	Depth UNITS:	Velocity UNITS:	Distance from initial point UNITS:	Depth UNITS:	Velocity UNITS:	Distance from initial point UNITS:	Depth UNITS:	Velocity UNITS:

A.2. Water Temperature

Water temperature is one aspect of aquatic habitat that can be used to assess the quality of the existing habitat. The water quality protocols are based on the federal USFS guidelines for water temperature sampling established by Dunham et al. (2005). This protocol establishes the objective of water temperature monitoring activities; standards for equipment; sampling schedule; calibration, launching, deployment, and collection of water temperature data loggers.

A.2.1. Objective

The data gathered from the water temperature monitoring is used to address a specific objective: to determine the benefit of a flow transaction with regards to species-specific water temperature objectives. These objectives are established based on the target species identified in each watershed and standard metrics that are commonly used to assess the quality of habitat. The specific metric that is applied will depend on the hydrologic regime of the stream reach.

A.2.2. Site Selection

Water temperatures should be monitored at several locations in the beneficial reach of a flow transaction, including:

- the upstream boundary of the beneficial reach, in the thalweg,
- all point-flow inflow sources to the beneficial reach (i.e. tributaries, returns flows, and spring sources), and
- the thalweg at the downstream boundary of the beneficial reach.

In systems where water temperature trends, such as heating rates or vertical/lateral water temperature profiles, have not been characterized for the protected reach, or for transactions that focus on augmenting a specific habitat type (e.g. cool-water pools), additional monitoring sites can include:

- along the thalweg at approximately 500 m (1640 ft) intervals,
- the top and bottom of the water column at the upstream boundary of the beneficial reach, in the thalweg, and/or
- transects across representative habitat locations (e.g. pool, run, riffle) coinciding with survey monitoring transect locations.

A schematic of water temperature monitoring sites, including the optional additional sites, is provided in Figure A-1.

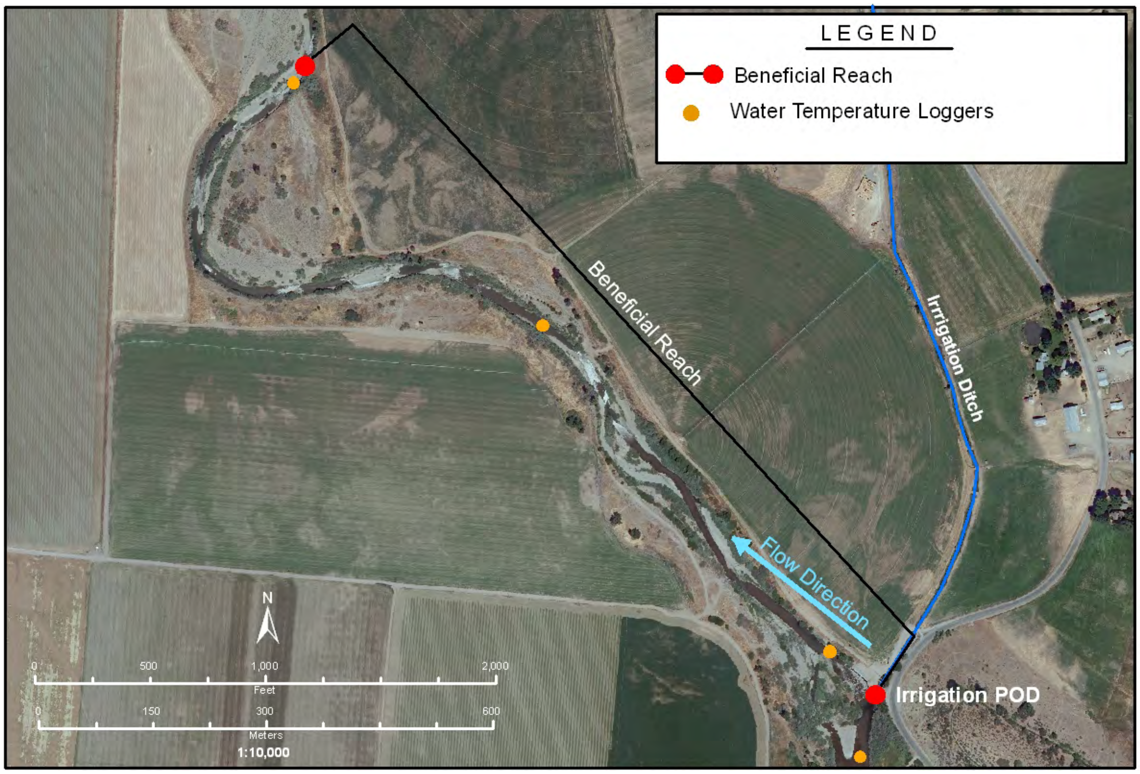

Figure A-1. An example of a water temperature monitoring array.

A.2.3. Sampling Schedule

Water temperatures should be monitored on a sub-hourly interval (e.g. 30 min) to ensure that diurnal maximum and minimum temperatures are well-characterized. Ideally, water temperature data will be available for several years prior to the flow transaction to characterize water temperatures during typical seasonal flows for the transaction period and location to determine if a flow transaction with a water temperature objective is appropriate. Regardless of historical data availability, monitoring is recommended for approximately two weeks prior to the transaction to characterize temperature trends during the current season – this data can be used to determine whether the flow transaction follows a period of moderate or rapid warming or cooling. Water temperature monitoring should occur during the flow transaction period and continue for approximately two weeks following the end of the flow transaction to similarly characterize the return to the thermal regime during typical seasonal flows.

A.2.4. Equipment

A variety of water temperature data logging devices are approved for water temperature monitoring. As water temperature loggers tend to have similar accuracy, specific makes and models should be selected based on available resources. Currently, Watercourse Engineering, Inc. (Watercourse) uses HOBO® Pro v2 Water Temperature Data Loggers (HOBO loggers) from Onset Computer Corporation to gather water temperature data. HOBO loggers can be used to collect data at 30-minute increments throughout the study area. These loggers have an accuracy of ±0.2^{o}C over the range from 0^{o}C to 40^{o}C, and a 90 percent response time of 5 minutes in water (Onset 2009).

A.2.5. Calibration

Data loggers should be calibrated prior to the monitoring season to ensure they are operating properly. Loggers should be calibrated according to manufacturer's recommendations. The "bucket" method is a simple and effective procedure for calibrating HOBO loggers (Dunham 2005, Onset 2009). The calibration steps are as follows (adapted from Dunham 2005):

1. Deploy the loggers at a short sampling interval (for example, 1 minute).
2. Submerge the loggers in a well-mixed fresh water bath (e.g. a 5-gallon bucket filled with hose or tap water)
3. After at least an hour, remove the data loggers and download the data. If the data loggers are calibrated correctly, they should all report data within the reported accuracy range.

A.2.6. Monitoring methodology

All loggers are launched prior to deployment using manufacturer's software. During the launch process, the user can select the logging interval for each logger as well as the time to start logging. Generally, the logging interval is set at a 30 minutes. The start date is set for the expected day of deployment. The start time is set for several hours prior to anticipated arrival at the study site to ensure the data collection captures the start of the deployment period.

Temperature loggers are deployed underwater where they record and store water temperature. In a stream mainstem, loggers are secured to a housing (e.g., a section of PVC pipe or metal pipe) to ensure they sink to the bed surface, reduce biofouling, and to reduce the effects of sunlight. The housing is then secured to the river bank using a stake and a chain leash. When monitoring water temperature at boundary conditions or regularly spaced downstream intervals, temperature loggers are placed in the main flow channel where water temperature is well mixed (i.e. the thalweg) (Figure A-2). When monitoring transects, temperature loggers are placed at increments approximately 10-20% of the total channel width. When monitoring the water column, temperature loggers are attached to stakes with the sensor facing downward. This is done to prevent direct sunlight from influencing the sensor in shallow water environments.

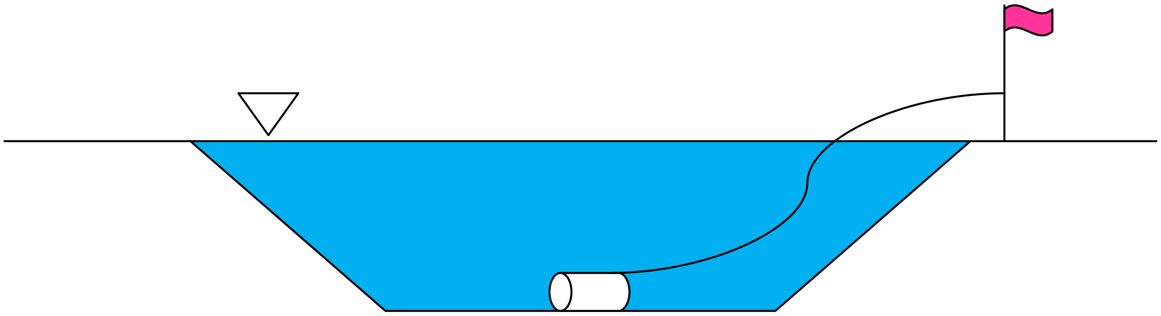

Figure A-2. A conceptual diagram of the deployment configuration of a water temperature data logger.

When the data logger is deployed to its monitoring site, several pieces of information are recorded in the project's field log or data sheet. An example of the field data sheet is provided at the end of this section. Take photo of site to help relocate; painting a rock nearby or placing a flag can also help, if vandalism is not a threat. The recorded information includes the serial number of the logger, a general description of the location, the GPS coordinates of the location, the time of deployment, and tethering method. A spot measurement is also taken to help assess the point prior to which data should be disregarded. If the logger is replacing another logger previously deployed to the site, the serial number of the previous logger is also recorded.

Water temperature data is downloaded monthly from all temperature loggers and data loggers are replaced in the channel to continue monitoring water temperature. Although temperature loggers can store 43,000 records, monthly downloads are important to ensure high quality data. Problems that affect temperature monitoring, such as aquatic macrophyte growth, sediment, logger movement within the channel, or defective loggers, can then be discovered and corrected before affecting the entire monitoring period.

When a data logger is retrieved, several pieces of information are recorded in the project's field log or data sheet including the serial number of the retrieved logger, the time of retrieval, and whether a new logger was deployed in its place. If a new logger was deployed, the information listed in the previous section must also be noted in the field log.

A.2.7. Documentation

To evaluate the effect of the flow transaction on instream water temperatures, several pieces of information should be documented by the monitoring team for assessment. These include:

- A monitoring plan, developed prior to implementation of monitoring activities, that details monitoring locations, methodologies, and periods,

- A map or aerial photo of the monitoring area, with each monitoring site indicated, and

- Time-series water temperature data at each monitoring site.

A.3. Aquatic Habitat

Stream habitat data is typically collected at a mesoscale level (< 1km (0.6 mi)) using protocols from monitoring programs established by federal and state agencies. Federal protocols and methods include those established by the U.S. Forest Service (USFS) Aquatic and Riparian Effectiveness Monitoring Program (AREMP 2005) and U.S. Environmental Protection Agency (USEPA) Environmental Monitoring Assessment Program (EMAP) (Kaufmann and Robison 1998). Applicable state protocols and methods are included in the California State Water Resources Control Board Surface Water Ambient Monitoring Program (SWAMP) bioassessment protocols (Ode 2007) and the Oregon Department of Fish and Wildlife (ODFW) Aquatic Inventories Project (AIP) (Moore et al. 2006). Existing assessment protocols are typically employed to establish “baseline” habitat conditions and facilitate trend monitoring over several years and/or decades. The scope and methods of physical habitat assessments described in the aforementioned federal and state protocols vary considerably, particularly with regards to sampling intensity and survey tools. Physical habitat data collection protocols established as part of the NFWF CIG assessment project will generally conform to existing state and federal protocols, facilitating data transferability between users. Habitat data will be collected using tape measures and surveyors rods to facilitate use by multiple field crews

Physical habitat monitoring methodologies presented herein are to be used by multiple field crews during the summer and fall of 2012. Below, the objectives of habitat monitoring activities are described, and metrics of habitat change following a flow transaction are presented. Furthermore, methods for pre-assessment site preparation are established, as are methods for “stick and tape” habitat survey techniques.

A.3.1. Objective

Aquatic habitat monitoring protocols presented herein are intended to measure and quantify changes to aquatic habitat in response to changes in streamflow associated with a given flow transaction. As such, this effort is project-level monitoring rather than trend monitoring. Most state and federal aquatic habitat assessment protocols [e.g. EMAP (USEPA); AREMP (USFS); SWAMP (SWRCB); AIP (ODFW)] call for the collection of a wide variety of physical habitat data including, but not limited to, channel slope/sinuosity, substrate size/distribution and visual estimation of fish cover components (e.g.: large-woody debris tallies, riparian canopy, undercut banks, aquatic plants). While such data is critical to assessing habitat suitability for aquatic organisms (particularly fish), it will not be collected under this experimental framework, as such data is not anticipated to measurably change over the short temporal periods (days to weeks) of summer or fall flow transactions. However, it is generally expected that habitat suitability assessments will be conducted by others prior to identification of possible flow transactions. These pre-transaction assessments should identify existing habitat structure (e.g. cover elements) necessary for a given flow transaction to hypothetically provide additional habitat that is useable by fish.

Metrics of aquatic habitat changes associated with a flow transaction will be based principally on hydraulic rating methods (e.g. Gordon, 2004). Such methods quantitatively relate discharge with measurable habitat characteristics, allowing for the development of habitat-discharge rating curves. Implicit in this method is that measureable hydraulic variables function as surrogates for changes in aquatic habitat, and that increases in potential habitat – vertically, horizontally or volumetrically – will enhance specific life stages of fish and any alternative objective of the flow transaction. Proposed hydraulic variables include the following parameters:

- wetted cross-sectional area
- wetted width
- mean depth
- wetted perimeter
- width to depth ratio
- pool volume

Each of the aforementioned variables can be quantified from physical habitat survey data collected using the survey methodologies described below. However, due the variability of hydrologic regimes and channel cross-section geometries in different streams, each metric of change may not be appropriate for developing site-specific rating curves relating physical habitat changes with flow alterations associated with a given flow transaction. Following the conclusion of a flow transaction, data processing will calculate each of the aforementioned metrics of change and identify the specific metrics appropriate to quantify habitat alteration following each flow transaction. Appropriate metrics will be those from which a mathematical relationship between discharge and the hydraulic variable can be developed.

A.3.2. Site Selection – Standard Cross-Section Surveys

Prior to habitat survey efforts, the upstream and downstream extent of each “aquatic habitat survey reach” will be established (Figure 3). The extent of this survey reach will vary depending on project conditions, but will always be less than or equal to the longitudinal extent of the “beneficial reach” described in Section 3.2. Habitat survey reach length will largely depend on professional judgment and local knowledge regarding the hypothesized downstream extent of impact for a given flow transaction. Following EMAP protocols, a “primary” aquatic habitat survey reach will be established below the proposed flow transaction location (e.g., point of diversion/augmentation or other specified location). The length of this primary survey reach be established at 40 times the average wetted channel width at the time of the first survey effort (with a minimum reach length of 150 m (492 ft), and maximum reach length of 500 m (1640 ft)). If local conditions suggest longer downstream effects from a flow transaction, reach length will be extended farther downstream through the addition of surveyed transects. The distance of this “extended” survey reach will be determined by professional judgment or legal requirements associated with the negotiated flow transaction and should be recorded with a Global Positioning System (GPS) or identified on maps prior to the transaction.

Benchmarked channel cross-sections will be established to facilitate repeatable habitat assessments throughout the “primary” and “extended” survey reaches over the course of the flow transaction. “Aquatic habitat” cross-sections are different from “discharge monitoring” cross-sections that were previously discussed. Herein, “cross-section(s)” refers to aquatic habitat monitoring locations and not to discharge monitoring locations. For flow transactions with unspecified aquatic habitat objectives, 11 cross-sections will be systematically located throughout the portions of the primary survey reach length corresponding to 40 channel widths (between 150 m (492 ft) and 500 m (1,640 ft) in length) downstream from the upstream boundary of the survey reach. If project budgets or labor constraints prohibit the completion of 11 cross-section surveys during each aquatic habitat sampling period, a subset of the 11 identified cross-sections should be selected. It is recommended that a minimum of 5 cross-sections be chosen for aquatic habitat surveys. This will allow for a systematic randomized sample design that generally conforms with existing EMAP protocols. In such cases, cross-sections will be established at the top and bottom of the primary survey reach, with nine (9) additional cross-sections placed at equidistant intervals between the top and bottom sections. Distances between sections will be measured along the curvature of the river bank. Further, it is imperative that the most stable channel cross-sections be selected for aquatic habitat assessment to help insure the development of useable habitat-discharge rating curves. Bank pins will be monumented (using rebar) above the highest expected water level anticipated during the period of the flow transaction on each side of the channel to allow repeatable topographic surveys during the field season. At each cross-section, bank pin monuments will be located at the same elevation, using standard topographic surveying methods. Elevated rebar will be placed adjacent to these bank pins to enable a level, constant elevation measuring tape or rope to be strung across each section, allowing for elevation control during subsequent habitat surveys conducted with only a tape and surveyors rod. Cross-sections within the primary survey reach will be identified alphabetically, with the top section identified as cross-section “A” and the bottom section identified as cross-section “K” (see Figure A-3).

For flow transactions with established aquatic habitat objectives (e.g. riffle crest passage, pool connectivity, etc.) additional cross-sections may be required to monitor aquatic habitat change at critical channel locations that may have not been encountered during the aforementioned systematic sampling efforts. In such cases the cross-section array may be altered as follows:

- Survey additional targeted cross-sections within the extended survey reach, or;
- Replace cross-sections B, D, F, H, and J with cross-section surveys located at targeted habitat features (e.g. riffle crests) found within either the primary or extended survey reaches. These cross-sections are to be considered part of the extended survey reach.

The location and number of these additional targeted cross-sections will be subjective and entirely based on professional judgment. These cross-sections will be identified alphabetically moving downstream, with the top section identified as cross-section “L”. Be careful about avoiding location of cross-sections through active or potential spawning redds to avoid disturbance. These cross-sections may be located within the primary survey reach (40 channel widths downstream from the flow transaction location), or along channel reaches farther downstream within the extended survey reach. Avoid locating targeted cross-sections through unstable channel reaches (e.g. salmon redd locations, extensive foot or vehicular traffic, etc.). Changes to channel morphology over the course of a flow transaction can prohibit the development of aquatic habitat-discharge rating curves necessary for the quantification of flow transaction effects.These cross-sections will be identified alphabetically moving downstream, with the top section identified as cross-section “L”.

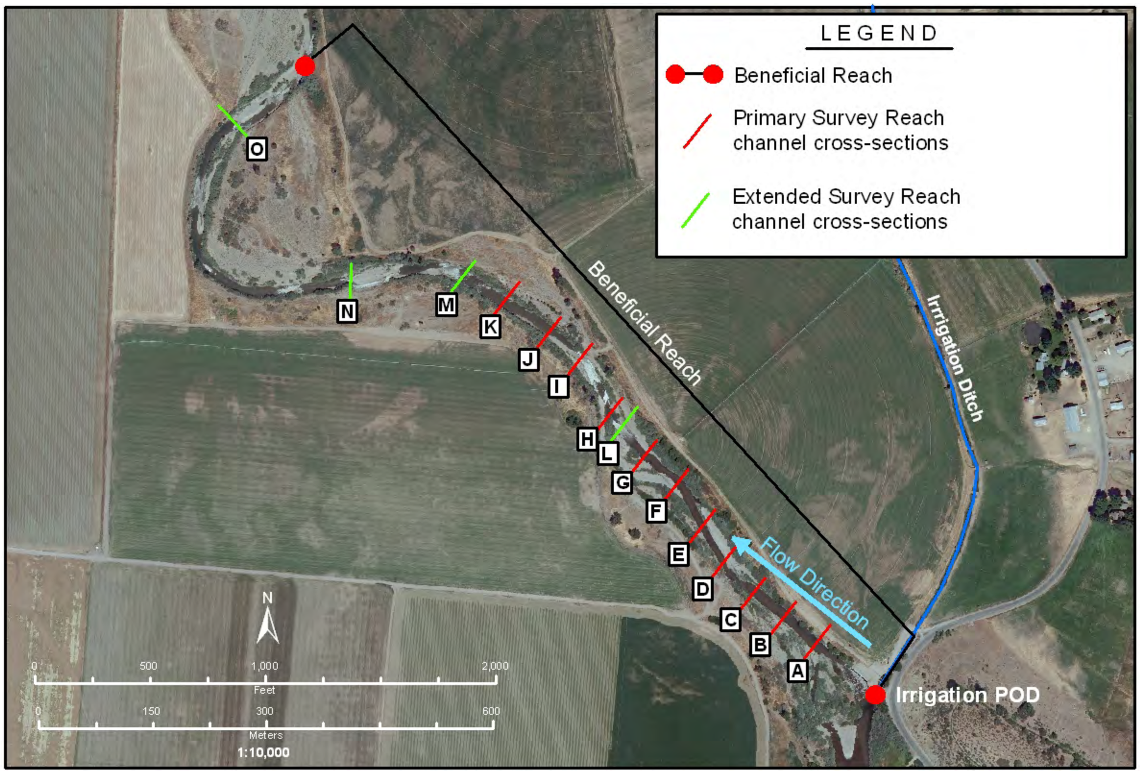

Figure A-3. An example of an aquatic habitat monitoring array, including the primary reach (cross-sections “A” through “K”) and the extended reach (“L” through “P”).

A.3.3. Site Selection – Pool Volume surveys

Criteria for defining the areal extent of a pool can vary considerably. Hilton and Lisle (1993) suggest three (3) criteria for defining pools, including: 1) generally flat water surface during low water conditions (i.e. free of surface obstructions); and 2) a maximum depth that is more than twice the depth of the water flowing out of the pool. Regardless of the methods used to determine pools and their areal boundaries, the methods must be objectively implemented in the channel reach to be affected by a flow transaction. Subsequently, cross-section surveys must be located throughout the length of an identified pool in order to calculate volumetric changes associated with a flow transaction.

Determining the upstream and downstream boundaries of a pool is of critical importance to measuring changes in pool volume associated with a flow transaction. While the length of a given pool may change depending on the volume of flow through the pool, at lower flows during which most transactions are conducted, the dominant geometric change in pool will likely be associated with widths and depths. Once the upstream and downstream boundaries of a pool are identified, channel cross-section surveys should be placed at the following locations (Figure A-4):

1. Upstream and downstream boundaries of an identified pool (in low gradient streams, pools are often bounded by shallow riffles). These measurement locations may be considerably shallower than much of the pool;

2. Three to five locations along the length of the pool. In pools exhibiting homogenous channel cross-section shape, cross-sections may be systematically placed at equidistant intervals throughout the pool. However, if channel shape is more complex, cross-sections may be manually placed to help generate more accurate volume estimates.

Figure A-4. Spatial layout of cross-section surveys within a pool.

A.3.4. Sampling Schedule

Aquatic habitat sampling schedules will be largely dictated by the range of streamflows observed during the water transaction. For short duration (i.e.,. days) water transactions, where "snapshot" quantification of aquatic habitat changes associated with a flow transaction, aquatic habitat data will be collected to capture the widest range of flows that occur and may take place frequently over a few days or weeks. For "snapshot" flow transactions, it is necessary that flows above the P.O.D. remain as stable as possible (e.g., are unaffected by upstream diversions that may off-set the flow contributed by the water transaction and result in a narrow range of streamflows) to enable accurate quantification of habitat changes associated with transacted volume of water. Additional sampling events will be required for longer flow transactions where discharge often exhibits large seasonal variations. At a minimum, the established sampling frequency must allow for quantification of habitat changes associated with the range of discharges observed during the period of the flow transaction. It is recommended that aquatic habitat data be collected a minimum of four times over the course of longer (i.e. weeks to months) flow transactions. Efforts should be made to ensure that habitat data are collected across the entire range of flows observed during the course of a transaction (Figure A-5). Ultimately, sampling schedules should be dictated by the number of measurement periods needed to develop quantitative relationships between measured hydraulic variables and discharge, however, collecting stream-discharge data at varying stage levels is necessary and recommended to accurately capture stream-flow changes.

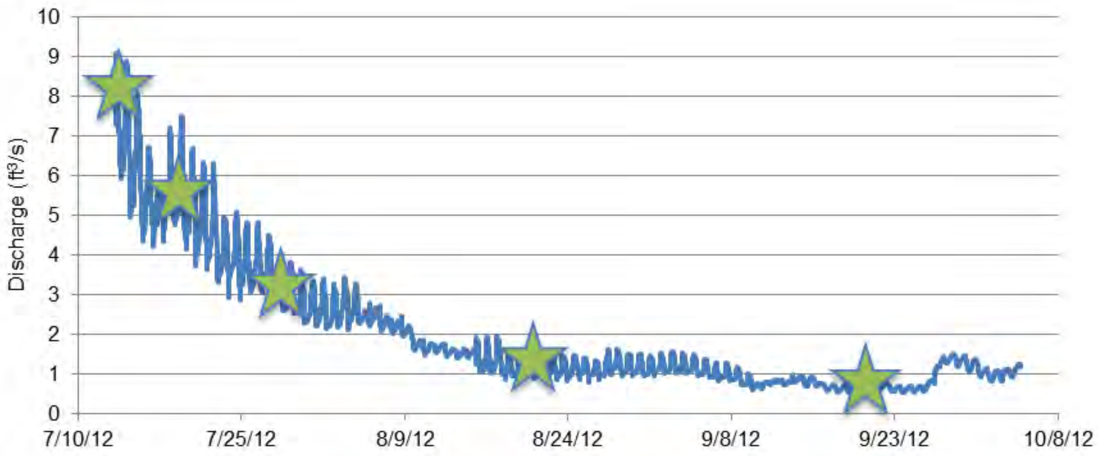

Figure A-5. Appropriate distribution of aquatic habitat data collection periods (green stars) such that habitat data is collected across the range of streamflows observed during a flow transaction.

A.3.5. Equipment

Assessment activities may initially require some topographic surveying during site preparation prior to the beginning of each flow transaction. Following site preparation, habitat assessment activities will require only the use of a surveyor's rod and a measuring tape[3]. Topographic surveying will require the use of an autolevel (with telescoping surveyors rod), robotic total station, or real-time kinematic (RTK) GPS survey equipment. Equipment choice will depend on availability, time constraints and survey precision needs. Harrelson (1994) presents detailed methods regarding topographic surveying. Survey site preparation will require, at a minimum, twenty five 0.6 m (2 ft) lengths and twenty five 0.3 m (1 ft) lengths of 3/8 inch rebar, to establish channel cross-section bank pins and elevation benchmarks. During subsequent habitat assessment, a minimum of 11 copies of the "channel cross-section profile form" (Table 1) will be needed. Two field personnel will likely be required to perform surveying and note-taking activities.

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[3] A metric measuring tape or cable/rope should be chosen that allows for repeatable survey locations (± 0.1 m) along each cross-section. In this regard, attempts should be made to place the measuring tape/rope under the same amount of tension during each survey visit.

A.3.6. Calibration

No calibration of the sampling equipment is required.

A.3.7. Monitoring methodology

The following methods will be followed during each survey. Channel depth measurements will be conducted at repeatable locations to facilitate comparison of measurements.

A.3.7.1. Channel Cross-Sections:

Depth measurements will be systematically performed across each of the monumented cross-sections. Measurement transects will be conducted perpendicular to the observed discharge, traversing from the left bank pin to the right bank pin. To enable consistent elevation control, a level measuring tape will be strung across each section at the elevation of the bank pins. The depth from the tape to the stream bed and the depth from the tape to the water surface will be measured using a metric surveyors rod at a minimum of 22 points located between the left and right bank pins, including the left edge of water (LEW), right edge of water (REW) and the channel thalweg (deepest part of the channel). The remaining 19 survey points will be located at intervals of 5% of the distance between both bank pins (5, 10, 15…95%) (Figure A-6). This will allow cross-section measurement locations to be reoccupied during subsequent surveys. Depth measurement data for each cross-section will be recorded on an individual “channel cross-section profile form” (see the end of this section). For measurement points located out of the water, only the distance below the measuring tape will be recorded.

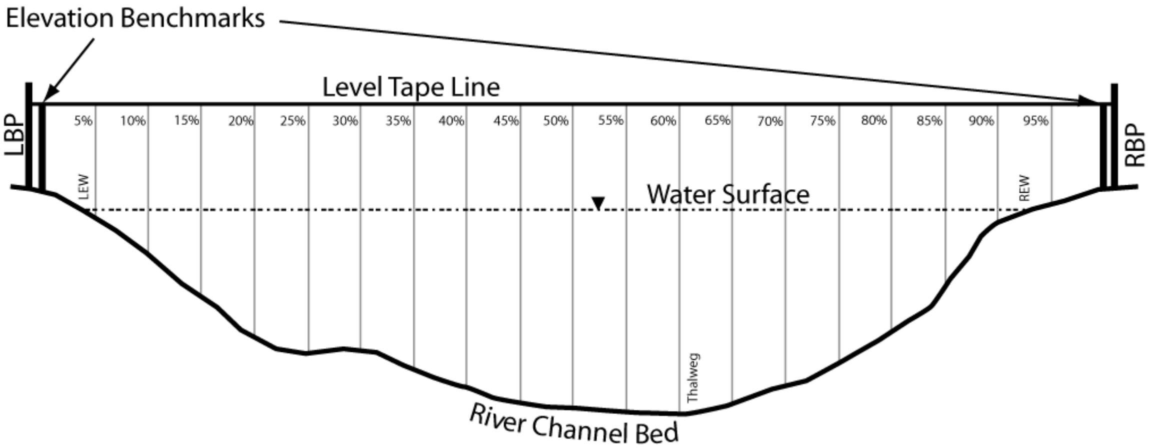


Figure A-6. Channel cross survey schematic illustrating measurement locations.

Measurement protocols may be abridged when surveying cross-sections where the channel bed is anticipated to remain stable over the course of the flow transaction. In such cases, the first habitat survey will be conducted according to the aforementioned survey methodologies. Following the initial cross-section surveys, subsequent survey efforts can be minimized by collecting data from measuring locations at only the right and left-edge of the water (REW and LEW). These data will allow for the determination of the width and elevation of the water surface, enabling subsequent quantification of habitat variables using the bed topography measurements from the initial surveys. Also, measurement protocols may be adjusted when surveying cross-sections that are actively used (e.g., spawning areas). In these situations, water surface elevations are recorded, as well as the relative location of the wetted edges of the channel on each bank relative to the monumented survey pins.

A.3.7.2. Pool Volume

Pool volumes are calculated from a series of habitat cross-section surveys along the length of a selected pool. Each cross-section will be surveyed following methodologies presented in Section 4.2.7.1.

A.3.8. Documentation

To evaluate the effect of the flow transaction on aquatic habitat, several pieces of information should be documented by the monitoring team for assessment. These include:

- A monitoring plan, developed prior to the implementation of monitoring activities, that details monitoring locations, methodologies, and periods,
- A map or aerial photo of the survey reach, with each monitoring site indicated,
- Upstream and downstream photographs of every surveyed cross-section, and
- Aquatic habitat surveys for all transects and survey events, documented both in hard copy (i.e. data sheets) and electronic (i.e. spreadsheet) form.

Channel Cross-section Profile Form

NFWF CIG Field Monitoring

Site Name:_______________ Date:________________ Team:___________________
Transect ID: ☐A ☐B ☐C ☐D ☐E ☐F ☐G ☐H ☐I ☐J ☐K ☐L ☐M ☐N ☐O ☐P ☐Q ☐___

Cross-Sectional Information:

Location ID	Distance from LBP(m)	Stadia Rod Depth(m)		Velocity (m/s)	Notes
		Water Surface	Tape Line		
0% (LBP)					
5%					
10%					
15%					
20%					
25%					
30%					
35%					
40%					
45%					
50%					
55%					
60%					
65%					
70%					
75%					
80%					
85%					
90%					
95%					
100% (RBP)					
LEW					
REW					
Thalweg					

A.3.9. Summary

Various monitoring protocols may be implemented depending on the objective of a flow transaction. No matter what the objective, flow monitoring is required for any transaction. Each protocol includes guidelines for a monitoring array that is designed to quantify changes related to the flow transaction. These changes may relate to aquatic habitat, water temperature, or water quality characteristics.

Though a flow transaction may not require the implementation of all monitoring protocols, an example of a monitoring array that includes monitoring sites for all potential elements of a flow transaction monitoring program is illustrated in Figure A-7. A discussion of the individual protocol set-ups is provided in previous sections.

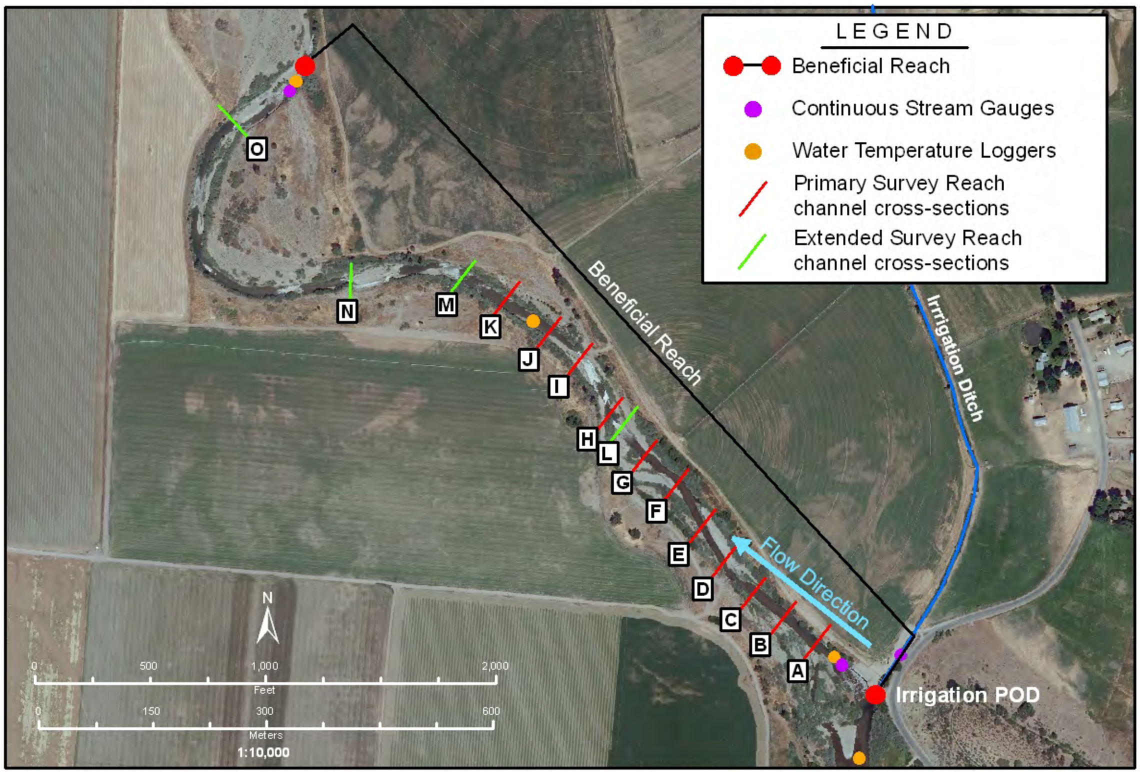


Figure A-7. An example of a flow transaction monitoring array that includes flow, aquatic habitat, water temperature, and water quality.

Appendix B. Flow monitoring equipment

8.1. *Flow current meters*

A variety of current meters are available and tend to be the most widely used for measuring in-stream velocity. Typical meters use a top-setting wading rod to allow for depth adjustment and measure velocity by mechanical, electromagnetic, or ultrasonic doppler design. Mechanical meters operate where stream velocity is related to the angular velocity of the rotor, with the rotors operating on a vertical (cup-type) or horizontal (propeller-type) axis counting the revolutions of the rotor over a defined period of time (Herschy 1985). The Price-AA and pygmy current meters discussed below operate on a vertical axis. Electromagnetic meters, such as the Marsh-McBirney Flow Mate series, have a bulb or head with two electronic contact points which measures stream velocity using electronic magnetic induction (Marsh-McBirney 1994). Ultrasonic (acoustic) doppler meters integrate a velocity sensor, depth sensor, data logger, and cross-section information to estimate discharge based on the velocity area-method for calculating flow (SonTek - www.sontek.com).

To identify the optimal flow meter for a specific project, one must determine the anticipated stream velocities and cross-sectional depths. Below are several common current meters and their recommended specifications for in-stream gauging to better assist with determining the optimal current meter for a specific project or monitoring program.

(i) Marsh McBirney – Flo Mate 2000 – Specified operating range is 0.5 feet per second (ft/s) to 19.99 ft/s, with an accuracy of +/- 2% of the measured velocity + zero stability. The zero stability is estimate to be +/- 0.05 ft/s, and is the variability of the velocity readings in still water (Marsh-McBirney 1994).

(ii) Price-AA Meter Model 6200 – Designed by the USGS, this mechanical meter's range is .1 ft/s to 25 ft/s (Rickly Hydrological Company - http://www.rickly.com/sgi/AA.htm) . It comes with a USGS standard rating table to convert revolutions to stream velocity in either feet per second (English) or meters per second (metric).

(iii) Price Pygmy Current Meter – this meter is designed for small, shallow stream gauging with less than 1 ft depths. It is similar in design to the Price-AA meter developed by the USGS, however, it is two-fifths the size and has no tail-piece. Its velocity ranges are 0.20 ft/s to 4 ft/s or less.

(iv) Son Tek – Flow Tracker ADV – this acoustic doppler velocimeter is designed for depths down to 2 cm (1 in.) with velocity ranges of +/- .0003 ft/s to 13 ft/s, making it ideal for small flow rates or small stream flow gaging.

8.2. *Continuous stage recorders*

Continuous stage recorders are devices that collect time-series water depth (stage) data for a specified interval. With daily discharge fluctuations, stage recorders allow for the ability to capture this variability as well as displaying points of maximum and minimum stage height over a certain time period.

Figure B-1. An example of a continuous stage recorder deployed with a pipe housing and staff gauge.

There are a variety of continuous stage recorders that represent a range of costs, accuracy, software requirements, and deployment hardware requirements. The latter should be taken into account prior to deciding which stage recorder is optimal for a specific monitoring program. Steel pipe or PVC pipe housing (**Error! Reference source not found.**), is typically required to protect the instruments and act as a "stilling well," however, these hardware configurations and installations can be costly for organizations with restricted monitoring budgets. Most stage height recorders are generally programmed to function over a specific depth range. The accuracy for each recorder is a percentage of the maximum recommended depth. Some continuous stage recorders currently available are:

- **(i) Solinst – Levelogger Gold Model 3001**
- **(ii) Geo Scientific Ltd - Aqua-Rod**
- **(iii) TruTrack ltd – WT-HR Water Height Data Logger**
- **(iv) Global Water Instrumentation Inc. – WL 16 Data Logger**

8.3. Staff gauges

There are two types of staff gauges, vertical and inclined. The vertical staff gauge is the most commonly used and will be what is referenced in this document. Staff gauges are typically a metal, plastic, or fiberglass plate with calibrated incremental lengths usually expressed in tenths of a foot, which are used to measure stage height. Usually, a staff gauge is used to reference other continuous stage recording devices to check for calibration, however, they can be used instream with periodic flow measurements to develop discharge rating curves.

Appendix V

Environmental Credit Calculator Applications

Watercourse Engineering, Inc.
424 2nd Street, Suite B
Davis, CA 95616
530-750-3072 (tel.)
530-750-3074 (fax)

An Example Application of W3T: Rudio Creek

Introduction

The Water Temperature Transaction Tool (W3T) was designed to be relatively easy to use. The model is set up and run in an Excel workbook. All data required for the model are organized on worksheets in the W3T workbook. Results are available in Excel spreadsheets and some results are displayed graphically on an interface sheet. But to run the model effectively, site conditions must be described with an appropriate level of detail. Establishing the data to describe site conditions in detail can be time consuming and requires a certain amount of judgment. This document is intended to accompany the User's Guide and provides guidance in gathering and organizing data for the W3T model. An example application is used as the basis for this guidance.

Based on field data received from The Freshwater Trust (TFT) and guidance from TFT staff and others, this example application of the W3T was completed for Rudio Creek, a tributary to the John Day River (Figure 1). Outlined herein are discussions of basic data requirements of the W3T, model data assumptions and results.

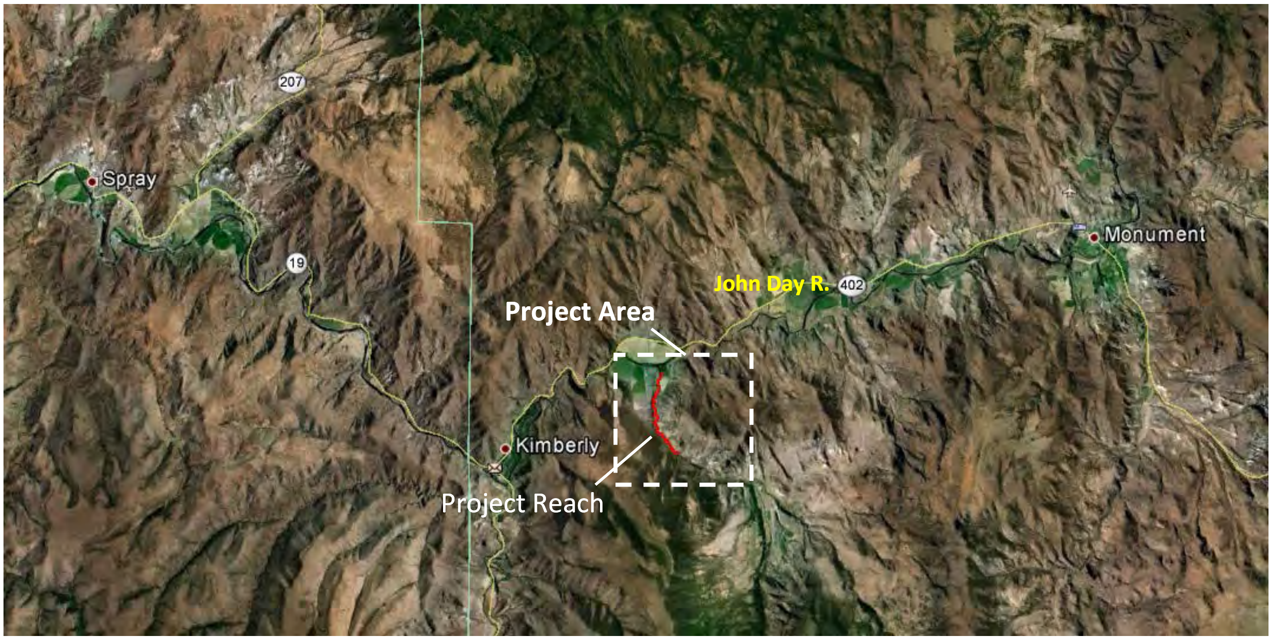


Figure 1. Project Location.

Data requirements

Before beginning a simulation, the user must gather and organize a variety of information. The model requires five different kinds of data acquired from various sources. These data types include:

- Meteorological data
- Channel geometry
- Riparian vegetation and topographic shade
- Water temperatures
- Flows

In addition, maps of the study area are very helpful in orienting the user. Sources for data are listed in the Appendix.

The different types of data include specific data sets, and each dataset may have a different scope of application in the model. In the model, data are applied to either the entire reach, each subreach, or to the different vegetation zones associated with each subreach.

In addition to data required to run the model, an effective model simulation requires values for calibration variables and verification. Calibration variables are values that may be adjusted to bring model results into accordance with observed values. These variable may include Manning's roughness and the evaporative coefficients, a and b. Verification data provide the backdrop upon which to calibrate the model and verify that, under measured or assumed conditions, measured values can be matched. Verification data may include water temperatures, flow rates, and depth of flow measured within the study area.

Types of data, specific data required, and the scope of data are detailed in Table 1. Data typically used for calibration and verification are noted.

Table 1. W3T data types and their scope

Data type	Specific datasets	Units	Scope
Meteorological	Air temperature Cloudiness Wind Relative humidity Wet bulb temperature Evaporative coefficients(1)	°C percent as a fraction m/s percent as a fraction °C unitless	Entire reach
Channel geometry	Bottom width Side slope, avg. of both banks Channel slope Manning roughness, n(1)	m m/m m/m no units	Each subreach
Topographic shade	Elevation angle	degrees	Entire reach
Riparian vegetation (general)	Width of riparian zones Height of emergent vegetation Density of emergent vegetation	m m percent as a fraction	Entire reach
Riparian vegetation (by subreach)	Overhang	m	Each subreach in each direction
Riparian vegetation (by zone)(2)	Height Density Elevation at ground	m percent as a fraction m	Each zone in each direction
Water temperatures	Inflow water temperatures Instream water temperatures(1)	°C °C	Specific to each inflow or location
Flows	Inflow rates Diversion rates Instream flow rates(1)	cfs cfs cfs	Specific to each inflow, diversion or location

(1) Typically used for model calibration and/or verification

(2) Specified for each band, or zone, of vegetation away from stream in each compass direction

Meteorological Data

Meteorological data are collected at stations throughout the United States and data from these stations are becoming more and more easy to access. Even with an abundance of meteorological stations, judgment must be exercised in applying reported values to local conditions. Some conditions, like wind speed, may change on a very local scale and a meteorological station, tens of miles away, may represent data for these conditions only generally. Also, not all data required by the model are always available from local meteorological stations. These data must be inferred from other meteorological conditions or from familiarity with the site. Finally, not all data at all stations are controlled for quality, so comparing data from two or more stations is always recommended.

Two meteorological stations were found in vicinity of the project area, Tupper and Board Creek. Tupper, RAWS is located approximately 21 miles north-northwest and the Board Creek RAWS located 20 miles southeast of the project site (Figure 2 and Table 2).

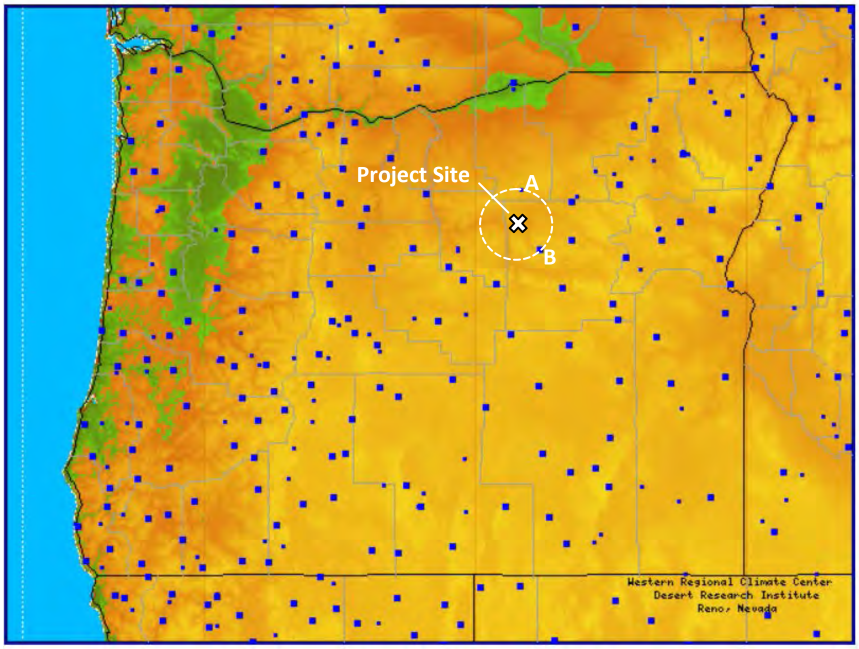
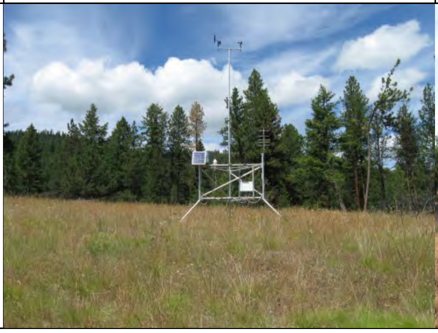
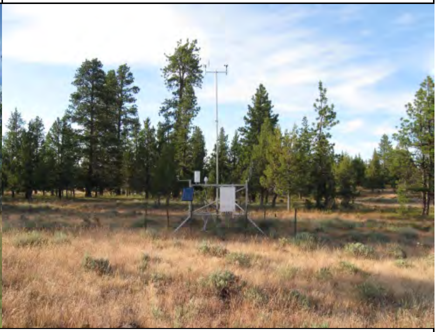


Figure 2. Project Site and Remote Automatic Weather Stations (RAWS) data (Source: Western Regional Climate Center, Dessert Research Institute, Reno Nevada. wrcc@dri.edu) locations, with Tupper (location A) and Board Creek (location B) sites shown.

Table 2. Tupper and Board Creek Metadata (source: http://www.raws.dri.edu/)

	Tupper, Oregon	**Board Creek, Oregon**
Latitude	45° 04' 15"	44° 35' 36"
Longitude	119° 29' 24"	119° 16' 40"
Elevation (approx.)	4000 feet	5000 feet
Agency	USFS	USFS
NESS ID	3245D76E	325D4134
NWS ID	351202	352330
Station photograph		

* Meta data elevations from RAWS differed from elevation on Google Earth. Google Earth elevation for Board Creek was 4,500 ft. This latter elevation was used for lapse rate calculations.

Station Comparison

Maximum daily air temperatures at Tupper and Board Creek were similar, while minimum temperatures at Board Creek were generally cooler. Solar radiation at Tupper was systematically higher by approximately 10 percent, suggesting a fouled pyranometer at Board Creek. Wind speed and relative humidity were similar among the two sites. While either site was acceptable, the Tupper RAWS data were employed herein as a conservative estimate (higher air temperatures) and more representative solar radiation.

Assumed Meteorology Data

Although available meteorological data were located in the project vicinity, site-specific considerations were necessary to ensure conditions were appropriately represented. While wind and solar radiation data were taken directly from the Tupper RAWS, air temperature was adjusted for a difference in elevation via a lapse rate relationship. Lapse rate is a measure of the rate at which air temperature decreases with increasing altitude. Site elevation in the project area ranged from 2,140 to 1,920 ft, and a representative site elevation of 2,000 ft was used for lapse rate calculations. While lapse rate can vary diurnally, with season, slope orientation, and latitude, lapse rates were only modified for elevation following Linacre (1992), where temperatures change approximately 6 ^{o}C per 1000 meters (3280.0 ft) of elevation change. Based on this lapse rate adjustment and an elevation difference of 2,500 ft., air temperatures were increased 4.6 ^{o}C. Wet bulb temperature was also adjusted to account for the change in air temperature based on Synder and Shaw (1984). Because local data were unavailable, relative humidity was assumed unchanged. Finally, although cloud cover may be roughly assessed as a function of local solar radiation, no local data were available and cloud cover was assumed zero throughout the planning period. Such an assumption is conservative. Final air temperature, wet bulb temperature, relative humidity; wind; and solar radiation for the chosen study period (August 2011) are shown in Figure 3. Solar radiation is calculated by the model, but it is shown here as part of the observed meteorological data set and can be used to verify model calculations.

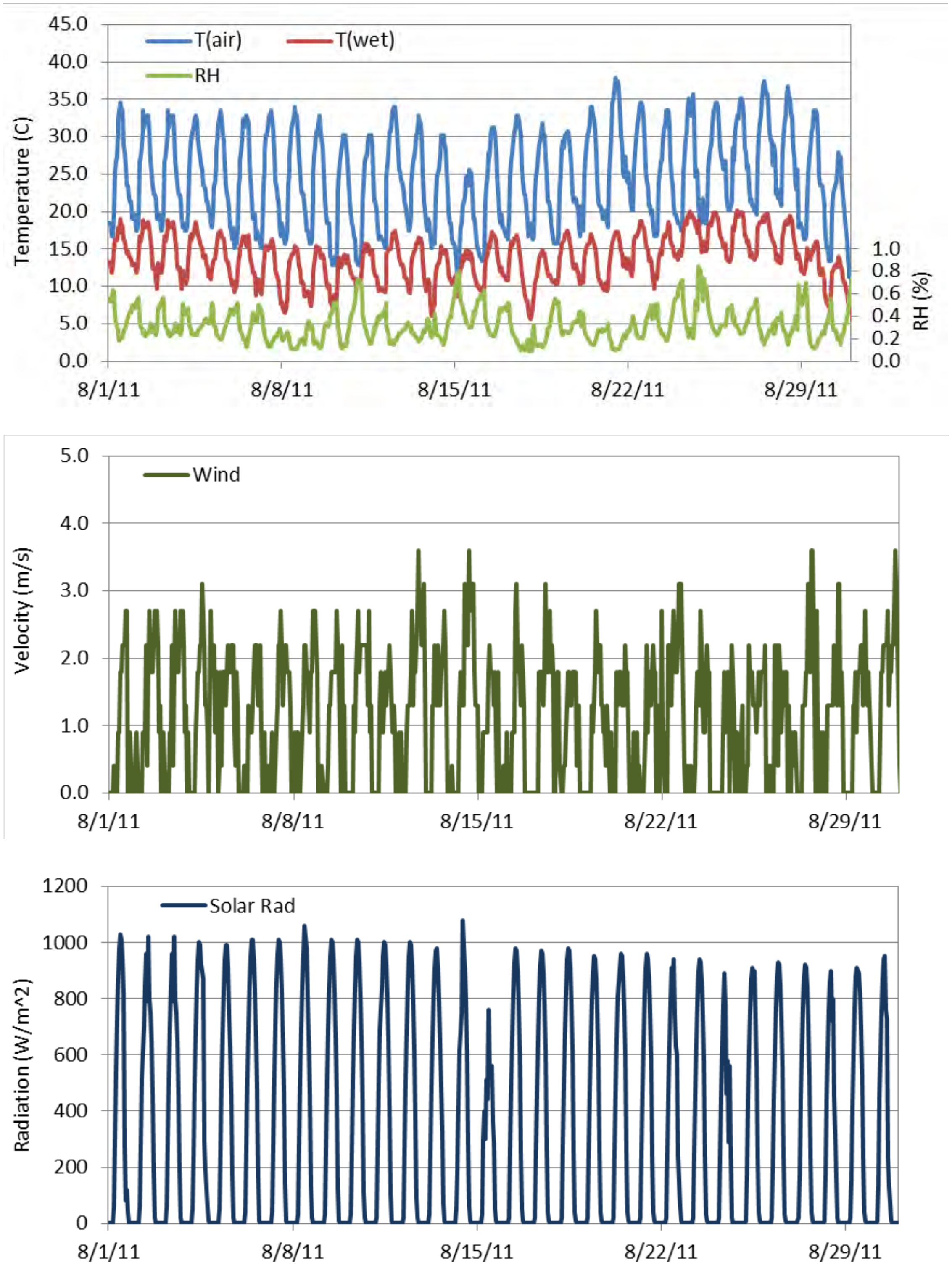


Figure 3. Rudio Creek assessment meteorological data: air temperature, wet bulb temperature, and relative humidity (RH) (top), wind speed (middle), and solar radiation (bottom): August 2011.

Geometric Information

Each subreach of the model is represented by a single set of geometric data. These data include bottom width, side slope, channel gradient, and roughness. In this model, one value for side slope is applied to both left and right banks. Assuming steady flows, this geometric information determines the constant depth of flow that will be used in temperature calculations throughout the simulation for each subreach. Therefore, it is important that each set of geometric data fairly represent the subreach it is associated with. When detailed information is available, representative values may be estimated from length-weighted averages or some other averaging technique. For this example, The Freshwater Trust (TFT) provided cross sections and channel gradients at five locations along Rudio Creek. Planform (aspect) information, used in configuring vegetation zones, was reported by TFT as part of their geometric survey and is presented here, also. Each of these data types is presented below, with a summary of model assumptions concluding the section.

Cross Section

System geometry was provided for five cross sections and riffles were surveyed at each location. At three sites, pools were also surveyed. Further, local longitudinal profiles were completed at each site. The files and basic information are provided in Table 3 (see also Figure 7).

Table 3. Geometry data provided by TFT.

Filename	Cross Sections available	Longitudinal Profile
CP30+00 Graphs.xls	Riffle (1)	n/a
CP36+00 Graphs.xls	Riffle (1) and pool (1)	Yes (431.62 ft)
CP86+00 Graphs.xls	Riffle (1) and pool (1)	Yes (397.49 ft)
CP90+00 Graphs.xls	Riffle (1)	Yes (338.95 ft)
CP112+00 Graphs.xls	Riffle and pool (1)	Yes (368.62 ft)

Table 4. Total Station GPS: latitude, longitude, elevation.

Station	Longitude	Latitude	Elevation (ft)
Total Station GPS (CP30+00)	n/a[1]	n/a[1]	n/a[1]
Total Station GPS (CP36+00)	44.7782	-119.5848	1949.53
Total Station GPS (86+00)	44.7685	-119.5825	2035.47
Total Station GPS (CP90+00)	44.7679	-119.5815	2036.26
Total Station GPS (CP112+00)	44.7630	-119.5782	2091.45

[1] no data available.

From these five cross sections, channel geometry was estimated by fitting trapezoids to each cross section up to the measured water surface (Figure 4 and Figure 5). Because evaluation of transactions typically concerns low flow conditions, floodplains above the bankful elevation are not included in estimating flow channels for these analyses. Pool cross sections were not considered in this analysis, partly due to the overall relatively high gradient of the creek and partly due to local longitudinal surveys indicating few pools are present along the creek. Local longitudinal survey data (only completed in the vicinity of the cross section) were used to estimate local gradient. Cross sectional information and gradient data are included in Table 5. Local gradient was not reported for station 30+00 and depth was not reported for station 120+00.

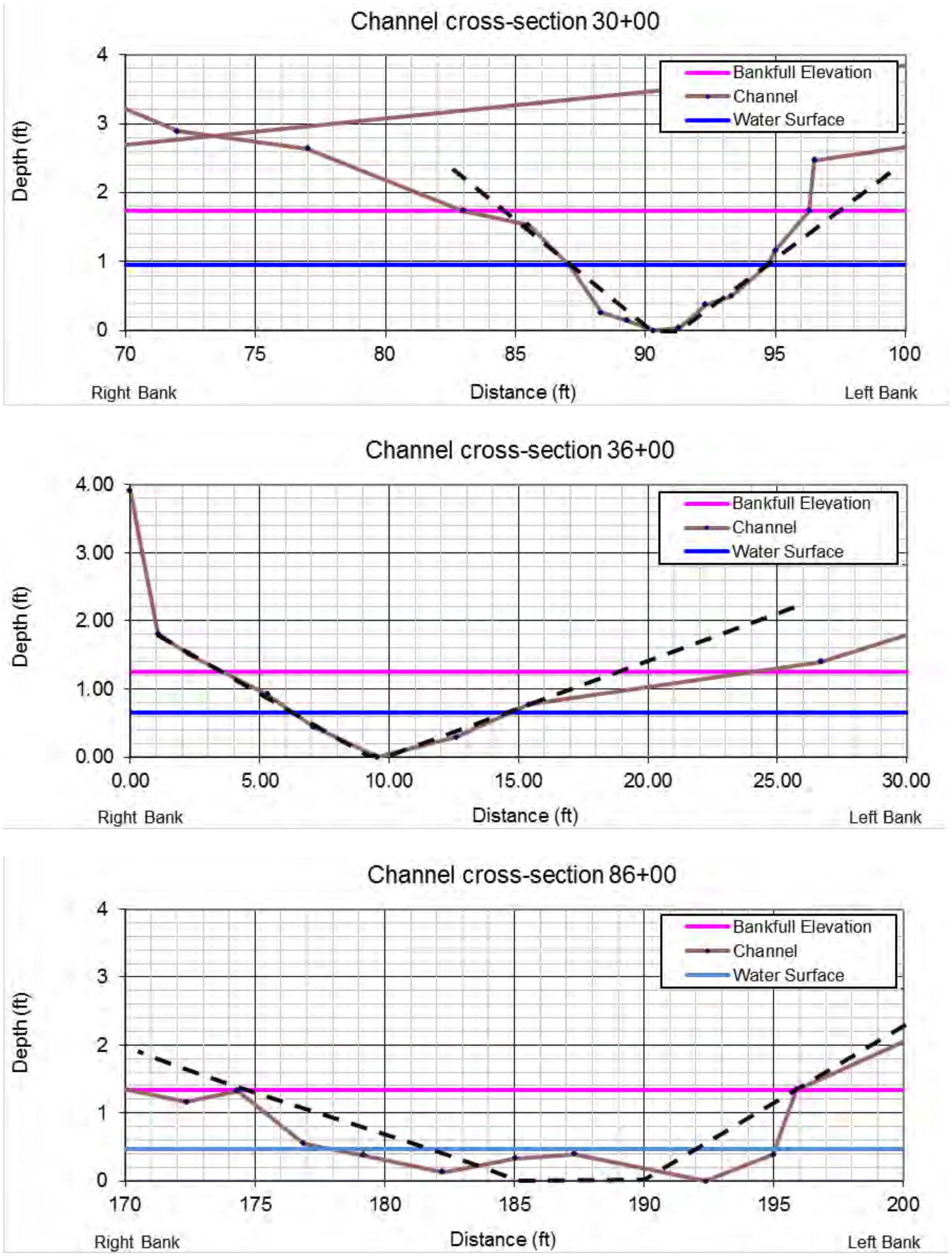
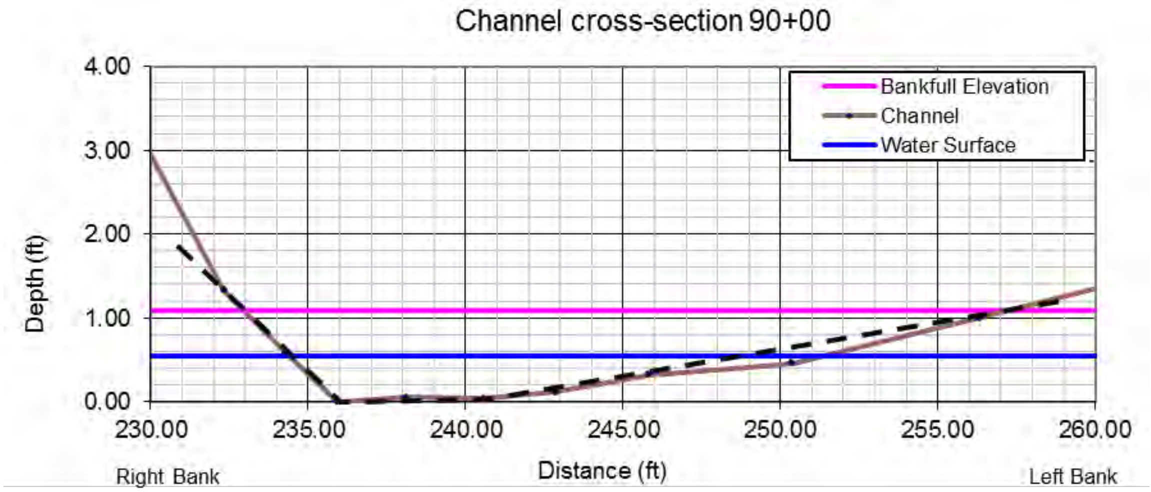


Figure 4. Channel cross sections provided by TFT with representative trapezoids shown at riffles for sections 30+00 (top), 36+00 (middle), and 86+00 (bottom).



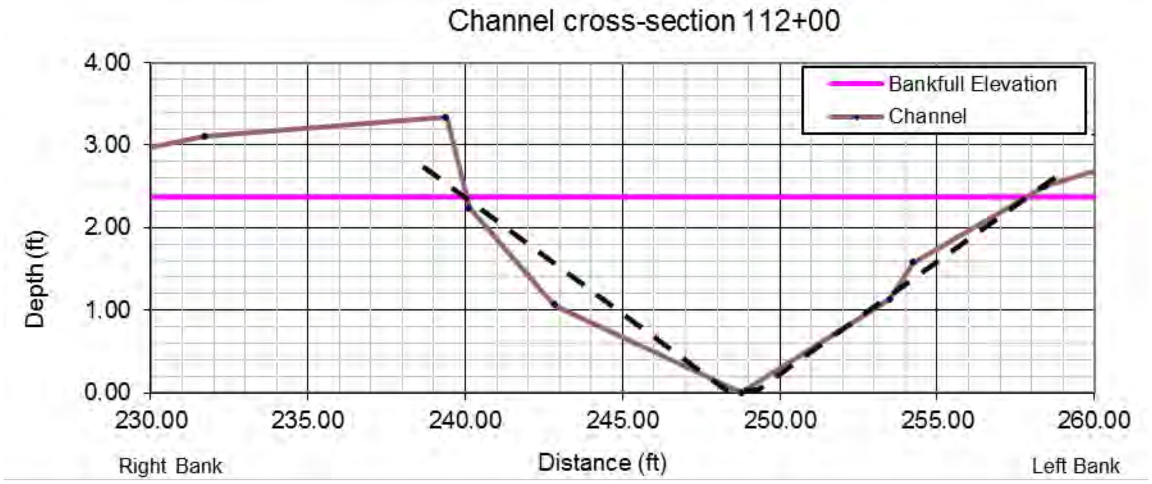


Figure 5. Channel cross sections provided by TFT with representative trapezoids shown at riffles for sections 90+00 (top) and 112+00 (bottom).

Table 5. Bottom width, side slopes and measured depth at time of the survey for each channel cross section.

Station	Bottom Width (ft)	SS1 (ft/ft)	SS2 (ft/ft)	Local Gradient (ft/ft)	Measured Depth[1] (ft)
30+00	1.0	3.4	3.3	n/a	0.95
36+00	1.0	4.5	7.7	0.019	0.65
86+00	5.0	7.5	4.3	0.023	0.45
90+00	5.0	1.9	16	0.013	0.55
112+00	1.0	3.8	4.0	0.020	n/a

[1] Measured at deepest part of creek and represented by “water surface” in figures above.

Channel Gradient and Aspect

The channel gradient in the study reach is fairly uniform, on the order of 0.020 (Table 6 and Figure 6). There are a few local steep locations, particularly in the upper reaches of the study area. Further, there is a low gradient reach adjacent to the John Day River. Neglecting these deviations, the average gradient is 0.0195 ft/ft. Rudio Creek in the project area runs roughly south to north (Figure 7). While there are deviations from this path, the overall aspect is north-south. For simplicity, the average gradient and the overall north-south aspect of the creek were used to represent all reaches in this analysis.

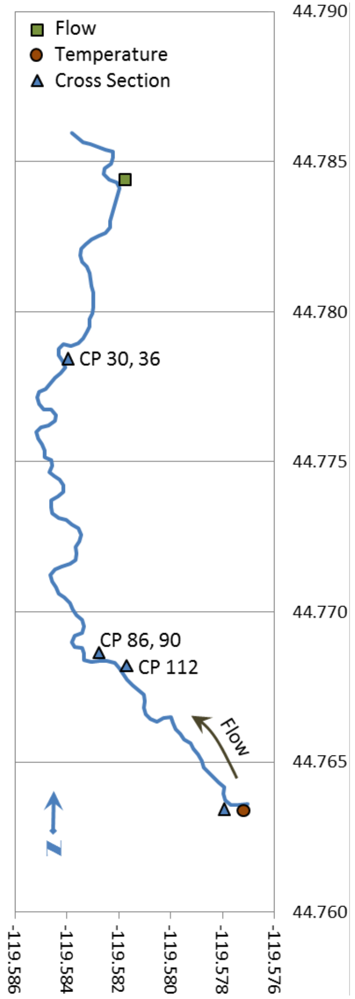


Figure 7. Rudio Creek planform view.

Table 6. Channel gradient at each channel cross section location (locations shown in Figure 7).

Station	Local Gradient (ft/ft)
30+00	n/a
36+00	0.019
86+00	0.023
90+00	0.013
112+00	0.020

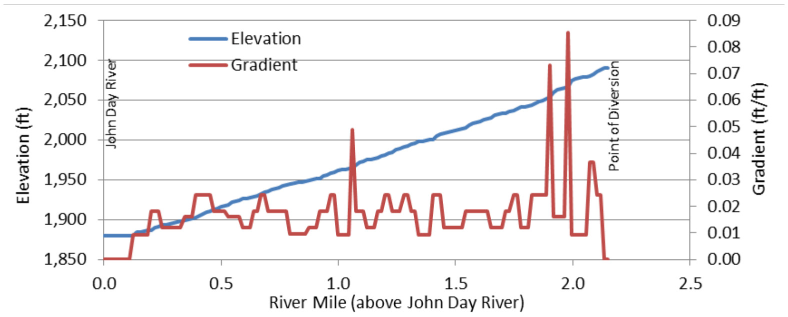


Figure 6. Rudio Creek elevation and gradient from Point of diversion to John Day River.

Assumed Model Geometric Data

The reach was broken into five subreaches to represent reported cross-sections and to provide the potential for assessing longitudinal variability in future analyses. In this analysis, subreach geometries are based on survey results, but have been simplified for demonstration. Stream bottom roughness is assumed equal for all subreaches and given a value of 0.045 typically associated with a natural stream that has a slightly rough bed (Thomann and Mueller, 1987). Assumed subreach geometries for W3T are provided in Table 7 and Table 8.

Table 7. W3T Rudio Creek reach description.

Name/Location	Inflow Temperature	Flow[b]	Distance from top of reach (ft)	Approx. River Mile
Above Diversion	Scenario#1[a]	8	0	2.15
POD (Diversion)	N/A	-4.98	10	2.15
112+00	N/A	0.00	247	2.10
86+00	N/A	0.00	2,880	1.61
36+00	N/A	0.00	7,653	0.70
John Day River	N/A	3.02	11,356	0.0

[a] Rudio Creek water temperature data from above POD

[b] Flows are for illustration purposes only in this table

Table 8. W3T Rudio Creek reach parameters.

Reach	Bottom Width (ft)	Side Slope (ft/ft)	Gradient (ft/ft)	Manning n	Aspect
1. Above Diversion to POD	1	3.0	.0195	.045	N-S
2. POD to 112+00	5	3.0	.0195	.045	N-S
3. 112+00 to 86+00	5	3.0	.0195	.045	N-S
4. 86+00 to 36+00	1	3.5	.0195	.045	N-S
5. 36+00 to mouth	1	3.5	.0195	.045	N-S

Riparian Vegetation and Topographic Shade

The W3T simulates both riparian shade and topographic shading. Riparian shading is determined by the distribution and structure of the vegetation along the banks of a stream. Topographic shading describes the shade cast by large topographic features such as hill or mountains. In the current version of W3T, topographic shade is assumed to be the same for the entire. Riparian vegetation is defined in detail for each individual subreach and is represented by vegetation zones that are defined for each of four zones, or bands, away from the river in each of seven directions. Aerial photographs, geographic information systems (including readily available applications like Google Maps), and field surveys can provide information to define topographic shade and riparian vegetation.

Examination of aerial photos suggests that Rudio Creek is somewhat typical of a high dessert stream. Small-stature deciduous riparian vegetation dominates streamside, but in places is absent. Set back from the stream are large conifers, except where the stream meanders adjacent to forested areas.

Assumed Model Shade

The W3T uses Shade-a-lator logic to calculate the effects of topographic shade and riparian vegetation on solar radiation. The information needed by W3T is the same as that used by Shade-a-lator and that information is organized in a fashion similar to Shade-a-lator. Currently, W3T is being modified to accept shade information directly from a shade-a-lator simulation, but this feature has not been added as of the date of this memoranda.

Shade was assumed to be small deciduous vegetation adjacent to stream (type 601, zone 1), barren ground (type 305, zones 2 and 3), and large conifer (type 750, zone 4). Because of its north-south aspect, the river was assumed to be open water (code 301) in the southern direction. Heights and densities associated with each of these vegetation types are taken from Shade-a-lator and listed in W3T for reference. This vegetation structure was assumed consistent over the length of the study area and was applied to all subreaches throughout the reach. All vegetation was assumed to be at the river elevation (insignificant bank height), except zone 4 conifers that were assumed to be 15 feet (4.57 m) above the stream elevation based on review of aerial imagery on Google Earth. All vegetation zones were assumed to be 15 meters in width. The shade template used for this simulation is provided in Table 9.

Table 9. Shade assumptions by direction, zone, type with height and density information.

Direction	Zone	Type	Height (m)	Density
NE	1	601	5	0.75
NE	2	305	1	1
NE	3	305	1	1
NE	4	750	30	0.3
E	1	601	5	0.75
E	2	305	1	1
E	3	305	1	1
E	4	750	30	0.3
SE	1	601	5	0.75
SE	2	305	1	1
SE	3	305	1	1
SE	4	750	30	0.3
S	1	301	0	0
S	2	301	0	0
S	3	301	0	0
S	4	301	0	0
SW	1	601	5	0.75
SW	2	305	1	1
SW	3	305	1	1
SW	4	750	30	0.3
W	1	601	5	0.75
W	2	305	1	1
W	3	305	1	1
W	4	750	30	0.3
NW	1	601	5	0.75
NW	2	305	1	1
NW	3	305	1	1
NW	4	750	30	0.3

Topographic shading was assessed globally (i.e., equally for all reaches) based on average elevation angle of topographic features. Data were provided by TFT and are summarized in Table 10.

Table 10.Topographic shade information used in W3T.

Statistic	Direction (degrees)		
	West	South	East
Average	16.24	14.80	15.66
Minimum	4.14	10.06	7.71
Maximum	28.74	34.88	33.05
Std. Dev.	4.22	3.75	5.76

Water Temperature

Water temperatures are specified hourly for each inflow to the W3T. Typically, water temperatures are measured in the field, but they can be derived from other models or by assumption. In this study, there are no tributaries and the only required water temperature record is one for upstream flow.

Water temperature was measured above the diversion, at a location labeled "above Gilmore Creek." The exact location was not identified but Gilmore Creek is quite a distance, approximately 9400 feet (1.8 miles), upstream of the point of diversion. Water temperatures at this site ranged from approximately 12 °C to over 22 °C (Figure 8). These are the only water temperature data available near the study area. No information was provided on Gilmore Creek (flow or temperature), or flows in Rudio Creek above Gilmore Creek. Further, no channel information above the project area (i.e., above the POD) was provided.

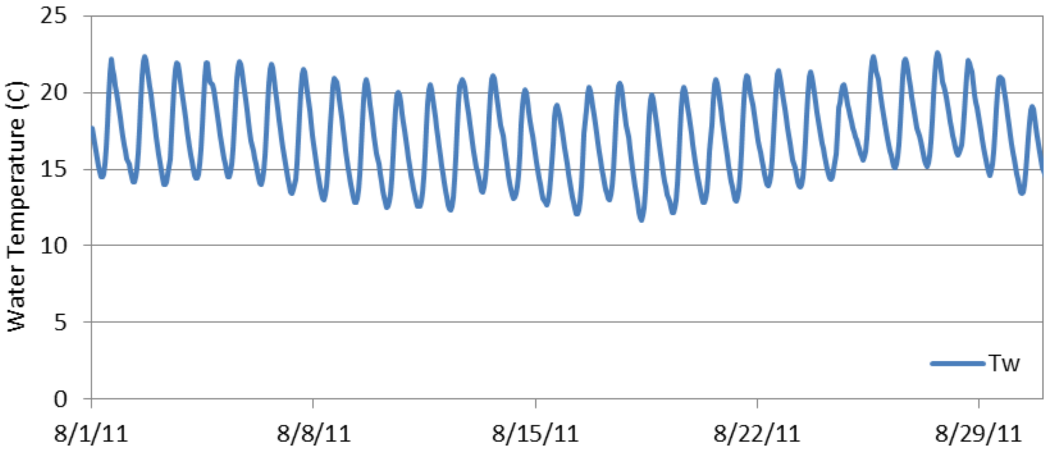


Figure 8. Rudio Creek water temperature above Gilmore Creek.

Assumed Water Temperature Conditions

To accurately assess potential flow transaction impacts on water temperature, water temperature of flow into the study reach must be estimated from the temperature trace recorded "above Gilmore Creek." Two approaches were applied.

1. Above POD: Apply measured water temperatures at the POD. In this case, the water temperature trace from "above Gilmore Creek" was simply applied to the POD assuming no significant change during transit.
2. Gilmore-Rudio: Simulate water temperature from Gilmore Creek to the POD and apply these temperatures at the POD. In this case, measured data from "above Gilmore Creek" were assumed to be representative of water temperatures just downstream of the Gilmore Creek-Rudio Creek confluence. Using W3T, water temperature was then simulated downstream approximately 9,400 feet (as measured in Google Earth) to the POD to account for any heating that might occur. Because channel geometries were not available for this length of stream, Reach 1 channel geometry was assumed. Based on review of maps, the aspect of this reach was assumed East-West. Riparian and topographic shade assumptions were unchanged.

Both of these approaches establish water temperatures at the top of the study reach where there are no data, and both may be considered reasonable. But they produce different results. Because actual water temperatures at the top of the study reach are unknown, results from both approaches are considered and compared in evaluating flow transactions. Including results from both approaches illustrates the importance of temperature logger location and provides an extra level of confidence for decision makers. Water temperature entering the reach under the two water temperature approaches is shown in Figure 11.

Flow

Flow in Rudio Creek is measured at two locations. Daily flow data are reported above the confluence of Rudio Creek and the John Day River. Flow below the POD is reported in 15-minute intervals. Flow varies throughout the year. Because instream water temperatures are most sensitive to low flows we have selected a period in late summer for this analysis.

Flows in Rudio Creek for August 2011 are shown in Figure 9. The 15-minute record below the POD suggests that the study reach experiences a diel variation in flow of approximately 50 percent. The reason for such variability may include evapotranspiration due to riparian vegetation in upstream reaches, upstream water use activities, and/or other conditions. Maximum diversion rate at the current point of diversion is 4.98 cfs. The target minimum instream flow for the August 1 to September 5 period is 2 cfs, as described TFT. A time interval for this criterion was not provided, so this analysis assumes this is an instantaneous criteria and not a daily average.

Average flow for August (2011) at the mouth was 3.78 cfs (max. 5.74 cfs, min. 2.93 cfs), while average flow below the POD near the top of the reach was 1.67 cfs (max. 2.37 cfs, min. 0.91 cfs). From these records, it is apparent that there are accretions in the study reach that must be accounted for.

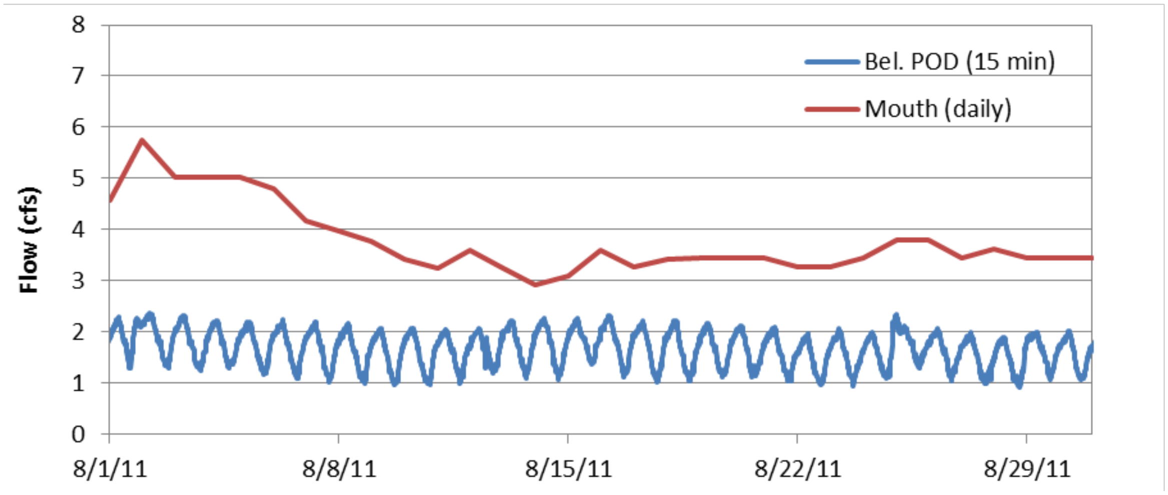


Figure 9. Rudio Creek flow below the POD and near the mouth (confluence with John Day River): August 2011.

Assumed Model Flow Data

For model assessment, a range of flows was applied under the two temperature conditions identified in the previous section. Because neither flow data above the POD nor diversion quantity was available, an assumption of instream flow was required. Flow records shown in Figure 9, wherein downstream flows at the mouth are greater than upstream flows below the POD, suggest the possibility of agricultural return flows.

Reviewing aerial photographs of the area, there appear to be return flows to the John Day River at the north and west ends of the fields (A and B, in Figure 10) and to Rudio Creek below a small pond (C in Figure 10). There may also be diffuse return flows downstream to Rudio Creek (north of location C). But the location of such return flows is uncertain, the quantity and timing were unknown, and a representative water temperature was unknown. Therefore, return flow was not included in this assessment. Further, neglecting return flows may represent a conservative assumption, where smaller instream volumes would be more prone to heating under adverse thermal loading conditions.

Figure 10. Potential return flow locations to Rudio Creek and the John Day River.

Based on considerations of flow data, water rights and instream requirements, four scenarios were constructed to assess flow transactions on Rudio Creek. These scenarios are intended to bracket flow conditions and illustrate the potential range of water temperature responses to flow transactions. The "Baseline" scenario represents current flow conditions with mean August flow and full water right diversions. Other scenarios represent the imposition of a 2 cfs minimum flow requirement, together with full water right diversions, on current flow conditions, low flow conditions and periods of high flow, respectively. The scenarios and their assumptions are:

1. <u>Baseline</u>

   Description: current flow; full water rights diversions

   Assumptions:

   a. Flow upstream of the project was assumed to be the mean August 2011 flow (1.67 cfs), plus the full diversion water right (4.98 cfs), for a total of 6.65 cfs.
   b. Diversions assumed to be full water right of 4.98 cfs
   c. Remaining instream flow was 1.67 cfs (mean August 2011 flow)

2. <u>Minimum Instream (I)</u>

   Description: current flow; full water rights diversions; 2 cfs instream flow requirement

   Assumptions:

   a. Same as Baseline, except impose the 2 cfs minimum instream flow below the POD
   b. This results in a full water right shortfall of 1.33 cfs

3. <u>Minimum Insteam (II)</u>

   Description: low flow; full water rights diversions; 2 cfs instream flow requirement

   Assumptions:

   a. Upstream flow is assumed to be 4 cfs
   b. Impose the 2 cfs minimum flow below the POD

    c. Results in a full water right shortfall of 2.98 cfs

4. Excess
   Description: excess flow; full water rights diversions; 2 cfs instream flow requirement
   Assumptions:
    a. Upstream flow is assumed equal to 8 cfs (i.e., in excess of water right and minimum instream flow)
    b. Downstream flows is 3.02 cfs

All of these scenarios were simulated under each of the two inflow temperature traces developed for this analysis. Flow scenarios are summarized in Table 11. Inflow temperature traces are identified by the location at which the “above Gilmore Creek” water temperature record was applied: “Above POD” and “Gilmore-Rudio” confluence as discussed previously.

Table 11. Rudio Creek scenario summary.

Inflow Tw approach		**Scenario**			
		Baseline	**Min instream (I)**	**Min Instream (II)**	**Excess**
Above POD					
	Upstream Flow (cfs)	6.65	6.65	4	8
	Diversion Qty (cfs)	4.98	4.65	2	4.98
	Downstream Flow (cfs)	1.67	2	2	3.02
Gilmore-Rudio					
	Upstream Flow (cfs)	6.65	5.65	4	8
	Diversion Qty (cfs)	4.98	4.65	2	4.98
	Downstream Flow (cfs)	1.67	2	2	3.02

Results

Rudio Creek water temperatures were simulated for several days in August 2011. Results are reported for August 2 and 3 2011 – two of the hottest water temperature days in the month. Although air temperatures were warmer late in the month, day length was shorter and results were nearly identical. Water temperature entering the reach under the two water temperature approaches is shown in Figure 11. Results of the scenarios, each compared to the baseline condition, are shown in Figure 12 to Figure 17.

In general, using the Gilmore-Rudio approach leads to warmer water temperatures than “above POD,” indicating that stream temperatures were not at equilibrium and increased with transit time in hot weather. Minimum instream flows result in reduced maximum daily temperatures – on the order of 1 ^{o}C for Min Instream (I) under the Gilmore-Rudio approach and slightly less under the “above POD” approach, as shown in Figure 12 and Figure 15, respectively.

More or less water in the stream will affect heat exchange dynamics, so low and high flow scenarios cannot be directly compared to baseline. But the overall effect of inflow and instream flow requirements can be seen in such comparisons. With less water in the stream, Min Instream (I), both approaches led to slightly lower water temperatures over baseline as shown in Figure 13 and Figure 16. With excess water in the stream, Min Instream (II), both approaches led to noticeably lower water temperature on the order of 2 °C, as shown in Figure 14 and Figure 17.

One of the strengths of W3T is its ability to simulate and compare the effects of riparian shading on water temperatures. To illustrate the potential effect of vegetation on water temperatures, an additional simulation based on "above POD" inflow temperatures for Min Instream (I) was made assuming riparian vegetation matured from current "small deciduous" to "large deciduous" trees. This simulation assumed simply that near-stream (zone 1) vegetation height changed from 5 meters to 15 meters and that density was unchanged at 0.75. The results of this simulation, shown in Figure 18, illustrate that the simple assumption of mature trees leads to a notable change in the stream temperature regime, with downstream temperatures at or significantly cooler than upstream temperatures.

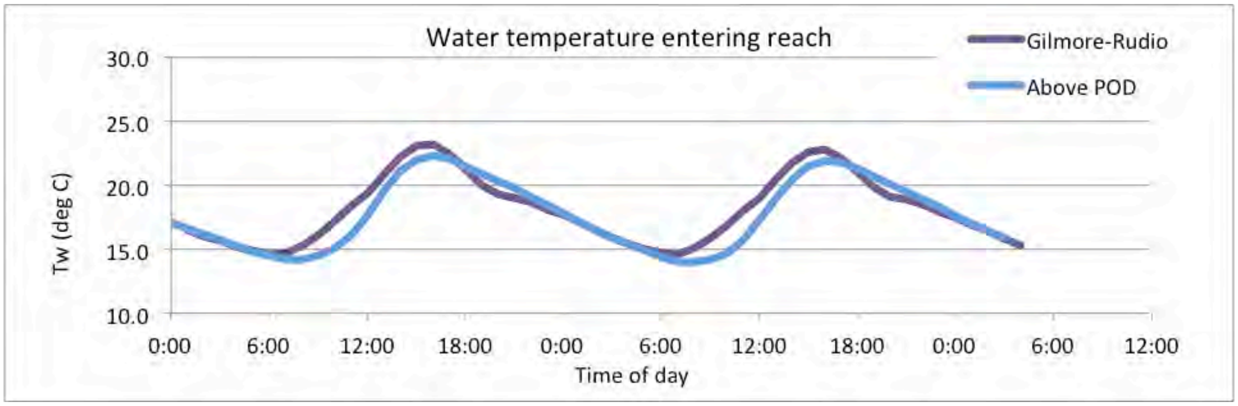


Figure 11. Water Temperature at top of reach for both inflow Tw options: August 2 and 3, 2011.

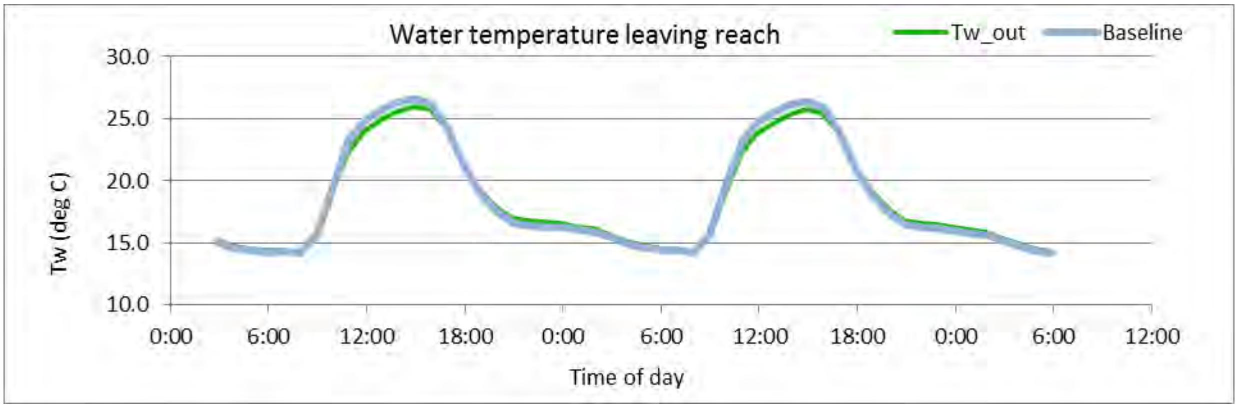


Figure 12. Inflow Tw: Gilmore-Rudio – Baseline and Min Instream (I): August 2 and 3, 2011.

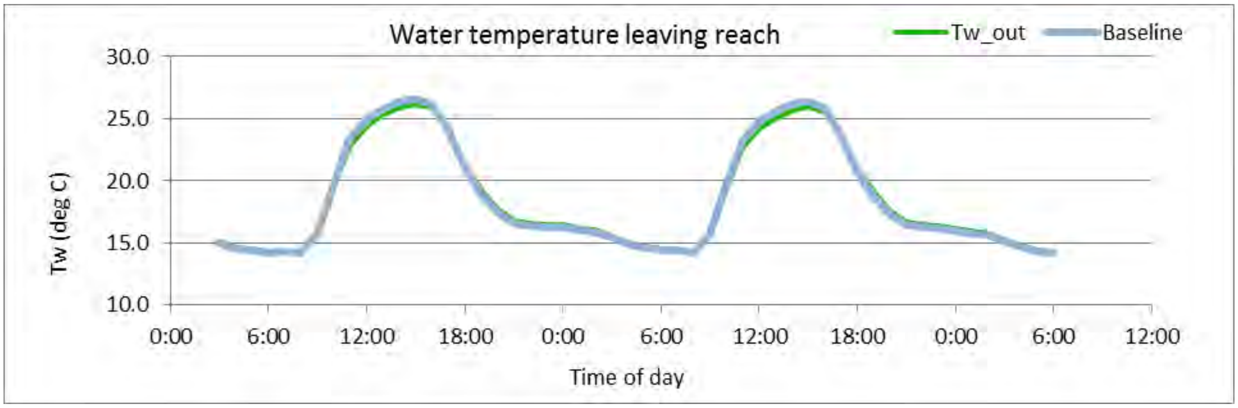


Figure 13. Inflow Tw: Gilmore-Rudio – Baseline and Min Instream (II): August 2 and 3, 2011.

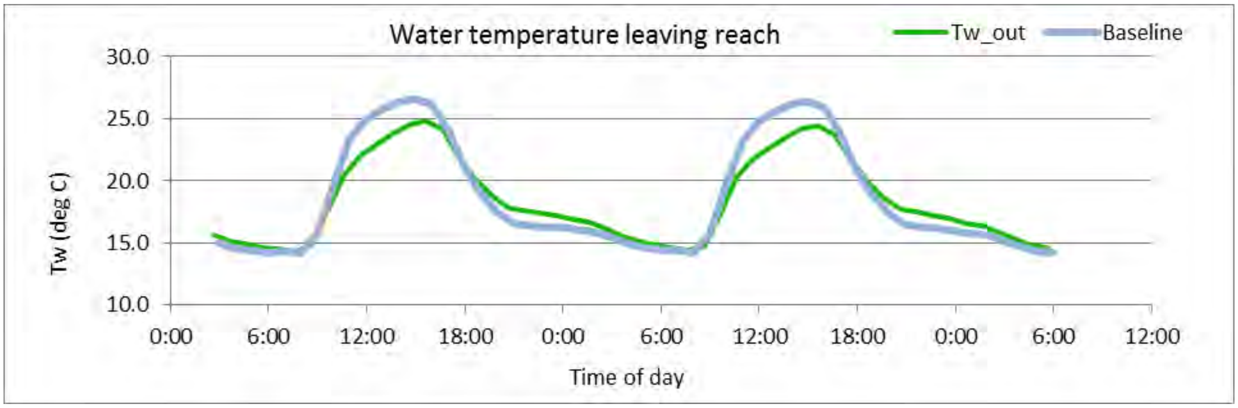


Figure 14. Inflow Tw: Gilmore-Rudio – Baseline and Excess: August 2 and 3, 2011.

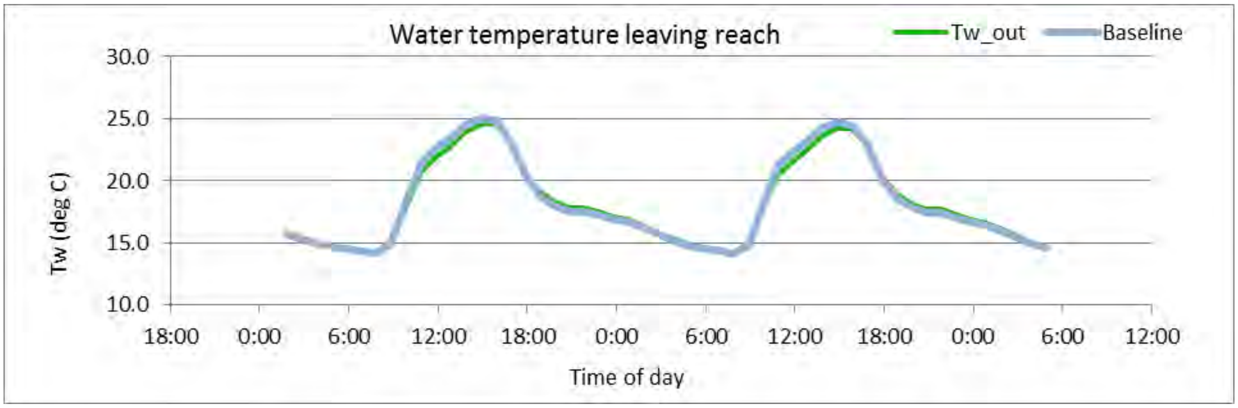


Figure 15. Inflow Tw: POD – Baseline and Min Instream (I): August 2 and 3, 2011.

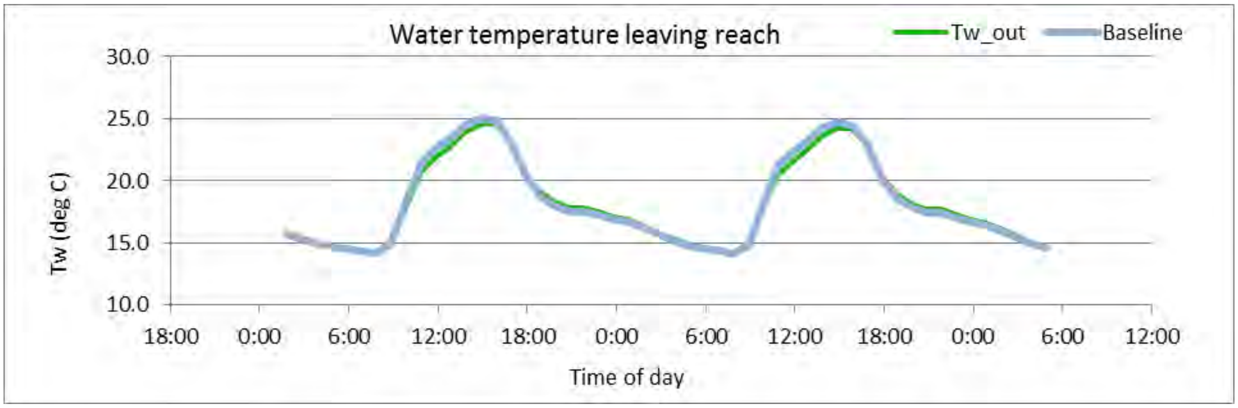


Figure 16. Inflow Tw: POD – Baseline and Min Instream (II): August 2 and 3, 2011.

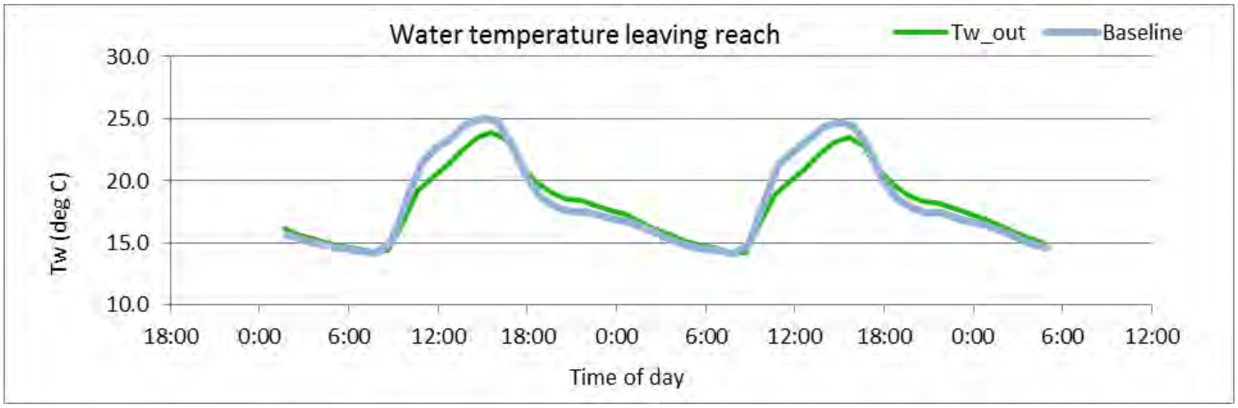


Figure 17. Inflow Tw: POD – Baseline and Excess: August 2 and 3, 2011.

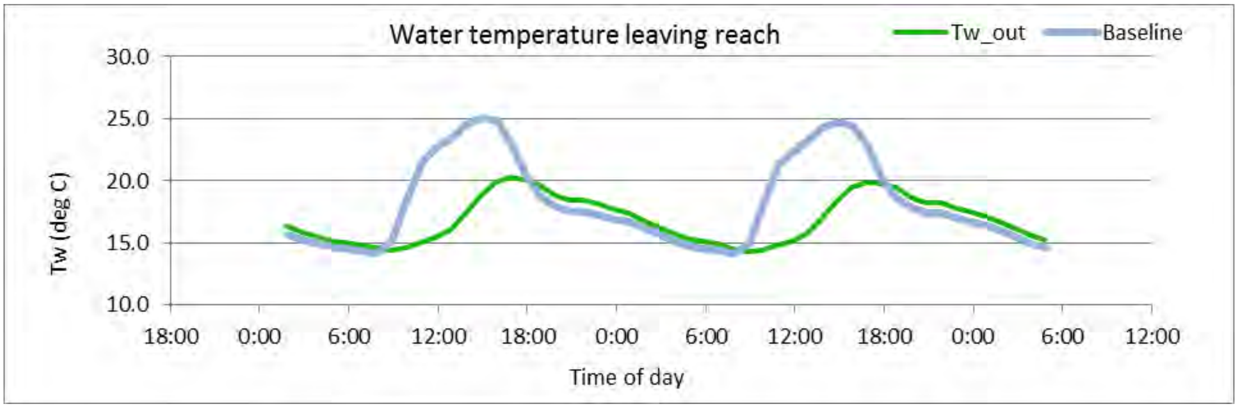


Figure 18. Inflow Tw: POD – Baseline and Min Instream (I) with large deciduous riparian vegetation restored to zone one: August 2 and 3, 2011.

Conclusion

This brief analysis wherein W3T was applied to available data for Rudio Creek indicates that a flow transaction would benefit temperature. Based on a modest amount of data, various scenarios can quickly be assessed to identify and prioritize potential actions. Improvements to the analysis can be completed considering the analysis limitations, below.

Analysis Limitations

1. Additional water temperature data near the bottom of the reach would be useful to calibrate the model.
2. Water temperature at the POD would reduce uncertainty associated with (a) simulating water temperature for nearly two miles to establish an upstream boundary condition or (b) applying the “above Gilmore Creek” temperature trace nearly two miles downstream at the POD.
3. A flow gage upstream of the point of diversion and quantifying the diversion would provide critical information regarding the temperature signal at the top of the reach.

Citations

Linacre, E. 1992. *Climate Data and Resources – A Reference and Guide*. Routledge. New York. 366 pp.

Snyder, R. L. and Shaw, R. H. 1984. *Converting humidity expressions with computers and calculators*. Leaflet 21372. University of California Cooperative Extension. 23 pp.

Thomann, R.V. and J.A. Mueller. 1987. *Principles in Surface Water Quality Modeling*. Harper and Row, New York, NY

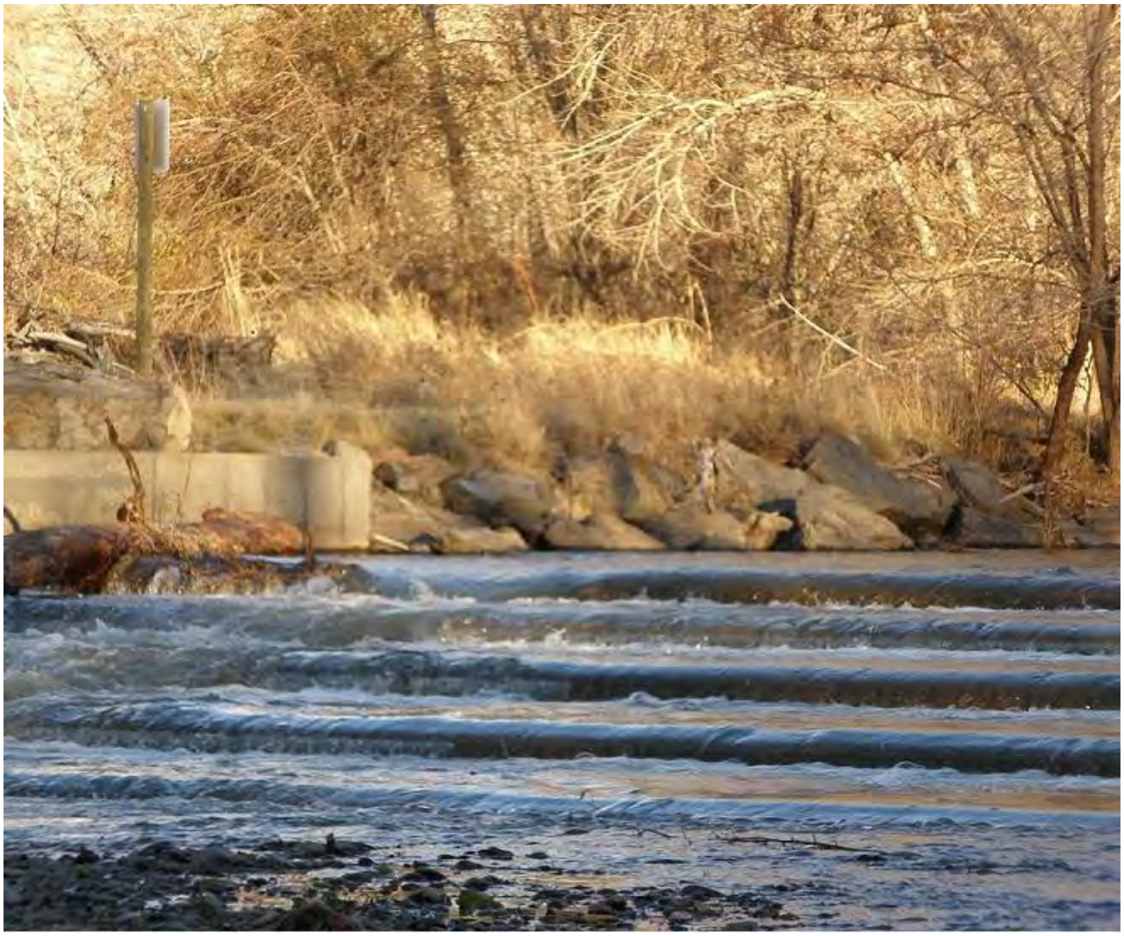
Appendix

Data type	Specific datasets	Source
Meteorological	Air temperature (dry bulb) Cloudiness Wind Relative humidity Wet bulb temperature	RAWS Estimated (zero) RAWS RAWS Calculated
Channel geometry	Planform, gradient, cross section Manning roughness, n	TFT Literature
Topographic shade	Elevation angle	TFT
Riparian vegetation (general)	Width of riparian zones Height of emergent vegetation Density of emergent vegetation	Aerial photos (Google Earth)
Riparian vegetation (by zone)	Height Density Elevation at ground	Based on shade-a-lator tabulated codes
Water temperatures	Inflow water temperatures	TFT
Flows	Inflow rates Diversion rates (1) Instream flow rates (1)	TFT TFT TFT

Abbreviations and notes:
RAWS – Remote Automatic Weather Stations (http://www.raws.dri.edu)
TFT – The Freshwater Trust

(1) Diversion and instream flow rates assessed through a range of values constrained by available water and water rights.

Water Temperature Transaction Tool



Catherine Creek Pilot Test

Prepared by The Freshwater Trust

CONFIDENTIAL: ATTORNEY WORK PRODUCT

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Project Overview

Following the results of biological response modeling, the Bonneville Power Administration and other agencies have chosen Catherine Creek in the Grande Ronde River subbasin as a high priority area for restoration, particularly for flow and temperature. The Freshwater Trust has increased its presence in the area, and is very interested in measuring and modeling water quality parameters affected by its flow transactions both there and elsewhere. One method for doing that is by using the Water Temperature Transaction Tool (W3T), a model developed for the National Fish and Wildlife Foundation (NFWF).

W3T was used to model the effect of a .52 ft^3/s (cfs) change in late summer flow on surface water temperatures throughout, and leaving, a designated reach.

Executive Summary

W3T was run comparing two flow scenarios from above the town of Union, Oregon, past three diversions, to a point at Bellwood Street bridge, 4,335 feet below. The first scenario (“baseline”) modeled Catherine Creek with .52 cfs instream through flow deals on two of the three diversions, the real-world scenario in summer 2012. The second scenario (“current”) modeled what temperatures would have been if the flow deal weren’t in place, with .52 additional cfs being diverted. The modeled temperature difference between the scenarios was negligible, showing the flow deals contributed to a temperature increase of .01 degrees Celsius, as described in Table 1.

Table 1 Baseline (Flow Deal) vs. Current (No Flow Deal) Scenario

Scenario	Inflow discharge (cfs)	Outflow Discharge	In-Reach avg. temperature change (°C)	Water Leaving Reach			
				Max Temp (°C)	Min Temp (°C)	Mean Temp (°C)	Kilocalories/ day leaving reach
Flow Deal	20.07	14.76	-.37	17.25	8.86	12.63	497,000,000
No Flow Deal	20.07	14.24	-.38	17.25	8.83	12.62	479,000,000
Difference	0	.52	.01	0	.03	.01	18,000,000

Reach Selection

A reach from River Mile 41 to River Mile 40 in Catherine Creek was selected and delineated based upon three factors: presence of a flow transaction, data availability, and modeling ease.

FLOW TRANSACTION PRESENCE

The modeled reach included two flow transactions for a total of .52 cfs instream: .19 cfs under a split-season lease of Certificate 57428 (SL-15), and .33 cfs under a full season lease of Certificate 45105 (IL-1153), both with a priority date of 1874.

DATA AVAILABILITY

The reach had a significant amount of both temperature and discharge data available. The Freshwater Trust took multiple manual discharge measurements in that segment during the 2012 irrigation season as part of ongoing flow monitoring, and temperature and water elevation loggers were also deployed throughout that period, establishing good endpoints for the chosen model reach. See Appendix A for a more in-depth accounting of field measurements.

MODELING EASE

An added benefit of the chosen reach was that it had a limited number of inputs and removals. There were only three diversions, all within close proximity relative to the overall reach length, allowing for less error when distributing unaccounted losses among the diversions. Beyond that, the reach had no known tributary inputs, allowing that variable to be disregarded.

Finally, the chosen reach length was short, at .82 miles. Keeping the reach length short minimized inaccuracies that were byproducts of unaccounted input or removal locations, as well as any error associated with establishing a single representative vegetation sample over a much longer, and likely more varied, subreach.

Date Selection

The model was run using a period of time during which instream flows were ostensibly not regulated off for senior priority consumptive uses, and where low flows were manually measured. The use of actual discharge measurements side-stepped any inaccuracies associated with an imperfect rating curve. September 10th was chosen, because manual discharge measurements were taken on September 11th, at a mid-point in the 48-hour modeling period, ensuring that inflows and outflows in the model were as accurate as possible given the availability of data.

Model Setup

REACH

The reach length was 4,335 feet, beginning where TFT deployed a joint temperature/elevation logger, at RM 41 on the BOR map, as seen in Figure 1. The first subreach was 875 feet, down to Prescott Ditch, which diverted 2.47 cfs under the flow deal, and 2.8 cfs without the flow deal (.33 cfs full season deal). The second subreach, from Prescott Ditch to Swackhammer Ditch, was 1,015 feet in length, with Swackhammer Ditch diverting 1.09 cfs in both scenarios. The third subreach, from Swackhammer to Guild, is approximately 124 feet long, with Guild diverting 1.75 cfs with the flow deal and 1.94 cfs without the deal (.19 cfs split-season lease). The final reach, from Guild Ditch to the outflow measurement site at Bellwood Street bridge, was 2,321 feet long. All “paper water” diversion data for the three ditches is located in Table 2. The flow deal protects .52 cfs of 1874 water from being diverted into the Prescott and Guild ditches, so the “current” model run assumed .52 cfs more water was being diverted to reflect a lack of flow transactions.

Figure 1. Reach Map.

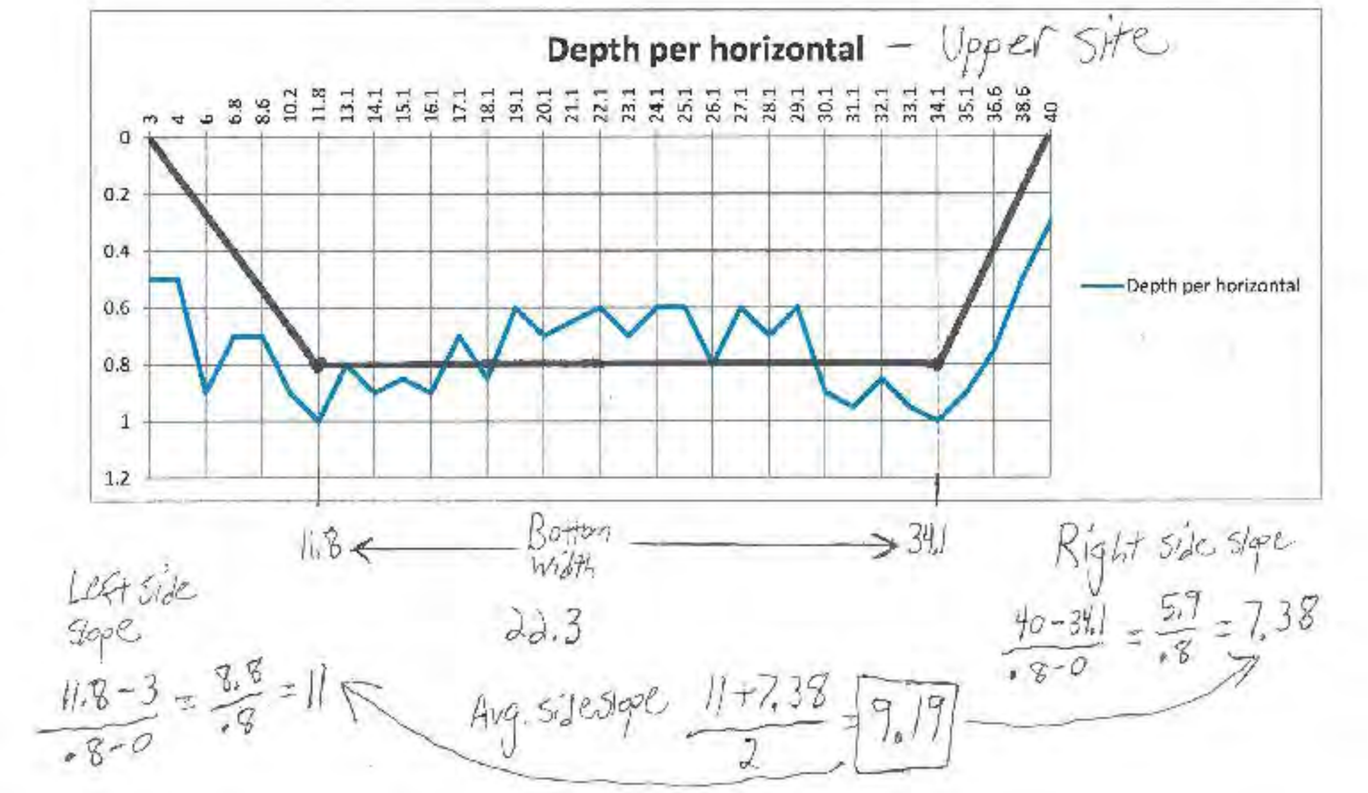
The blue triangles on the Reach Map above signify the inflow and outflow gaging sites, which acted as reach boundaries. The red circles are the three ditches. Here, the pump is so close to the Prescott Ditch that it was included in the Prescott diversion rate, because only three diversions are allowed by the model.

Table 2. Diversion rates by priority date for each of the three PODs.

PODS			
Ditches	Swackhammer	Guild	Prescott
1863		0.4	
1864	0.57		
1865		0.14	
1866	0.03		
1867		0.03	
1868			
1869			
1870			
1871			
1872		0.03	
1873		0.37	
1874		1.52	4.86
1875		0.06	
1876	0.1	0.59	
1877			
1878			
1879			0.075
1880		0.07	
1881		0.01	
1882	0.01	0.04	
1883			
1884		0.1	
1885			
1886		0.03	
1887			
1888			
1889			
1890		0.1	
1891		0.93	
1892		0.09	
1893			
1894		0.03	
1895			

SIDE SLOPE DATA

The side slope data was calculated as is shown in Figures 2 and 3. Channel cross sections were collected as part of the discharge computation performed by TFT's Acoustic Doppler Velocimeters. Trapezoids were fit to the channel cross-sections, and a side slope was calculated. Only two cross sections were available in the modeled reach, one at the inflow and one at the outflow.

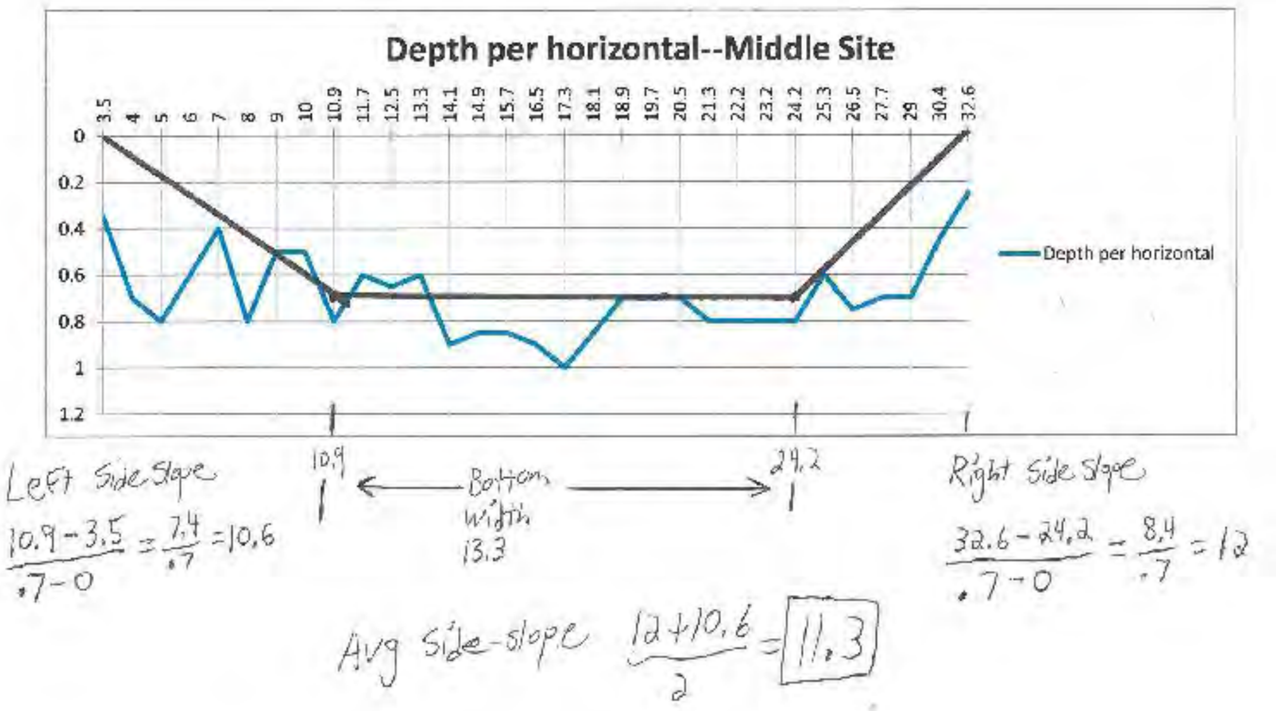


$\frac{11.8-3}{.8-0} = \frac{8.8}{.8} = 11$

$\frac{40-34.1}{.8-0} = \frac{5.9}{.8} = 7.38$

$\frac{11+7.38}{2} = \boxed{9.19}$

Figure 2. Cross section establishment for the reach inflow site.



Left Side Slope

$\frac{10.9-3.5}{.7-0} = \frac{7.4}{.7} = 10.6$

Bottom width 13.3

Right Side Slope

$\frac{32.6-24.2}{.7-0} = \frac{8.4}{.7} = 12$

Avg Side-slope $\frac{12+10.6}{2} = \boxed{11.3}$

Figure 3. Cross section establishment for the reach outflow site.

CHANNEL SLOPE DATA

The channel slope was calculated by using Google Earth elevations for the inflow and outflow points and determining the slope between them. From inflow to outflow, the river elevation drops by 39 feet over the course of 4,335 feet, for a slope of .0090.

INFLOW AND OUTFLOW TEMPERATURES

Inflow and outflow temperatures were collected by temperature loggers deployed at the inflow and outflow gaging sites, reported on an hourly basis. The inflow temperature was used as a model input, and the outflow temperature was compared to the modeled “baseline” outflow temperature to reinforce model accuracy.

SHADE

Shade Input page data was derived from visual inspection or aerial photography (BING maps, 2010) and field notes (TFT staff BPJ). An example of the vegetation sampling regime is pictured below.

Figure 4. Example of vegetation sampling.

METEOROLOGICAL DATA

For the met data, TFT used the Remote Automatic Weather Station data obtained at the (http://www.raws.dri.edu/), maintained by the National Interagency Fire Center (www.nifc.gov). The closest MET station to our project site was the Point Prom II Oregon station:

Location	Point Prom II Oregon		
Latitude	45° 21' 17"	NESS ID	326B7210
Longitude	117° 42' 16"	NWS ID 351419	
Elevation	6607 ft.	Agency USFS	

Air Temperature (deg. C), Wind speed (m/s), Relative Humidity (RH%), and Wet Bulb (deg. C) were all collected from RAWS. A lapse rate of 6 deg. C per 1000 ft. was used to calibrate Air Temperatures at the project site to the

RAWS. "ELEVATION CORRECTION TABLES FOR BAROMETRIC PRESSURE SENSORS" (NOVALYNX CORPORATION, 2008) was used to adjust the barometric pressure between the model site and RAWS.

Model Output

TEMPERATURE

The following graph shows outflow temperatures for both the current (Tw_out) and baseline model runs. Because the change was only .01 degrees Celsius, the lines are very close to each other.

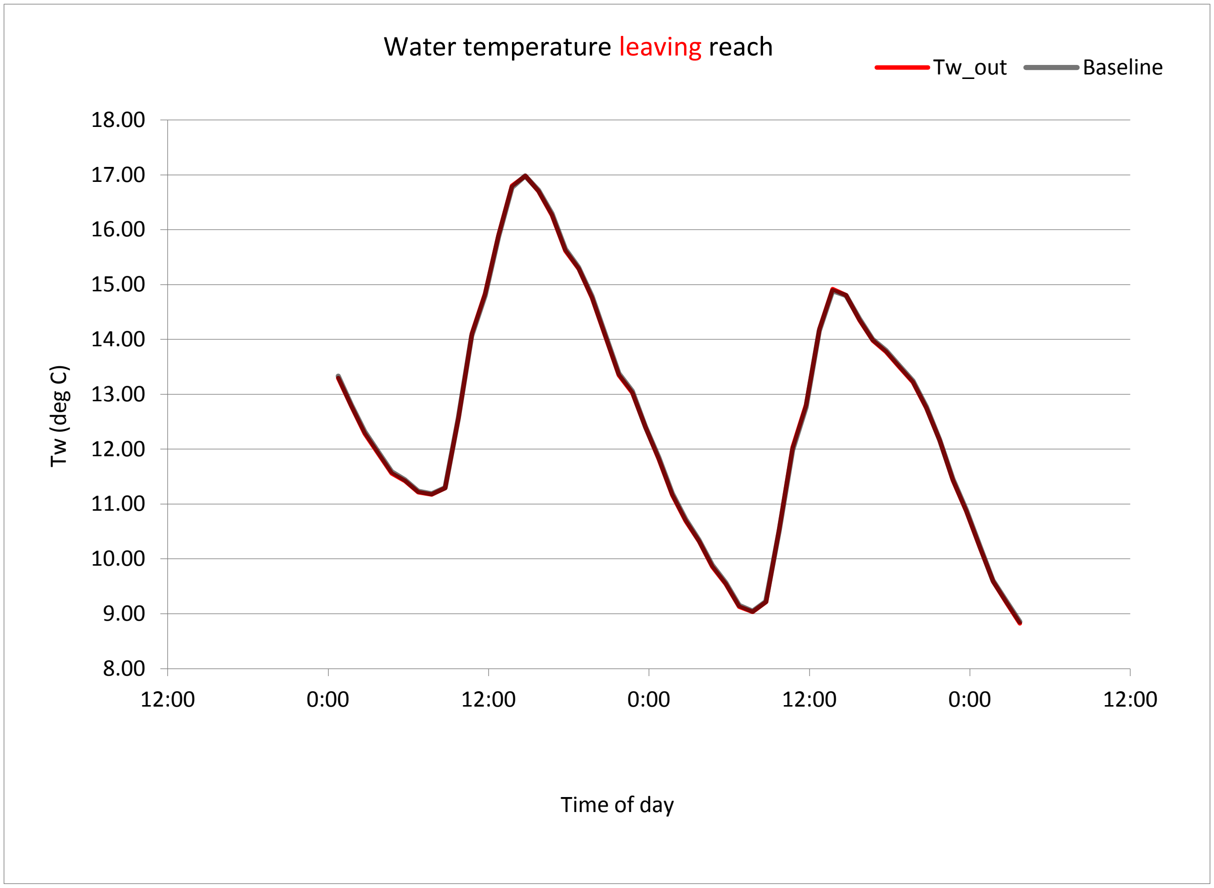


Figure 5. Comparison of modeled baseline (black) and current (red) outflow temperatures

The next figure shows a comparison between the baseline model run with, and the measured outflow temperatures at the end of the reach with the flow deal in place. The modeled outflow temperature closely tracks the actual measured temperature.

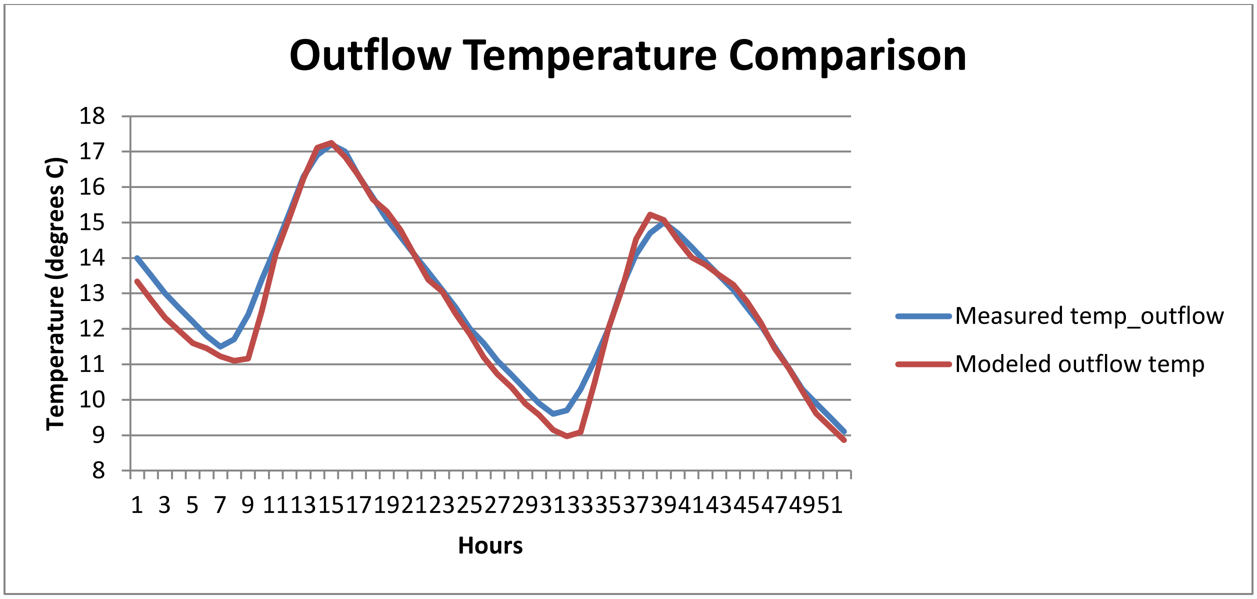


Figure 6. Comparison of measured and modeled outflow temperatures.

Modeled and measured outflow temperatures were compared using a t-distribution function in Excel with the following null hypothesis: the difference between modeled and measured values is not large enough to rule out sampling error or random chance as the source of variation. If the p-value was >.05, we should accept the null hypothesis. The p-value was determined to be .22, so the null hypothesis should be accepted. There is a 95% probability that the difference between the modeled values and measured values was due to chance or random sampling error. The table below shows the values used in this statistical analysis.

Table 3. Values used in statistical comparison of modeled and measured outflow temperatures

Measurement Average (mu)	Model Average (xbar)	Model Standard Deviation	Sample Size (n)	Level of significance	No. of Tails	T value	P value
12.86	12.63	2.12	52	.05	1	.79	.22

The t value was calculated using the following equation:

Equation 1 **t = abs(xbar-mu)/(std dev./square root(n)).**

The p value was calculated using the Tdist function in Excel:

Equation 2 **Tdist(t value, n-1, 1).**

KILOCALORIES

The following table shows the total direct solar radiation the reach receives each day under the two modeled scenarios. There is more solar radiation above the stream with the baseline scenario, which can be expected given that increased surface area is a consequence of increased discharge, and increased surface area leads to increased direct solar radiation.

Table 4. Comparison of direct solar radiation for baseline and current modeling scenarios.

Direct solar radiation (kcal/day)

scenario	above land cover	above stream	Change
baseline	48,000,000	32,000,000	(16,000,000)
current	48,000,000	31,000,000	(17,000,000)

The table below shows the total heat leaving the modeled reach each day, and the difference between the model runs with and without the flow transaction in place. There are eighteen million more kilocalories leaving the reach with the flow deal in place (baseline), than without it in place.

Table 5. Comparison of total heat leaving the modeled reach under baseline and current modeling scenarios.

Heat leaving reach (kcal/day)

scenario	
baseline	495,000,000
current	477,000,000
change:	18,000,000

Conclusion

The model output is a .01 C increase in temperature attendant to an 18,000,000 increase in kcals leaving the reach.

MODEL ASSUMPTIONS

The three modeled points of diversion did not have measurement devices on them during the modeled time period, so paper water values had to be assumed for each diversion. To match measured discharge in the creek, the diversions were assumed to be withdrawing the total difference between the upper and lower manual measurements (channel loss was assumed to be negligible in such a short reach). This diversion quantity was allocated roughly among the diversions to reflect the proportion of each diversion's water rights senior to 1895. A ditch with more senior water was allocated a higher proportion of the diverted amount. Although the rough allocation of loss among PODs by senior water quantity was less than ideal, the choice to model a reach where the points of diversion were in close proximity hopefully helped minimize large variations any change in allocation by POD would have had on the model output.

The regulation structure of water rights on Catherine Creek is relaxed and largely reactive. The watermaster provided little information about specific regulation dates by priority, so it was assumed that the instream water rights, both with 1874 priority, were not regulated for senior consumptive uses during the modeled period. This assumption is reinforced by the fact that to account for the total loss throughout the short reach, the three PODs must have been diverting water for all rights with priority dates 1895 and senior.

MODEL SUGGESTIONS/LIMITATIONS

Questions

The first issue we encountered running the model is the cross section profile requirement by subreach. On both Catherine Creek and Fifteenmile, we only had data for two cross sections (one at inflow, one at outflow), instead of the 6-8 Mike Deas recommended during his presentation. But based on a sensitivity analysis of the model performed by Willamette Partnership, the cross sections have a minimal impact on the model compared to other inputs. Is it acceptable to use only one or two cross sections for the whole river?

Is there a way to have the model self-calibrate against a real output temperature? For example, when we run a baseline scenario, being able to plug in mid-reach or outflow temperature measurements which would cause the model adjust before running a new scenario would be helpful.

The model provides no way to track distributed losses, such as channel loss, within the modeled system. What is the best way, for now, to account for that loss (e.g., distribute losses equally across PODs, vs. attribute just to the bottom POD, etc)?

The diversion/tributary limits make it difficult to model many reaches without clustering PODs. Would it be more accurate to model a large reach by clustering PODs, or model reaches in a daisy chain fashion where one model's input is the output of the model run above it?

Would it be possible for the model to import Sontek flowtracker files directly and utilize the cross section information provided by them, rather than manual input and trapezoid fitting?

Suggestions

A document providing descriptions of all model data needs and any associated collection standards would be helpful. We are uncertain whether elevations and vegetation sampling with online maps are sufficient.

The model interface is cluttered. Streamlining it/cleaning it up would be nice. For example, on the River sheet, highlighting tabular data showing temp comparison in very simple terms between Baseline and Tw_out. Total change in max, mean, min that is easily accessible to non-modeling staff who just want to play with flow values and compare temp outputs would be a good feature. This would make the model more intuitive, and allow faster reporting of various flow/shade scenarios.

We often have trouble decrypting the model error messages. It would be nice if the messages were more specific about what was wrong. Otherwise, a guide helping troubleshoot error messages would be very useful.

When ground-truthing our model output compared to outflow temperature measurements, how do we know when the model needs to be adjusted? Can the model give us confidence intervals to compare measurements to?

It would be nice to have all elevations in the same units. Elevation of the land in feet and elevation of vegetation in meters can be confusing.

Improving Model Performance

The primary way to improve model performance involves putting measuring devices on the points of diversion. According Willamette Partnership's sensitivity analysis, the second-most sensitive input parameter was Point of

Diversion information, so accurate GPS coordinates of exact diversion locations, combined with measurements of the actual diversion quantities could improve model performance significantly.

If putting measuring devices on diversions is not possible, the watermaster should be pressed for specific regulation information around the dates transacted water goes instream, as this provides a better proxy for diversion rates than was used in the model run. Because the watermaster didn't provide any specific regulation data, we made assumptions about the diversion rates of each POD.

It would help to collect more data in the field. Field visits to sample vegetation and get more accurate shade estimates, collect at least one cross section per sub-reach, take channel slope elevations with a gps, and deploy local meteorological data collection units would all improve the model performance.

It would be nice to see a simplified vegetation code list and perhaps "frozen" sheet ranges that allow the user to scroll to the far right (when multiple veg scenarios are created) and still see the code list.

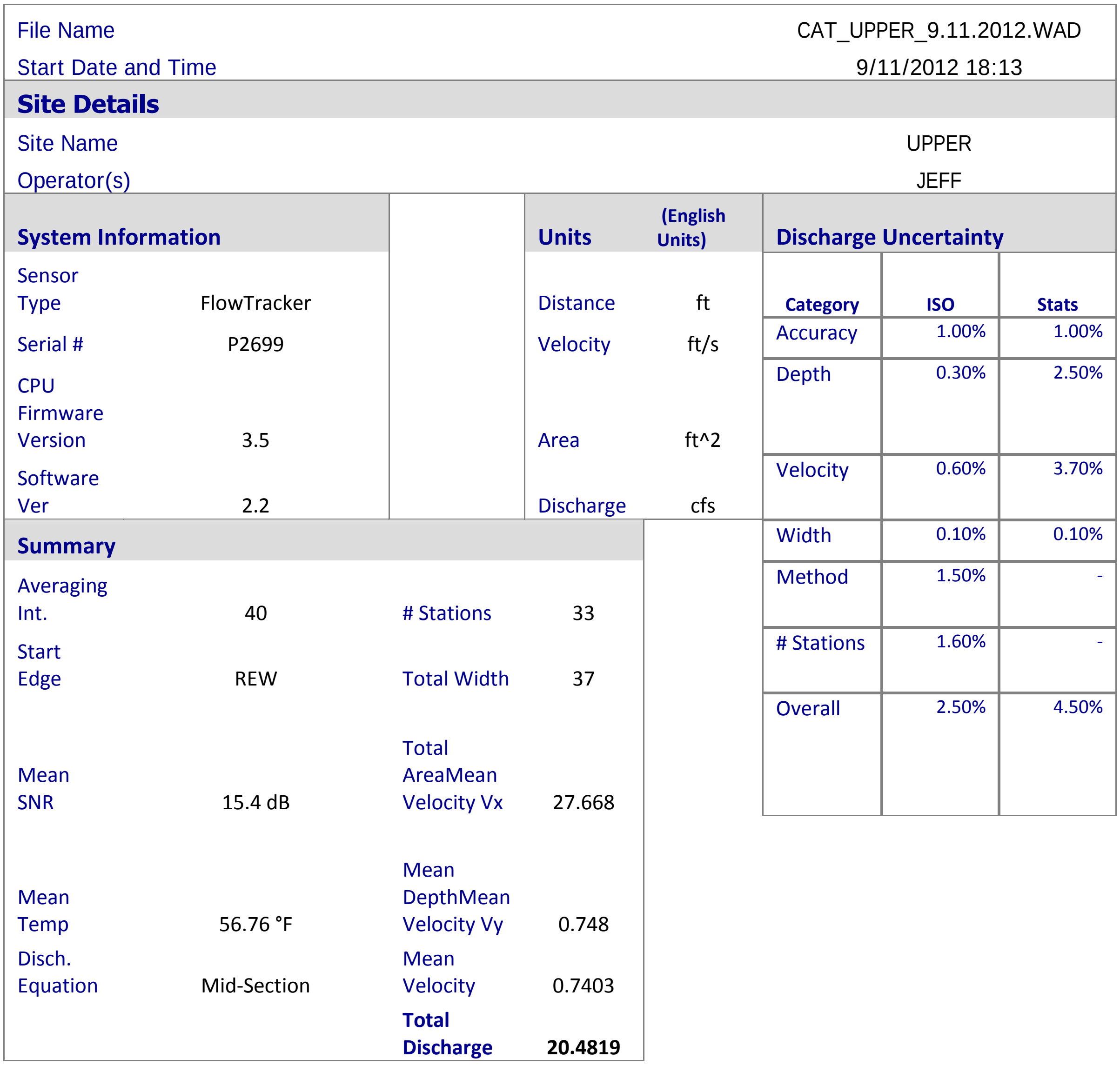
The code for Residential Development should be changed to the 400 series (as part of human built environment), Upland Grasses changed to the 300 series (with the other grasses), and Active Channel and Water should be grouped under a new series (200). The codes can be defined in anyway the user likes, but changes above will make a better example/guide to users unfamiliar with riparian codes. In that vein, it would also be appropriate to include some metadata for the codes, such as date and agency whence they came (e.g., perhaps a study helped create them).

It would be nice to modify the shade input diagrams to allow users to insert a scaled screenshot of the chosen representative node/spot (within a sub-reach) used for vegetation coding (riparian description). This added visual cue could make vegetation coding a bit faster. To our knowledge this is possible, but we are unsure if it will interfere with entering data on the cells.

In the "Reach" page it would be helpful to include a drop-down menu for the assignment of riparian vegetation by subreach. It can be inefficient to have the user type and retype the vegetation scenario names every time they wish to compare model results that include veg or no veg (pre vs. post project).

Appendix A

DISCHARGE MEASUREMENTS



File Name	CAT_UPPER_9.11.2012.WAD
Start Date and Time	9/11/2012 18:13

Site Details

Site Name	UPPER
Operator(s)	JEFF

System Information	
Sensor Type	FlowTracker
Serial #	P2699
CPU Firmware Version	3.5
Software Ver	2.2

Units	**(English Units)**
Distance	ft
Velocity	ft/s
Area	ft^2
Discharge	cfs

Discharge Uncertainty

Category	**ISO**	**Stats**
Accuracy	1.00%	1.00%
Depth	0.30%	2.50%
Velocity	0.60%	3.70%
Width	0.10%	0.10%
Method	1.50%	-
# Stations	1.60%	-
Overall	2.50%	4.50%

Summary

Averaging Int.	40	# Stations	33
Start Edge	REW	Total Width	37
Mean SNR	15.4 dB	Total AreaMean Velocity Vx	27.668
Mean Temp	56.76 °F	Mean DepthMean Velocity Vy	0.748
Disch. Equation	Mid-Section	Mean Velocity	0.7403
		Total Discharge	**20.4819**

Figure 7. Discharge measurement at inflow gaging station.

File Name	CAT_MIDDLE_9.11.2012.WAD
Start Date and Time	9/11/2012 17:24

Site Details

Site Name	MIDDLE
Operator(s)	SCOTT

System Information

Sensor Type	FlowTracker
Serial #	P2699
CPU Firmware Version	3.5
Software Ver	2.2

Units **(English Units)**

Distance	ft
Velocity	ft/s
Area	ft^2
Discharge	cfs

Discharge Uncertainty

Category	ISO	Stats
Accuracy	1.00%	1.00%
Depth	0.30%	3.00%
Velocity	0.70%	5.50%
Width	0.10%	0.10%
Method	1.50%	-
# Stations	1.60%	-
Overall	2.50%	6.40%

Summary

Averaging Int.	40	# Stations	32
Start Edge	REW	Total Width	30.6
Mean SNR	16.4 dB	Total AreaMean Velocity Vx	20.22
Mean Temp	57.30 °F	Mean DepthMean Velocity Vy	0.661
Disch. Equation	Mid-Section	Mean Velocity	0.7256
		Total Discharge	**14.6729**

Figure 8. Discharge measurement at outflow gaging station.

TEMPERATURE MEASUREMENTS

Table 6. Measured and modeled outflow temperatures.

	Outflow Temperature (°C)	
Date/Time	Measured	Modeled
9/10/2012 2:00	14	13.34
9/10/2012 3:00	13.5	12.81
9/10/2012 4:00	13	12.32
9/10/2012 5:00	12.6	11.96
9/10/2012 6:00	12.2	11.60
9/10/2012 7:00	11.8	11.45
9/10/2012 8:00	11.5	11.23
9/10/2012 9:00	11.7	11.10
9/10/2012 10:00	12.4	11.16
9/10/2012 11:00	13.4	12.51
9/10/2012 12:00	14.3	14.10
9/10/2012 13:00	15.3	15.16
9/10/2012 14:00	16.3	16.24
9/10/2012 15:00	16.9	17.11
9/10/2012 16:00	17.2	17.25
9/10/2012 17:00	17	16.85
9/10/2012 18:00	16.3	16.31
9/10/2012 19:00	15.7	15.65
9/10/2012 20:00	15.1	15.31
9/10/2012 21:00	14.6	14.79
9/10/2012 22:00	14.1	14.09
9/10/2012 23:00	13.6	13.38
9/11/2012 0:00	13.1	13.06
9/11/2012 1:00	12.6	12.42
9/11/2012 2:00	12	11.85
9/11/2012 3:00	11.6	11.20
9/11/2012 4:00	11.1	10.72
9/11/2012 5:00	10.7	10.35
9/11/2012 6:00	10.3	9.89
9/11/2012 7:00	9.9	9.57
9/11/2012 8:00	9.6	9.14
9/11/2012 9:00	9.7	8.97
9/11/2012 10:00	10.3	9.09
9/11/2012 11:00	11.1	10.47
9/11/2012 12:00	12	12.02
9/11/2012 13:00	13.2	13.14
9/11/2012 14:00	14.1	14.53
9/11/2012 15:00	14.7	15.23
9/11/2012 16:00	15	15.07
9/11/2012 17:00	14.7	14.51
9/11/2012 18:00	14.3	14.02
9/11/2012 19:00	13.9	13.80
9/11/2012 20:00	13.5	13.52
9/11/2012 21:00	13.1	13.25
9/11/2012 22:00	12.6	12.77
9/11/2012 23:00	12.1	12.18
9/12/2012 0:00	11.5	11.45
9/12/2012 1:00	10.9	10.89
9/12/2012 2:00	10.3	10.24
9/12/2012 3:00	9.9	9.61
9/12/2012 4:00	9.5	9.23
9/12/2012 5:00	9.1	8.86

Appendix VI

Instream Flow Monitoring Protocol

Deliverable 6

Please refer to the Final Agreement Programmatic Report section for information related to this deliverable.

Appendix VII

Flow Calculator

Watercourse Engineering, Inc.
424 2nd Street, Suite B
Davis, CA 95616
530-750-3072 (tel.)
530-750-3074 (fax)

Transmittal

DATE:	May 14, 2013
TO:	Brian Kasper, Watershed Sciences Tarin Lewis, Watershed Sciences Matt Boyd, Watershed Sciences
COPIES:	Andrew Purkey, National Fish and Wildlife Foundation Rankin Holmes, On Farm Solutions
FROM:	Mike Deas, Watercourse Engineering, Inc. (WEI)
RE:	W3T Review Package

Please find enclosed the materials in support of a review of the Water Transactions Temperature Tool (W3T). This tool is being developed for National Fish and Wildlife Foundation as part of the Conservation Innovation Grant (CIG) exploring flow transactions and their potential effect on habitat and water quality. The objective of W3T is to provide a simple, transparent tool to quantify the effects of flow transactions on water temperature and utilize existing shading logic included in Shade-a-lator. The tool was developed in a spreadsheet to provide a transparent and uncomplicated environment that can readily be shared with stakeholders, resource managers, and others involved in flow transactions where water temperature may be affected. The W3T model approach aims strike a balance that provides sufficient accuracy to support and inform a transaction program and minimize data needs and computational time.

Included in this package are six files:

- **Tw Transaction Model v0.9g.xls** (Excel) – the model
- **W3T User's Guide DRAFT_5-13-13.doc** – a user's guide
- **An Example Application of W3T on Rudio Creek.doc** – supporting example
- **W3T Comments Memo.doc** – comment summary from The Freshwater Trust and Willamette Partnership
- **W3T Heat Transfer.xls** (Excel) – an excel file illustrating the heat transfer calculations for verification purposes
- **W3T Excel heat transfer.doc** – brief summary of the W3T Heat Transfer.xls file.

We appreciate and welcome feedback on all elements of the model, e.g., structure, functionality, assumptions, interface, documentation, etc. Thank you for your time and effort, and if you have any questions, comments, or need additional information, please contact me at 530-750-3072 x101 or at mike.deas@watercourseinc.com.

Memorandum

DATE: May 14, 2013

TO: Brian Kasper, Watershed Sciences
Tarin Lewis, Watershed Sciences
Matt Boyd, Watershed Sciences

COPIES: Andrew Purkey, National Fish and Wildlife Foundation
Rankin Holmes, On Farm Solutions

FROM: Mike Deas, Watercourse Engineering, Inc. (WEI)

RE: Heat Source heat budget reproduced in Excel worksheets

In the course of building the Water Temperature Transaction Tool (W3T) based on Heat Source code, Watercourse Engineering has reviewed the Heat Source heat budget in detail. Part of this review included reproducing the heat budget code (written in Visual Basic for Applications), line-by-line, in Excel spreadsheets. This reconstruction allowed us to follow the structure of calculations and observe results under changing meteorological conditions. A similar re-creation was made with QUAL2E heat budget code (written in FORTRAN) and preliminary comparison indicates that Heat Source and QUAL2E heat budget calculations produce similar results.

The W3T heat budget taken from Heat Source is reproduced along with original VBA code in “W3T Heat Transfer,” an Excel workbook with macro capabilities (see accompanying notes for comments/ modification). Constants and values for boundary conditions are listed in a worksheet called “BCs.” The heat budget code is reproduced line-by-line in two worksheets corresponding to the organization of the code in Heat Source. Longwave radiation calculations are listed in the “Longwave” worksheet. Evaporative and convective flux calculations are listed in “Evaporative-Convective.” At its top, each calculation sheet has a listing of locally-used constants and boundary conditions and lists locally calculated “named” variables. Below is a listing of the VBA code and, next to each line of code is an associated calculated value. Units and notes are also included. The worksheet calculations use “named” variables for clarity.

The “W3T Heat Transfer” workbook also contains the W3T heat budget in code in its macro sheets. This code is the same as used in W3T and is set up to use the same constants and boundary conditions as the Excel calculations in the worksheets. A button at the bottom of the “BCs” worksheet runs the VBA code and a small table allows users to compare results from Excel and VBA calculations after changes to boundary conditions.

An apparent inconsistency was found in calculation of evaporative heat flux. In the Heat Source code, a saturation vapor pressure is calculated at water temperature. Then, this vapor pressure is multiplied by humidity to get a value for air vapor pressure that is used in the calculations. Chapra (1997) identifies air vapor pressure calculations based on saturation vapor pressure at air temperature.

WATER TEMPERATURE TRANSACTION TOOL (W3T): TECHNICAL AND USER'S GUIDE (V1.0)

A Report for

National Fish and Wildlife Foundation (NFWF)

PREPARED BY
<u>DRAFT</u>

WATERCOURSE ENGINEERING, INC.
424 SECOND STREET, SUITE B
DAVIS, CALIFORNIA 95616
(530) 750–3072

MAY 13, 2013

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Executive Summary

The Water Temperature Transaction Tool (W3T) is an easy-to-use, interactive model for quickly evaluating stream temperatures under a variety of scenarios. The tool allows users to define a simple river reach and change basic characteristics, such as surrounding shade, cross-section form, channel slope, and tributaries and diversions, to evaluate potential benefits of flow transactions as they relate to river temperature. In defining the river reach, tributaries and diversions may be placed anywhere along the reach length and can be moved, removed, or added to develop different scenarios for comparison. Users may interactively specify reach length, inflow, tributary flow, and diversion amount. Water temperature can be assigned within W3T from a list of records and assigned to each inflow. Unique shade scenarios can be developed within W3T and assigned to individual sections of a reach.

To evaluate potential management decisions and compare scenarios, a set of summary tables and graphs are included. These summaries include tables of input parameters and results and graphs of inflow versus outflow temperatures, longitudinal daily minimum, mean and maximum temperatures, and solar radiation resulting from scenario assumptions. W3T includes the ability to save a baseline scenario for comparisons. Outflow temperatures and solar radiation under baseline conditions may be graphically compared to results from current scenario conditions. Solar reductions (compared to theoretical maximum as well as versus a “pre” and “post” condition) are also reported (consistent with Shade-a-lator reporting). In addition, heat leaving the reach (kcal/day) is calculated and compared to baseline.

A companion document, “An Example Application of W3T: Rudio Creek,” is available to provide guidance in identifying data needs, collecting data, and running the W3T model.

Water Temperature Transaction Tool (W3T): Technical and User's Guide (V1.0)

1. Background

W3T was developed for the National Fish and Wildlife Foundation (NFWF) as part of the Conservation Innovation Grant (CIG) exploring flow transactions and their potential effect on habitat and water quality. Ideally, such a tool should be capable of calculating stream water temperature for shaded and un-shaded reaches for a variety of flow conditions. Flows may affect temperature in several ways: increasing flow volume can moderate daily maximum water temperatures, reduce daily range (maximum minus minimum), and reduce travel time (and thus exposure time of waters to meteorological conditions) through a reach. If added flows are colder than in-stream waters, the benefits can lead to locally cool conditions or longer, cool water river reaches/habitats. Finally, woody riparian vegetation shading can notably reduce incoming solar radiation, thus directly reducing energy input to the stream. (Topographic shade can also lead to reductions in solar energy, but this is a largely uncontrollable factor.) Thus, a water temperature tool to quantitatively assess flow transaction would necessarily require a flow component (including volume and velocity information), a heat budget to assess energy transfer across the air-water interface (and ground-water interface, i.e., bed conduction), and a representation of vegetation (and topographic) shading. Further, the tool should calculate daily minimum, mean, and maximum water temperature for use in various biological metrics. Finally, such a tool would need to be transparent and uncomplicated, require modest data inputs, and calculate results quickly. These assumptions result in a tradeoff between simplicity and uncertainty; however, the approach outlined herein aims to strike a balance that provides sufficient accuracy to support a transaction program and minimize data needs and computational time.

W3T is based on a steady flow approach (e.g., based on the Manning equation) requiring basic stream parameters (velocity, depth, cross sectional area, and surface area). Subsequently, this information is used to model water temperature based on energy transfer to and from the water across the air-water interface and accounts for transport of heat energy in the downstream direction. The current model for heat budget is consistent with Heat Source (v 7) and includes simulation of topographic and riparian shade. Other heat budget formulations from other water quality models may be included in future as user-selected options to provide flexibility and transferability among different regions or regulatory areas.

The maximum size and complexity of the river and canopy are limited only by ease-of-use. Currently, the model is limited to 7 reaches with a maximum of 3 tributaries and 3 diversions. Each reach may have its own hydrodynamic characteristics and 4 zones of riparian vegetation. Energy transfer across the ground-water interface is not currently modeled.

2. Technical Development

The Water Temperature Transaction Tool (W3T) uses river and landscape characteristics to estimate hourly solar radiation and overall heat loss or gain, and from these estimations it calculates temperature changes in a river reach. The reach is described by reach length and width, bed roughness, and topographical and vegetation features such as surrounding zones of vegetation that provide shade and inhibit solar radiation. Meteorological data are included to describe the local environmental conditions affecting heat transfer at the air-water interface. A schematic of the modeling framework is shown in Figure 1.

The user specifies inflow rates and water temperatures. As water travels downstream from the top to the bottom of the reach, the model estimates incoming solar radiation and atmospheric heat exchange. Summing short wave (direct solar), longwave, evaporative, and conductive heat fluxes, the model calculates a net change in temperature in short computational segments. Along the reach, tributary inflows with distinct temperature signals mix with river water, and diversions from the stream are represented. Parcels of water are tracked and outflow temperatures are reported for every hour of a simulation.

To capture varying meteorology and tributary inputs, and to accommodate varying vegetation structure, a reach is subdivided into subreaches and computational segments. Reach length is divided by the user into subreaches that are defined by hydrodynamic and/or vegetation characteristics. Each subreach is homogeneous along its length and characterized by consistent channel geometry, vegetation structure, and flow. These subreaches are subdivided by the model into equal computational segments so that meteorological conditions are interpolated at intervals no longer than 15 minutes. For example, a subreach with a travel time of 17 minutes is subdivided into two computational sections of 8 ½ minutes each, and a subreach with a travel time of 10 minutes is not subdivided at all. Meteorological conditions are established at the beginning of each computational section by interpolation of reported hourly data. The resulting meteorological conditions are used to estimate average heat flux over the length of each computational segment, and this estimated heat gain or loss is used to compute a change in water temperature.

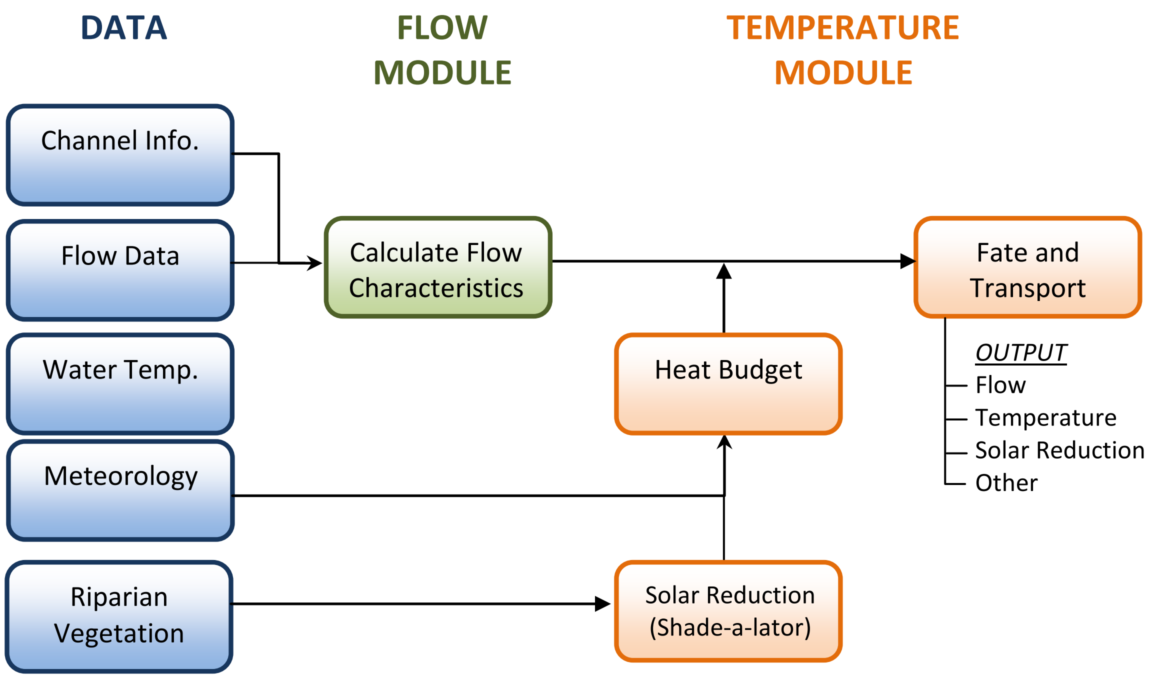


Figure 1. W3T schematic of data and flow and temperature modules.

The W3T simulates a minimum of a 24-hour period, even if travel time through the reach is less than a day. This is achieved by calculating an outflow temperature for each hour in a day (or longer if the specified simulation period is greater than a day). For each hour of the simulation, the model reads inflow water temperature for a parcel of water entering the reach and computes changes to that temperature as the parcel moves through the reach. The water temperature at the end of the reach is a function of initial water temperature, reach configuration (flow, tributaries and diversions), shade, and meteorological conditions. In this manner, the model can produce a full diurnal signal in the study area, providing resource managers with daily maximum, mean, and minimum temperatures, which may be useful in assessing potential transactions in light of ecologically meaningful metrics.

W3T resides in an Excel workbook with various worksheets used to collect and store model data and results. The model depends upon user-supplied input data that includes:

- Flow data (inflows and outflows and location of tributaries and diversions),
- Channel information (reach length, bottom width, side slope, bed roughness, and bed slope),
- Inflow water temperatures,
- Meteorology (e.g., air temperature, cloudiness, wind speed, relative humidity, and wet bulb temperature, atmospheric pressure), and
- Riparian vegetation for each subreach (height and density of vegetation in each of the 4 vegetation zones in 7 directions: NE, E, SE, S, SW, W, and NW. The model assumes that the sun is never due north.). This description of vegetation comes

from Shade-a-lator, and these parameters may be taken directly from Shade-a-lator input files.

3. Quick-Start Guide to Running the Model

To run the model, a reach must be fully described with tributaries and diversions characterized, all relevant parameters given values and boundary conditions defined. Relevant parameters include both global reach and subreach-specific parameters describing hydrodynamic qualities and riparian vegetation. Steps to set up and run the model, which need not be taken in any particular order include:

1. Set global parameters.
2. Set subreach parameters.
3. Define shade scenarios.
4. Describe inflow water temperature records.
5. Describe meteorology.
6. Configure reach.
7. Run model.
8. Save baseline.
9. Repeat steps 1 through 7 for alternatives.

To run the model, eleven specific worksheets must be present in the workbook. These required worksheets are identified in Table 1.

4. User's Guide

W3T resides in an Excel workbook with various worksheets used to collect and store model data and results. The following sections provide basic information and instructions on using W3T.

The W3T workbook contains four different types of worksheets to provide model parameters and boundary conditions, run the model, and display results. The types of worksheets and the names of the associated worksheets are listed in Table 1.

Table 1. W3T worksheet types, names and descriptions

Worksheet Type	Name	Description
Model Interface[1]	*River*	*Reach schematic, temperature graphs, reach summary information*
Input[1]	*Parameters*	*Global parameters for heat calculations*
	Reach	*Reach-defining parameters (channel geometry and vegetation structure for each subreach)*
	Shade_input	*Vegetation structures for different scenarios*
	Met	*Hourly meteorological data*
	Inflow_Tw	*Hourly water temperatures*
Output[1]	*Summary*	*Information describing current reach and results*
	Solar_Summary	*Hourly solar radiation above and below vegetation for each subreach*
	Results_# [2]	*Hourly inflow and outflow temperatures and heat fluxes for subreach "#"*
	Solar_Results_# [2]	*Hourly results from Shade-a-lator logic for subreach "#"*
	Baseline	*"Summary" sheet for the Baseline simulation*
General Information	*Notes*	*Misc notes including conversions and constants*
	Versions	*A list of model version releases*

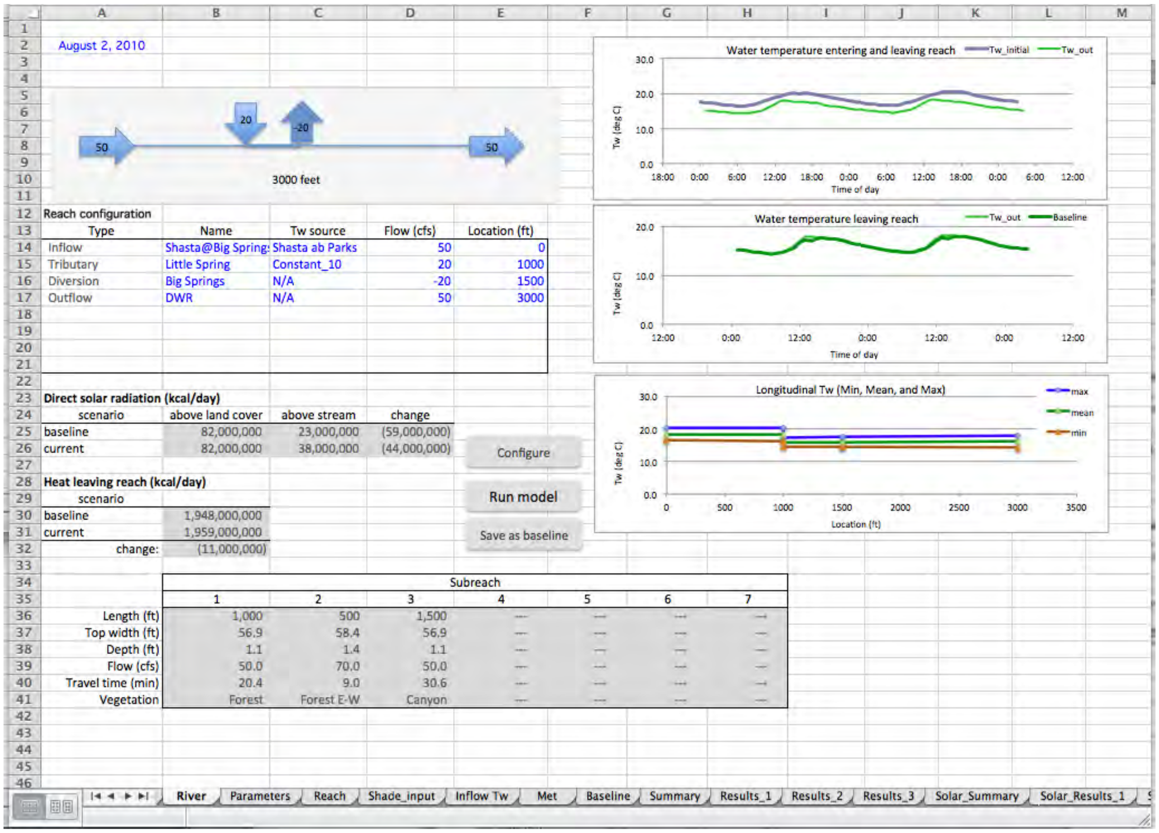
[1] All sheets of this type are required.

[2] Represents a set of sheets. "Results_1" and "Solar_Results_1" sheets are required. Other sheets are created by the model, up to total number of reaches.

Each of these worksheet types and the information layout are discussed below. Worksheets contain reference values and calculated values as well as input data. In general within any worksheet, only values in blue font should be changed by the user. Values in shaded worksheet cells are for reference only.

4.1. Model Interface (River Worksheet)

The *River* worksheet provides an interface to easily change reach configuration, set simulation date, and to run the model. The interface includes an interactive schematic of the reach, a table for specifying inflow and outflow configuration (i.e., name, temperature record, flow and location), tables and graphs to view results, and buttons to run the model (Figure 2).



August 2, 2010

Reach configuration

Type	Name	Tw source	Flow (cfs)	Location (ft)
Inflow	Shasta@Big Spring:	Shasta ab Parks	50	0
Tributary	Little Spring	Constant_10	20	1000
Diversion	Big Springs	N/A	-20	1500
Outflow	DWR	N/A	50	3000

Direct solar radiation (kcal/day)

scenario	above land cover	above stream	change
baseline	82,000,000	23,000,000	(59,000,000)
current	82,000,000	38,000,000	(44,000,000)

Heat leaving reach (kcal/day)

scenario	
baseline	1,948,000,000
current	1,959,000,000
change:	(11,000,000)

	Subreach						
	1	2	3	4	5	6	7
Length (ft)	1,000	500	1,500	---	---	---	---
Top width (ft)	56.9	58.4	56.9	---	---	---	---
Depth (ft)	1.1	1.4	1.1	---	---	---	---
Flow (cfs)	50.0	70.0	50.0	---	---	---	---
Travel time (min)	20.4	9.0	30.6	---	---	---	---
Vegetation	Forest	Forest E-W	Canyon	---	---	---	---

Figure 2. The *River* worksheet.

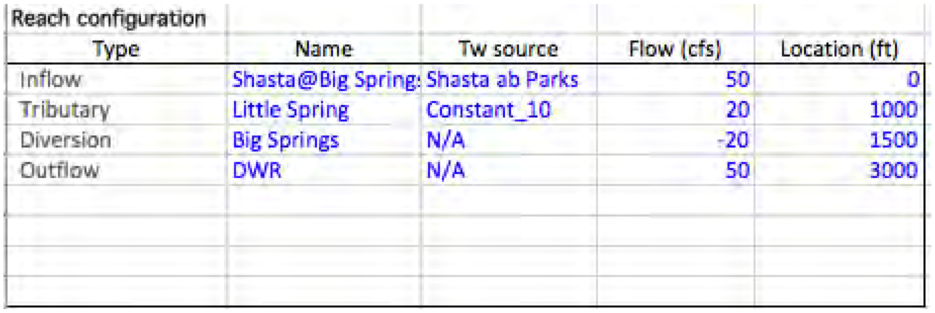
4.1.1. Reach Configuration

A reach is configured in the "Reach Configuration" table (Figure 3). In this table, a user sets up the river reach by entry (i.e., row). Tributaries and diversions may be removed or added to the simulation (maximum of 3 tributaries and 3 diversions), but entries must be listed contiguously with no empty rows. The order in which inflow, outflow, tributaries, and diversions are listed does not matter. The model will re-order the entries from upstream to downstream and the entry farthest downstream will become the outflow. The model will assign an entry "Type" based on location and flow (e.g., an entry with a positive flow in the middle of the reach will be assigned as a "Tributary" type, while a negative flow in the middle of the reach will be assigned as a "Diversion" type).

Entries in the "Reach Configuration" table have four attributes: name, water temperature, flow, and location. "Name" is provided for the user to identify the entry and is not used by the model. "Tw source" provides the name of the hourly water temperature record associated with the entry. This name must match one of the headers on the *Inflow_Tw* worksheet. "Flow" describes the flow associated with an inflow or diversion and is constant throughout the simulation. Diversion flows are defined by negative values. "Location" describes the position of a tributary or outflow downstream relative to the inflow (upstream-most location). The model designates the entry with the most downstream location as the outflow, and any water temperature associated with that entry is discarded. Reach length and outflow location are equivalent. Configuring the reach need not be the last step, but if parameters and input data (even default values) are not specified for each subreach, error warning messages will be generated to identify missing information.

The reach schematic is a visual representation of the Reach Configuration table (Figure 4). This schematic, located directly above the Reach Configuration table, depicts inflows and outflows as arrows located on a line representing the reach. Tributaries and diversions are placed on the reach according to their specified locations. In Figure 4, the river reach is defined by an inflow, an outflow, a tributary, and a diversion. The two inflows and two outflows delineate three “subreaches.”

Once tributaries and diversions have been specified, the user may choose to change reach attributes using the graphical interface built into the schematic. Single-clicking any of schematic arrows will allow the user to change attributes for the selected the inflow or outflow. A drop-down menu provides convenient access to a list of available water temperature sources. Also, by selecting the text box showing reach length at the bottom center of the schematic, the user can change reach length (i.e., the location of the outflow). Making any changes through the graphical interface will cause the reach configuration table to be updated and the schematic to redraw to the new specifications



Reach configuration

Type	Name	Tw source	Flow (cfs)	Location (ft)
Inflow	Shasta@Big Spring	Shasta ab Parks	50	0
Tributary	Little Spring	Constant_10	20	1000
Diversion	Big Springs	N/A	-20	1500
Outflow	DWR	N/A	50	3000

Figure 3. Example “Reach configuration” table.

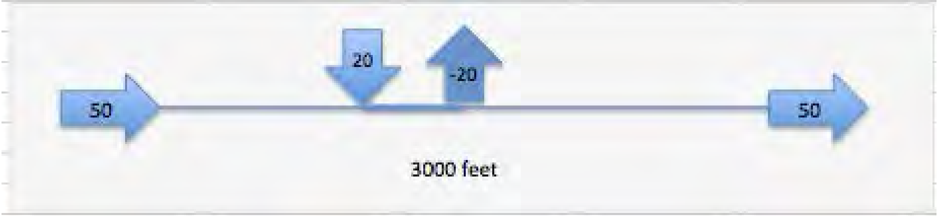


Figure 4. Example reach schematic.

4.1.2. Graphs and Tables

Graphs and tables on the *River* worksheet present simulation results and provide immediate feedback to the user. Graphs include:

- Inflow and outflow water temperature,
- Outflow water temperatures from current and baseline simulations, and
- Longitudinal minimum, mean and maximum water temperatures along the reach over the simulation period.

An example graph, showing outflow temperatures under currently-simulated and baseline scenarios, is presented in Figure 5. This graph comes from an example application of W3T to a flow transaction.

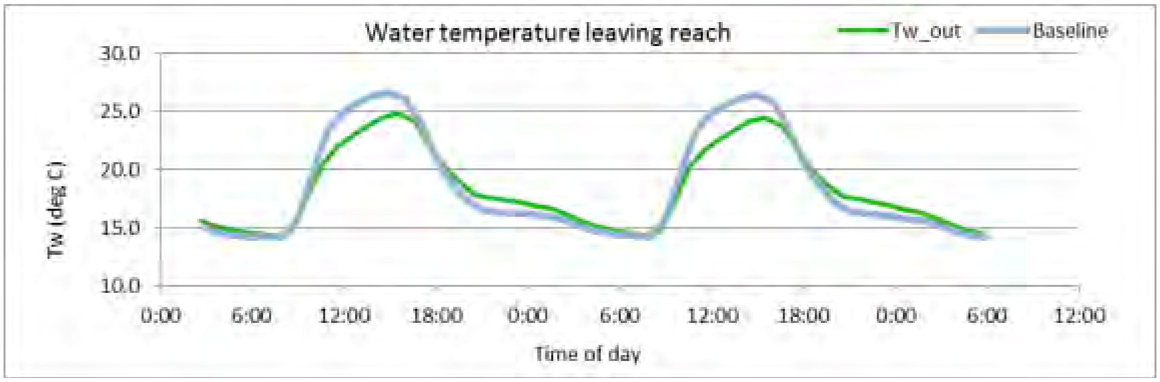


Figure 5. Water temperature leaving reach from example analysis.

Tables on the *River* interface worksheet display:

- Direct solar radiation above land cover and at water surface for baseline and current simulations (kcal/day),
- Total heat leaving the reach under current and baseline simulations (kcal/day), and
- General reach characteristics (length, top width, depth, flow, travel time, and type of riparian shade) assigned under the current simulation.

4.1.3. Buttons

Three buttons on the *River* interface worksheet control macros that redraw a reach configuration, run the model, and save baseline results. The buttons and their functions are listed in Table 2.

Table 2. Buttons and button functions.

Button Name	Function
“Configure”	Places inflows and outflows in order, calculates outflow and redraws the reach schematic
“Run Model”	Configures the reach (using the “Configure” routines), runs shade and heat budget simulations, and outputs results
“Save as baseline”	Saves the current simulation as the baseline for comparison purposes

After tributaries, diversions, flows, locations and temperature sources have been specified in the reach configuration table, the reach schematic will be updated when the “Configure” button is clicked. This button causes the entries from upstream to downstream to be re-ordered, calculates outflow, and redraws the reach schematic to reflect the new reach configuration. This button does not run either the shade or heat budget calculations and may be used to simply arrange the physical layout of the reach before simulation.

Once the reach is configured, and input parameters and data are specified for the simulation period, press the “Run Model” button to estimate water temperatures along the reach for the simulation period. The model will read in reach data and boundary conditions (i.e., inflow temperatures, meteorology and riparian vegetation), simulate shade and the heat budget, and print out results.

To save the current simulation as a baseline simulation, press the “Save as baseline” button. This button runs a macro that copies all the data on the simulation *Summary* sheet to the *Baseline* sheet. Data on the baseline sheet are automatically linked to comparison charts and tables on the *River* and *Solar_Summary* sheets.

4.2. Input Data

The W3T workbook contains five worksheets containing input data describing global reach, meteorological, topographical shade, riparian shade, and hydrodynamic characteristics of the reach. These worksheets and their contents are listed in Table 3. Guidance in collecting and estimating input data values may be found in a companion document, “An Example Application of W3T: Rudio Creek.”

Table 3. Input worksheets and contents.

Worksheet name	Contents
Parameters	Global parameters describing attributes applied to the entire reach including evaporation coefficients and topographic angles.
Reach	Reach-specific hydrodynamic parameters and shade.
Shade_input	Riparian vegetation scenarios used in specifying shade.
Inflow_Tw	Hourly records of water temperature. Any of these records may be associated with any inflow.
Met	Hourly meteorological record for the reach.

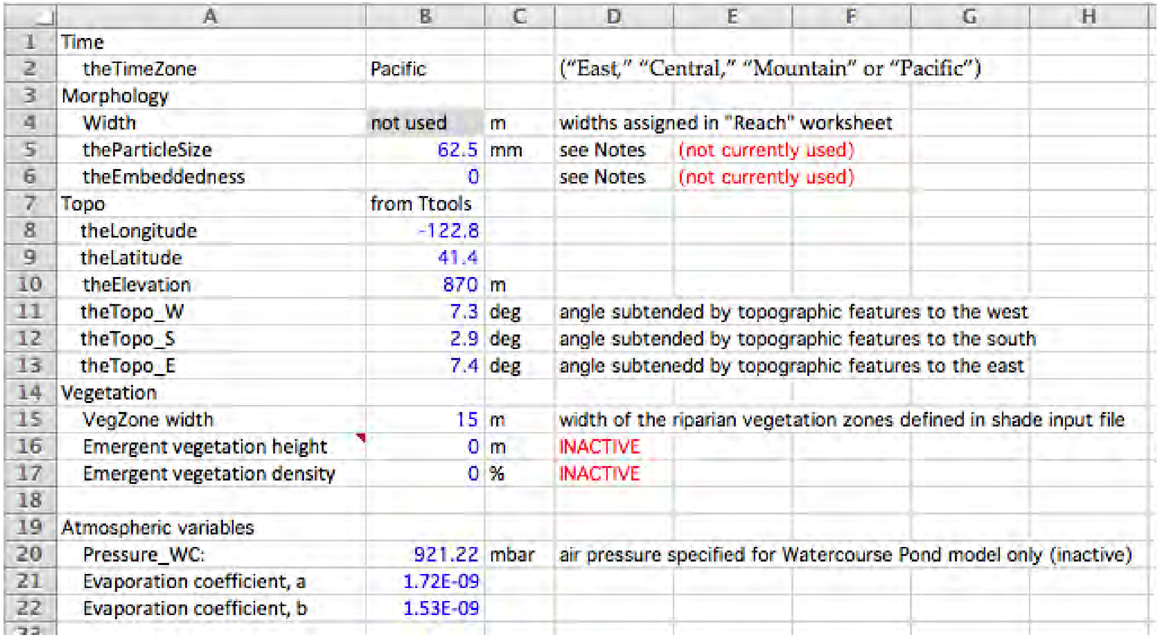
4.2.1. *Parameters* Worksheet

The global parameters describe conditions that are applied to the entire reach. These parameters are set in the *Parameters* worksheet and describe location on earth (time zone, longitude, latitude, elevation), topography (the angles subtended by topographic features in the west, south, and east directions), vegetation characteristics (width of the vegetation zones that define riparian shade, and height and density of emergent vegetation), and atmospheric variables (e.g., air pressure and evaporative coefficients) (Figure 6). A list of data required on the *Parameters* worksheet includes:

- Time
    - Time zone (limited to “East,” “Central,” “Mountain” or “Pacific”),
- Sediments (currently not used by model)
    - Particle size (mm)

  - Embeddedness (%)
- Topo
  - Longitude,
  - Latitude,
  - Elevation (meters),
  - Angles subtended by topography in the west, south, and east directions (degrees above horizontal),
- Vegetation
  - Width of the vegetation zones (meters),
  - Height of emergent vegetation (meters),
  - Density of emergent vegetation (%),
- Misc
  - Air pressure (mbar), and
  - Evaporative coefficients "a" and "b".

Particle size and embeddedness are used in modeling heat interactions between the water and the bed. Although planned for implementation in future versions, bed interaction is not currently modeled and these variables are not currently used by W3T. Air pressure is necessary for some formulations of the heat budget, but it also is not used in the current calculation method. Note that the evaporative coefficients "a" and "b" control wind-driven evaporation rate and are often used to calibrate a water temperature model (Brown and Barnwell, 1987).



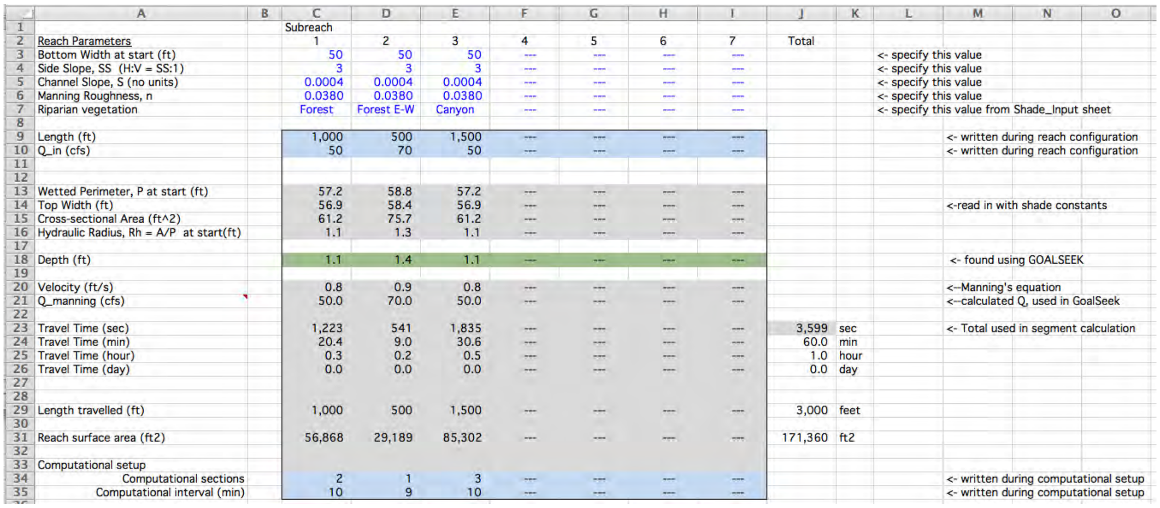
	A	B	C	D	E	F	G	H
1	Time							
2	theTimeZone	Pacific		("East," "Central," "Mountain" or "Pacific")				
3	Morphology							
4	Width	not used	m	widths assigned in "Reach" worksheet				
5	theParticleSize	62.5	mm	see Notes	(not currently used)			
6	theEmbeddedness	0		see Notes	(not currently used)			
7	Topo	from Ttools						
8	theLongitude	-122.8						
9	theLatitude	41.4						
10	theElevation	870	m					
11	theTopo_W	7.3	deg	angle subtended by topographic features to the west				
12	theTopo_S	2.9	deg	angle subtended by topographic features to the south				
13	theTopo_E	7.4	deg	angle subtenedd by topographic features to the east				
14	Vegetation							
15	VegZone width	15	m	width of the riparian vegetation zones defined in shade input file				
16	Emergent vegetation height	0	m	INACTIVE				
17	Emergent vegetation density	0	%	INACTIVE				
18								
19	Atmospheric variables							
20	Pressure_WC:	921.22	mbar	air pressure specified for Watercourse Pond model only (inactive)				
21	Evaporation coefficient, a	1.72E-09						
22	Evaporation coefficient, b	1.53E-09						

Figure 6. *Parameters* worksheet.

4.2.2. *Reach* Worksheet

Parameters that describe subreach hydrodynamic qualities are assigned in the *Reach* worksheet along with the type of riparian shade that is associated with each subreach (Figure 7). This page contains a mix of variables: some specified by the user, some calculated for use by the model, and some written by the model during execution. All variables that may be specified by the user are grouped at the top of the worksheet and, in keeping with the protocols of this workbook, are displayed in blue color. A list of these required data includes:

- Bottom width (ft),
- Side slope,
- Channel slope,
- Manning roughness, and
- Vegetation (shade scenario; as defined on “Shade_input” worksheet)[1].



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1			Subreach												
2	Reach Parameters		1	2	3	4	5	6	7	Total					
3	Bottom Width at start (ft)		50	50	50	---	---	---	---			<- specify this value			
4	Side Slope, SS (H:V = SS:1)		3	3	3	---	---	---	---			<- specify this value			
5	Channel Slope, S (no units)		0.0004	0.0004	0.0004	---	---	---	---			<- specify this value			
6	Manning Roughness, n		0.0380	0.0380	0.0380	---	---	---	---			<- specify this value			
7	Riparian vegetation		Forest	Forest E-W	Canyon	---	---	---	---			<- specify this value from Shade_Input sheet			
8															
9	Length (ft)		1,000	500	1,500	---	---	---	---				<- written during reach configuration		
10	Q_in (cfs)		50	70	50	---	---	---	---				<- written during reach configuration		
11															
12															
13	Wetted Perimeter, P at start (ft)		57.2	58.8	57.2	---	---	---	---						
14	Top Width (ft)		56.9	58.4	56.9	---	---	---	---				<-read in with shade constants		
15	Cross-sectional Area (ft^2)		61.2	75.7	61.2	---	---	---	---						
16	Hydraulic Radius, Rh = A/P at start(ft)		1.1	1.3	1.1	---	---	---	---						
17															
18	Depth (ft)		1.1	1.4	1.1	---	---	---	---				<- found using GOALSEEK		
19															
20	Velocity (ft/s)		0.8	0.9	0.8	---	---	---	---				<--Manning's equation		
21	Q_manning (cfs)		50.0	70.0	50.0	---	---	---	---				<--calculated Q, used in GoalSeek		
22															
23	Travel Time (sec)		1,223	541	1,835	---	---	---	---	3,599	sec		<- Total used in segment calculation		
24	Travel Time (min)		20.4	9.0	30.6	---	---	---	---	60.0	min				
25	Travel Time (hour)		0.3	0.2	0.5	---	---	---	---	1.0	hour				
26	Travel Time (day)		0.0	0.0	0.0	---	---	---	---	0.0	day				
27															
28															
29	Length travelled (ft)		1,000	500	1,500	---	---	---	---	3,000	feet				
30															
31	Reach surface area (ft2)		56,868	29,189	85,302	---	---	---	---	171,360	ft2				
32															
33	Computational setup														
34	Computational sections		2	1	3	---	---	---	---				<- written during computational setup		
35	Computational interval (min)		10	9	10	---	---	---	---				<- written during computational setup		

Figure 7. *Reach* worksheet.

4.2.3. *Shade_input* Worksheet

Defining the shade scenarios is the most complicated step in setting up a representative model. Shade scenarios describe riparian vegetation surrounding any given subreach based on zones and directions (Figure 8). All vegetation zones have the same width, specified on the *Parameters* worksheet (“VegZone” width in Figure 6). In the model, each subreach may be assigned its own shade scenario and any number of shade scenarios may be defined on the *Shade_input* worksheet.

---

[1] Shade scenario is a text tag (e.g., “No shade” or “Forest” or “Residential”) that matches one of the shade scenario tables specified on the *Shade_input* worksheet.

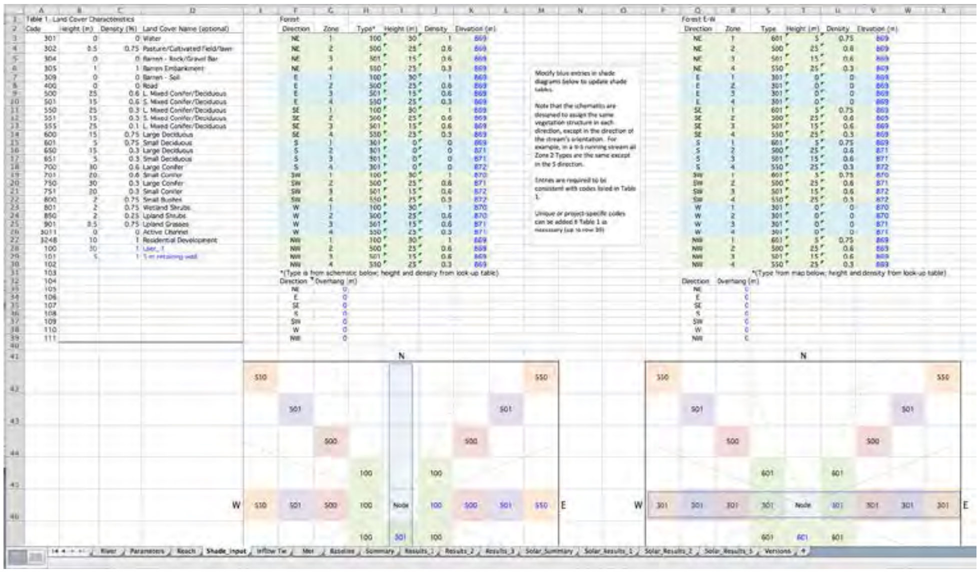


Table 1. Land Cover Characteristics

Code	Height (m)	Density (%)	Land Cover Name (optional)
301	0	0	Water
302	0.5	0.75	Pasture/Cultivated Field/lawn
304	0	0	Barren - Rock/Gravel Bar
305	1	1	Barren Embankment
309	0	0	Barren - Soil
400	0	0	Road
500	25	0.6	L. Mixed Conifer/Deciduous
501	15	0.6	S. Mixed Conifer/Deciduous
550	25	0.3	L. Mixed Conifer/Deciduous
551	15	0.3	S. Mixed Conifer/Deciduous
555	25	0.1	L. Mixed Conifer/Deciduous
600	15	0.75	Large Deciduous
601	5	0.75	Small Deciduous
650	15	0.3	Large Deciduous
651	5	0.3	Small Deciduous
700	30	0.6	Large Conifer
701	20	0.6	Small Conifer
750	30	0.3	Large Conifer
751	20	0.3	Small Conifer
800	2	0.75	Small Bushes
801	2	0.75	Wetland Shrubs
850	2	0.25	Upland Shrubs
901	0.5	0.75	Upland Grasses
3011	0	0	Active Channel
3248	10	1	Residential Development
100	30	1	User_1
101	5	1	5 m retaining wall
102			
103			
104			
105			
106			
107			
108			
109			
110			
111			

Forest

Direction	Zone	Type*	Height (m)	Density	Elevation (m)
NE	1	100	30	1	869
NE	2	500	25	0.6	869
NE	3	501	15	0.6	869
NE	4	550	25	0.3	869
E	1	100	30	1	869
E	2	500	25	0.6	869
E	3	501	15	0.6	869
E	4	550	25	0.3	869
SE	1	100	30	1	869
SE	2	500	25	0.6	869
SE	3	501	15	0.6	869
SE	4	550	25	0.3	869
S	1	301	0	0	869
S	2	301	0	0	871
S	3	301	0	0	871
S	4	301	0	0	872
SW	1	100	30	1	870
SW	2	500	25	0.6	871
SW	3	501	15	0.6	872
SW	4	550	25	0.3	872
W	1	100	30	1	870
W	2	500	25	0.6	870
W	3	501	15	0.6	871
W	4	550	25	0.3	871
NW	1	100	30	1	869
NW	2	500	25	0.6	869
NW	3	501	15	0.6	869
NW	4	550	25	0.3	869

*(Type is from schematic below; height and density from look-up table)

Direction	Overhang (m)
NE	0
E	0
SE	0
S	0
SW	0
W	0
NW	0

Modify blue entries in shade diagrams below to update shade tables.

Note that the schematics are designed to assign the same vegetation structure in each direction, except in the direction of the stream's orientation. For example, in a N-S running stream all Zone 2 Types are the same except in the S direction.

Entries are required to be consistent with codes listed in Table 1.

Unique or project-specific codes can be added to Table 1 as necessary (up to row 39)

Forest E-W

Direction	Zone	Type	Height (m)	Density	Elevation (m)
NE	1	601	5	0.75	869
NE	2	500	25	0.6	869
NE	3	501	15	0.6	869
NE	4	550	25	0.3	869
E	1	301	0	0	869
E	2	301	0	0	869
E	3	301	0	0	869
E	4	301	0	0	869
SE	1	601	5	0.75	869
SE	2	500	25	0.6	869
SE	3	501	15	0.6	869
SE	4	550	25	0.3	869
S	1	601	5	0.75	869
S	2	500	25	0.6	871
S	3	501	15	0.6	871
S	4	550	25	0.3	872
SW	1	601	5	0.75	870
SW	2	500	25	0.6	871
SW	3	501	15	0.6	872
SW	4	550	25	0.3	872
W	1	301	0	0	870
W	2	301	0	0	870
W	3	301	0	0	871
W	4	301	0	0	871
NW	1	601	5	0.75	869
NW	2	500	25	0.6	869
NW	3	501	15	0.6	869
NW	4	550	25	0.3	869

*(Type from map below; height and density from look-up table)

Direction	Overhang (m)
NE	0
E	0
SE	0
S	0
SW	0
W	0
NW	0

Figure 8. ***Shade_input*** **worksheet.**

The scenarios are described from the perspective of a single representative location (or, “node”) on the subreach. Each shade scenario is defined by a table listing height, density and elevation of riparian vegetation in each of four zones radiating away from the stream in seven directional lines (NE, E, SE, S, SW, W, and NW). The model assumes that the sun is never in the due north direction.

The shade scenario table is tied to the land cover characteristics table and schematic. Values for elevation are entered directly into the shade scenario table (blue font). Values for height, and density are established indirectly from the specified “type” (vegetation code) for each direction and zone. An example shade scenario table is shown in Figure 9. This shade scenario is named “Forest,” which is one of the Vegetation types listed on the *Reach* worksheet (Figure 7).

Type codes are not entered directly into the shade scenario table. Instead, to provide a visual reference when defining land cover, they are read from a schematic view of the vegetation structure (Figure 11). A lookup table, depicted in Figure 10 (land cover characteristics), provides values for height and density given the landscape type code. Up to ten codes may be added to the current list to describe site-specific land cover.

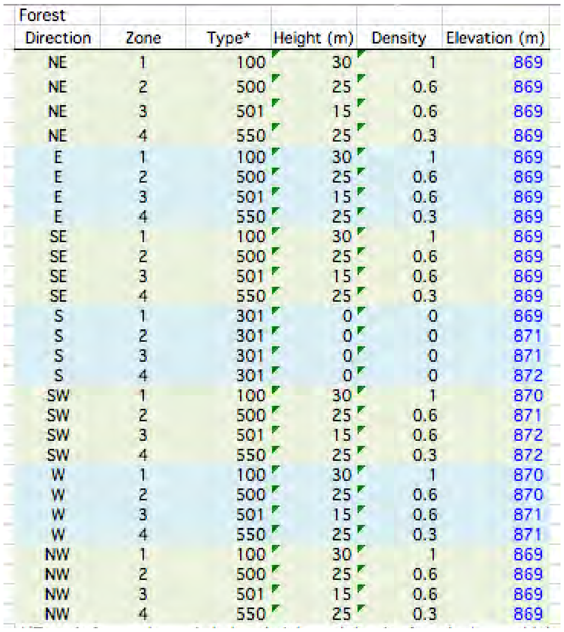
To help visualize riparian vegetation, a schematic is provided below each shade scenario table. The schematic contains a land cover characteristic code for each zone in each direction. Each zone (1 through 4) is distinguished by color. In Figure 11a, the direction and zone numbers (e.g., W1) were placed in lieu of the land cover characteristic code for visual purposes only. For example, all of zone 1 is light green and closest to the center “node”. When developing a shade scenario, the user must specify a land cover characteristic code in the land cover schematic. Land cover codes in the scenario table are linked to corresponding locations on the schematic. Through use of the lookup table, the codes establish height and density of riparian vegetation surrounding any subreach. An example land cover schematic is shown in Figure 11.

As an example of establishing vegetation height and density, suppose that land cover between 30 and 45 meters away from the stream in the NW direction is best described as “small mixed conifers.” Because zone widths are 15 meters, this area defines Zone 3 (light purple in Figure 11). “Small mixed conifers” have a land cover code of “501.” To designate land cover for this area, set the worksheet cell corresponding to Zone 3 in the NW direction in the schematic to “501.” (These would be the cell labeled NW3 in Figure 11a.) Once set, this code automatically appears in the shade scenario table at the appropriate location under “Type” and produces a corresponding height of 15 meters and a density of 60 percent (based on the information in the land cover characteristic table).

A scenario is defined by its name as listed directly above the “Direction” header in the upper left corner of a scenario table. When processing a subreach, the model looks along the first row of the *Shade_input* worksheet for the name of the shade scenario specified for that subreach. Finding that name it reads the height, density and elevation for each zone in each direction from the table below it. The model also reads the length of riparian overhang in each direction from a small table below the main table.

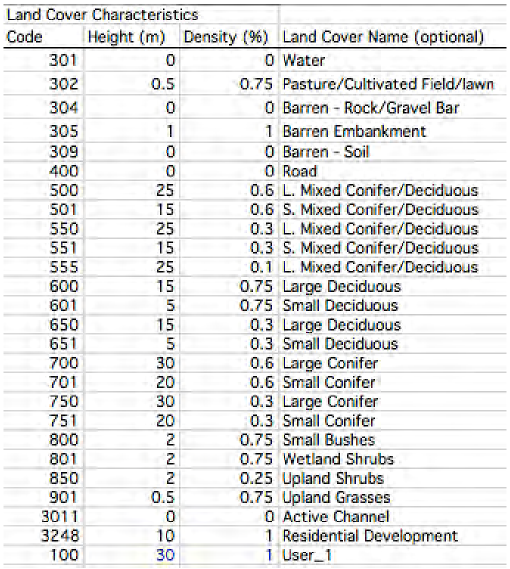
Additional shade scenarios may be developed by the user. This is most easily done by copying the columns containing an existing scenario table and schematic and pasting this information to the right of the last existing scenario. Changing the name of the scenario and the vegetation codes in the schematic creates a new scenario. No two scenarios should be given the same name.

Note: In constructing a new shade scenario it is only important to configure the input table correctly. The name must be in the top row of the worksheet, and height, density, elevation, and overhang must be listed in the same position relative to the name as shown in existing examples. The lookup table and the schematic are provided for ease-of-use and clarity, but the user could specify the land cover characteristic code directly in the shade scenario table (deleting the links to the land cover schematic).



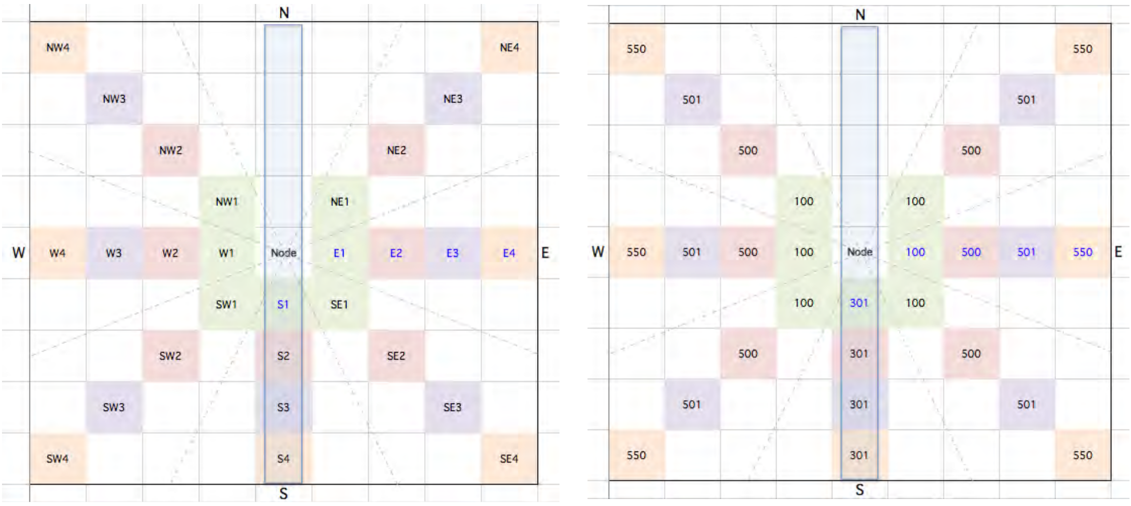
Forest					
Direction	Zone	Type*	Height (m)	Density	Elevation (m)
NE	1	100	30	1	869
NE	2	500	25	0.6	869
NE	3	501	15	0.6	869
NE	4	550	25	0.3	869
E	1	100	30	1	869
E	2	500	25	0.6	869
E	3	501	15	0.6	869
E	4	550	25	0.3	869
SE	1	100	30	1	869
SE	2	500	25	0.6	869
SE	3	501	15	0.6	869
SE	4	550	25	0.3	869
S	1	301	0	0	869
S	2	301	0	0	871
S	3	301	0	0	871
S	4	301	0	0	872
SW	1	100	30	1	870
SW	2	500	25	0.6	871
SW	3	501	15	0.6	872
SW	4	550	25	0.3	872
W	1	100	30	1	870
W	2	500	25	0.6	870
W	3	501	15	0.6	871
W	4	550	25	0.3	871
NW	1	100	30	1	869
NW	2	500	25	0.6	869
NW	3	501	15	0.6	869
NW	4	550	25	0.3	869

Figure 9. Example shade scenario table.



Land Cover Characteristics			
Code	Height (m)	Density (%)	Land Cover Name (optional)
301	0	0	Water
302	0.5	0.75	Pasture/Cultivated Field/lawn
304	0	0	Barren - Rock/Gravel Bar
305	1	1	Barren Embankment
309	0	0	Barren - Soil
400	0	0	Road
500	25	0.6	L. Mixed Conifer/Deciduous
501	15	0.6	S. Mixed Conifer/Deciduous
550	25	0.3	L. Mixed Conifer/Deciduous
551	15	0.3	S. Mixed Conifer/Deciduous
555	25	0.1	L. Mixed Conifer/Deciduous
600	15	0.75	Large Deciduous
601	5	0.75	Small Deciduous
650	15	0.3	Large Deciduous
651	5	0.3	Small Deciduous
700	30	0.6	Large Conifer
701	20	0.6	Small Conifer
750	30	0.3	Large Conifer
751	20	0.3	Small Conifer
800	2	0.75	Small Bushes
801	2	0.75	Wetland Shrubs
850	2	0.25	Upland Shrubs
901	0.5	0.75	Upland Grasses
3011	0	0	Active Channel
3248	10	1	Residential Development
100	30	1	User_1

Figure 10. Example land cover characteristics table for shade scenarios.



(a) (b)

Figure 11. Land cover schematic showing a reach node for a N-S oriented stream and adjacent vegetation zones with (a) direction and zone code and (b) vegetation type and shade characteristic (land cover characteristics) codes.

4.2.4. *Inflow_Tw* Worksheet

The *Inflow Tw* worksheet contains water temperatures that will be assigned to inflow. This worksheet contains a first column listing date and time and adjacent columns listing water temperature records (Figure 12). Each time series must be given a unique name (in first row) that identifies it. That identifier is used to assign a water temperature time series to each inflow or tributary on the *Reach* worksheet.

Consider the reach configuration in Figure 3. The inflow is assigned the “Shasta ab Parks” water temperature time series. When the model is run, it will search the *Inflow_Tw* worksheet to find a time series with the “Shasta ab Parks” identifier (column C, Figure 12). Once it has found the matching identifier, it will assign the inflow the temperature from that time series.

	A	B	C	D	E	F	G
1	Date-time	Trinity@Hoopa	Shasta ab Parks	Trinity+2	Trinity+5	Constant_20	Constant_10
2	1/1/2010 0:00	6.56	6.611	8.56	11.56	20	10
3	1/1/2010 1:00	6.61	6.636	8.61	11.61	20	10
4	1/1/2010 2:00	6.61	6.763	8.61	11.61	20	10
5	1/1/2010 3:00	6.67	6.839	8.67	11.67	20	10
6	1/1/2010 4:00	6.67	6.914	8.67	11.67	20	10
7	1/1/2010 5:00	6.72	6.914	8.72	11.72	20	10

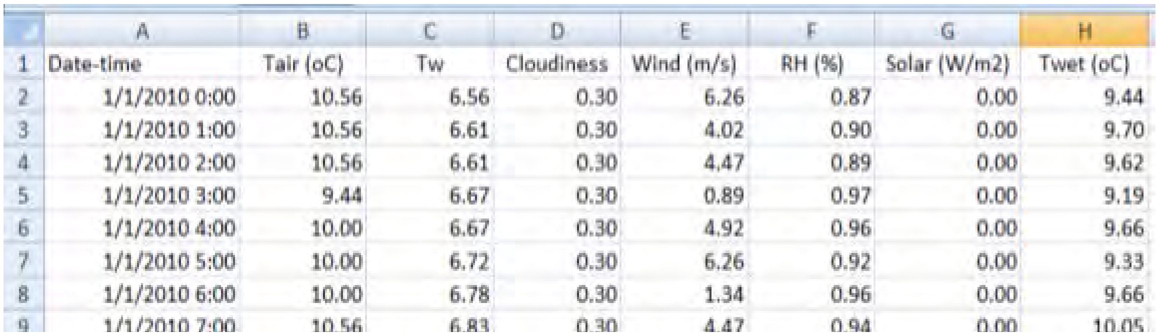
Figure 12. *Inflow_Tw* worksheet.

There can be additional (unused) water temperature time series on the *Inflow_Tw* worksheet, but every identifier used in the reach configuration table (*Reach* worksheet) must correspond to a time series on the *Inflow_Tw* worksheet. There can be up to fifteen temperature records listed in the worksheet and there can be no empty columns between the time and records that will be used in simulation.

4.2.5. *Met* Worksheet

There is only one meteorological record for the reach and that record is set up on the *Met* worksheet in a range of contiguous columns, similar in this respect to inflow water temperatures (Figure 13). In the first column of the meteorological record is a list of dates and times. The record must span the period of time simulated and the record must contain one entry for each of these variables for each hour of simulation. Adjacent columns contain data used in calculating shade and heat exchange. The following meteorological data is required by the model (in the order specified):

- Air temperature (degC),
- Water temperature (degC)
- Cloudiness (fraction),
- Wind speed (m/s),
- Relative humidity (%),
- Solar radiation (W/m^2), and
- Wet bulb temperature (degC).



	A	B	C	D	E	F	G	H
1	Date-time	Tair (oC)	Tw	Cloudiness	Wind (m/s)	RH (%)	Solar (W/m2)	Twet (oC)
2	1/1/2010 0:00	10.56	6.56	0.30	6.26	0.87	0.00	9.44
3	1/1/2010 1:00	10.56	6.61	0.30	4.02	0.90	0.00	9.70
4	1/1/2010 2:00	10.56	6.61	0.30	4.47	0.89	0.00	9.62
5	1/1/2010 3:00	9.44	6.67	0.30	0.89	0.97	0.00	9.19
6	1/1/2010 4:00	10.00	6.67	0.30	4.92	0.96	0.00	9.66
7	1/1/2010 5:00	10.00	6.72	0.30	6.26	0.92	0.00	9.33
8	1/1/2010 6:00	10.00	6.78	0.30	1.34	0.96	0.00	9.66
9	1/1/2010 7:00	10.56	6.83	0.30	4.47	0.94	0.00	10.05

Figure 13. *Met* worksheet.

Note: The simulation doesn't end until after the last parcel of water travels through the reach. Meteorological data must be supplied through the end of simulation as calculated by: end_time (hours) = start_time + simulation length + reach_travel_time.

4.3. Output

The W3T model writes heat budget and solar radiation summary results for the reach, and detailed results for each subreach. As a result, there will be multiple *Results_#* and *Solar_Results_#* worksheets (where "#" refers to the subreach number).

4.3.1. *Summary* Worksheet

The *Summary* worksheet contains all of the data describing reach parameters and configuration along with all results used in comparison charts and tables. These data are organized in four sections:

- Reach description,
- Reach inflow and outflow water temperature,
- Solar radiation, and
- Subreach inflow and outflow water temperature.

The first columns of the worksheet are copied from the *Reach* interface worksheet and describe reach configuration and calculated characteristics such as top width, depth of flow, and travel time. A second section of the worksheet lists time and water temperature in and out of the reach along with calculated heat flux of water leaving the reach. A third section lists solar radiation above land and above stream for each reach. A final section lists inflow and outflow water temperature for each subreach and calculates minimum, mean and maximum values over the first 24-hour period. These data are used in graphically describing water temperature longitudinally along the reach.

4.3.2. *Solar_Summary* Worksheet

The *Solar_Summary* worksheet compiles solar radiation above land and above the stream for each hour of the simulation for each subreach. "Above stream" solar radiation from baseline conditions is also listed for each subreach. Small graphs above the data provide a comparison of "above land," "above stream," and baseline "above stream" solar radiation for each reach over a day's time. An example graph is shown in Figure 14.

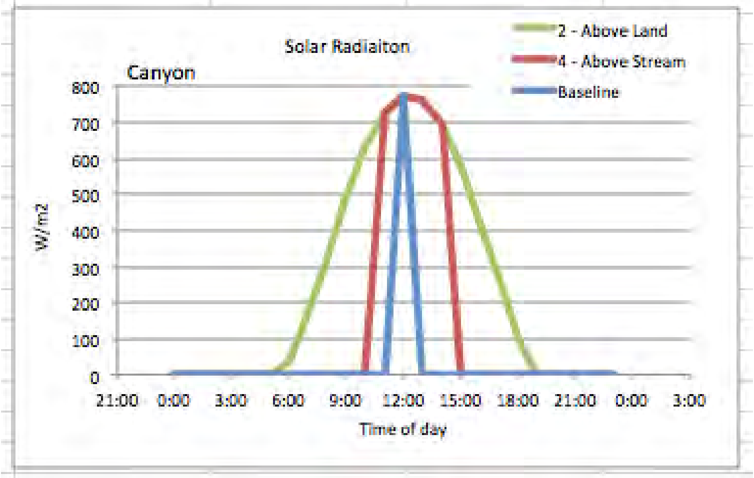


Figure 14. Example graph showing solar energy summary for a subreach.

4.3.3. *Results_#* Worksheets

The *Results_#* sheets contain time and water temperature into and out of the subreach, and average heat flux terms (solar, longwave, evaporative, and conductive radiation) for each time step of the simulation. There is one worksheet for each subreach.

4.3.4. *Solar_Results_#* Worksheets

The *Solar_Results_#* sheets contain the results of shade modeling for each time step of simulation and include time, sun direction and altitude, estimated “view to sky,” and both direct and diffuse solar radiation at each of seven steps along light’s path from the atmosphere to its reflection from the reach bed. There is one worksheet for each subreach.

4.3.5. *Baseline* Worksheet

The W3T maintains a *Baseline* worksheet that holds all the data of a *Summary* worksheet. This *Baseline* worksheet is a copy of the *Summary* worksheet and is updated with summary information for the current run when you press the “Save as Baseline” button on the *Reach* worksheet. Data from this worksheet are used in comparison graphs and tables.

4.4. General Information

Currently, there are two informational sheets in the W3T workbook: *Notes* and *Versions*. The *Notes* worksheet contains unit conversions, constant values, and miscellaneous information on parameter selection. The *Versions* worksheet provides a history of model versions and release dates.

5. Next Steps

[W3T is currently under continued development. During this third year of the three-year grant, the project team is both developing future direction, as well as soliciting information from external review to consider for next steps. This information will be included in the final draft project documentation]

6. Citations

Boyd, M., and Kasper, B. 2003. Analytical methods for dynamic open channel heat and mass transfer: Methodology for heat source model Version 7.0.

Brown, L.C. and Barnwell, T.O. 1987. *The Enhanced Stream Water Quality Model QUAL2E and QUAL2E UNCAS: Documentation and Users Manual.* Environmental Research Laboratory, Environmental Protection Agency, Athens, GA Report EPA/600/3-87/007.

Martin, J.L. and S.C. McCutcheon. 1999. *Hydrodynamics and Transport for Water Quality Modeling*. Lewis Publishers. New York. 794 pp.

Watercourse Engineering, Inc. 2013. *Example application of W3T to Rudio Creek flow transaction to assess potential water temperature implications (DRAFTv2).* Memorandum. January 30, 2013.

Appendices

Appendix A. Model Formulation

The W3T currently consists of a flow module and a temperature module. Other water quality modules are envisioned for future development. The flow module calculates flow characteristics such as depth, cross-sectional area, velocity, and travel time. The temperature module is comprised of units estimating solar radiation and heat budget. The solar radiation unit calculates direct solar radiation based on solar flux routines in Oregon DEQ's Heat Source Model version 7. This is the latest version for which documentation and code were available. Heat budget calculations are based on standard formulations for calculating longwave, evaporative, and conductive heat flux. Currently, the W3T uses the heat budget as implemented in Heat Source. A heat budget option similar to the QUAL2E heat budget is also available, but is not implemented in the model. The HeatSource and QUAL2E heat budgets have both been run in W3T and have been found to yield similar results.

A.1. Flow Module

Flow characteristics in W3T are calculated assuming steady flow using the Manning's Equation substituted into the continuity equation. This formula describes flow, Q, as a function of channel hydraulic radius and slope:

$$Q = \frac{C_0}{n} A_c R^{2/3} S_e^{1/2} \qquad (L^3/T)$$

where,

C_0 = a constant depending upon units
n = Manning's roughness coefficient
R = channel's hydraulic radius = A_c/P
A_c = channel's cross-sectional area = f(depth, width)
P = wetted perimeter = f(depth, width)
S_e = channel slope

Flow, Q, is determined for each subreach by mass balance as the sum of instream flow, Q_s, and net tributary flow, where net tributary flow is the difference between tributary flow, Q_t, and diversion flow, Q_d, at the upstream boundary.

$$Q = Q_i + (Q_t - Q_d) \qquad (L^3/T)$$

Given flow, Manning's equation and values for Manning's roughness coefficient, bottom width and side slope, W3T determines flow depth for each subreach by iteration using Microsoft Excel's Goal Seek feature. Channel flow characteristics such as top width, cross-sectional area, velocity and travel time result from the determination of depth.

A.2. Temperature Module

The temperature module of W3T establishes incident solar radiation, performs a heat budget, and calculates resultant changes in water temperature. Solar radiation incident on a stream's surface is a function of atmospheric solar radiation and shade features such as topography and vegetation. Solar radiation is calculated using methods and algorithms from Heat Source 7.

Shade features such as topography and riparian vegetation attenuate or block solar radiation depending upon their height and density. Using the methods and algorithms of Heat Source and Shade-a-lator, W3T calculates solar radiation at four levels above the stream and estimates the heat penetrating the stream surface. At each calculation step, W3T determines the location of the sun and calculates the following fluxes:

1. Solar Radiation Heat above Topographic Features.
2. Solar Radiation Heat below Topographic Features.
3. Solar Radiation Heat below Land Cover.
4. Solar Radiation Heat above Stream Surface.
5. Solar Radiation Heat Penetrating the Stream Surface.

A schematic showing the location of these calculations is given in Figure A-1. Details of these calculations are given in the Heat Source Model Version 7.0 manual (Boyd and Casper, 2003).

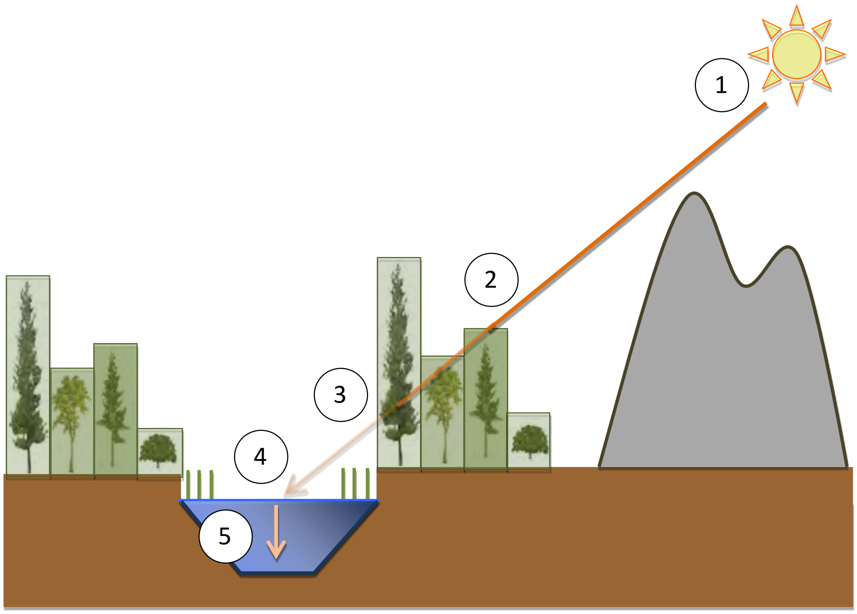


Figure A-1. Shade calculation schematic.

Direct solar radiation that penetrates the stream surface is used in W3T heat budget calculations. In addition to solar (shortwave) radiation, a heat balance includes terms describing heat exchange with the atmosphere. The net rate of thermal energy exchange at the air-water interface can be represented as the sum of heat fluxes, as given by Martin and McCutcheon (1999):

$$H_{net} = H_{sn} + H_{at} - (H_{ws} + H_{\square} + H_e) \qquad (E/L^2T)$$

where:

H_{net} = net heat flux
H_{sn} = net short wave (solar) radiation flux,
H_{at} = net atmospheric longwave radiation flux,
H_{ws} = net water surface longwave radiation flux,
H_h = sensible (conductive) heat flux, and
H_e = evaporative (latent) heat flux.

W3T is capable of using sets of equations from either Heat Source or QUAL2E to estimate these heat fluxes. Both sets are similar and produce similar results. Currently, the W3T uses equations from Heat Source.

W3T calculates water temperature in Lagrangian space. That is, the model follows parcels of water as they travel through the reach, calculating change in water temperature over a discreet time. Because spatial temperature gradients are generally slight in the stream systems that W3T is designed to analyze, diffusion is neglected. In Lagrangian space with diffusion neglected, the change in temperature for any parcel of water over a discreet time is a function of net heat flux, H_{net}, surface area, A_s, and volume, V, and is given by:

$$\frac{\Delta T_w}{\Delta t} = S = \frac{H_{net} A_s}{C_p \rho V} \qquad (\theta/\mathrm{T})$$

where:

T_w	:	water temperature (θ)
Δt	:	computational time step (T)
S	:	heat sources and sinks (θ/T)
H_{net}	:	net heat flux (E/L^2)
A_s	:	area of water body surface (L^2)
C_p	:	specific heat of water at 15°C (4185.5 $Jkg^{-1}°C^{-1}$ where 1 J = 1 W-s)
ρ	:	calculated density of water (M/L^3)
V	:	volume of water body (L^3)

At the top of each subreach, initial water temperature, T_i, is determined from conservation of energy:

$$T_i = (Q_{up} \cdot T_{up} + Q_{trib} \cdot T_{trib})/Q_T$$

where:

Q_{up} : flow just above subreach (L^3/T)
T_{up} : water temperature just above subreach (θ)
Q_{trib} : net tributary inflow (L^3/T)
T_{trib} : tributary water temperature (θ)
Q_T : $= Q_{up} + Q_{trib}$; total flow at top of subreach (L^3/T)

Applied
Remote Sensing
and Analysis

October 10, 2013

Water Temperature Transaction Tool (W3T)

Version 0.9i

Model Review

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Contents

1.0 Introduction

The Water Temperature Transaction Tool (W3T) was developed by Watercourse Engineering, Inc. for the National Fish and Wildlife Foundation (NFWF) as part of the Conservation Innovation Grant (CIG) exploring flow transactions and their potential effect on habitat and water quality. The W3T model was designed with the intent to provide sufficient accuracy while minimizing data needs and computational time.

The NFWF contracted WSI to review the W3T model (version 0.9g beta) in June 2013. In September 2013, a new version of the model (version 0.9i) was provided in response to many original comments. This review provides commentary relevant to version 0.9i. WSI provides the following within this review:

- Comments and questions regarding model equations and inputs
- Results of various input parameters for channel, flow, climate, and vegetation
- VBA code review
- Review of model limitations
- Overall impressions and specific endorsements of model application

WSI's goal is to provide an unbiased review that focuses solely on the W3T model, while keeping in mind the original intent and scope of W3T development.

It is the opinion of WSI that the W3T model has successfully struck a balance between simplicity and robustness. If used for its intended purpose of assessing the impacts of flow transactions on smaller scales, W3T should prove to be a valuable tool to expert and non-expert modelers alike.

2.0 Results of Various Input Parameters for Channel, Flow, Climate, and Vegetation

As part of this review, a wide variety of W3T model inputs were assessed for their impacts on the model results. Input parameters related to channel morphology, flow, vegetation, and climate were changed one at a time and the model results were plotted against a baseline condition. In each model scenario, only a single input parameter was altered, while all other inputs remained at their baseline values. For example, to test the effects of tributary inflow volume, only the tributary flow volume was changed, while all other input parameters remained as-is.

This type of assessment is similar to a "sensitivity analysis," however it should be noted that it was not a true sensitivity analysis because only a single model baseline was used. A true sensitivity analysis would have examined a variety of combined input parameter permutations in order to assess how uncertainty in the output is attributed to its inputs.

The analysis performed for this review was conducted primarily to search for errors in the model (i.e., unexpected relationships between inputs and outputs). This section contains graphical results for various model input parameter tests.

Overall, the W3T model performed as expected and no anomalies were identified.

The model used for this analysis was the sample Shasta River model (version 0.9g beta) that was provided by Watercourse Engineering, Inc. as part of the W3T model review package. The simulation reach was 3,000 feet long and was set up for August 2, 2010. The flow volume was 50 cfs at the boundary, with a 20 cfs tributary and a 20 cfs diversion (Figure 1). There were three sub-reaches, each with unique vegetation conditions.

The model as received from Watercourse Engineering, Inc. is considered to be the "baseline" condition for all scenarios presented in this section.

Figure 1 - Reach schematic of the model used for testing various input parameters.

Below is a summary of the input parameters that were tested.

- Boundary flow
- Diversion rate
- Tributary flow rate
- Tributary number and locations
- Diversion number and locations
- Vegetation height
- Vegetation density
- Topographic shade
- Channel bottom width
- Manning's n
- Air temperature
- Relative humidity
- Wind speed

2.1 Upstream Boundary Flow Volume

The flow volume at the upstream boundary was changed to a variety of values and the stream temperature at the lower end of the simulation was recorded. All other input parameters remained unchanged.

The W3T model performed as expected under the different flow conditions (Figure 2). The lower flow volumes resulted in higher daily maximum and lower daily minimum temperatures. Maximum daily temperatures approached the air temperature while the model remained stable. Higher flow volumes resulted in less temperature change between the boundary and the end of the model reach.

Additionally, lower flow volumes displayed greater variability in the resultant temperature profile in response to riparian shade conditions. For example, the rapid decline just after noon is a result of the stream surface being shaded by riparian vegetation. The higher flow volumes are less sensitive to hourly changes in solar radiation.

All results were consistent with the general concept that lower flow volumes are more sensitive or responsive to various heat sources.

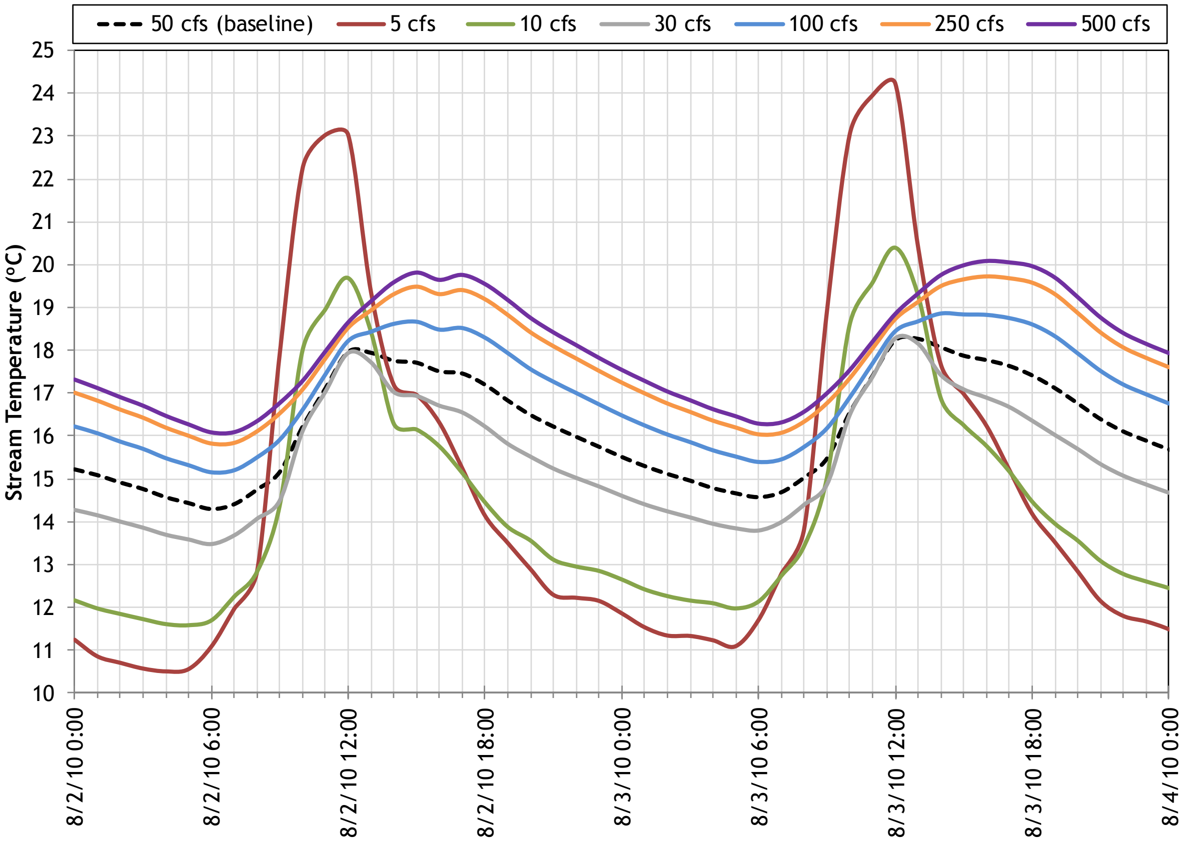

Figure 2 - Simulated stream temperature for various boundary flow volumes.

2.2 Diversion Rate

Diversion rates were altered in order to observe the impacts that a mass removal was having on stream temperature. In the baseline model, there was a 20 cfs diversion occurring. Scenarios with 10, 30, 50, and 65 cfs were run (figure 3). The maximum available flow of the stream was 70 cfs; therefore, no larger diversion rates were simulated.

The W3T model behaved as expected under each of the diversion scenarios. Diverting more water resulted in elevated stream temperatures. Diverting less water resulted in moderated daily maximum temperatures. The model remained stable at each simulated diversion rate.

The W3T model displays an error message when the user tries to simulate a diversion rate that is greater than the available instream flow. This is a valuable feature that prevents users from unintentionally "running the river dry" and getting erroneous results or a failed model run.

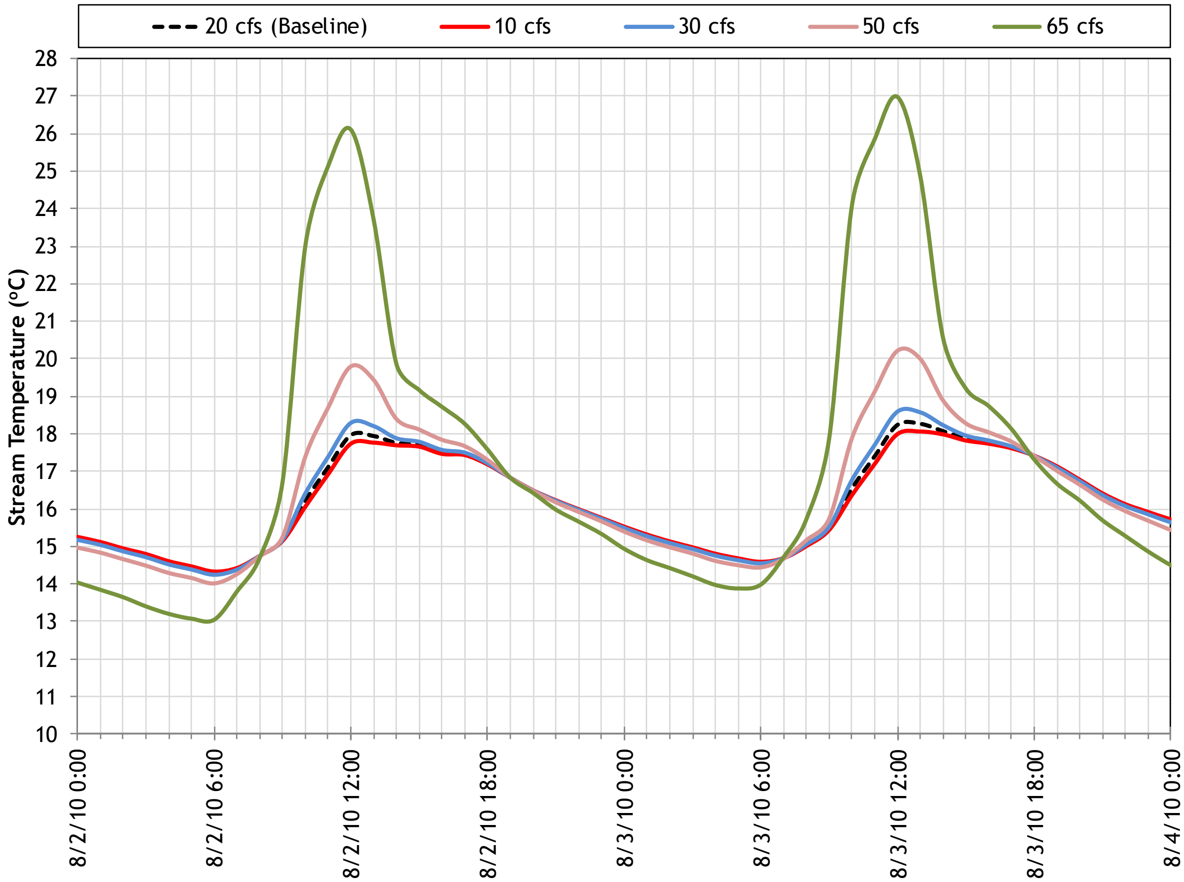

Figure 3 - Simulated stream temperature for various diversion rates.

2.3 Tributary Flow Rate

Tributary flow rates were adjusted in order to examine the effect on the downstream simulated temperatures. The W3T model behaved as expected (Figure 4). Higher tributary flow rates increased the stream volume and moderated the maximum temperature and diel variation. Tributary flows less than the baseline of 20 cfs resulted in higher simulated stream temperatures.

The mass balance calculations of the model are proven to be accurate for a variety of tributary inflow rates. In addition, the model remained stable when the tributary flow was increased to 200 cfs, indicating that hydraulic conditions were appropriately updated by the model.

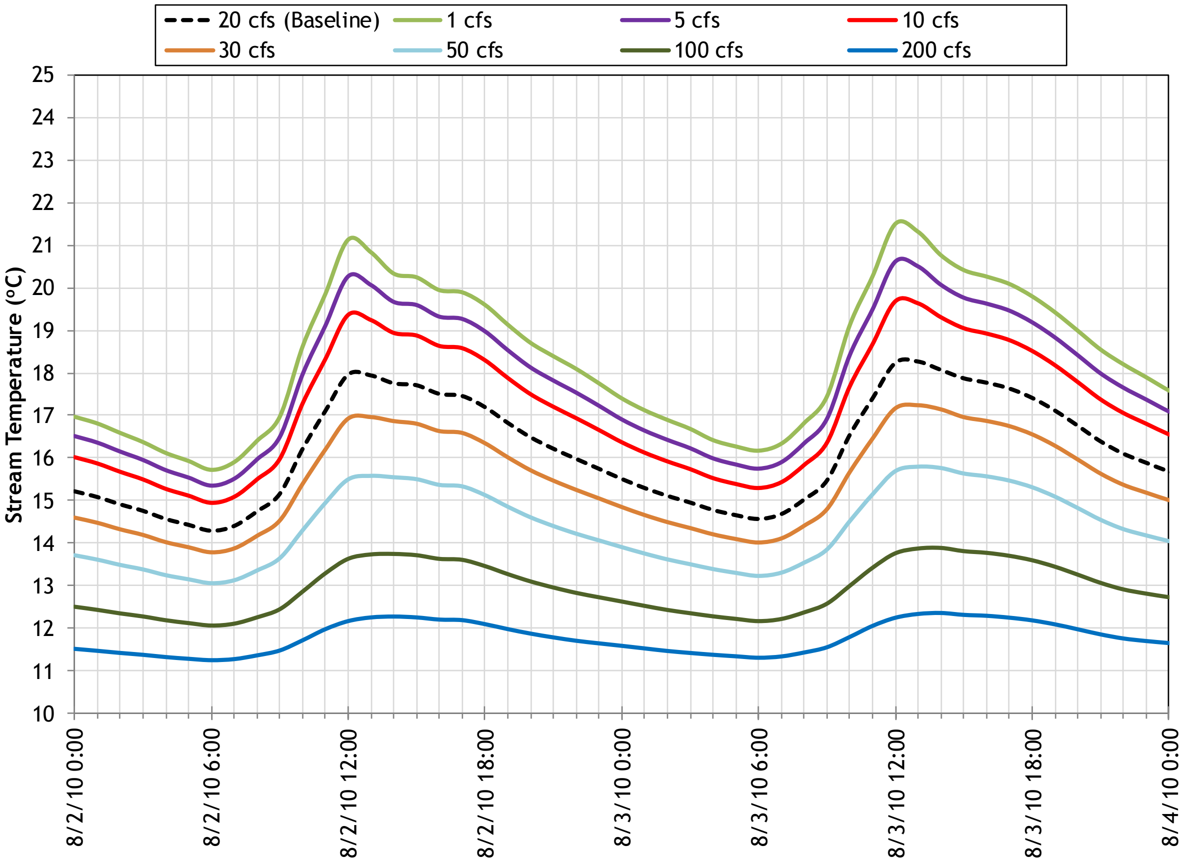

Figure 4 - Simulated stream temperature for tributary flow rates.

2.4 Tributary Number and Locations

The effects of tributary location and quantity were also assessed. Figure 5 shows the baseline scenario (from the sample model) which contained a single tributary and a single diversion. In two scenarios, the existing tributary was moved to a different location while all other inputs remained unchanged (Figure 6 and Figure 7). In a third scenario, the existing tributary was in place and two tributaries were added at 500 and 2500 feet (Figure 8). In all instances, the simulated temperatures and flow mass balance were properly simulated by the W3T model.

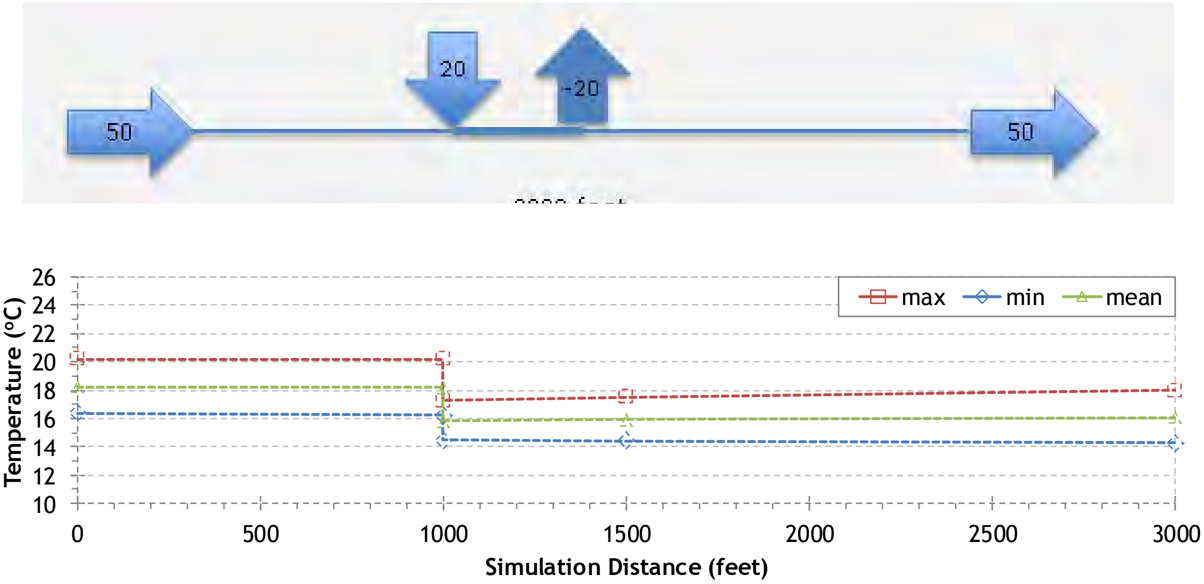

Figure 5 - Baseline condition of the sample W3T model.

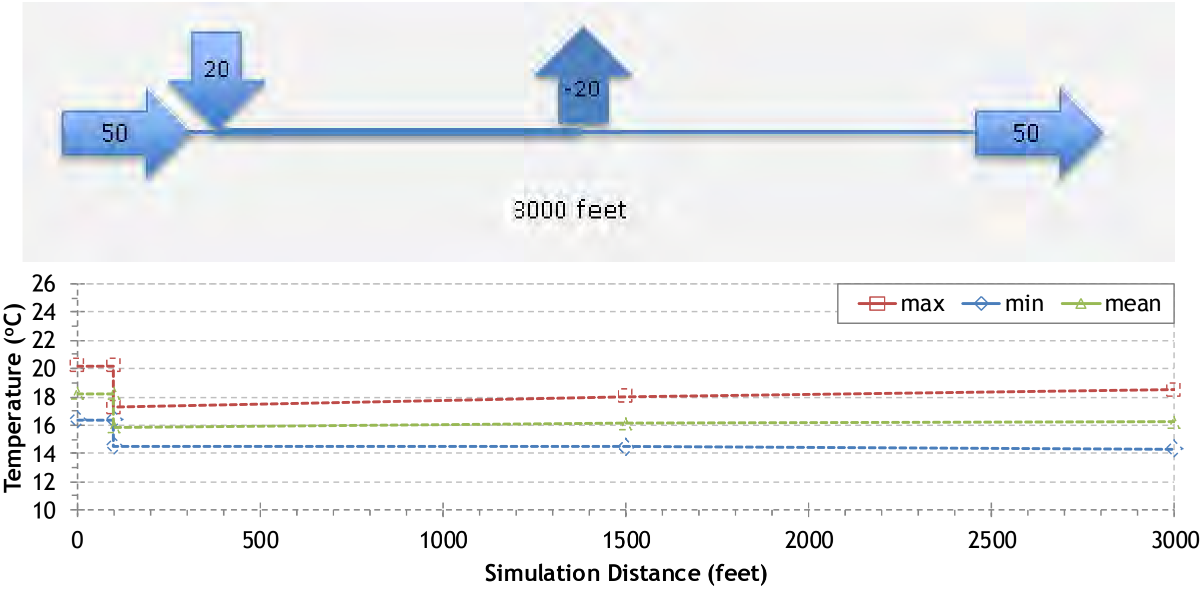

Figure 6 - The single tributary was moved from 1000 feet to 100 feet from the upstream boundary.

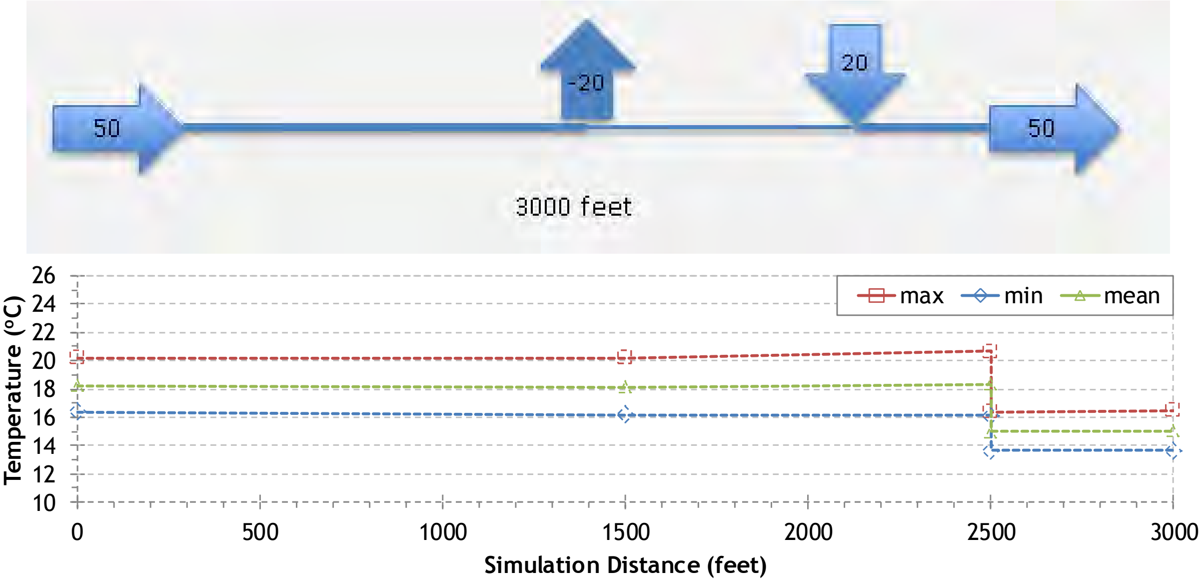

Figure 7 -The single tributary was moved from 1000 feet to 2500 feet from the upstream boundary.

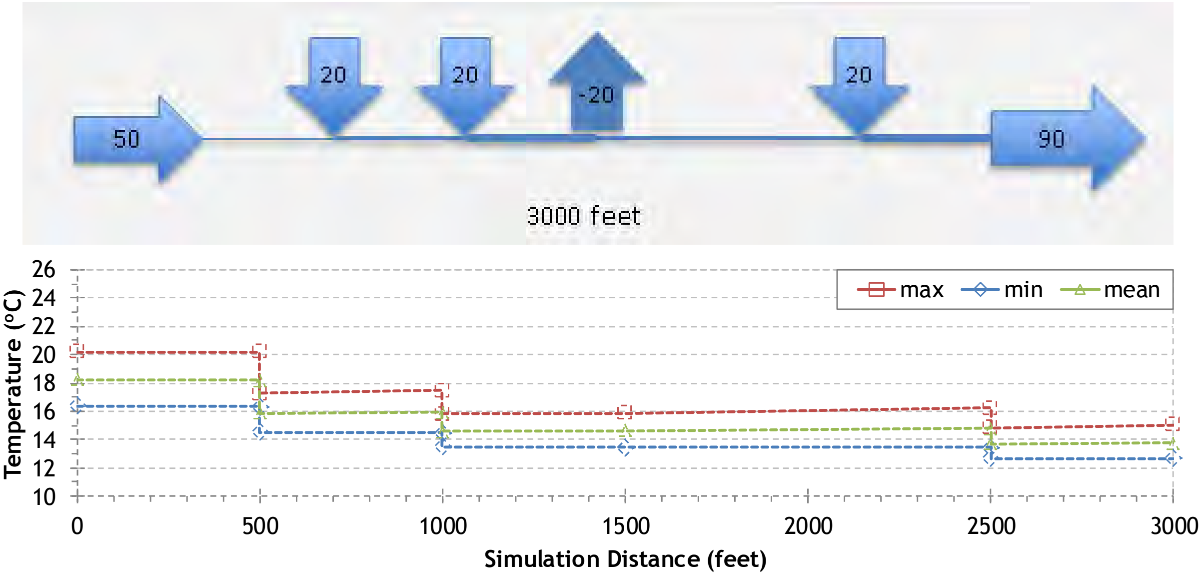

Figure 8 - The original tributary remained at 1000 feet, while two tributaries were added at 500 and 2500 feet from the upstream boundary.

2.5 Diversion Number and Locations

The number and location of diversions was tested separately. In the baseline condition (W3T sample model), there was a single diversion of 20 cfs at 1500 feet from the upstream boundary (Figure 9). In two separate scenarios, the diversion was moved to 500 feet and then to 2500 feet from the upstream boundary (Figure 10 and Figure 11). Finally, in addition to the original diversion, two were added at 500 feet and 2500 feet from the upstream boundary (Figure 12). In all cases, the W3T model simulated accurate locations, quantities and temperatures. The third scenario showed the most significant difference (increased maximum temperatures) because the total amount of water diverted was 60 cfs, compared to 20 cfs in the baseline condition.

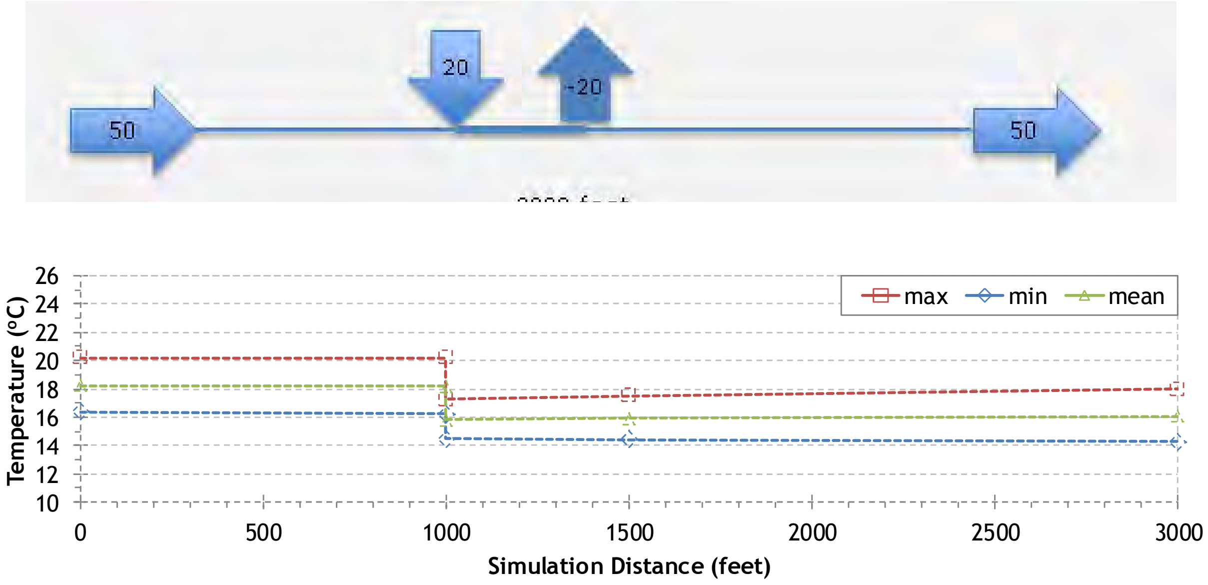

Figure 9 - Baseline condition of the sample W3T model.

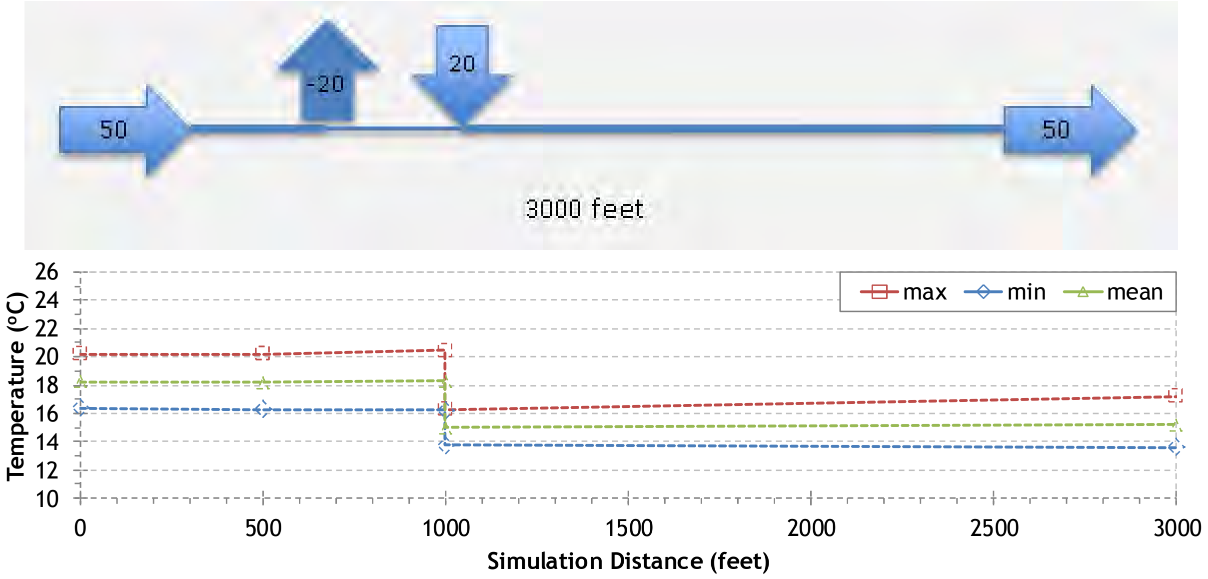

Figure 10 - The single diversion was moved from 1500 feet to 500 feet from the upstream boundary.

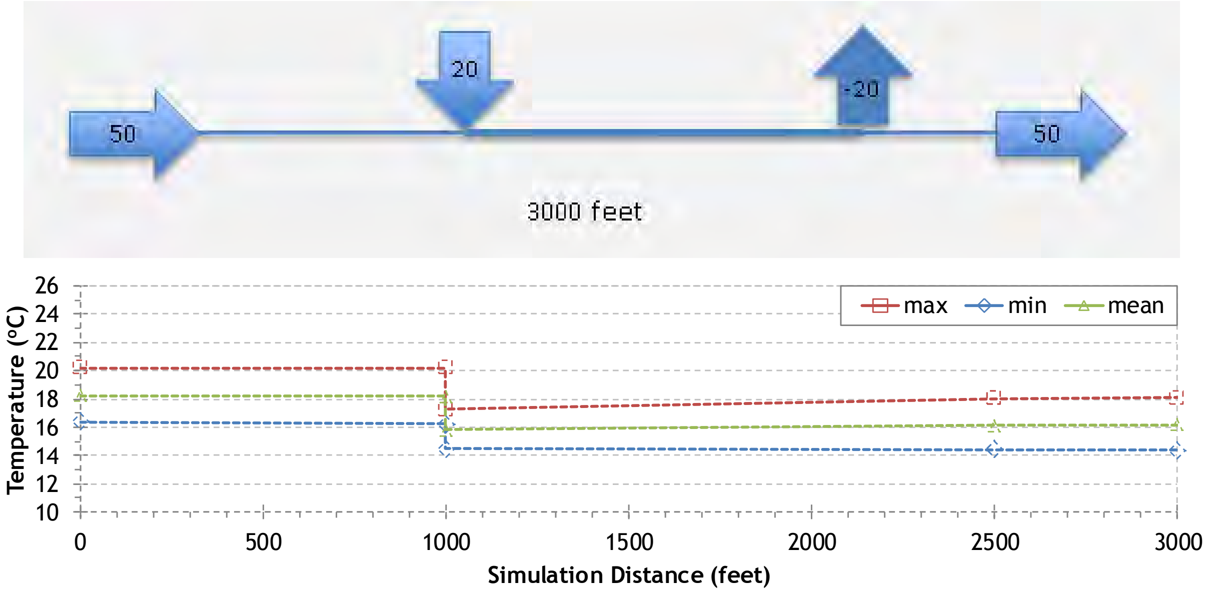

Figure 11 - The single diversion was moved from 1500 feet to 2500 feet from the upstream boundary.

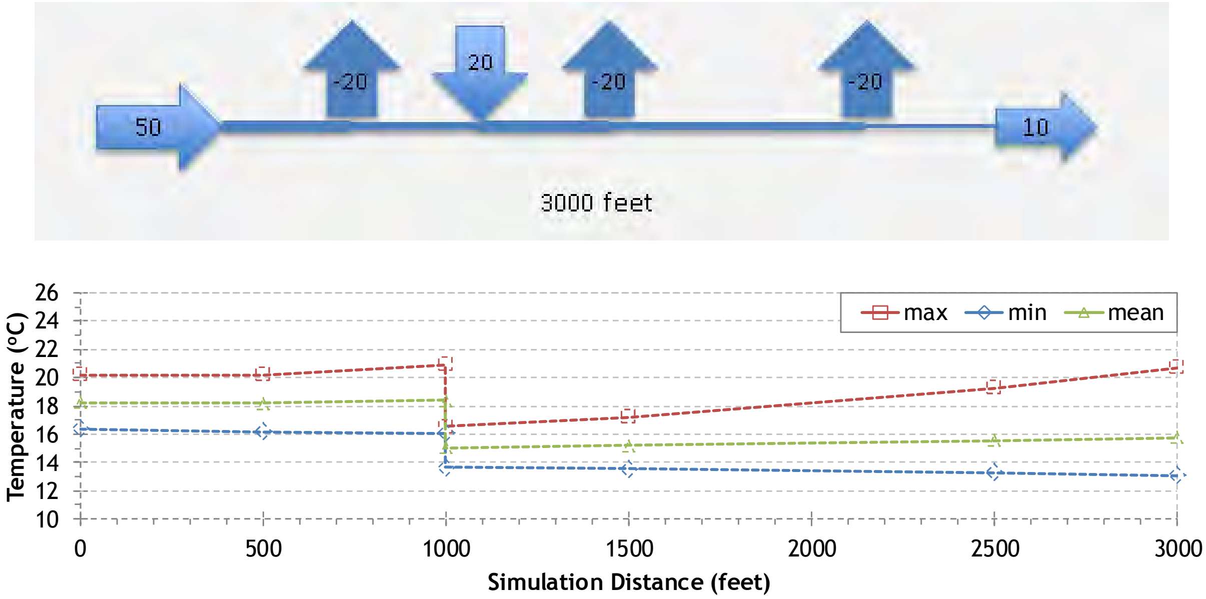

Figure 12 - Diversions were added at 500 and 2500 feet from the upstream boundary.

2.6 Vegetation Height

Vegetation heights were adjusted in order to observe the effects on simulated temperatures. The table below describes the vegetation conditions that were used in the baseline simulation.

Table 1 - Riparian vegetation conditions of the baseline model condition.

		Reach 1 - Forest			Reach 2 - Forest E-W			Reach 3 - Canyon		
Direction	Zone	Type	Height (m)	Density	Type	Height (m)	Density	Type	Height (m)	Density
NE	1	400	0	0	601	5	0.75	3248	10	1
NE	2	500	25	0.6	500	25	0.6	3248	10	1
NE	3	501	15	0.6	501	15	0.6	3248	10	1
NE	4	550	25	0.3	550	25	0.3	3248	10	1
E	1	400	0	0	301	0	0	3248	10	1
E	2	500	25	0.6	301	0	0	3248	10	1
E	3	501	15	0.6	301	0	0	3248	10	1
E	4	550	25	0.3	301	0	0	3248	10	1
SE	1	400	0	0	601	5	0.75	3248	10	1
SE	2	500	25	0.6	500	25	0.6	3248	10	1
SE	3	501	15	0.6	501	15	0.6	3248	10	1
SE	4	550	25	0.3	550	25	0.3	3248	10	1
S	1	301	0	0	601	5	0.75	3248	10	1
S	2	301	0	0	500	25	0.6	3248	10	1
S	3	301	0	0	501	15	0.6	3248	10	1
S	4	301	0	0	550	25	0.3	3248	10	1
SW	1	400	0	0	601	5	0.75	3248	10	1
SW	2	500	25	0.6	500	25	0.6	3248	10	1
SW	3	501	15	0.6	501	15	0.6	3248	10	1
SW	4	550	25	0.3	550	25	0.3	3248	10	1
W	1	400	0	0	301	0	0	3248	10	1
W	2	500	25	0.6	301	0	0	3248	10	1
W	3	501	15	0.6	301	0	0	3248	10	1
W	4	550	25	0.3	301	0	0	3248	10	1
NW	1	400	0	0	601	5	0.75	3248	10	1
NW	2	500	25	0.6	500	25	0.6	3248	10	1
NW	3	501	15	0.6	501	15	0.6	3248	10	1
NW	4	550	25	0.3	550	25	0.3	3248	10	1

When vegetation was set to heights less than the baseline, the simulated stream temperatures began to increase earlier in the day, indicating that the sun was reaching the stream sooner (Figure 13). Additionally, the daily maximum simulated temperatures were higher than the baseline condition, which was expected.

When vegetation heights were increased to values above the baseline condition, the simulated stream temperatures showed a more moderate rate of increase. At 200 percent, the daily maximum stream temperature was lower than the baseline condition because of the decreased solar load.

The W3T model was proven to appropriately handle vegetation height inputs.

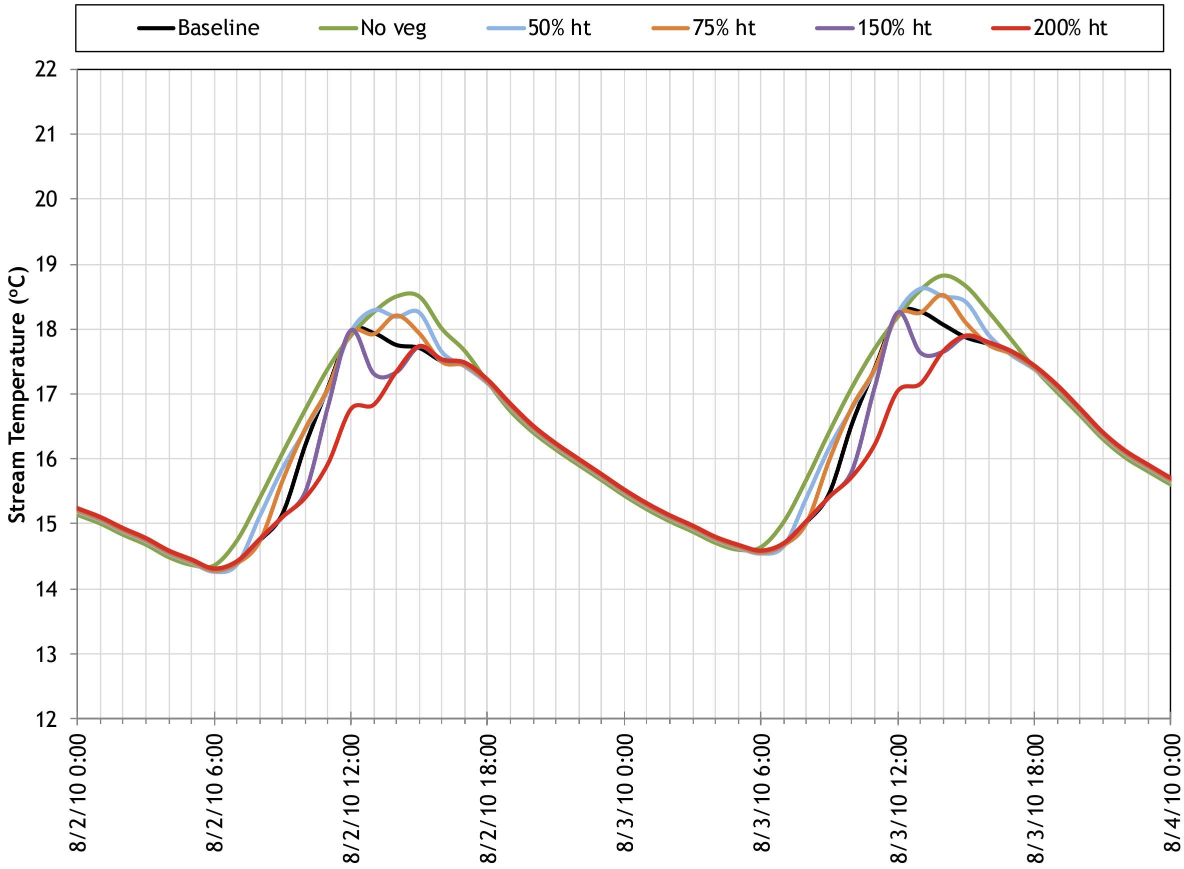

Figure 13 - Simulated stream temperature for various vegetation heights.

2.7 Vegetation Density

Vegetation density was tested for five different scenarios. In each scenario, all land cover inputs were assigned the same density, regardless of type. (The baseline condition contained various density values depending on the near stream land cover type, and therefore was not included in the following charts.)

The direct solar radiation above the stream decreased as vegetation density increased (Figure 14). This was the expected result.

The total heat leaving the simulation reach generally decreased as the vegetation density was increased. However under the 100 percent density scenario, there was slightly more heat leaving the simulation reach than in the 75 percent density scenario. This may seem counter-intuitive, but it is an accurate result because at 100 percent density, there is more longwave radiation from the vegetation.

Overall, these scenarios helped to confirm that shortwave and longwave radiation are correctly accounted for in the W3T model.

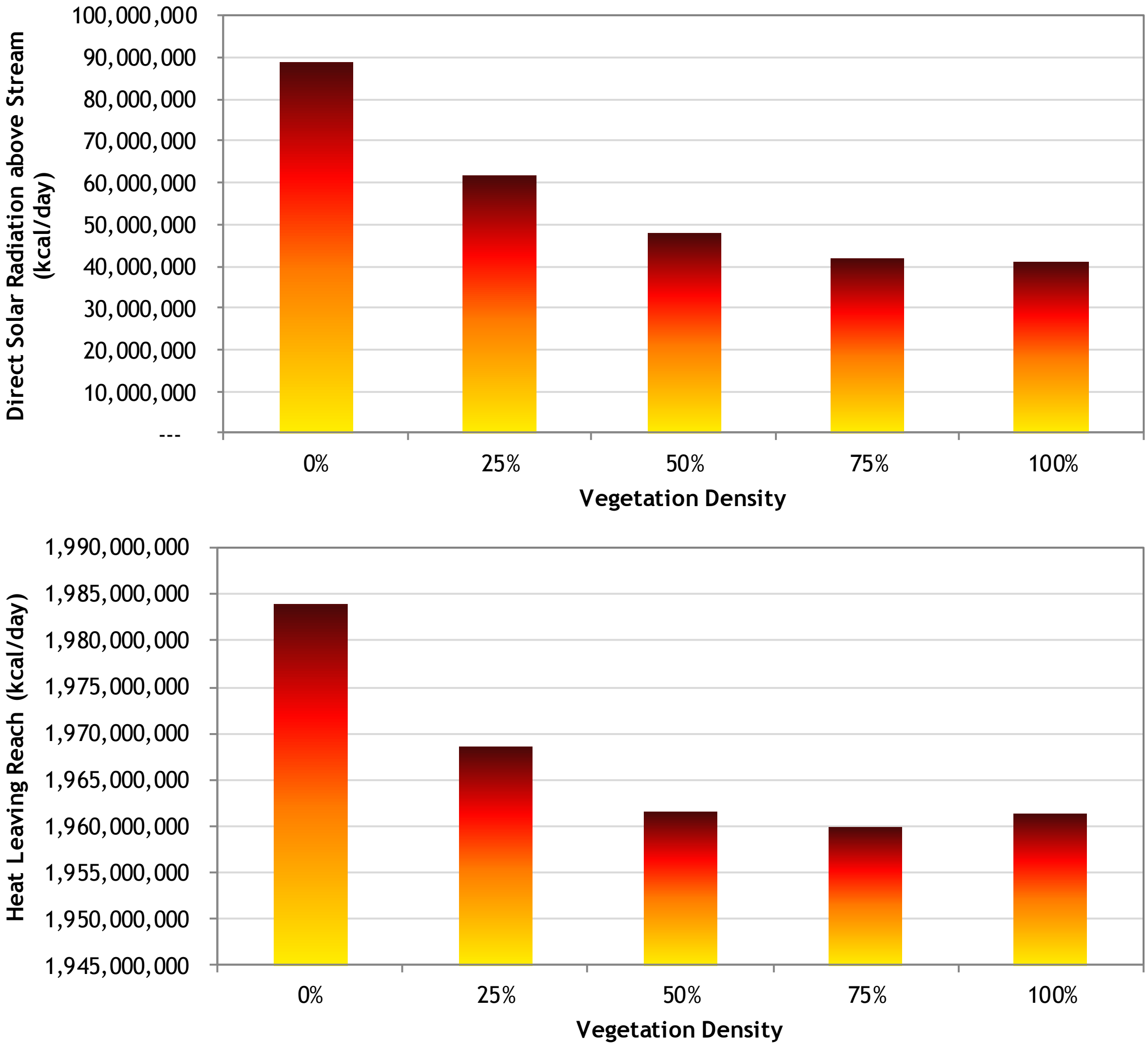

Figure 14 - Simulated direct solar load and heat leaving the reach for various vegetation densities.

The simulated stream temperatures for each vegetation density scenario are shown below (Figure 15). The 75 percent and 100 percent density scenarios had nearly identical results. The zero percent density scenario resulted in higher daily maximum temperatures, as is to be expected from the increased solar load. The zero percent density scenario is equivalent to the “no vegetation” scenario presented earlier.

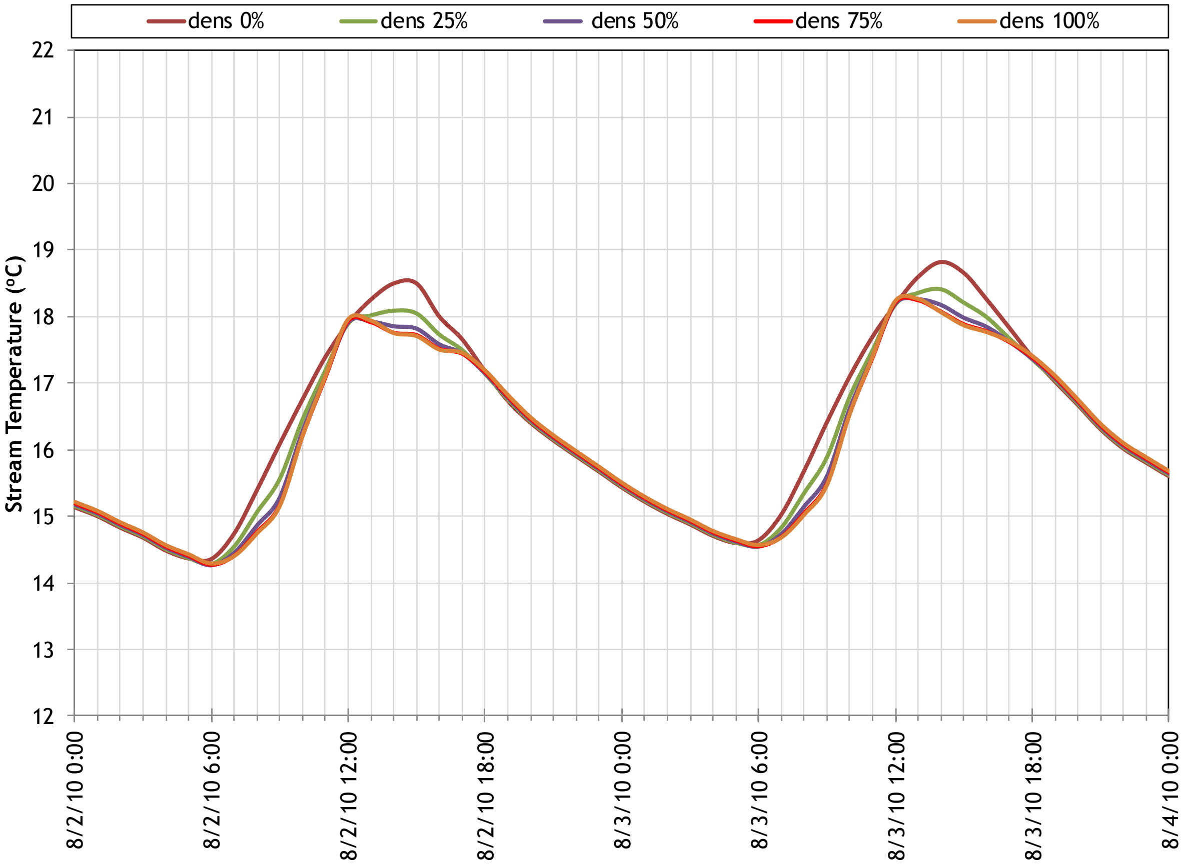

Figure 15 - Simulated stream temperature for various vegetation densities.

2.8 Topographic Shade

Topographic shade was assessed and the W3T model produced expected results (Figure 16 through Figure 19). Eastern topographic shade reduced morning solar flux, western topographic shade reduced evening solar flux, and southern topographic shade had no influence at this time of year because the solar altitude is above 45 degrees.

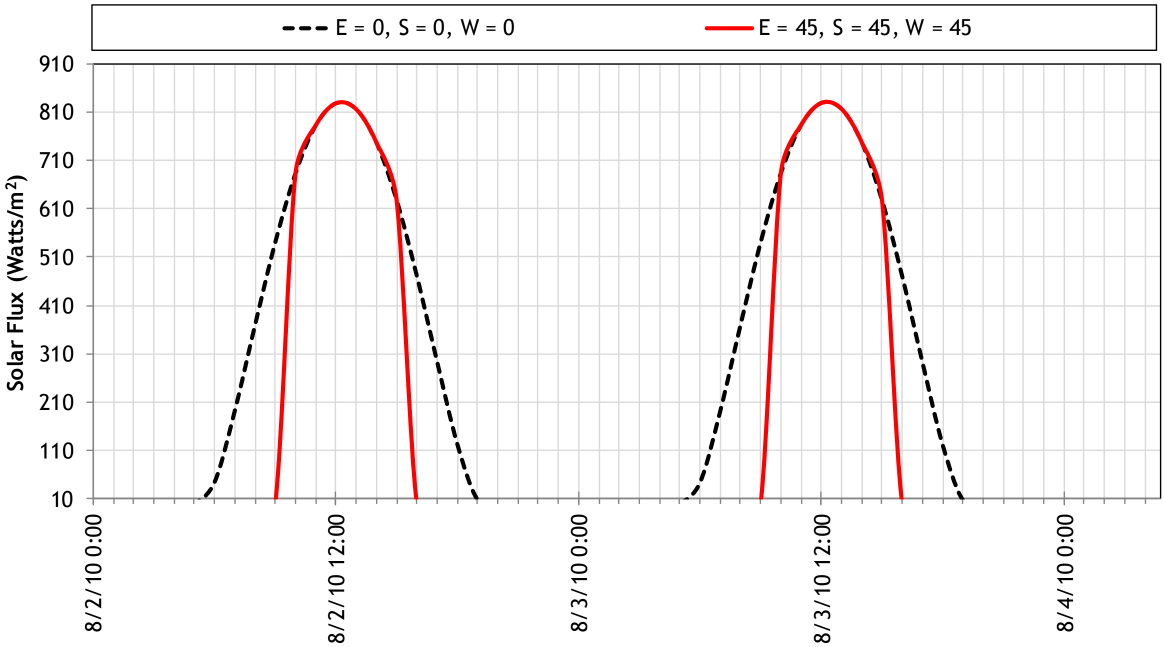

Figure 16 - Simulated solar flux with topographic shade of 45 degrees in the east, south, and west.

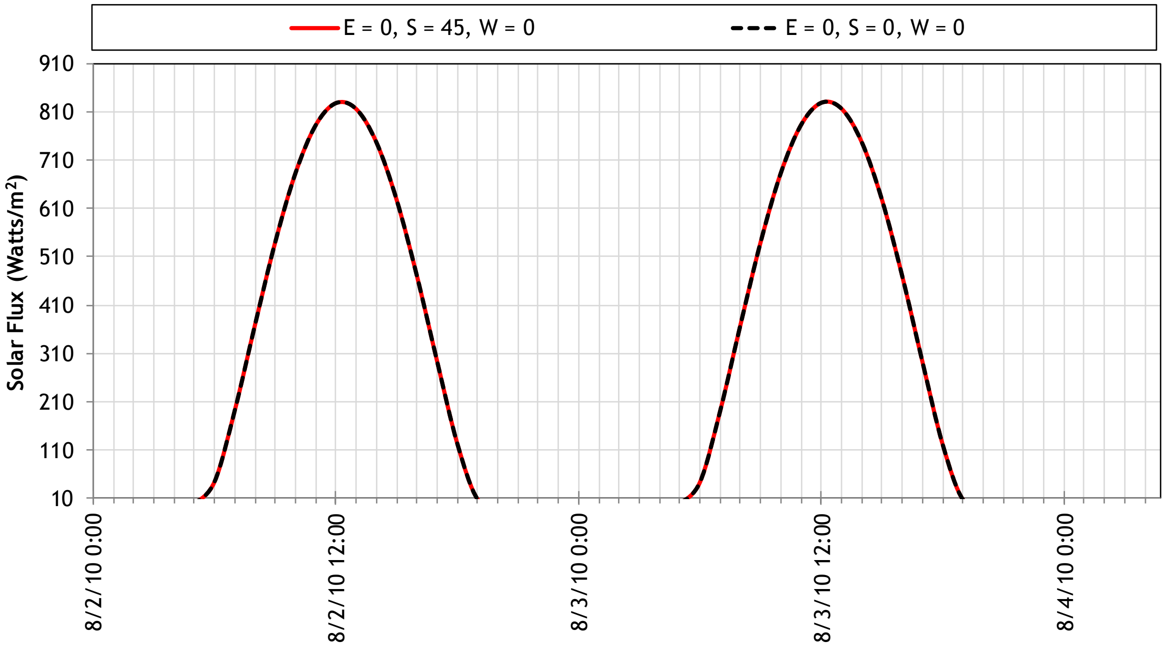

Figure 17 - Simulated solar flux with topographic shade only to the south.

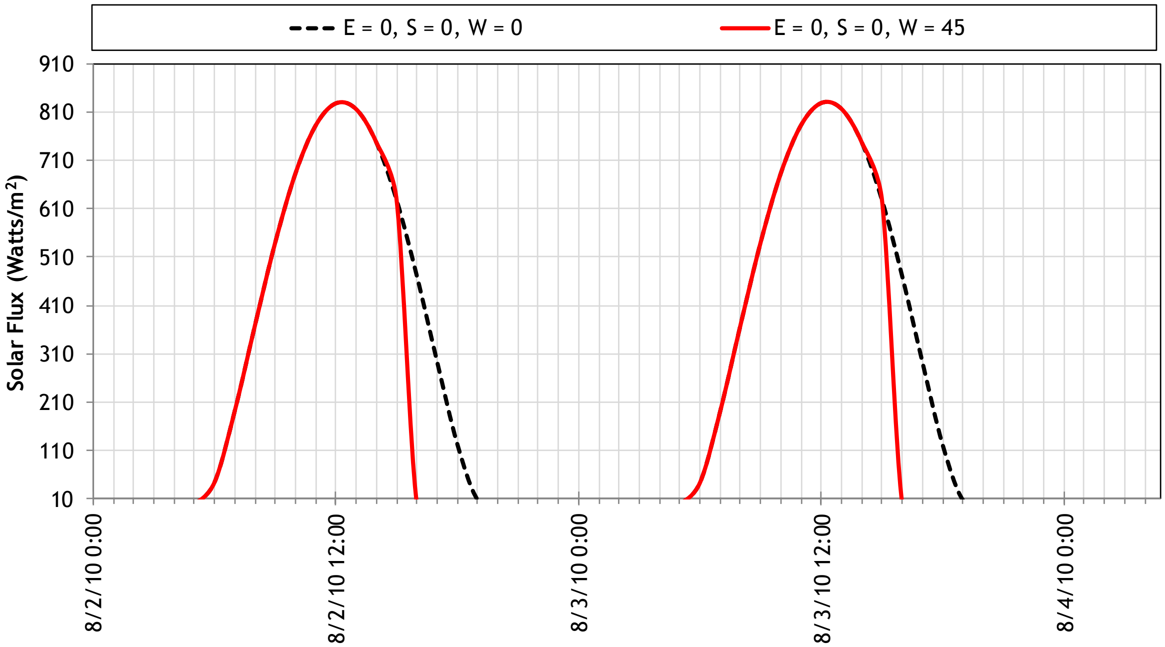

Figure 18 - Simulated solar flux with topographic shade only to the west.

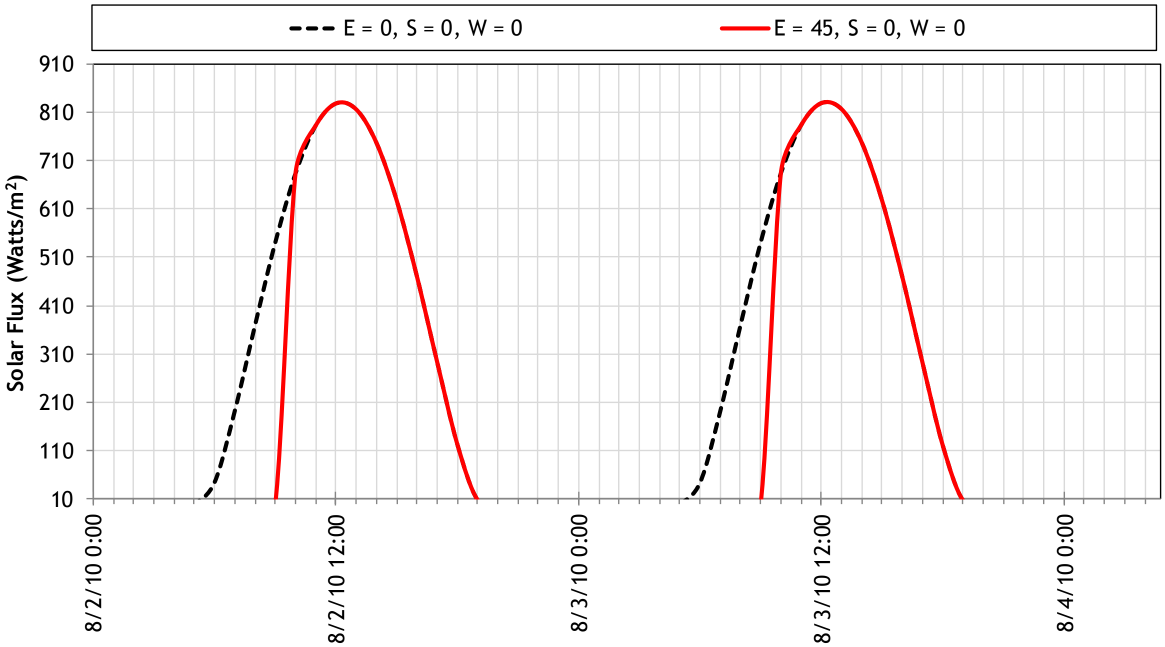

Figure 19 - Simulated solar flux with topographic shade only to the east.

2.9 Channel Bottom Width

Various channel bottom width values produced expected results (Figure 20). Narrower widths resulted in lower stream temperatures than the baseline condition, while wider widths resulted in higher temperatures. This is simply due to the changes in surface area and depth which impact the total solar load the stream receives. The model remained stable at all channel widths that were tested.

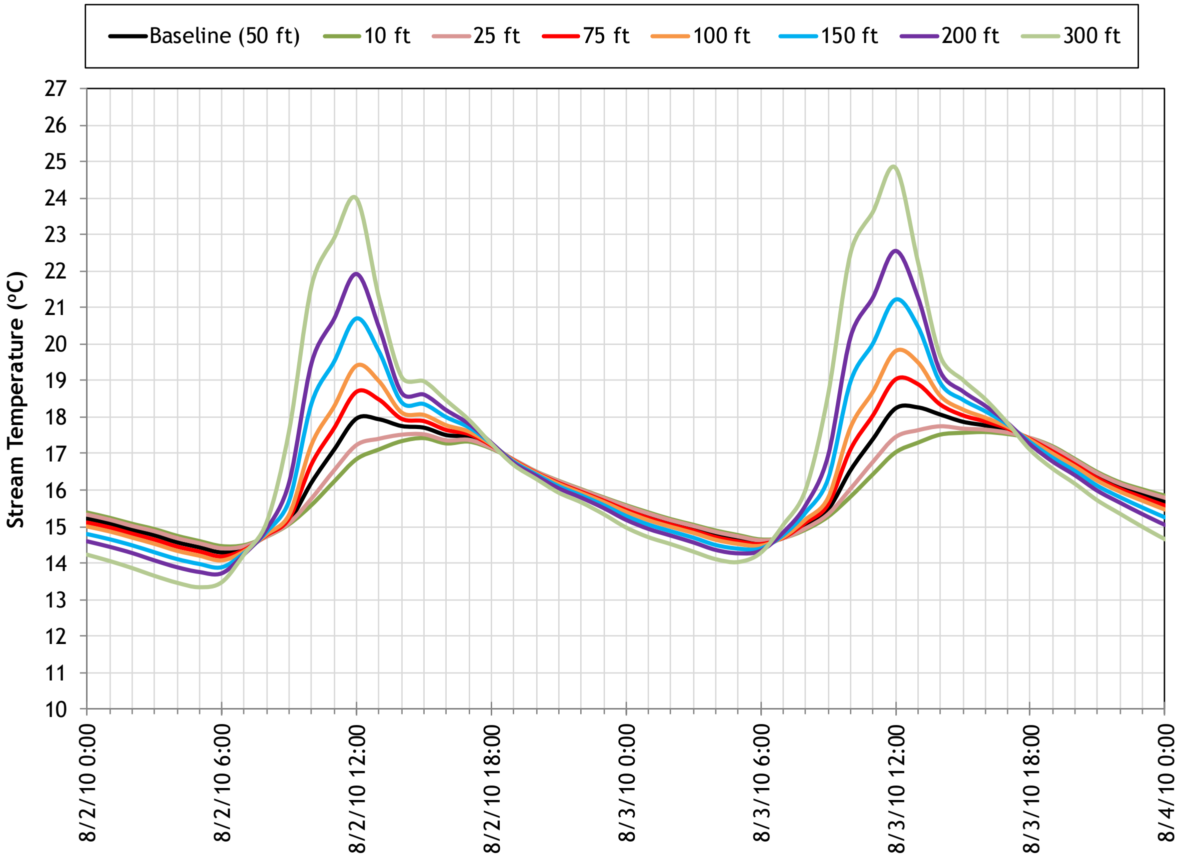

Figure 20 - Simulated stream temperature for various channel bottom widths.

2.10 Manning's n (Roughness Coefficient)

Changing the Manning's n value affected the model hydraulics as expected (Figure 21). Lower values resulted in faster travel time, shallower depth, and decreased width. Higher values resulted in quicker travel time, deeper depths, and wider top widths. All results fell within the expected ranges based upon the Manning's equation and the baseline channel morphology.

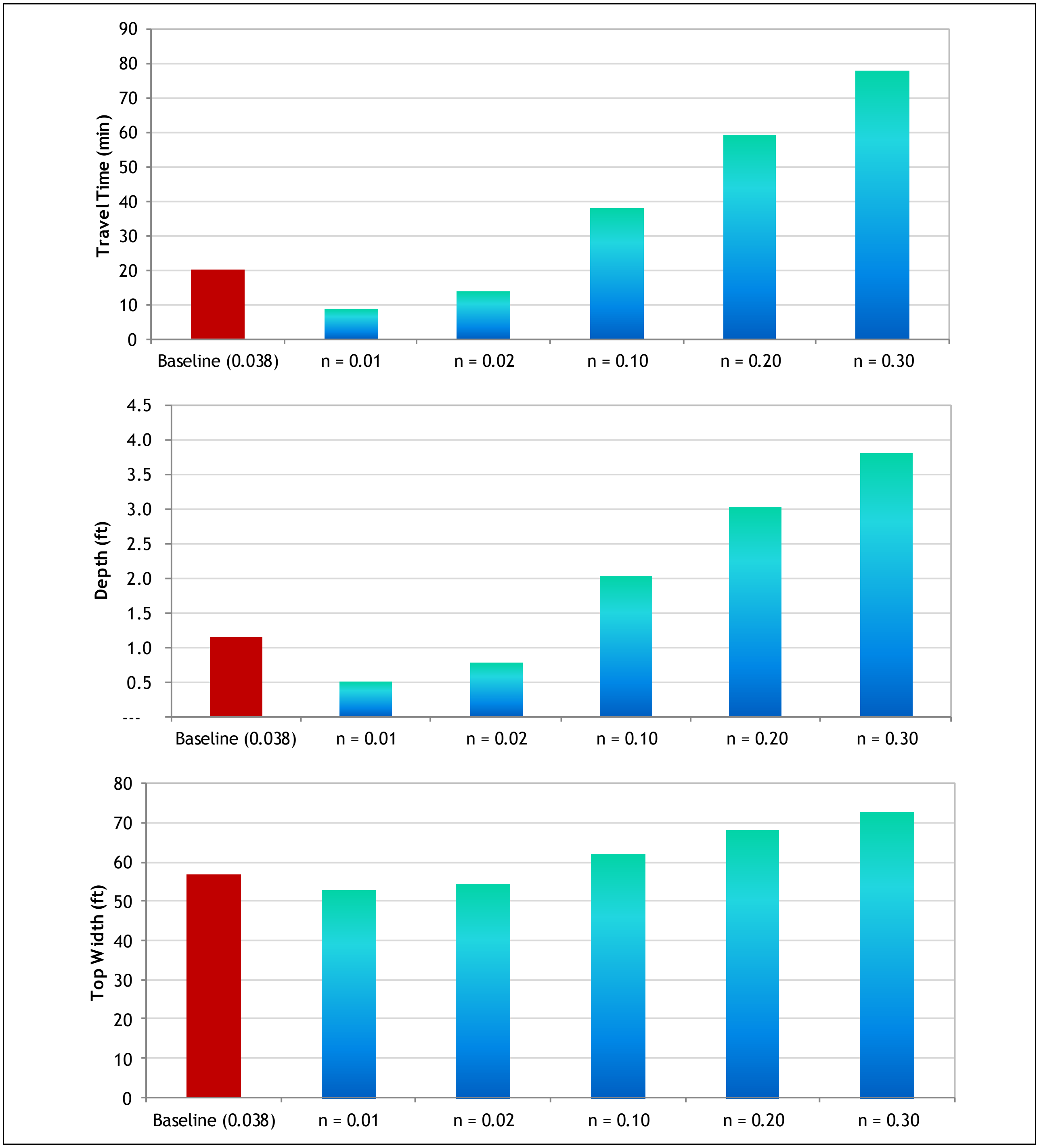

Figure 21 - Simulated travel time, depth, and top width for various Manning's n values.

Higher Manning's n values resulted in moderated diurnal stream temperature fluctuations (Figure 22). The highest Manning's n value tested was 0.30. Values greater than 0.30 resulted in unrealistic depths and travel time.

The user should examine both the hydraulic values (depth, travel time, and top width) and stream temperatures when adjusting the Manning's n value. Using values that are too high may produce inaccurate stream temperatures by causing travel time to be unrealistically slow. Ideally, users will have field data to confirm that the simulated travel time and depths are representative of the actual conditions.

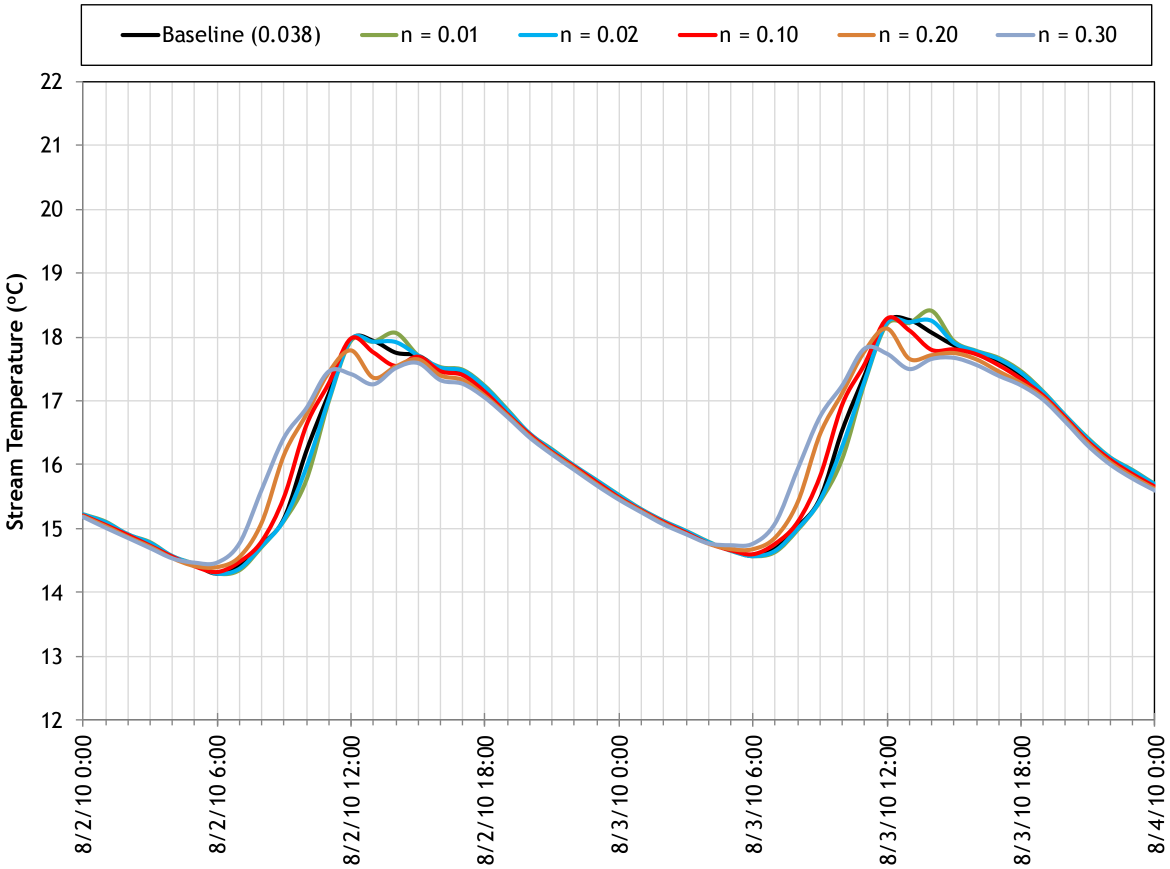

Figure 22 - Simulated stream temperature for various Manning's n values.

2.11 Air Temperature

The W3T responded to different air temperature inputs as expected (Figure 23). Higher air temperatures increased the stream temperature, while lower temperatures decreased the stream temperature. If this were an actual sensitivity analysis, air temperature may have been assessed at various flow volumes as well. But for the purpose of this review, stream temperature differences and timing were observed to be coincident with the air temperature inputs.

It was confirmed that hourly air temperature inputs are being used appropriately by the model.

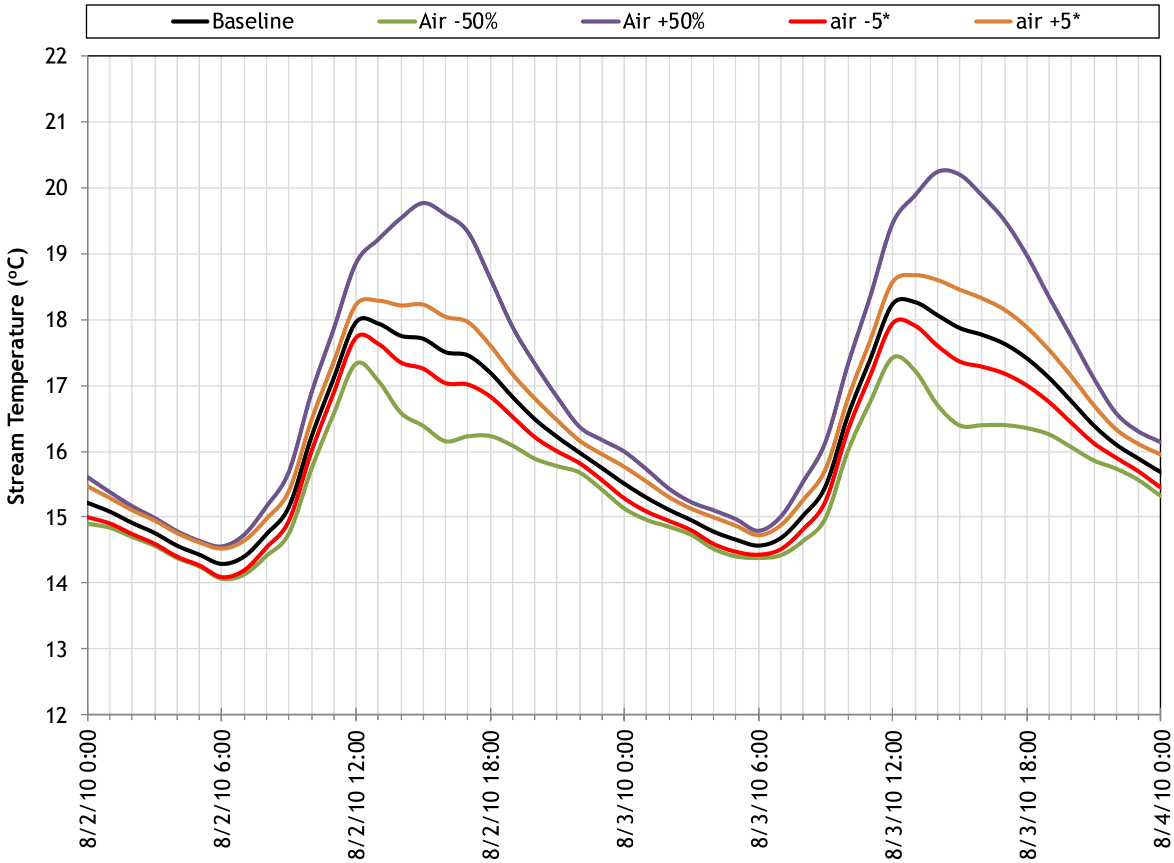

Figure 23 - Simulated stream temperature for various air temperatures.

2.12 Relative Humidity

Altering the relative humidity input had the expected effect on simulated stream temperatures (Figure 24). Most notable are the scenarios where humidity was set at zero percent for every hour and then set at 100 percent for every hour. When there was zero percent humidity, the stream temperatures were lowest which is to be expected since evaporative cooling at is more pronounced. When there was 100 percent humidity, the stream temperatures were notably higher than the baseline because of the stream's reduced ability to shed heat via the air-water interface.

The other three scenarios were simple percentages of the baseline humidity values and the stream temperatures were slightly warmer than baseline. It was concluded that the W3T model is correctly using the hourly relative humidity inputs.

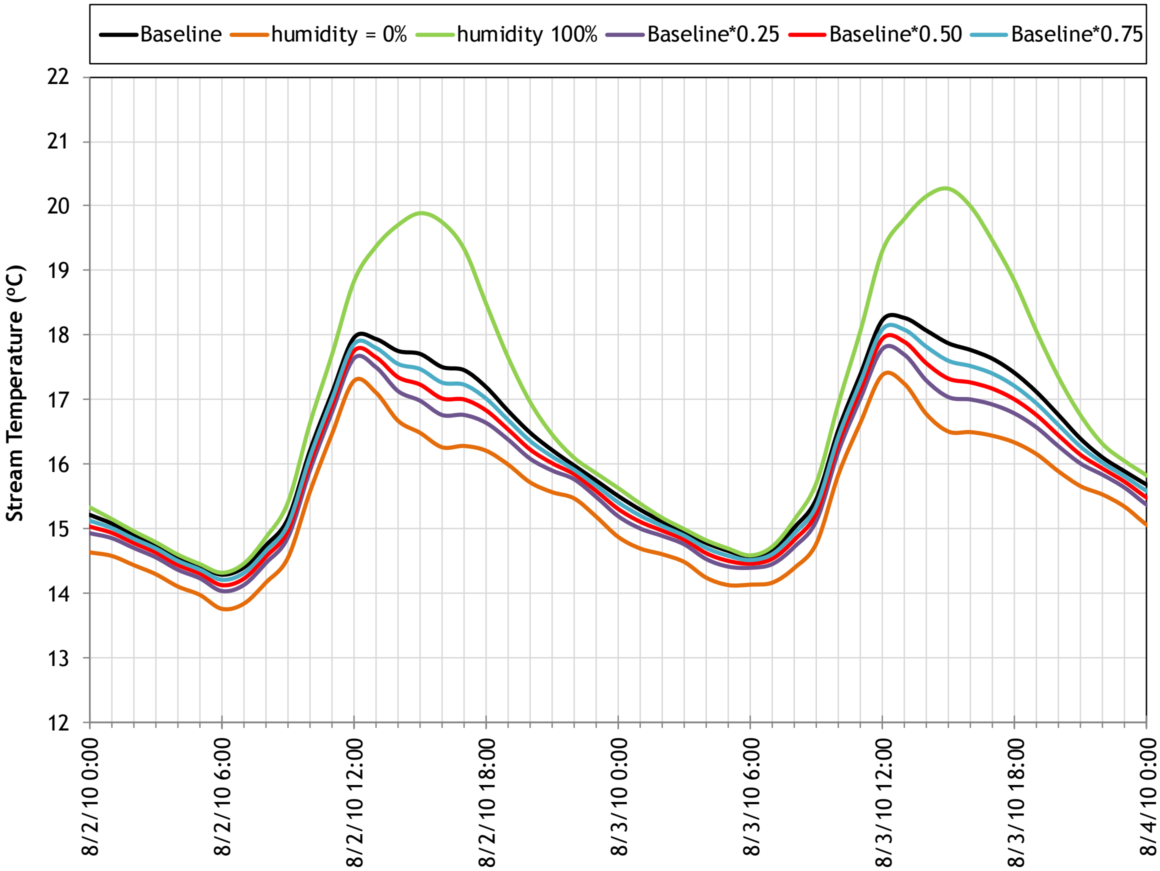

Figure 24 - Simulated stream temperature for various relative humidity values.

2.13 Wind Speed

The effects of wind speed on the simulated stream temperatures were somewhat unexpected (Figure 25). Eliminating wind from the model resulted in slightly lower daily maximum temperatures. Increasing wind speed resulted in higher daily maximums. Intuitively, one would initially expect that higher wind speeds would increase evaporation, thereby removing heat from the stream.

Further investigation revealed that lowering the humidity values while increasing the wind speeds resulted in lower simulated stream temperatures. Therefore, the anomaly seen below is directly tied to the baseline condition humidity values. Another contributing factor is the air/water temperature gradient.

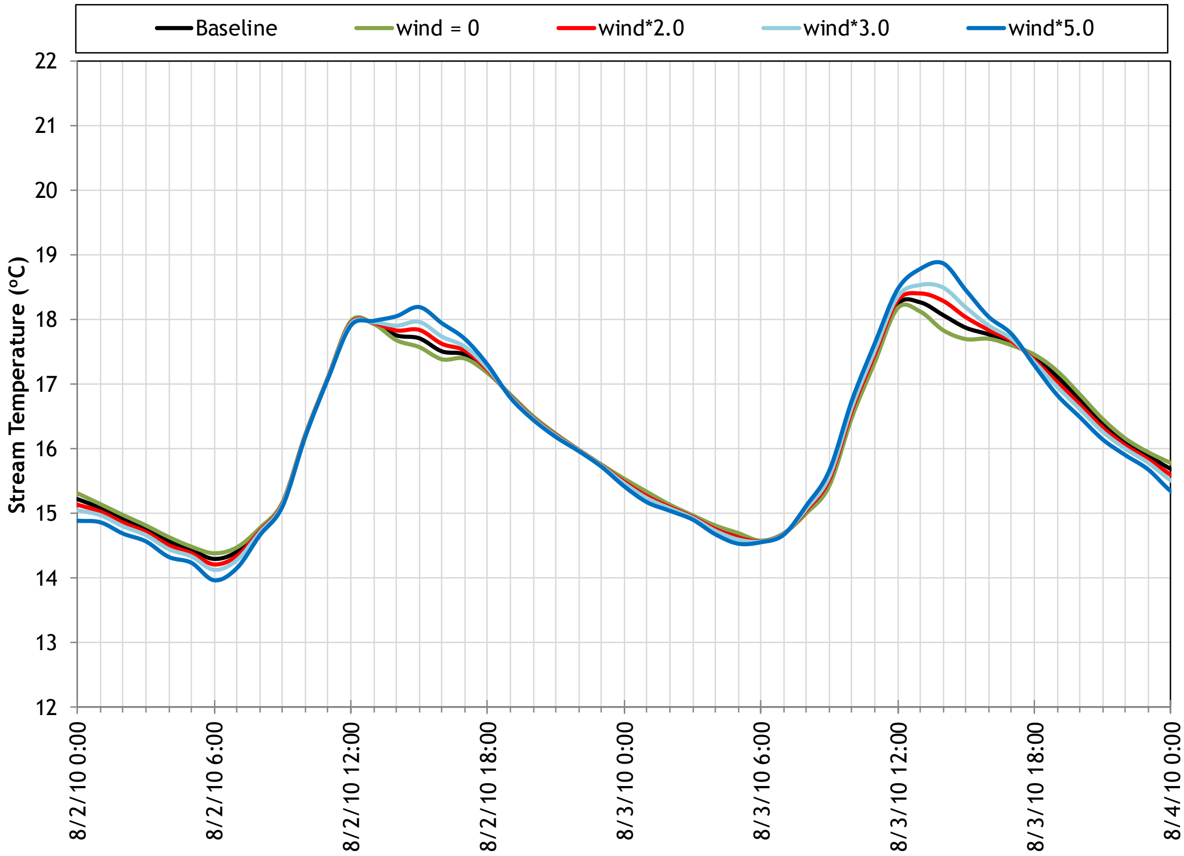

Figure 25 - Simulated stream temperature for various wind speeds.

Additional testing was performed to illustrate the influence of wind speed and relative humidity on the simulated evaporative flux (Figure 26). Lower humidity values facilitated higher evaporation rates, while higher humidity values reduced evaporation. When humidity was set to 75 percent, the net evaporation flux was positive, indicating a net heat gain to the stream. This correlates with increased stream temperatures at higher wind and higher humidity as seen on the previous page.

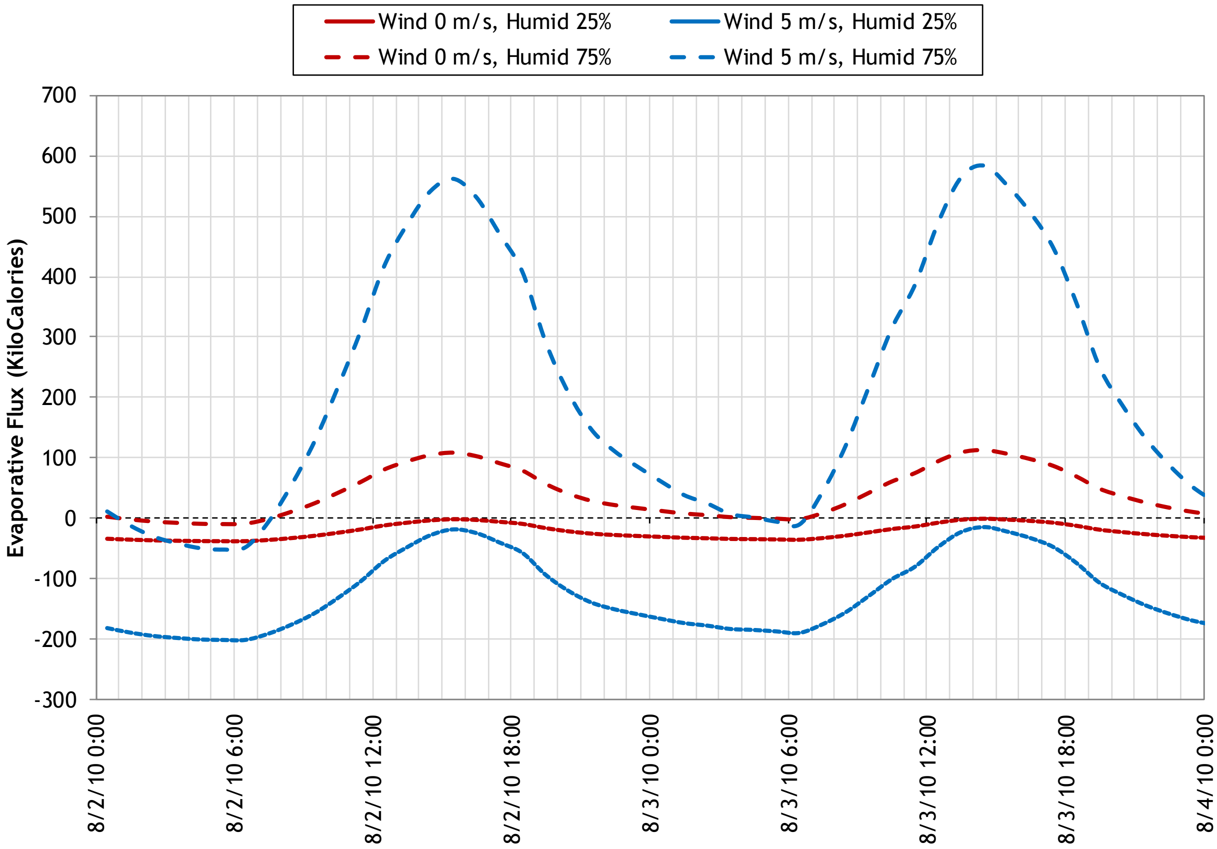

Figure 26 - Simulated evaporative flux at various wind speed and relative humidity combinations.

3.0 VBA Code Review

The VBA code for the W3T model was examined for accuracy and completeness. The algorithms and methods are adapted from Heat Source version 7.0. At the time of this review, there were no errors or insufficiencies identified within the W3T model code. The equations are accurate and the code is written so that all calculations and results are properly routed, transformed, and used by the model.

The air vapor equation used in Heat Source v 7.0 was flagged by Watercourse Engineering, Inc. as potentially containing an error. The error was confirmed and it should be noted that later versions of Heat Source (v 8.0+) contain the correct equation (as does the W3T model). Below are the incorrect and correct equations:

Table 2 - Air vapor equations identified as incorrect in Heat Source 7.0 and correct in W3T.

Models	Equation	Consensus
Heat Source 7.0	*Air_Vapor = Humidity * Sat_Vapor_Tw* where, *Sat_Vapor_Tw = 6.1275 * Exp(17.27 * Tw / (237.3 + Tw))*	**Incorrect**
Heat Source 8.0+ W3T 0.9g Beta	*Air_Vapor = Humidity * Sat_Vapor* where, *Sat_Vapor = 6.1275 * Exp(17.27 * Air_T / (237.3 + Air_T))*	**Correct**

4.0 General Discussion and First Impressions of the W3T Model

This section contains a general discussion of the W3T model based upon initial impressions after running the sensitivity analysis and becoming familiar with the application. These discussion points do not necessarily fit into the other sections of this document, but are provided to help spur conversation and provide perspective.

- The W3T model uses methods and code from Heat Source v 7.0 (Oregon DEQ version). As the original developers of Heat Source and TTools, WSI staff is in a unique position to review the W3T model because of our extensive modeling experience and intimate knowledge of the Heat Source code.

- W3T outputs are hourly simulated stream temperatures at the bottom of the reach. The seven-day averages of the daily maximums (7DADM) are also reported by W3T. In most cases, the 7DADM is used in the context of stream temperature regulation by the state of Oregon in their regulatory framework.

- While running the W3T model, the option to save the baseline condition was valuable and time saving. Some models require another copy of the software to be opened and then the results have to be manually harvested and plotted in order to compare results from current and previous runs.

- The W3T model runs quickly, producing nearly instant results. This trait makes the model more user friendly to novices and is conducive to quickly changing various parameters to observe their effects on the simulated stream temperatures. Future versions of the model could benefit from having a simple pop-up window that indicates the model has successfully run.

- The user guide is well-written and it was very helpful to read it before opening the model for the first time. The language is such that a novice can easily grasp the W3T concepts. The user guide will be invaluable to W3T users.

- Perhaps the user guide would benefit from including a table describing quantitative and qualitative sources of model error. Discussion of the model accuracy and error could encourage users to use W3T properly since they will be fully aware of its limitations. For example, natural systems models rarely have the accuracy to support results on the order of one-tenth of a degree.

- The solar loading values are reported as "kilocalories per day" in the W3T model outputs. In the Pacific Northwest, these units are the most commonly used and understood by the majority of stakeholders. This factor adds to the overall usefulness of W3T.

- Bed interaction is not currently included in the W3T model. In larger streams, bed interactions may have a negligible influence on stream temperature. Conversely, in small streams, bed interactions may measurably influence stream temperatures. W3T could benefit from including an option for bed interactions, even if they were more simplified interactions such as absorption and conduction of heat via the substrate and diffuse groundwater upwelling.

- Velocity and wetted width could be used as additional validation parameters (in addition to flow rate and depth). If the user is collecting flow measurements in the field, these data are usually available.

- A common question about the W3T model is "how does the model account for cumulative effects of flow trading upstream, downstream, from tributaries, etc.?" After reviewing the model and understanding the intended purpose of W3T, this point is moot. W3T was developed to be a user-friendly, simplified model for use on smaller reaches. If the effects of upstream or tributary influences are important to the scope of work, then perhaps a more complex modeling effort is warranted. Nevertheless, W3T will be a valuable tool for helping determine if a more in-depth analysis is necessary under such circumstances.

- When more water was diverted than was available in the stream, W3T immediately produced an error message indicating that the stream reach has run dry. That is a very useful feature and contributes to the model's user-friendliness.

5.0 Overall Impressions and Specific Endorsements

Review of the W3T model and discussions with The Freshwater Trust and Watercourse Engineers, Inc. have clarified that the model was developed to be a user-friendly, affordable, and simplified model for assessing the potential impacts of flow transactions on stream temperature. It is a tool designed to be accessible to a wide audience, including technical and non-technical stakeholders alike. It is envisioned to be easily explained and easily run, as opposed to some of the more complex "black-box" models currently available. Data collection and model set up are intended to be more straight-forward, less time consuming, and more affordable than what is required by other traditional water quality models. With this background information in mind, the current version of W3T successfully meets its intended scope and purpose.

The W3T model has great potential to help a wide variety of people gain a better understanding of water transactions. It is simple to adjust the inputs, it runs very quickly, and the results are almost instantaneous. It could be a valuable tool for stakeholders such as watershed councils who have few resources but are interested in assessing the impacts of water transactions in small reaches. With little time and money, a watershed council could gather the required data, set up the model, and run various what-if scenarios. The model itself is compact and runs through a readily available Microsoft Excel interface. It could be run on a laptop while being projected on a screen for meeting participants to actively engage in determining what parameters to change, while providing results very quickly. Such use of W3T could encourage landowners and stakeholders to be more engaged or proactive in assessing flow transactions in their streams. More complex models are not as suitable for such activities because they take a long time to run and have much more complex interfaces.

Another aspect of W3T that helps it reach a wide audience is the fact that it does not require GIS software or highly detailed spatial data inputs. The data required to run W3T can be collected at a lower cost and with less rigidity than many traditional water quality models require. Other models often require GIS and modeling expertise in order to be set up and run with confidence.

With the addition of a W3T protocol document (currently under development by Watercourse Engineering, Inc.), data collection and model set-up will be made even more accessible to a wide variety of users. It is common for the monitoring objectives of one group to differ radically from those of another group, so having a companion protocol document will be extremely beneficial to the success of W3T. For example, a group studying amphibian habitat may place thermistors in warm, slow pools of the stream that do not necessarily represent the overall stream temperatures. Using such data in stream temperature modeling would introduce inaccuracies and produce questionable results. A protocol document will help guide proper location and timing of thermistor placement (and other data collection), thereby increasing the chances for successful W3T modeling.

In the instance of limited field data, W3T can still be used as a valid initial analysis to reveal if a water transaction is going to have a positive or negative impact on stream temperature, essentially providing information that was previously unknown to the interested party. It could be used to help prioritize water transactions within a watershed by revealing which ones have the most positive or most negative impact on the stream reach. In many watersheds, there are numerous stream reaches on the 303(d) list but limited resources for TMDL development. The W3T model could be used as an initial assessment tool to help prioritize TMDL development by identifying streams that may be most responsive to restoration and conservation activities.

The Rudio Creek example supplied with the W3T model review package is a good example of how the model could be used to reveal information that was previously unavailable. It indicated that the flow transaction would have no negative impact on the stream.

Given that the W3T model was developed to be a simplified approach, the next question that comes to mind is, “what types of streams is the model best suited for?” It was designed to simulate limited reaches of small to medium sized streams. It would not be an appropriate application of W3T to simulate an industrial point source or diversion canal along the lower Willamette River. Large rivers often require more complex models capable of simulating long reaches and accounting for multiple point and non-point source inputs. The point of maximum impact for a water transaction on the Willamette River may be many miles downstream or off to one side of the river, which may not be adequately addressed via W3T modeling.

Complex river networks that are influenced by multiple flow transactions may also not be ideal candidates for the W3T model. In such systems, the cumulative effects of tributaries, landscape features, and non-point sources may need to be accounted for across a wide area. Analysis of these systems may require extensive data collection and GIS analysis in order to be accurate. W3T is a single-reach model designed to accommodate a limited number of inputs. While some modelers will “daisy-chain” reach models in order to assess a larger system, it would not be recommended to do so with W3T, except in the case of simulating a tributary reach and then using those results to seed a model of its receiving stream.

Smaller streams with less complex arrays of flow transactions are best suited for W3T simulations. In small streams, the thermal effect of a flow transaction often impacts a much shorter reach. In addition, smaller streams are generally more responsive to changes in effective shade and channel morphology, so W3T could also be used to adequately simulate the effects of riparian and channel parameters.

As with all water quality models, it is the responsibility of the user to be educated about the software, collect adequate field data, and apply the results appropriately while recognizing the strengths and limitations of the model. W3T has the potential to be an extremely useful tool assuming that the inputs are adequate and that the results are applied with all assumptions and model limitations in mind.

6.0 Model Strengths and Limitations

When reviewing a model such as W3T, it is important to keep in mind the intended applications, audience/users, and scientific objectives. As previously mentioned, the W3T model was designed to strike a balance between accuracy and efficiency. The draft materials accompanying the W3T model describe proper setup and use of the model.

It is the responsibility of the user to ensure that a model is set up properly and used only for its intended purpose. Strengths and limitations of a model should be well understood by the user and that information should be considered while drawing conclusions based upon the model results.

This section describes the strengths and limitations that WSI has identified in the W3T model. Given the limited time spent with W3T, this section is by no means comprehensive. Natural systems vary greatly and each type of system may reveal different strengths and weaknesses of W3T. The discussion herein serves as a basic overview and results may vary depending upon the type of system being modeled, the amount and types of data available, and the intended purpose of the modeling exercise.

Strengths

- User-friendly model and documentation
- Simplified model setup does not require GIS expertise
- Limited reach length and complexity means less rigorous field data collection effort
- Lagrangian method is easier understood by a wider audience
- Fast run time allows user to easily explore effects of various input parameters
- Microsoft Excel user interface - requires no additional software

Limitations

- Sub-reaches are generalized and may not account for small-scale heterogeneity of stream channel and riparian conditions
- Limited number of reaches and tributary or flow transaction inputs allowed
- Lagrangian method is less robust than Eulerian method
- Non-point source inputs are not accounted for in the current version
- Excludes bed interactions in the heat budget
- User interface could be more intuitive and robust

Despite the limitations listed above, the W3T model meets its intended objective of being a simplified, accessible and accurate flow transaction model. If more complex riparian or channel morphology and longer simulation reaches are desired, alternative models may be used.

It is the opinion of WSI that the W3T model has successfully struck a balance between simplicity and robustness. If used for its intended purpose of assessing the impacts of flow transactions on smaller scales, W3T should prove to be a valuable tool to expert and non-expert modelers alike.

Appendix VIII

Event Attendance

In 2011, the Soil and Water Conservation Society annual meeting in Washington, D.C. The meeting was attended by many NRCS representatives.

In 2012, the 2012 Western Water Transactions Meeting held in Reno, NV. This conference included attendees from the National Resource Conservation Service (NRCS) including Astor Boozer (DC) and James Gore (CA) as well as other USDA Agency personnel.

In 2013, the W3T model was presented and shared with stakeholders in the Klamath Basin, at the Klamath Basin Monitoring Program (KBMP) meeting in March. www.kbmp.net

In 2013 this work was again presented to the 2013 Western Water Transactions Workshop Meeting held in Bend, Oregon. This CIG presentation focused primarily the rollout of the W3T model where it received good feedback and interest.

Additionally, in 2013, the W3T model and NFWF CIG work objectives were presented at the 2013 American Water Resources Association (AWRA) Conference in Portland, OR.

Appendix IX

Semi-annual Performance Progress Reports

Semi-Annual Progress Report

09/24/2010 – 03/31/2011

NRCS CONSERVATION INNOVATION GRANTS
69-3A75-10-141

Grantee Name:	National Fish and Wildlife Foundation
Project Title:	Establishing an Ecosystem Market Credit for Flow Restored in Northern California
Agreement Number:	69-3A75-10-141
Project Director:	Andrew Purkey Director, Western Water Programs National Fish and Wildlife Foundation
Contact Information:	National Fish and Wildlife Foundation, Western Partnership Office 421 SW 6th Avenue, Suite 950 Portland, OR 97204 Tel: (503) 417-8700 ext. 6009 E-mail: Andrew.Purkey@nfwf.org
Period Covered by Report:	09/24/2010 – 03/31/2011
Project End Date:	09/24/2012

A) Summarize the work performed during the project period covered by this report:

First, a decision was made to focus implementation of the CIG in the Klamath Basin, including the Sevenmile Creek drainage on the Oregon side of the basin. This was supported by NRCS staff in California, including State Conservationist Ed Burton.

The two primary objectives of the first six months of the National Fish and Wildlife Foundation's (NFWF) CIG were to conduct outreach to agency staff and key local stakeholders as well as assemble the technical team to implement the grant. We met with federal and state agency staff in Davis, Eugene, Redding, San Francisco and Santa Rosa. We traveled to the Klamath Basin four times to meet with the staff and board of directors of key local stakeholder organizations, including the Klamath Basin Rangeland Trust, Scott River Water Trust, Shasta Resource Conservation District and the Siskiyou Resource Conservation District. The primary goal of these trips was to introduce relevant agencies and groups to the objective of the CIG and to receive their input on how best to implement the effort. Another objective of the meetings with the local stakeholders was to seek their participation in implementation of the initiative in the Klamath Basin.

NFWF also assembled the technical team to help develop the accounting protocol and flow calculator. The team is coordinated by Rankin Holmes of Ecosystem Economics and includes Mike Deas and Ann Willis of Ecosystem Economics, Carson Jeffres and Drew Nichols of the U.C. Davis Center for Watershed Science. Local partners under contract to work with the technical team including Shannon Peterson and Carolyn Doehring of the Klamath Basin Rangeland Trust, Sari Sommerstrom of the Scott River Water Trust, David Webb of the Shasta Resource Conservation District, and Gary Black and Erich Yokel of the Siskiyou Resource Conservation District. The organizations will assist in implementing the monitoring activities intended to inform development of the accounting protocol starting this Fall. NFWF is also working with other organizations, including the Freshwater Trust, Klamath Watershed Partnership, Nature Conservancy, Willamette Partnership and others on implementation of the CIG.

B) Describe significant results, accomplishments, and lessons learned. Compare actual accomplishments to the project goals in your proposal:

As described above, the first six months of the CIG were focused on outreach and development of the technical team and approach. Attached is the outreach document produced by NFWF to describe the initiative, as well as the Draft Field Monitoring Protocols that will be used this summer. We are now poised to implement monitoring activities over the next six months to inform development of the flow accounting protocol and ultimately the flow calculator.

NFWF has learned about the political sensitivity associated with development of ecosystem credit tools in a regulated community. The priority watersheds are under both water quality and habitat obligations through both the Clean Water Act and the Endangered Species Act. We are working closely with both the local communities and the regulatory agencies through the Klamath Basin Tracking and Accounting Program to develop voluntary credit tools that will enable willing landowners and others to address environmental factors such as increased water temperature and decreased spawning and rearing habitat.

C) Describe the work that you anticipate completing in the next six-month period:

Over the next six months, NFWF, its' technical team and local partners will focus on conducting field monitoring, using the Draft Field Monitoring Protocols, centered on flow restoration activities being implemented in the Scott, Sevenmile and Shasta subbasins. These monitoring activities will then inform development of the draft accounting protocols during the following six month period.

D) Provide the following in accordance with the Environmental Quality Incentives Program (EQIP) and CIG grant agreement provisions:

1. A listing of EQIP-eligible producers involved in the project, identified by name and social security number or taxpayer identification number; No EQIP-eligible producers have been involved in the project to date. This is likely to change when water

transactions are negotiated this summer to restore instream flow that will then be monitored.

2. The dollar amount of any direct or indirect payment made to each individual producer or entity for any structural, vegetative, or management practices. Both biannual and cumulative payment amounts must be submitted.
3. A self-certification statement indicating that each individual or entity receiving a direct or indirect payment for any structural, vegetative, or management practice through this grant is in compliance with the adjusted gross income (AGI) and highly-erodible lands and wetlands conservation (HEL/WC) compliance provisions of the Farm Bill.

Semi-Annual Progress Report
04/01/2011 – 09/30/2011

NRCS CONSERVATION INNOVATION GRANTS
69-3A75-10-141

Grantee Name:	National Fish and Wildlife Foundation
Project Title:	Establishing an Ecosystem Market Credit for Flow Restored in Northern California
Agreement Number:	69-3A75-10-141
Project Director:	Andrew Purkey Director, Western Water Programs National Fish and Wildlife Foundation
Contact Information:	National Fish and Wildlife Foundation, Western Partnership Office 421 SW 6th Avenue, Suite 950 Portland, OR 97204 Tel: (503) 417-8700 ext. 6009 E-mail: Andrew.Purkey@nfwf.org
Period Covered by Report:	04/01/2011 – 09/30/2011
Project End Date:	09/24/2012

A) Summarize the work performed during the project period covered by this report:

The primary objectives for the second six months of the National Fish and Wildlife Foundation's (NFWF) CIG award for our *Ecosystem Market Credit* project were to continue conducting outreach to engage agency staff and key local stakeholders and to focus on the development of metrics to account for changes in aquatic habitat and water quality resulting from restored flow. During the reporting period, we implemented the design and development of draft Flow Credit System Framework and Flow Credit Certification processes (Attachments A and B). Objectives of the protocol are to better track and account for leased water and their anticipated ecological impact. These processes will form the basis of a funding mechanism framework, which could administer funding for voluntary incentive based flow transactions in the Klamath Basin and regulatory credits in other basins, particularly in Oregon where the Department of Environmental Quality has a water quality trading program in place. These two draft model documents, although still in evolutionary stages, are reflective of lessons learned on the ground by flow restoration experts and credit market analysts.

NFWF and consultants then worked with local partners in three sub-basins of Klamath to "test" this monitoring protocol on actual flow transactions as well as flow transactional scenarios. In the Scott River Sub-basin, we worked with Siskiyou County RCD to implement monitoring protocol on two water transactions coordinated by the Scott River Water Trust. On Patterson Creek the water transactional objective was to extend over-summering conditions. On the Scott River the water transaction objective was to enhance autumn passage conditions on main-stem of Scott River for Chinook, Steelhead and Coho. In the Shasta River Sub-basin, NFWF staff and consultants worked with The Nature Conservancy (TNC), local contractors and Shasta Valley RCD to understand general basin flow issues and assess potential water transactional opportunities.

We monitored a simulated flow transaction on Little Springs located on the TNC Big Springs Ranch property. In the Wood River Sub-basin, NFWF worked with the Klamath Basin Rangeland Trust (KBRT) and Graham Mathews Inc, to test the monitoring protocol. On Sevenmile Creek, NFWF worked with Graham Mathews Inc to implement monitoring for a KBRT deal which was designed to enhance fishery habitat.

This fall we intend to review the results of the monitoring activity and incorporate the outcomes into the flow accounting protocol and ultimately the flow calculator for generating aquatic habitat and water quality credits.

B) Describe significant results, accomplishments, and lessons learned. Compare actual accomplishments to the project goals in your proposal:

As described above, the second six months of the CIG were focused on implementing monitoring activities to inform development of the flow accounting protocol and ultimately the flow calculator. We are now poised to develop version 1.0 of our flow-based temperature model. This model will allow users to calculate the temperature impact of increments of restored flow to specific stream reaches. Voluntary or regulatory credits could be issued based on this change.

NFWF continues to work closely with both the local communities and the regulatory agencies through the Klamath Basin Tracking and Accounting Program to develop voluntary credit tools that will enable willing landowners and others to address environmental factors such as increased water temperature and decreased spawning and rearing habitat.

C) Describe the work that you anticipate completing in the next six-month period:

We have begun to develop the flow-based temperature model and version 1.0 should be ready for testing this upcoming irrigation season. The flow-based temperature and aquatic habitat credits will take further shape as monitoring over the course of the next two years allows us to better quantify ecological results from flow transactions. We are currently analyzing 2011 data with results expected by end of January. NFWF will adapt monitoring protocol from lessons learned from the 2011 irrigation season monitoring, to be most affective during the 2012 monitoring season. NFWF will continue working with local partners to report and update stakeholders of CIG project status and achievement and with planning for the 2012 water transaction monitoring season.

NFWF will sponsor a Water Transactions Workshop for local CIG partners to be held in Yreka in late Feb (proposed dates Feb. 28 and 29th). This workshop will cover water deal basics such as water pricing, water right changes, irrigation practices and deal structure. We are working with basin stakeholders to finalize a Funding Mechanism Framework to be the Klamath Basin Water Transactions Program. This program would oversee the administration and management of awarding funds for flow transactions in the Klamath Basin.

D) Provide the following in accordance with the Environmental Quality Incentives Program (EQIP) and CIG grant agreement provisions:

1. A listing of EQIP-eligible producers involved in the project, identified by name and social security number or taxpayer identification number;

   No EQIP-eligible producers have been involved in the project to date. This is likely to change when water transactions are negotiated this summer to restore instream flow that will then be monitored and used to test version 1.0 of the temperature model.

2. The dollar amount of any direct or indirect payment made to each individual producer or entity for any structural, vegetative, or management practices. Both biannual and cumulative payment amounts must be submitted.

3. A self-certification statement indicating that each individual or entity receiving a direct or indirect payment for any structural, vegetative, or management practice through this grant is in compliance with the adjusted gross income (AGI) and highly-erodible lands and wetlands conservation (HEL/WC) compliance provisions of the Farm Bill.

Semi-Annual Progress Report
10/01/2011 – 03/31/2012

NRCS CONSERVATION INNOVATION GRANTS
69-3A75-10-141

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Project Title:	Establishing an Ecosystem Market Credit for Flow Restored in Northern California
Agreement Number:	69-3A75-10-141
Project Director:	Andrew Purkey Director, Western Water Programs National Fish and Wildlife Foundation
Contact Information:	National Fish and Wildlife Foundation, Western Partnership Office 421 SW 6th Avenue, Suite 950 Portland, OR 97204 Tel: (503) 417-8700 ext. 6009 E-mail: Andrew.Purkey@nfwf.org
Period Covered by Report:	10/01/2011 – 03/31/2012
Project End Date:	09/24/2012; Request to extend to 09/24/2013 included

A) Summarize the work performed during the project period covered by this report:

The National Fish and Wildlife Foundation (NFWF) continued to conduct outreach to both state and federal agencies to advance our *Ecosystem Market Credit* project. NFWF continued to meet with local partner organizations and their respective Boards of Directors.

Local partners in the Scott Basin implemented an autumn flow transaction (Oct-Dec) on the Scott River to improve passage for in-migrating Coho, Steelhead and Chinook. This opportunity developed by the Scott River Water Trust, allowed the NFWF CIG team and other partners to monitor and assess our Instream Flow Field Monitoring Protocol, to best assess impacts and changes in the river system resulting from this agreement.

NFWF and consultants were able to implement data processing and analysis from summer flow transactions, in addition to identifying potential summer 2012 flow transactions to be further tested under the CIG.

NFWF and local partners the Scott River Water Trust, the Nature Conservancy, Siskiyou County Resource Conservation District, Shasta Valley Resource Conservation District, Klamath Basin Rangeland Trust and others, gathered in Yreka, CA in late February, for a two-day "Flow Transactions Workshop".

This workshop provided the opportunity for local groups to learn more about flow restoration activities, including challenges and opportunities. Flow restoration experts came to the basin to assist with sharing their lessons learned in this field, and to listen and share recommendations to the group on strategies to overcome local obstacles and challenges.

NFWF and technical consultants, worked to update our "Instream Flow Field Monitoring Protocol" handbook, which has been developed under this grant (attached). This latest version incorporated feedback on the initial draft from multiple experts in the field of stream monitoring.

NFWF continued to develop strategies with many of the aforementioned local groups for our 2012 flow restoration activities, identifying ideal flow transactions to continue to test our monitoring approach.

NFWF and consultants began development of a Flow Temperature Calculator. This Calculator will model flow temperature changes due to changes in flow rates and volumes. We expect the first version of this model to be operational by June 2012, and tested on summer 2012 flow transactions. Then we will further calibrate and refine this Flow Temperature Calculator as a tool for potential crediting and transactional management.

Lastly, NFWF and consultants continue to work in the area of flow credit development, with hopes that the necessary state and federal agency support and other administrative hurdles may be overcome to initiate the future trading of flow credits based on these and other flow restoration actions.

B) Describe significant results, accomplishments, and lessons learned. Compare actual accomplishments to the project goals in your proposal:

Significant accomplishments were achieved at the water transactions workshop held in February. This event allowed all partners involved with the "on the ground" work to come to one central location within the basin to share and discuss ideas and strategies for future accomplishments in flow restoration in the Klamath Basin. It allowed NFWF to share with the partners our approaches and strategies for achieving success in this flow restoration field in addition to the CIG work. It also provided the opportunity for us hear concerns and desires of our local partners. This type of communication creates stronger foundations for long-view successes, necessary for building upon within the basin.

Other accomplishments were the development of version 1.0 of the Flow Temperature Calculator tool. This tool is currently 99% functional and will be fully operational by June, ready to test on summer flow transactions. This tool took quite a bit of time in development to ensure that it accurately captured to its best abilities the complexities of modeling flow and temperature through flow transactions.

Additionally, we have around ten flow transactions scheduled for this summer to test all of our CIG tools, which have been in development. This number is about twice as many as last year, and is indicative of the growing interest and support of this work at the local level.

C) Describe the work that you anticipate completing in the next six-month period:

The next six months will involve the completion of the development of our Flow Temperature Calculator to test on planned Flow Restoration Projects this summer. Currently there are an estimated 10 scheduled flow transactions throughout the Klamath Basin where we anticipate testing our monitoring protocol with the Flow Calculator, in addition to possible autumn flow transactions.

The monitoring of these flow transactions requires a high level of communication between our team, landowners, agencies and local groups. Spatial and temporal monitoring, stream access, equipment needs and personnel capacity are all being planned amongst these entities. Field and monitoring work will begin around the first of May and continue through the autumn.

NFWF hopes to make a significant push in the areas of outreach to Federal and State Agencies with regards to Flow Restoration work in the basin, and attempting to get their support of such work and actions. NFWF will also be seeking agency buy in and understanding of how a flow credit system could work.

While the outreach effort is underway, NFWF and partners will continue with the development of Flow Credits, as well as continue to plan our autumn flow transaction monitoring, data collection and analysis.

D) Provide the following in accordance with the Environmental Quality Incentives Program (EQIP) and CIG grant agreement provisions:

1. A listing of EQIP-eligible producers involved in the project, identified by name and social security number or taxpayer identification number;

   No EQIP-eligible producers have been involved in the project to date.

2. The dollar amount of any direct or indirect payment made to each individual producer or entity for any structural, vegetative, or management practices. Both biannual and cumulative payment amounts must be submitted.

   N/A

3. A self-certification statement indicating that each individual or entity receiving a direct or indirect payment for any structural, vegetative, or management practice through this grant is in compliance with the adjusted gross income (AGI) and highly-erodible lands and wetlands conservation (HEL/WC) compliance provisions of the Farm Bill.

   N/A

Semi-Annual Progress Report
04/01/2012 – 09/30/2012

NRCS CONSERVATION INNOVATION GRANTS
69-3A75-10-141

Grantee Name:	National Fish and Wildlife Foundation
Project Title:	Establishing an Ecosystem Market Credit for Flow Restored in Northern California
Agreement Number:	69-3A75-10-141
Project Director:	Andrew Purkey Director, Western Water Programs National Fish and Wildlife Foundation
Contact Information:	National Fish and Wildlife Foundation, Western Partnership Office 421 SW 6th Avenue, Suite 950 Portland, OR 97204 Tel: (503) 417-8700 ext. 6009 E-mail: Andrew.Purkey@nfwf.org
Period Covered by Report:	04/01/2011 – 09/30/2011
Project End Date:	09/24/2013

A) Summarize the work performed during the project period covered by this report:

During the second half of year two of this CIG project, the National Fish and Wildlife Foundation (NFWF) continued to support a variety of instream flow transactional activities in the Klamath Basin with local partner organizations to further the development of an *Ecosystem Market Credit* based upon restored flow.

In April, NFWF and project consultants put on an "Instream Flow Field Monitoring Protocol" training in the Shasta Sub-basin, on the Shasta River. This involved bringing staff and consultants from the Scott River Water Trust (SRWT), Shasta Valley Resource Conservation District (SVRCD), the Nature Conservancy (TNC) and the Freshwater Trust (TFT) together to update and train them on the NFWF-CIG developed monitoring protocol. These groups have been local on-the-ground partners for NFWF in the greater Klamath Basin, whom NFWF has been assisting with instream flow transactional work.

During the summer, NFWF continued its support and partnership with the Scott River Water Trust (SRWT). NFWF directly supported flow restoration monitoring activity and research of a flow restoration project on French Creek, an important tributary to the Scott River. The French Creek project restored instream flow during the mid to late summer irrigation period (July-Sept), enhancing over-summering instream conditions for juvenile and young fish species, including biologically important species such as coho, steelhead and Chinook. This project allowed further testing of the NFWF designed "Instream flow Field Monitoring Protocol" developed under this CIG. Supporting the work of local partners such as SRWT, allows for "real world" testing of these monitoring protocol recommendations. Like many places throughout the western U.S., the Klamath Basin's river conditions for summer 2012 were characterized as "drought-like", with a record number of consecutive dry days (days without precipitation) recorded. Critical low flow stream conditions create resource condition variability, which presents new implementation challenges of monitoring the protocol, allowing for opportunities to learn new techniques, re-test the old and adapt from lessons learned.

This approach was also utilized in the Shasta Sub-basin of the Klamath. Here NFWF partnered with the Nature Conservancy (TNC) to assist them in testing and quantifying the instream flow benefit of several water rights appurtenant to the Big Springs Ranch property, currently owned and managed by TNC. NFWF and project consultants conducted two flow experiments here on Little Springs Creek and Big Springs Creek. In addition to learning the potential environmental benefit of the TNC irrigation water rights, these experiments were designed to continue the refinement of the monitoring protocol development, as well as for testing and calibration of the NFWF Flow-Temperature Calculator (FTC).

The FTC, developed by NFWF and their consultants, assesses reach-scale instream flow temperature change due to change instream flow discharge. This FTC tool which was being developed over the winter and spring of 2012, inputs a variety of data, such as but not limited to the stream channel geometry, discharge, gradient, meteorological conditions, travel time, solar influence, the flow inputs and outputs. By analyzing these data inputs the FTC allows for a solid estimate of how a stream's temperature would respond to changes in flow (+/-). NFWF see's the FTC as a strong planning tool, when assessing and/or prioritizing flow habitat restoration projects, something which is badly needed throughout the western U.S., where instream flow is often cited as the "limiting factor" for stream ecological function. This past summer's monitoring work has really brought the development of FTC along, and NFWF looks forward to further testing of this tool at more robust levels over the fiscal year 2013, anticipating its release in the spring of 2013.

NFWF also supported autumn stream monitoring work on the Shasta River's in-migration of steelhead, coho and record number of Chinook. This year has presented some unique conditions in the Shasta, with the highest returning Chinook numbers in more than three decades, coupled with low flows, emphasizing the importance of this work. NFWF supported TNC staff and SCRCD staff in assessing "passage" flows in the Shasta River. A coalition of groups in the Shasta formed and broadcast a voluntary call too irrigators in the Shasta River basin to cease irrigation in the latter half of September, with hopes of enhancing passage conditions on the river. Areas assessed were temperature, dissolved oxygen (DO) and passage availability (i.e. physical habitat). Due to this on-going work, which will continue into November, achievements to date are inconclusive, however, numerous lessons and successes are anticipated.

Additionally, NFWF and the SRWT are conducting similar autumn flow work on the Scott River. Like the Shasta, it too is experiencing a record return of Chinook, in addition to more normal fish returns of coho and steelhead, coupled with lower than average stream flow. The SRWT and NFWF are assessing critical riffle habitat changes focused on an autumn stream lease conducted by the SRWT. This deal has kept the upper reaches of the Scott River (above the Town of Etna) flowing with a minimal flow going into autumn with hopes of a quicker river system response once autumn rains do arrive to the region, allowing for a quicker migration once conditions improve and offer passage. These "passage" flow deals are vital for the fishery, as tens of thousands of fish stack up in the main Klamath River at the mouths of the Shasta and Scott Rivers, waiting on flow conditions to improve so that they may return to their historical spawning grounds. Overcrowding of fish in very limited available habitat areas is known to exacerbate certain conditions and increase the spread of disease, the ruining of redds (e.g. fertilized salmonid fish eggs) and the dissolved oxygen conditions, to name a few. Like the work in the Shasta basin, this autumn flow transactional work on the Scott will likely continue into November or December, however, NFWF looks forward to sharing results and lessons learned later this year.

Lastly, NFWF continues to reach out to all federal and state agencies involved with river and aquatic habitat restoration and/or administration work. NFWF also continues to meet with local partner groups and their respective Board of Directors to further learn how these joint partnerships can continue to aid everyone's mission and work direction.

B) Describe significant results, accomplishments, and lessons learned. Compare actual accomplishments to the project goals in your proposal:

NFWF has achieved numerous accomplishments and results over this last grant period. The "Instream Flow Field Monitoring Protocol" (IFFMP) continues to be standardized with partners on the ground in the Klamath, through training and implementation. Additionally, NFWF has been sharing highlights of this protocol manual work with other flow restoration organizations throughout the western U.S. at conferences and meeting and are receiving good feedback. A standardization of instream flow monitoring work would be hugely beneficial for all in this field, as currently organizations practice a variety of levels of instream flow monitoring (i.e. weak to strong), often with inadequacies for assessing real stream benefit. As NFWF continues to receive feedback on the IFFMP, building upon these requests and suggestions have created a collaborative product with necessary "buy-in" from project partners.

Also, initial results and developmental progress of the Flow-Temperature Calculator (FTC) are going as planned. Predicted stream temperature changes by the FTC have been verified with on-the-ground data. The FTC's functionality and user-friendly operations have exceeded all expectations. NFWF looks forward to this tools further development and subsequent sharing with partner agencies and organizations.

C) Describe the work that you anticipate completing in the next six-month period:

Currently, NFWF has plans to further test and calibrate the FTC on numerous flow transactions around the Klamath and western U.S. NFWF will then finalize the development of the FTC and begin to finish all associated operational manuals for the model, with preparation for launching to the public and stakeholders.

NFWF will assess all 2012 flow transactional data, monitoring protocol results, and feedback from project partner's regarding the IFFMP. NFWF will then update and finalize the IFFMP and prepare it for dissemination, in addition to the Transactional Verification Protocol, which was initially developed in year one of this grant. The Transactional Verification Protocol is important for the Ecosystem Credit framework, which could support future flow transactional work.

NFWF will continue to engage, work and support all local partners to the best of abilities. NFWF will attempt to understand the future goals and needs of these partnerships to best determine how might NFWF continue to support these groups noble efforts in the flow restoration realm.

NFWF will be continuing ongoing discussions with State and Federal agencies regarding Ecosystem

Market Credits, and the implementation of a flow based credit for “temperature” or “aquatic habitat”.

NFWF will be continuing the discussions with Oregon DEQ with the hopes of a possible Ecosystem Credit trade for a flow restoration project in the upper Klamath Basin. The chances of such a transaction occurring in the State of California are extremely low as regulatory agencies have not embraced Ecosystem Credit Trading like their counterparts in the State of Oregon.

D) Provide the following in accordance with the Environmental Quality Incentives Program (EQIP) and CIG grant agreement provisions:

1. A listing of EQIP-eligible producers involved in the project, identified by name and social security number or taxpayer identification number; No EQIP-eligible producers have been involved in the project to date.

2. The dollar amount of any direct or indirect payment made to each individual producer or entity for any structural, vegetative, or management practices. Both biannual and cumulative payment amounts must be submitted.

   N/A

3. A self-certification statement indicating that each individual or entity receiving a direct or indirect payment for any structural, vegetative, or management practice through this grant is in compliance with the adjusted gross income (AGI) and highly-erodible lands and wetlands conservation (HEL/WC) compliance provisions of the Farm Bill.

   N/A

Semi-Annual Progress Report
10/01/2012 – 03/31/2013

NRCS CONSERVATION INNOVATION GRANTS
69-3A75-10-141

Grantee Name:	National Fish and Wildlife Foundation
Project Title:	Establishing an Ecosystem Market Credit for Flow Restored in Northern California
Agreement Number:	69-3A75-10-141
Project Director:	Andrew Purkey Director, Western Water Programs National Fish and Wildlife Foundation
Contact Information:	National Fish and Wildlife Foundation, Western Partnership Office 421 SW 6th Avenue, Suite 950 Portland, OR 97204 Tel: (503) 417-8700 ext. 6009 E-mail: Andrew.Purkey@nfwf.org
Period Covered by Report:	10/01/2012 – 03/31/2013
Project End Date:	09/24/2013

A) Summarize the work performed during the project period covered by this report:

Over the past six months NFWF has been at work on multiple fronts as we entered the last year of our Conservation Innovation Grant (CIG) award. These include a) working with our local partners in the Klamath Basin on wrapping up the autumn streamflow monitoring b) monitoring data processing and analysis c) working within our project team on our work implementation timeline, reporting and final products/deliverables; and d) the final phase of development of the Water Transaction Temperature Tool (W3T).

The autumn period in the Klamath Basin experienced below average precipitation and above normal temperatures, with the largest run of returning Chinook salmon since the 1970's, requiring the need of our local project partners to lease streamflow/water rights to enhance the in-migration passage conditions, which were experiencing lingering summer low flow - high stream temperature conditions. Local partners with NFWF guidance and instruction, implemented our CIG developed "Instream Flow Monitoring Protocol" techniques for quantifying the improved passage and pool volume conditions on the Scott and Shasta Rivers due to their water right leases.

Additionally, NFWF's project team met numerous times throughout this period, in Davis CA (Oct and Jan), Portland OR (Dec, Jan, and Feb) and in Yreka CA (Mar), to work internally as well as meet with project partners on work implementation. The meeting in March in Yreka coincided with the Klamath Basin Monitoring Program (KBMP) spring meeting where the NFWF Team presented the W3T application to agencies, tribes and NGO's working throughout the basin. It proved to be a great opportunity to share with all the functionality and practicality of the W3T application for instream flow restoration work.

The project team also has been finalizing the 2011 and 2012 instream flow project monitoring results for aquatic habitat, where our local partners applied the NFWF developed "Instream Flow Monitoring Protocol" techniques. A document of these results was produced which summarizes a) compliance monitoring b) aquatic habitat benefits and c) water temperature benefits, due to our partners flow transactions.

Lastly, the development of the W3T application has seen a significant push of time and effort, with the production of a) an updated/final version of the W3T including the users manual, technical documents, model reviews and W3T project testing and application summaries.

Currently, the NFWF Team is working with project partners on finalizing and refinement of the W3T application for public/partner use, as well as integrating edits to final versions of our flow transactional monitoring documents and environmental flow credit framework recommendations.

B) Describe significant results, accomplishments, and lessons learned. Compare actual accomplishments to the project goals in your proposal:

Over the last six months, several results, accomplishments and lessons learned were experienced. First, with the wrapping up our second season of flow transactional monitoring, which allowed our local project partners to implement the NFWF Instream Flow Monitoring Protocol techniques for a second year, enabling NFWF to acquire some "lessons learned" as well as some accomplishments. NFWF was able to further identify 1) areas where "streamlining" monitoring techniques made sense without compromising data quality (e.g. time equals cost) 2) Which of our recommended hydraulic parameters/metrics were most effective/responsive for quantifying change due to certain types of flow transactions – typically with specific biological objectives (e.g. over-summering/rearing, or passage); and 3) Areas of our Instream Flow Monitoring Protocol which needed further development of instruction, or a more robust monitoring approach implemented to effectively capture habitat changes with stream discharge changes.

Second, NFWF and our project partners, through the development and testing of the W3T application are seeing how useful and needed a flow-temperature modeling tool is for entities (i.e. agencies, tribes and NGOs) working in streamflow restoration and irrigation water conservation. To date, the W3T tool has been openly received by all, and NFWF is more aware now than ever of the need of such a tool, whether an entity is working in irrigation efficiency improvements, traditional flow transactions, water quality projects or even riparian shading projects. The W3T application has proven to be versatile, transparent and user friendly, as well as robust and sophisticated enough to adequately capture "potential" temperature changes due to streamflow discharge changes for projects. In our original CIG proposal, NFWF fully understood the need for a W3T type of application to enable the calibration of streamflow discharge changes to temperature change at our organization and few others however, NFWF did not fully understand the need of project partners and watershed stakeholders for such a tool. NFWF is extremely happy to report that the response and eagerness of project partners for the W3T development has been great and we look forward to working them on obtaining and integrating this tool into their flow restoration activities.

Lastly, over the last six months NFWF has continued to make a concerted effort to reach out to regulatory agencies on our CIG progress and the tools being developed through this work. We always receive great interest, however, also realize that there is no such thing as too much communication, and the more we're able to reach out, communicate and attempt to work with these folks, the better we all understand how best to work with one another down the road.

C) Describe the work that you anticipate completing in the next six-month period:

For the remaining six months of the CIG, the NFWF Team will continue to test the W3T application on numerous flow transactions and river systems, in addition to finalizing all accompanying documentation for this tool.

The NFWF Team will also be finalizing a) the "Instream Flow Monitoring Protocol" documents and b) the framework for an Ecosystem Credits based on streamflow enhancement projects.

NFWF will also be continuing work with regulatory agencies regarding the W3T application and its ability to assist with developing a "flow credit" based on Temperature or water quality improvements due to water conservation work. Additionally, NFWF is working with several respected water quality modelers from the private sector, Oregon DEQ and the U.S. Forest Service for strong independent reviews and feedback of the W3T applications abilities and limitations.

D) Provide the following in accordance with the Environmental Quality Incentives Program (EQIP) and CIG grant agreement provisions:

1. A listing of EQIP-eligible producers involved in the project, identified by name and social security number or taxpayer identification number;

   No EQIP-eligible producers have been involved in the project to date.

2. The dollar amount of any direct or indirect payment made to each individual producer or entity for any structural, vegetative, or management practices. Both biannual and cumulative payment amounts must be submitted.

   N/A

3. A self-certification statement indicating that each individual or entity receiving a direct or indirect payment for any structural, vegetative, or management practice through this grant is in compliance with the adjusted gross income (AGI) and highly-erodible lands and wetlands conservation (HEL/WC) compliance provisions of the Farm Bill.

   N/A

Appendix X

Fact Sheet

Conservation Innovation Grant Fact Sheet

The National Fish and Wildlife Foundation's (NFWF) goal under this Conservation Innovation Grant (CIG) awarded by the Natural Resources Conservation Service (NRCS), through agreement 69-3A75-10-141, was to develop innovative instream flow monitoring methodologies, tools and model applications necessary to support emerging credit trading programs, with focus on flow and water quality/temperature. This goal was achieved as follows:

- Developed, tested and implemented a standardized Water Transaction Monitoring Protocol, for dissemination to groups, agencies and stakeholders working in instream flow restoration.
- Made the methods and monitoring approaches scalable and transferable.
- Field-tested and developed both monitoring and model approaches while assisting actual on the ground flow restoration activities in the Klamath Basin.
- Developed the Water Temperature Transaction Tool (W3T), which is a spreadsheet based program for modeling stream temperature. W3T is based on a steady flow approach and energy transfer, incorporating basic stream parameters, consistent with Heat Source (v7) and includes topographic and shade simulations.
- W3T allows users to interactively specify reach length, inflow, tributary flow, and diversion amount, customizing and designing unique scenarios for understanding impact of varying stream conditions on temperature.
- Developed the Instream Flow Crediting Protocol, which lays out elements and structure for calculating and developing water temperature credits generated from restored flow. The protocol integrates a) natural hydrograph variability, b) water right reliability, c) variability of hydrologic and water right data quality, d) project timing, and e) credit calculation utilizing W3T.
- Initiated discussions with Oregon Department of Environmental Quality regarding the refinement and integration of these aforementioned tools (i.e. Water Transactions Monitoring Protocol, Instream Flow Crediting Protocol and W3T) into their water quality credit trading program.
- Demonstrated that the W3T model and monitoring approaches are widely versatile to support ecosystem credit markets, standard flow restoration activities or basic project planning or scoping.
- Developed tools to provide a level of project outcome verification and transparency, which has been lacking in the field of flow restoration through water right transfers.

Although we recognize these tools have not yet been integrated fully into the "toolbox" of most flow practitioners around the West, NFWF is very pleased to see key strategic partners adopting and inquiring of their status. We look forward to further collaboration, training and sharing of these tools to better assist those on the ground with a) sharing project success b) assisting the project planning process and c) further development into environmental markets.

Appendix XI

Agreement Financials

FEDERAL FINANCIAL REPORT

(Follow form Instructions)

1. Federal Agency and Organizational Element to Which Report is Submitted NRCS	2. Federal Grant or Other Identifying Number Assigned by Federal Agency (To report multiple grants, use FFR Attachment) 69-3A75-10-141	Page 1 of 1 pages

3. Recipient Organization (Name and complete address including Zip code)

National Fish and Wildlife Foundation 1133 15th Street, NW: Suite 1100 Washington, DC 20005

4a. DUNS Number 17-517-2527	4b. EIN 52-1384139	5. Recipient Account Number or Identifying Number (To report multiple grants, use FFR Attachment) FR.2415	6. Report Type ☐ Quarterly ☐ Semi-Annual ☐ Annual ☑ Final	7. Basis of Accounting ☑ Cash ☐ Accrual

8. Project/Grant Period (Month, Day, Year) From: 9/24/2010	To: 9/30/2013	9. Reporting Period End Date (Month, Day, Year) 9/30/2013

10. Transactions	Cumulative
(Use lines a-c for single or combined multiple grant reporting)	
Federal Cash (To report multiple grants separately, also use FFR Attachment):	
a. Cash Receipts	$347,982.35
b. Cash Disbursements	$347,982.35
c. Cash on Hand (line a minus b)	$0.00
(Use lines d-o for single grant reporting)	
Federal Expenditures and Unobligated Balance:	
d. Total Federal funds authorized	$384,000.00
e. Federal share of expenditures	$347,982.35
f. Federal share of unliquidated obligations	$0.00
g. Total Federal share (sum of lines e and f)	$347,982.35
h. Unobligated balance of Federal funds (line d minus g)	$36,017.65
Recipient Share:	
i. Total recipient share required	$412,040.42
j. Recipient share of expenditures	$412,040.42
k. Remaining recipient share to be provided (line i minus j)	$0.00
Program Income:	
l. Total Federal share of program income earned	
m. Program income expended in accordance with the deduction alternative	
n. Program income expended in accordance with the addition alternative	
o. Unexpended program income (line l minus line m or line n)	

11. Indirect Expense	a. Type	b. Rate	c. Period From	Period To	d. Base	e. Amount Charged	f. Federal Share
[redacted]				g. Totals:	0	0	0

12. Remarks: Attach any explanations deemed necessary or information required by Federal sponsoring agency in compliance with governing legislation:

See attached for Recipient Share required remarks

13. Certification: By signing this report, I certify to the best of my knowledge and belief that the report is true, complete, and accurate, and the expenditures, disbursements and cash receipts are for the purposes and intent set forth in the award documents. I am aware that any false, fictitious, or fraudulent information may subject me to criminal, civil, or administrative penalties. (U.S. Code, Title 18, Section 1001)

a. Typed or Printed Name and Title of Authorized Certifying Official Brenda Kaechele Controller	c. Telephone (Area code, number, and extension) 202-857-0166
	d. Email Address Brenda.Kaechele@nfwf.org
b. Signature of Authorized Certifying Official Brenda Kaechele	e. Date Report Submitted (Month, Day, Year) 12/20/2013
	14. Agency use only:

Standard Form 425 - Revised 10/11/2011
OMB Approval Number: 0348-0061
Expiration Date: 2/28/2015

69-3A75-10-141

Remarks on Recipient Share total:

Total NRCS funds proposed were $384,000. Total matching funds proposed were $426,000. Total project proposed (NRCS and match) was $810,000.

Total actual NRSC funds expended were $347,982.35. Total actual matching funds expended were $412,040.42. Total project funds (NRCS and Match) expended were $760,022.77. Match was proposed at 52.6% of total project. Match expended was 54.2% of the total project so match was a proportionately higher percent of the total project expended and thus match obligations have been fulfilled.

NFWF Contact Information

Questions or comments regarding this report should be directed to the contacts listed below.

Contacts

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The National Fish and Wildlife Foundation is a 501(c)(3) non-profit that preserves and restores our nations native wildlife, species and habitats. Created by Congress in 1984, NFWF directs public conservation dollars to the most pressing conservation needs and matches those investments with private funds. **www.nfwf.org**