IX. FOCUSED STUDY: FISH USE OF COLD-WATER REFUGES

Introduction

This focused study will attempt to quantify the contribution of the release of cold spring water to Battle Creek to increases in production of adult and juvenile salmonids. The release of cold spring water to Battle Creek is a prominent component of the Battle Creek Salmon and Steelhead Restoration Project. However, key uncertainties exist regarding the biological benefits of this project element. Also, the potential transferability of this approach to other watershed restoration projects is not well documented.

This study will have physical and biological components. The physical extent and distribution of cold-water refuges[1] will be compared between pre-project and post-project conditions to quantify the relative contribution of this Restoration Project element. Pre-project conditions include some natural spring releases and groundwater interaction with a stream network characterized by relatively low instream flows. These natural spring releases and groundwater interaction are hypothesized to behave as thermal point sources (Figure 1). The post-project conditions will have the same natural inflows of cold-water, plus the Restoration Project cold spring water releases, all within the context of relatively higher instream flows. The first physical component of the study will map, quantify, and compare changes in extent and distribution between these two conditions using aerial thermal imaging surveys. The physical mapping of cold-water refuges can be completed at the same time as aerial surveys of riparian habitat (see Riparian Vegetation Focused Study, Section VII) for little additional cost. The second physical component of this study will include the deployment of a network of automated temperature recording devices (in addition to those deployed for Habitat Objective 2) to record micro-scale water temperature affects within the three specific areas affected by Restoration Project cold-water releases. These thermisters will also facilitate the calibration of thermal imaging surveys.

The biological component of this study will examine the biological importance of cold-water refuges identified during the post-project physical mapping component. The utilization of cold-water refuges by juvenile and adult salmonids will be characterized and compared to habitat utilization of areas that are not influenced by cold-water refuges. The biological component of this study would necessarily occur at some future time when populations of juvenile and adult anadromous salmonids are at sufficiently high levels at which statistically meaningful responses could be measured (see similar concept in the Juvenile Habitat Use Study, Section VIII). The design of this biological study will begin with a review of the Contemporary cold-water refuge literature and a review of the pre- and post-project physical mapping. It may be prudent to link the biological component of this study with Juvenile Habitat Use Study (Section VIII) if feasible.

[1] Cold-water refuges, in general, are areas colder than a specified temperature (e.g. some thermal criteria suitable for salmonid survival and growth) within stream reaches characterized by ambient water temperatures greater than a specified temperature. The specification of these upper and lower temperatures will be determined from examination of Contemporary literature and will be measured empirically in the physical mapping component of this study.

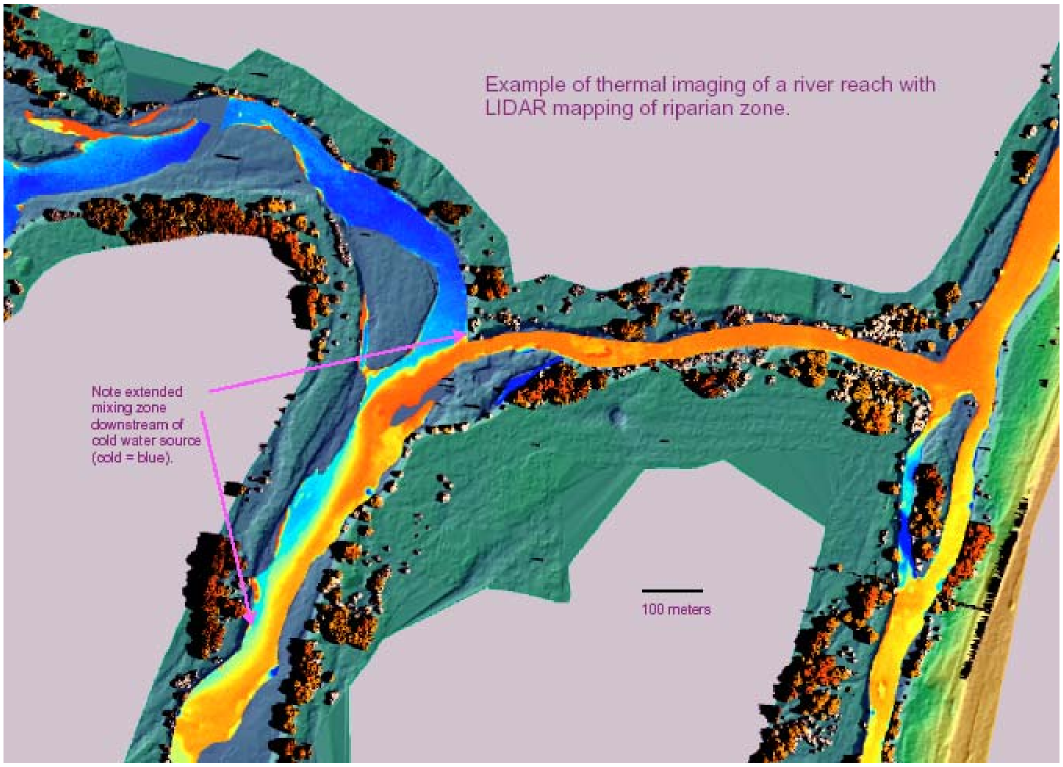

Figure 1. Example of thermal point sources.

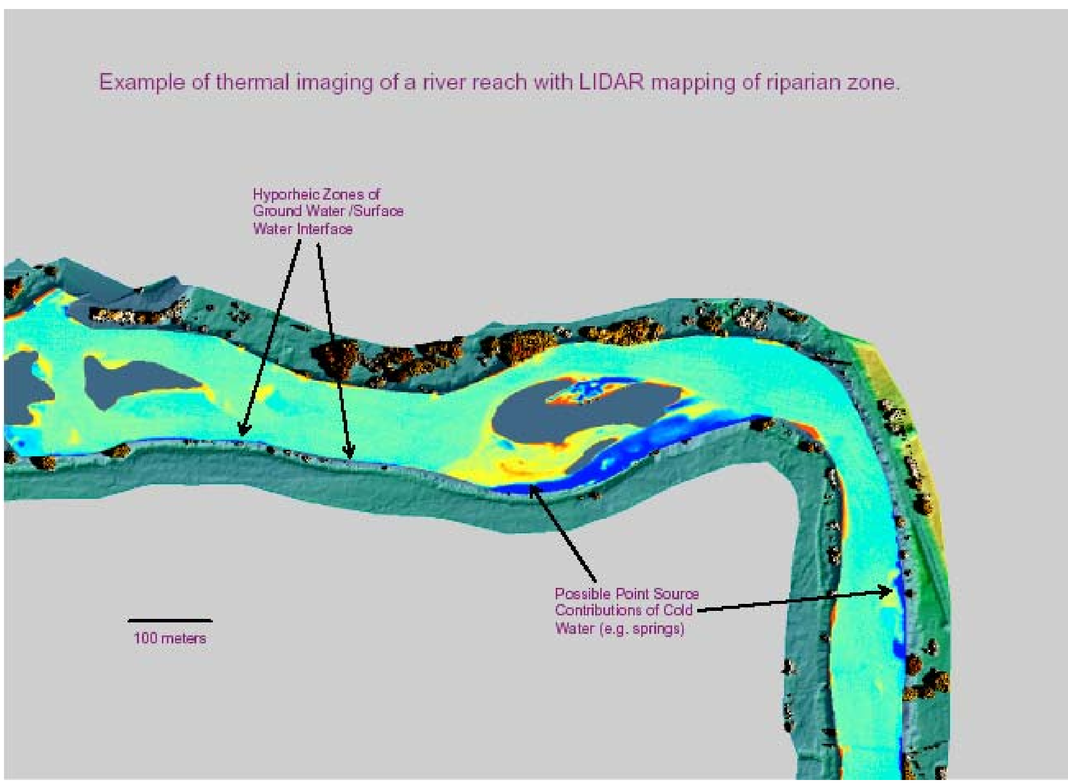

Figure 2. Example of thermal mixing zones.

Battle Creek Setting

A remarkable feature of Battle Creek is high volume of ground water that is contributed to the stream network during summer low-flow conditions (Ward and Kier 1999a). On average, the base flow of Battle Creek is approximately 250 cfs, the bulk of which enters the Battle Creek stream network directly from springs, seeps, and other hyporheic connections. Some seeps and springs arise in the uplands and flow to Battle Creek in tributary streams (e.g. Bluff Springs via Soap Creek flows at about 10 to 12 cfs, and Darrah Springs via Baldwin Creek will flow at 5 cfs after the Restoration Project). Other springs, such as Eagle Canyon Springs (flows at about 10 cfs) arise in riparian areas and immediately feed Battle Creek. Countless other, less-prominent areas of hyporheic connection, where cold-water seeps directly into the stream from the bed and banks, remain unnamed but are distributed widely within the North and South Forks of Battle Creek.

Under pre-Restoration Project conditions, many of the larger springs within the watershed, are captured in the hydroelectric project conveyance systems. An element of the Restoration Project is to restore the connectivity of some of these springs (Eagle Canyon Springs, Bluff Springs via Soap Creek, and Darrah Springs via Baldwin Creek) with Battle Creek.

An important aspect of the spring water is that is it relatively cold. For example, Eagle Canyon Springs are approximately 52 °F. In much of California, the temperature of surface waters often is near or in-exceedence-of the thermal criteria for anadromous salmonids, making water temperature a limiting factor in many streams. In Battle Creek, the abundant cold spring water cools most stream reaches to temperatures suitable for all or most life history stages of the native salmonids; this is perhaps the single most important characteristic of Battle Creek for fisheries restoration.

Conceptual Model

Battle Creek's cold spring water input can be thought of as playing two distinct roles in cooling the stream. The first concept is *reach-scale cooling* where the integrated contribution of many springs, or particularly voluminous springs, provides a general cooling affect on a macro-scale portion of the stream (i.e. stream reaches measured in kilometers). This concept of reach-scale cooling is what was used in Ward and Kier (1999a) for predicting which fish species and life stages would use the reaches of Battle Creek and in Tu's (2001) development of the predictive SNTEMP water temperature model. Habitat Objective 2 will employ this concept when monitoring the longitudinal water temperature regime of the stream to determine the attainability of water temperature goals. At this scale, cold water input is generally conceived as mixing completely and instantaneously with the ambient instream flow.

The second concept is that of *cold-water refuges*[1] which recognizes the contributions of individual cold-water sources at the meso- or micro-scales. At these smaller scales (meters to 10s of meters; see Figures 1 for examples of meso-scale point sources), it is apparent that spring water inputs do not mix completely or instantaneously with ambient stream flow, and in fact, often form distinct areas of cold water distinguishable from the relatively warmer stream environment (see Figure 2 for illustration of extended mixing zones). Juvenile and adult salmon and steelhead have been shown to recognize and use these "cold-water refuges." In critically warm stream reaches, cold-water refuges have been shown to be essential for the survival and production of some salmonids.

It is possible that extensive use of cold-water refuges in Battle Creek may alter the way we perceive reach classification systems and other models we used to inform the primary conceptual models for this AMP (see Conceptual Model 2). On the other hand, we may find that the relative contribution of cold-water spring releases provided by the Restoration Project is less important than we believed given the relative volume of these inputs compared to increased instream flows and the presumed abundance of other ground water connections.

Uncertainties

The AMP identifies three key uncertainties pertaining to possible changes in cold spring water releases to be implemented as part of the Restoration Project:

- **Will post project release of cold spring water result in predicted water temperatures targets in warm season?**
- **How are cooling affects of spring releases spatially distributed within stream network?**
- **Are there microhabitat benefits (thermal refuges) that could result from spring releases that were overlooked by reach-scale SNTEMP model?**
- **Uncertainties are inherent in SNTEMP model which averages temperatures by reach and over monthly time periods.**
- **Uncertainties are inherent Tu's (2001) application of the SNTEMP model in Battle Creek (e.g. is Redding climate data applicable to Battle Creek? What are the effects of canals and shading on thermal gain? Will potential temperature problems be restricted to June through September?)**
- **How will spawning success and egg survival be affected by water temperature regime in warm season?**
- **How will juvenile production (growth, survival, distribution, outmigration) be affected by water temperature regime in warm season?**

These uncertainties stem largely from a lack of detailed water temperature information and are exacerbated by simplistic assumptions within the SNTEMP water temperature model. SNTEMP assumes instantaneous mixing at thermal point sources when the actual contribution from thermal point sources takes place gradually over some longitudinal stream segment (Figure 1). These uncertainties also stem from lack of detailed information of how salmonids of various species at temperature-sensitive life stages will use habitats in Battle Creek.

Additional uncertainties regarding the distribution and habitat use of salmonid species and life stages can be addressed, in part, by comparing results from this study with the results of other monitoring elements like radiotelemetry, spawning and rearing distribution surveys, juvenile habitat use, and fish community structure. Fine-scale topographic information collected in this study may also help in the identification of potential natural fish barriers and assist in the implementation of the sediment monitoring study.

Possible Adaptive Responses

If cold-water spring releases are shown to have greater benefit than anticipated, then the AMPT may want to explore additional opportunities for acquiring and releasing more ground water to the stream. If cold-water spring releases are shown to have relatively less benefit than anticipated, then other future restoration projects would benefit from this knowledge in their ability to assess how to include spring releases into future project designs.

The California Wildlife Conservation Board and CALFED currently explores opportunities to obtain, from willing sellers, conservation water rights from cold water sources. These conservation water rights would allow the natural flow of cold water from springs or seeps into the Battle Creek stream channel.

Study Approaches

Goal 1. Understand the relative difference between pre-project and post-project contributions of cold spring water releases to reach-scale and meso-scale water temperature regimes.

Objective 1a. Quantify the amount of cold-water habitat and relative contribution of hyporheic connections in the 42 miles of mainstem, and North and South Forks portions of the Restoration Project area under pre- and post-project conditions through the use of aerial surveys using **t**hermal **i**nfra**r**ed (TIR) imaging and **li**ght **d**etection **a**nd **r**anging imagery (LIDAR), and GIS-based analysis. The purpose of this work would be to:

- quantify the wetted surface area at or below certain temperature criteria,
- map the distribution of cold-water habitat[2], and
- model the relative cooling effects of topographic and vegetative shading to separate those effects from hyporheic cooling effects.

Schedule for Objective 1a.

- Collect aerial imaging data and perform analysis during pre-project conditions in summer of 2005.
- Collect aerial imaging data and perform analysis during post-project conditions in year 10 after implementation of Restoration Project – as dictated by riparian vegetation study and juvenile fish abundance. Possibly link this to Juvenile Habitat Use study.

Deliverables for Objective 1a.

- All deliverables for objective 1a will be produced twice: once for pre-project and once for post-project conditions

[2] The AMTT will define "cold-water habitat" in absolute temperature units after we develop the vector contoured maps of isotherms because we may wish to use different temperature criteria for different life stages.

- Aerial imaging data collection on two occasions.
- Ortho-rectified color aerial photos (20 cm pixels) for whole study area – for use in vegetative mapping (see Riparian Vegetation Focused Study, Section VII), for use in modeling shade affects, and useful for checking georeferencing of all data layers.
- TIR data collection from whole study area.
- GIS map of TIR data for whole study area.
- Digital Elevation Model (DEM) and Digital Topographic Model with iso-vector contour map for whole study area – necessary to map water surfaces, also useful for other habitat work (e.g. channel morphology, identification of flood plains).
- Raw data in x, y, z ASCII format.
- Data summary report describing study objectives, technology and methods, work completed, results, deliverables, conclusions, and recommendations.

Objective 1b. Record micro-scale water temperature affects within the three specific areas affected by Restoration Project cold water releases using automated thermisters. The purpose of this work would be to:

- facilitate the calibration of thermal imaging surveys and to aid in design and implementation of biological study components.

Schedule 1b.

- Collect micro-scale water temperature data and perform analysis during pre-project conditions in summer of 2005.
- Collect micro-scale water temperature data and perform analysis during post-project conditions in summer of year 10 after Restoration Project implementation – as dictated by aerial imaging data collection , riparian vegetation study, and juvenile fish abundance. Possibly link this to Juvenile Habitat Use study.

Deliverables for Objective 1b.

- Data will be collected and summarized from up to 10 discrete locations at 3 Restoration Project cold water release sites (Eagle Canyon Springs, Bluff Springs and the mouth of Soap Creek, and Darrah Springs and the mouth of Baldwin Creek) using a network of 30 thermisters.
- These locations will be georeferenced by surveying them to a benchmark that can be identified in the aerial surveying so that thermister locations can be directly mapped on TIR images for TIR data calibration.

Goal 2. Understand the biological importance of cold-water refuges identified during the post-project physical mapping component.

Objective 2. The utilization of cold-water refuges by juvenile and adult salmonids will be characterized and compared to habitat utilization of areas that are not influenced by cold-water refuges. The purpose of this work would be to:

- refine estimates of fish habitat utilization and stream classification systems used in Conceptual Model 2.
- develop an understanding of the importance of restoring cold-water refuges in anadromous salmonid habitats of California.

Schedule 2. This work will best be performed once restored fish populations begin to utilize habitat throughout the Restoration Project area and once populations are at levels where density-dependent mechanisms would presumably result in a stronger fish habitat utilization signal. This work should be done in the same year as the post-project cold-water refuge mapping and calibration. We presume that sufficient levels of fish will be present by year 10 after Restoration Project implementation.

Deliverable for Objective 2. Because the biological importance of cold-water refuges is relatively poorly documented (at present) but is the subject of numerous on-going investigations, and because this study may not be conducted for at least 13 years from now, the design and pricing of this biological study will be deferred until year 8 after the Restoration Project is implemented. The design of this biological study will begin with a review of the Contemporary cold-water refuge literature and a review of the pre- and post-project physical mapping. It may be prudent to link the biological component of this study with Juvenile Habitat Use Study (Section VIII) if feasible.

Reporting and Analysis. Results from the aerial imaging and micro-scale thermister deployment will be described in a two reports (draft report for pre-project and final report for post-project). The final post-project report would include description of the biological studies. These results will be described in the context of Battle Creek adaptive management and will recommend changes to uncertainties, conceptual models, adaptive management objectives including possible adaptive responses, and future monitoring. The results will also be generalized to possible future restoration projects that might consider restoring cold spring water releases.

Cost Estimates

Objective/Year	2005	Year 10 after Restoration Project implementation (in 2005 dollars)
1a. Aerial Imagery and GIS Analysis.	$84,000*	$84,000*
1b. Micro-scale thermister deployment and analysis.	$4,000	$4,000
2. Fish utilization of cold-water refuges.	$0.00	To be determined
Reporting and Analysis	$15,000	To be determined
Total	$103,000	To be determined

Budget Notes:

- Aerial imaging costs were developed through discussions with Richard Duncan, GeoEngineers, Inc. Redmond, WA, who has conducted similar aerial imaging surveys, and were based on actual 2003 expenses for a similar study, adjusted for inflation to 2005. 42 miles x $2,000 per mile = $84,000.
- * Approximately $84,000 could be saved from pre-project and year 10 costs if this study and riparian vegetation study were done simultaneously. Both these studies use

much of the same data and methods and preliminary analysis. In 2005, when this study and the riparian vegetation overlap, both studies could be done for $69,610 (non aerial riparian study) + $19,000 (non-aerial cold-water study) + $84,000 (aerial imaging) = $172,610 if done simultaneously. If done separately, they would cost $153,610 + $103,000 = $256,610.