



## **Shasta River Instream Flow Methods and Implementation Framework**

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**In theory, there is no difference between theory and practice.  
In practice, there is.**

–Yogi Berra, Eminent Instream Flow Practitioner and Theorist

## **1 INTRODUCTION**

The Shasta River, tributary to the Klamath River, CA (Figure 1), supports populations of fall run Chinook salmon (*Oncorhynchus tshawytscha*), coho salmon (*O. kisutch*), and steelhead (*O. mykiss*). Quantifying instream flow needs (IFN) has been identified as a high priority action for the recovery and protection of these salmonid populations in the Shasta River mainstem and its principal tributaries (CDFG 2004, 2008). The *Shasta River Instream Flow Methods Project* (Project) was a collaborative effort of the CA Department of Fish and Game, California Trout (CalTrout), McBain and Trush, Inc. (M&T), and several UC Davis graduate researchers. The purpose of the project was to evaluate several alternative instream flow methods, then recommend a scientific framework and specific methods for determining instream flow needs to promote salmonid recovery and protection in the Shasta River basin.

Quantifying instream flow needs is critical to restoration. Our goal was to recommend a framework best suited for the Shasta River basin that will facilitate compliance with Fish and Game Code 5937 and the Watershed-wide Permitting Program (CDFG 2008). An instream flow needs study must assess the extent to which the natural flow regime can be altered while still ensuring the health of salmonid populations and riparian communities (Richter et al. 1997, Anderson et al. 2006). Or conversely given the status of water allocation and salmonid populations in the Shasta River basin, an instream flow needs study must determine how much additional streamflow is needed to promote recovery of viable salmonid populations. This determination requires a scientific framework rooted in ecological principles. An instream flow needs study must also be concise and transparent to ranchers, local non-profit groups, regulatory agency scientists and policymakers, the Resource Conservation District (RCD) staff, and other interested scientists.

A note on terminology: we use the term “Instream Flow Needs” specifically to refer to the technical scientific process of identifying the flows required for recovery and protection of native salmonids. We strongly support a broader assessment of all critical ecosystem components in the Shasta River basin, particularly restoring streamflows that promote geomorphic processes, recruit native riparian vegetation, and protect amphibians and other aquatic organisms. For example, Pacific Lamprey (*Lampetra tridentata*), always the forgotten anadromous cousin to salmonids, warrants attention as a member of the aquatic community. However, methods to address non-fishery ecosystem components were not assessed as part of this project.

### **1.1 Project Organization and Objectives**

The Project collaborators (CDFG, Cal Trout, M&T, UC Davis Scientists) participated in a Technical Advisory Committee (TAC) formed to discuss and select sites, review past instream flow methods and protocols for our habitat mapping methods, select habitat suitability criteria, and review the strengths and weaknesses of various methods. The Project also established a Project Advisory Committee (PAC) composed of community representatives. Outreach efforts through the PAC were intended to explain project findings, demonstrate field methods, and offer a forum for stakeholder feedback and guidance. We also conducted meetings with the “Save our Shasta and Scott” watershed group, and with the Siskiyou County Board of Supervisors, and the Shasta Valley Resource Conservation District (SVRCD).

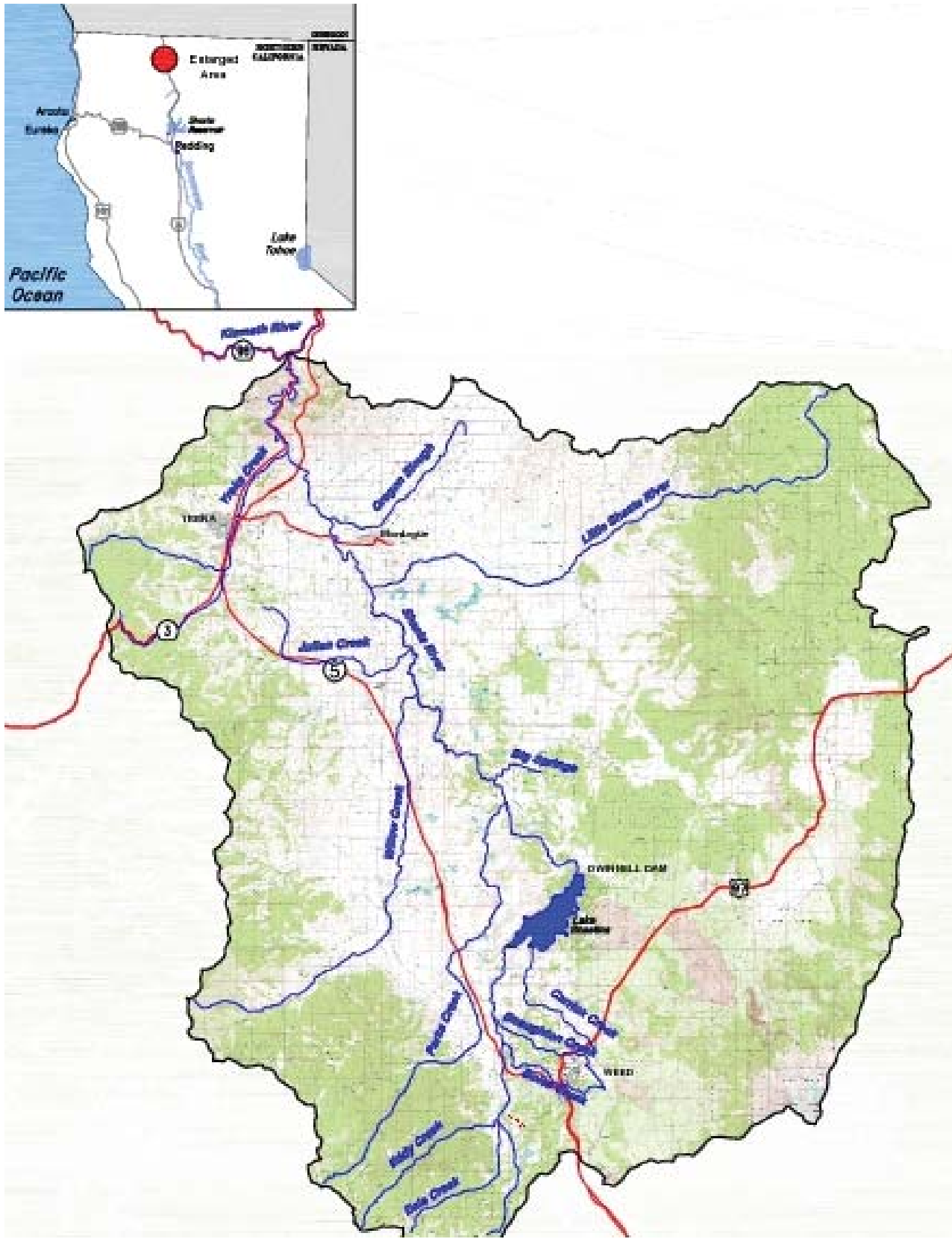


Figure 1. The Shasta River basin location, Siskiyou County, CA

Specific technical project objectives included:

- compile and evaluate streamflow hydrology and water temperature data from USGS gaging records, DWR Watermaster Reports, or other available sources, and collect additional streamflow and water temperature data at selected study sites;
- compile anadromous salmonid habitat criteria from out-of-basin studies and published literature, develop physical habitat criteria, then apply these criteria using microhabitat mapping methods to demonstrate feasibility and reproducibility for constructing streamflow-habitat curves;
- compare microhabitat mapping results with traditional standard-setting methods to recommend methodologies with the best overall efficacy and applicability to the Shasta River basin;
- recommend an analytical framework for assessing instream flow needs and identify future data requirements for implementing this framework.

## **1.2 Study Site selection**

There is no single method or ‘one-size-fits-all’ methodology that will adequately assess instream flow needs in the Shasta River basin. The low-gradient, meandering, spring creek morphology that dominates the Shasta River mainstem (Figure 2), Big Springs Creek, and lower reaches of the Little Shasta River and Parks Creek, requires different instream flow methods and approaches than does the alluvial channel morphology exemplified by the mainstem Shasta River above Big Springs Creek and Dwinnell Dam, upper Parks Creek, upper Little Shasta River, Yreka Creek, and the Shasta River canyon. (Figure 3). The mainstem “valley bottomlands” from approximately Big Springs confluence downstream to Yreka Creek confluence exhibits several distinctive features rarely encountered in the Western US rivers. First, the spring-dominated hydrology historically meant a steady year-around flow of cold water with only moderate peak flows (Deas et al. 2004; Deas 2006). Productivity is high in this reach (Jeffres et al. 2008). Second, the degree of water extraction and tail-water return-flow in the summer can render flow volume and water temperature independent (Deas et al. 2003; Null 2008). In this reach, water temperature is the master variable and will likely trump habitat-area considerations in assessing instream flow needs, particularly for summer rearing habitat. Third, dense aquatic macrophytes in the channel have strong control over streamflow hydraulics and salmonid habitat (Jeffres et al. 2008). Three project study sites were selected to represent different scales and morphologies within the Shasta river basin, with the explicit objective of examining a range of channel types and watershed scales. Land ownership was also considered in site selection.

This project selected three study sites based on the following rationale:

- The Shasta River Canyon has unique scale and morphology, and all anadromous salmonid species in the Shasta Basin utilize the Canyon reach during their life history.
- The Nelson Ranch exemplifies the mainstem Shasta River and is the heart of the potential for basin-wide recovery of salmonids in the Shasta River; the low-gradient meandering spring creek morphology warrants special attention with regard to instream flow and temperature issues;
- The Little Shasta River is an example of a smaller-scale spring creek morphology, and has the potential for high quality habitat for multiple life stages in the Little Shasta River with recovered instream flows; the Little Shasta River also offers the potential for re-establishing and maintaining multiple life history tactics.
- Our study sites were not representative of all different channel scales and morphologies. An important objective for resource managers and researchers in the Shasta Basin will be to continue to examine how instream flow methods perform when applied to new study sites, and refine those methods as needed.



*Figure 2. Mainstem Shasta River at The Nature Conservancy's Nelson Ranch in 2006, with a highly sinuous morphology as the channel traverses the valley floor.*



*Figure 3. Panoramic perspective of the Shasta River in the Canyon reach, near Salmon Heaven. Below the pool (foreground) the thalweg of the main channel is along the right bank. On river left, the bedrock-dominated floodplain with patchy emergent vegetation provides abundant salmonid rearing habitat above approximately 120 cfs. Photo taken February 18, 2009 at 187 cfs discharge at the USGS 'Shasta River near Yreka' gage (11-517500).*

### **1.3 Background: Regulatory Setting**

This Project has its roots in the regulatory process established over the past decade in the Shasta River basin. In 1997 the NMFS listed the Coho Salmon Southern Oregon – Northern California Coast Evolutionarily Significant Unit (SONCC ESU) as threatened under the Federal Endangered Species Act of 1973. In 2004 the SONCC ESU was listed as threatened under the California Endangered Species Act (CESA) (CDFG 2004). The Shasta River was also added to the EPA 303d list of impaired watersheds, resulting in a TMDL allocation developed by the Regional Water Board for temperature and dissolved oxygen (NCRWQCB 2006). The proposal to list coho under the California Endangered Species Act led the Fish and Game Commission to institute to a state-wide coho salmon recovery planning process and a Shasta-Scott pilot program. The Recovery Strategy for California Coho Salmon (CDFG 2004) lists coho salmon recovery tasks specific to the Shasta River watersheds identified by the Shasta-Scott Recovery Team (SSRT). The Coho Recovery Strategy stipulated that the acceptance of the pilot program by the local agricultural community was inextricably linked to the development of a Watershed-wide Permitting Program to bring agricultural diverters into compliance with Section 1602 of the California Fish and Game Code and the California Endangered Species Act (CESA) for routine agricultural activities. Permits issued pursuant to these programs will also require compliance with other sections of the Fish and Game Code, including Section 5937 (bypass flows) and Section 5901 (fish passage).

Thus, while the regulatory process has provided the impetus for an instream flow needs assessment, this *technical scientific* assessment will not attempt to balance water consumption for human uses with water supply needed for species recovery and protection; make recommendations on how or where water can be procured; or predict short- or long-term population responses to reallocated flow regimes.

## **2 THEORETICAL CONSIDERATIONS IN PRACTICE**

An instream flow methodology should be guided by the following principles:

Principle No. 1: An aquatic ecosystem such as the Shasta River had environmentally-imposed limits to population abundance, even under unimpaired ‘natural flow’ conditions. A regulated flow regime risks imposing additional limits on the carrying capacity and ultimately the population size. There is no objectively reliable method to *a priori* determine how much capacity and productivity can be diminished and still maintain a viable and robust salmonid population. Flow reduction and its consequences to the population must therefore be treated as an ecological experiment.

Principle No. 2: Not all ecological processes were accomplished in all water years. Natural, unregulated annual hydrographs (e.g., Figure 4) sustained good and perpetuated bad ‘salmon’ years. An instream flow needs determination should be bounded by, but still retain, the seasonal pattern and general changes in magnitude, frequency, timing and duration of the unimpaired hydrograph so that both intra-annual (within a year) and inter-annual (between years) variability of flow is maintained.

Principle No. 3: Always keep the integrity of each annual hydrograph intact throughout an instream flow needs analysis because each annual hydrograph harbors unique and significant ecological information. Taking all the daily average streamflows of an annual hydrograph(s) and ranking them from highest to lowest (e.g., constructing a monthly flow duration curve) obscures much of this information.

Principle No. 4: Remember that the “optimal streamflow” of a composite habitat rating curve (i.e., the streamflow with the most ft<sup>2</sup> of habitat) is a mathematical convenience and not a real optimal event in nature. Similar habitat total areas on opposing sides of a unimodal habitat-flow curve can be very different with respect to capacity, productivity, and risk, and should be differentiated in the instream flow analysis.

Principle No. 5: A diversion rate is generally better than a bypass flow. The subtle difference is in taking a restricted portion of the unimpaired streamflow (for consumptive uses) and leaving the remaining “in-stream”, versus diverting all available streamflow above a minimum bypass flow.

Principle No. 6: Analyses must be transparent and comprehensible to stakeholders where instream flow recommendations would be applied. Transparency requires that any computation can be traced forward to the ultimate X-Y graph as well as backward to basic physical variables and the targeted life history tactics. The ultimate cause-and-effect graph for any instream flow study has the flow prescription on the X-axis and beneficial use on the Y-axis (Figure 5).

Quantifying the ultimate cause-and-effect is not a simple task, but thinking how it might be done is crucial. One necessity is agreeing on what variable(s) should occupy the Y-axis. Candidate variables may include a healthy population of emigrating steelhead pre-smolts, self-sustaining red willow stands on floodplains, or both. The X-axis is no easier to deal with. Most instream flow prescriptions are complex, and are not presented as a single rate of diversion or baseflow release. Typically, baseflows will vary by water year type, or even from early-summer to early-fall within a water year. But rarely is an instream flow prescription too complex to accommodate on the X-axis.

Principle No. 7: You can’t protect the fish, if you won’t protect the stream ecosystem. Estimation of the magnitude, duration, frequency, and timing of important ecological river processes, other than salmon and steelhead habitat, using natural hydrographs is a good starting point for incorporating an instream flow analysis intended to focus on fish into an ecosystem perspective. Water quality, aquatic habitat, riparian vegetation, and channel maintenance processes should be considered in an instream flow needs assessment.

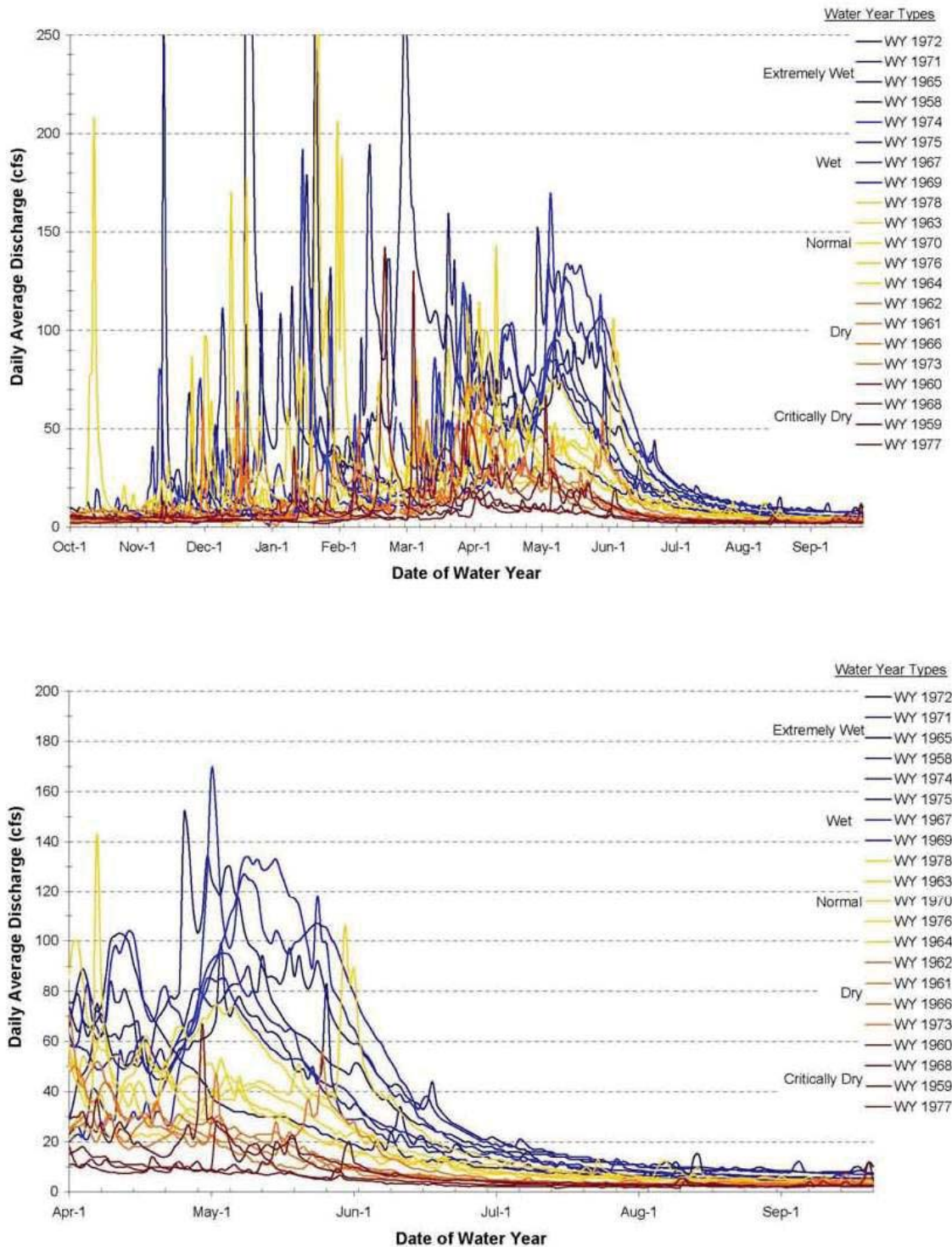
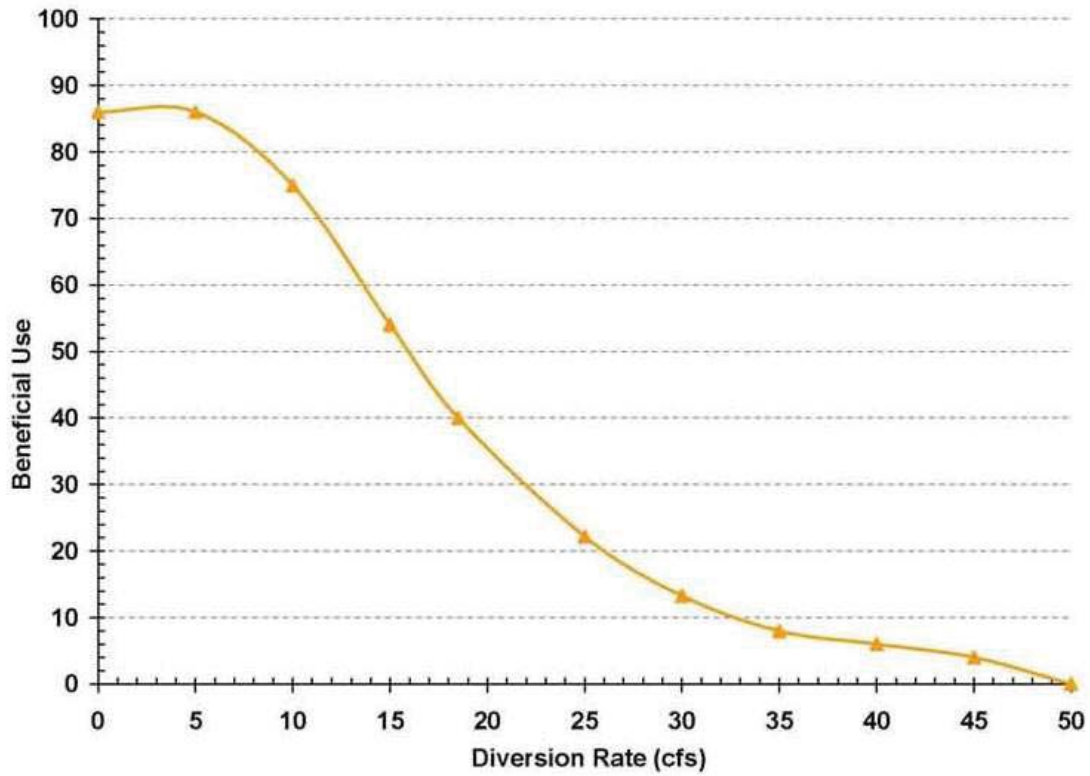


Figure 4. Annual hydrographs for the USGS ‘Little Shasta River near Montague’(USGS 11-516900) for the period of record (WYs 1958-1978) overlain for the entire water years (above) to demonstrate the inter- and intra-annual variability throughout different water years, and for the spring/summer snowmelt period (below) to demonstrate how visible patterns emerge among wet and dry water years.



*Figure 5. Hypothetical ultimate cause and effect relationship between management prescription and beneficial use, in this case indicating diminishing beneficial use resulting from stream flow diversion.*



### **3 FRAMEWORK FOR A BASIN-WIDE INSTREAM FLOW NEEDS METHODOLOGY**

#### **3.1 Life History Tactics Guide Identification of Instream Flow Needs**

Identifying instream flow needs at specific locations within the Shasta River basin must consider the needs of each freshwater life stage for each target species. Flow recommendations for specific sites or reaches must also treat as unique each portion of a salmonid population that resides there. Coho salmon juveniles in Parks Creek have a different life history than coho salmon juveniles in the Little Shasta River. Emphasizing salmonid life history diversity in the Shasta River basin is an essential component to species recovery.

Salmonid life history diversity can be viewed as multiple pathways or “tactics” that portions of each annual cohort of each species pursue in their attempt to survive successive freshwater life stages and complete their life cycle. A life history tactic is a same-age class or “school” of fish utilizing a common set of stream reaches in succession to meet their freshwater habitat requirements. Tactics result from behavioral responses to environmental cues that produce common patterns of habitat use, migration timing, and survival rates. A life history tactic begins with adult salmon or steelhead migrating to a stream reach and spawning; their eggs incubate and young-of-year fry emerge; those fry grow and transition through spring, summer, and winter rearing seasons (depending on the species); and eventually after 0+, 1+ or more years, juveniles migrate downstream, smolt, and enter the ocean. Our life history tactics do not include the ocean phase. Within this typical life history pattern is an enormous breadth of variation. For example, a portion of an emergent young-of-year fry cohort may stay and rear in the vicinity of the spawning reach, while another portion may disperse to a different rearing reach (perhaps due to density-dependent mechanism or innate nomadic tendencies). This initial cohort has thus split into two (or more) life history tactics, each with a potentially different survival outcome. Each tactic represents a different strategy of habitat utilization and survival, governed by flow and habitat conditions encountered in the specific reaches within which they reside. A critical element for each tactic is this: if any part of the sequence of habitats used by a particular tactic becomes degraded or unsuitable, then that tactic cannot persist.

The following examples illustrate the concept of life history tactics. Winter-run steelhead enter the Shasta River basin between December and April, migrate to the headwaters of a tributary, and spawn (Figure 6). Emergent fry may then follow one of numerous pathways: they could migrate downstream as fry in search of suitable habitat, spend a single summer season rearing, then emigrate to the Klamath River and enter the ocean as a small (120-160 mm) one year old smolt. Alternatively, they could remain in headwater reaches for several years until they’re large enough to smolt, and enter the ocean as a larger (220-260 mm) two year old smolt. Each of these alternative life histories is considered a different tactic.

Viewed in another way, each juvenile Chinook salmon captured at the Shasta River Fish Counting Facility (SRFCF) employed a successful tactic to arrive there. A 110 mm Chinook smolt captured on May 16 might have incubated in the foothills of the Little Shasta River, grew as a fry nearby, migrated slowly through the valley bottom of the Little Shasta River as a juvenile through April, then grew rapidly through the Shasta River mainstem and the Canyon, before being captured on May 16 close to the Klamath River. Another Chinook smolt captured the same day might have employed a different life history tactic, beginning its life history in Big Springs Creek or the mainstem Shasta River. The daily catch, therefore, is a collection of successful life history tactics.

The important concept with regard to life history tactics is that instream flow studies must address each life stage and habitat requirement for many life history tactics in order to achieve robust and resilient salmonid populations. Natural selection operates at the life history level to maximize the

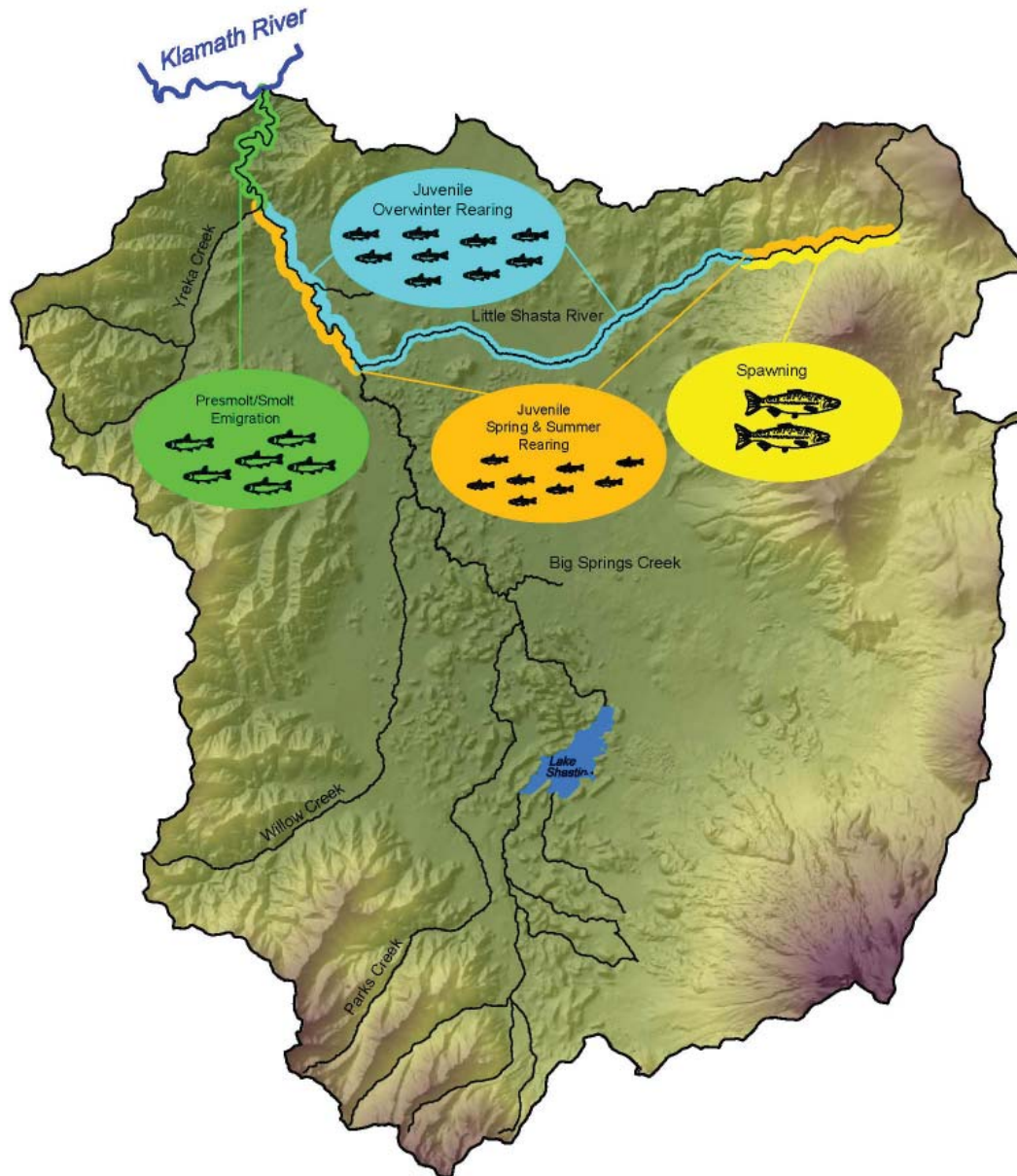


Figure 6. Example of a Shasta River life history tactic using the Little Shasta River Steelhead 1+ and 2+ tactics, each with different juvenile summer rearing habitat. Adult steelhead spawn in the Little Shasta River Headwaters reach in winter. Emergent fry may then follow several divergent pathways: stay and rear in the Headwaters reach, or redistribute in early spring to rear in the Shasta Canyon reach. Juveniles that remains in the Headwaters reach may persist through the summer rearing period, then descend to the Foothills and Bottomlands reaches to rear in winter. Upstream movement into suitable habitat is also a key element of many life history tactics. Juveniles that descended to the Shasta Canyon reach may encounter unsuitable habitat (high water temperatures) and be forced to emigrate or die. The following spring, the juvenile and pre-smolt survivors from the Headwaters tactic may then emigrate to the Klamath.

number of surviving offspring. Improved instream flows should increase the number and diversity of successful life history tactics, and that increase should be measurable at the Shasta River Fish Counting Facility (SRFCF) as well as at specific locations within the basin.

Our instream flow methodology begins with a set of existing and recoverable tactics that was developed in a Shasta River Study Plan prepared for the SVRCD with funding from the USFWS (M&T and SVRCD 2009 *in review*). These existing and recoverable tactics are presented in Appendix A. Each tactic is described in terms of four life stages: (1) spawning, incubation, and early fry rearing, (2) juvenile spring and summer rearing, (3) juvenile winter rearing, and (4) pre-smolt and smolt emigration.. Each life stage is linked to specific stream reaches that must provide suitable habitat for each life stage to survive.

Life history tactic help identify life stages and stream reaches where flow (and habitat) impairment has occurred. Superimposing life history tactics onto the stream habitat conditions identifies where instream flow needs must be quantified (Figure 7). This process addresses the entire life history tactic, ensuring that instream flow recommendations can be validated by monitoring the recovery and survival of each life history tactic. This instream flow methodology can be “incremental”, first protecting existing tactics, then incrementally recovering new tactics as new opportunities to improve flow and habitat conditions arise. Seventeen life history tactics are presented here; there are likely other recoverable tactics in the Shasta River basin.

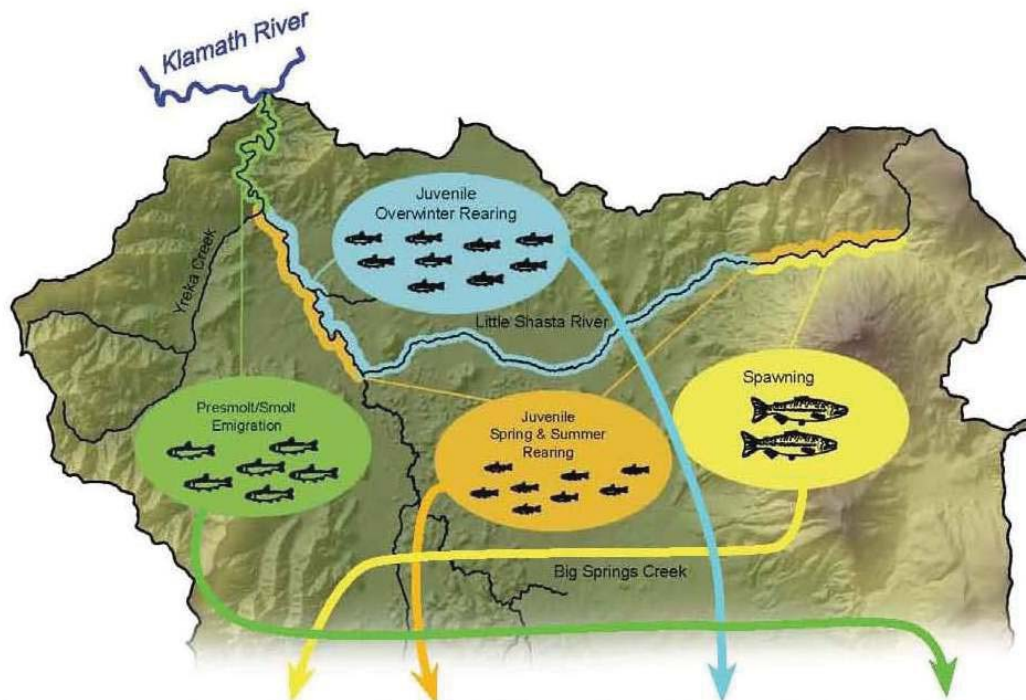
### **3.2 Basin-wide Instream Flow Needs and Flow Study Objectives**

Considering all life history tactics overlain on discrete river reaches, and with our current understanding of habitat and flow conditions within these reaches, specific objectives for quantifying instream flow needs were identified. We outline instream flow objectives for the entire basin, based on eight principal reaches that provide or could provide important anadromous salmonid habitat (Table 1). Several reaches in the Shasta River basin are only partially impaired, such as the Little Shasta River above the Musgrave diversion, Big Springs, Parks Creek above MWCD diversion, and Yreka Creek. A high priority is therefore to protect instream flows and continue to provide salmonid access to those reaches.

#### **3.2.1 Dwinnell Dam**

##### *Primary Life Stages and Habitat Functions Targeted through Instream Flow and Non-Flow Measures*

The Dwinnell Dam reach may offer the potential for abundant spawning and early fry rearing habitat that is needed to fully seed mainstem reaches downstream of Big Springs confluence, where spawning habitat is more limited, but where cold summer rearing habitat may be available. Providing spawning habitat in this reach would provide an alternative spawning reach to Parks Creek and Big Springs Creek, thus reducing risk of catastrophic loss of spawning cohorts. Instream flows in late-winter could increase fry rearing habitat. Instream flows in summer could increase juvenile salmonid rearing habitat, which is a potential limiting factor for salmonid recruitment. In addition, instream flows maintained downstream of Dwinnell Dam may allow juvenile salmonids to access cold off-channel springs in summer. A flow release from Dwinnell Dam to mimic snowmelt runoff (April or May) would benefit the entire mainstem Shasta River and all life history tactics utilizing the mainstem for rearing habitat in spring. A snowmelt release would (1) promote geomorphic functions, (2) promote recruitment of native riparian vegetation along the mainstem reaches, (3) provide salmonid access to high quality off-channel rearing habitat, (4) stimulate downstream migration of salmonid fry and juveniles, and (5) restore high quality aquatic habitat through woody debris recruitment.



Life Stage	Spawning/Incubation/ Fry Rearing	Juvenile Spring/ Summer Rearing	Juvenile Winter Rearing	Presmolt/Smolt Emigration
Timeline	Oct-Nov-Dec- Jan-Feb-Mar	Apr-May-Jun- Jul-Aug-Sept	Oct-Nov-Dec- Jan-Feb-Mar	Apr-May-Jun
Reach	Little Shasta Foothills	Little Shasta Bottomlands		Mainstem/Canyon
Instream Flow Objectives	<i>Instream Flow Objective-1:</i> establish a streamflow threshold for providing "good" upstream migration to the Foothills Reach spawning habitat, primarily targeting adult coho passage beginning in mid- October, and continuing through the winter for steelhead passage.	<i>Instream Flow Objective-2:</i> establish a habitat-flow relationship through April and into May for salmonid fry rearing; establish a habitat-flow relationship for summer rearing for Coho juvenile, and Steelhead 1+ and 2+.	<i>Instream Flow Objective-3:</i> establish a habitat- flow relationship for winter rearing for Coho juvenile, and Steelhead 1+ and 2+.	<i>Instream Flow Objective-4:</i> establish a flow threshold for a pulse-flow to mimic snowmelt runoff to provide "good" downstream rearing and migration conditions in spring for pre-smolts and smolts from the Little Shasta Bottomlands reach through the Mainstem and Canyon reaches, primarily during April and May.

Figure 7. Illustration of the process of developing instream flow needs objectives from life history tactics. Each life stage requires suitable habitat at the appropriate time period, and connectivity to habitat in subsequent life stages. This visual and chronological depiction of individual life history tactics provides a practical method for identifying the suite of instream flow and habitat needs for each species and life stage. Once instream flow needs objectives are identified, the appropriate methods can be selected.

*Table 1. Shasta River and tributary reaches common to the life history tactics we are investigating for instream flow needs.*

Reach		Upstream Boundary	Downstream Boundary	Reach Length (mi)
1	Dwinnell Dam	Dwinnell Dam	Big Springs Creek confluence	6.9
2	Nelson Ranch	Big Springs Creek confluence	Hwy A-12	9.0
3	Middle Mainstem	Hwy A-12	Yreka Creek confluence	17.0
4	Shasta Canyon	Yreka Creek confluence	Klamath River	7.8
5	Big Springs Creek	Big Springs Lake	Shasta River confluence	2.4
6	Parks Creek	Edson-Foulke canal	Shasta River confluence	21.2
7	Little Shasta River	Dry Gulch Cascades	Shasta River confluence	17.4
8	Yreka Creek	Greenhorn Creek confluence	Shasta River confluence	5.8

*Instream Flow Objectives*

- identify a threshold for fall baseflows to enable good upstream migration to Dwinnell Dam;
- establish habitat-flow relationship for salmonid spawning;
- establish habitat-flow relationship for winter salmonid fry rearing, and for spring juvenile rearing through April, into May, and occasionally into June (in wetter water years);
- identify spring snowmelt hydrograph to (1) promote geomorphic functions, (2) promote recruitment of native riparian vegetation along the mainstem, and (3) stimulate downstream migration of salmonid fry and juveniles.

*Non-Flow Restoration Objectives*

- manage or eliminate tail-water return flows;
- rehabilitate and protect channel morphology through channel reconstruction and riparian fencing;
- assess potential benefits of gravel augmentation to increase spawning habitat availability;
- assess location, accessibility, and summer habitat availability in small cold-water springs that are tributary to the mainstem;

**3.2.2 Nelson Ranch**

*Primary Life Stages and Habitat Functions Targeted through Instream Flow and Non-Flow Measures*

With restored instream flow and temperature conditions, the Nelson Ranch reach would provide abundant and high quality fry and juvenile rearing habitat in the mainstem year-around for juvenile Chinook and coho salmon and steelhead 1+ and 2+ life stages. Instream flows in the spring should sustain rearing habitat in off-channel margin areas identified by UC Davis researchers (Jeffres et al. 2008), until main-channel rearing habitat matures with aquatic vegetation growth. During summer, temperature criteria will dominate the determination of instream flow needs for salmonid rearing; habitat-flow relationships for summer rearing would be of secondary interest until summer water temperature conditions are addressed. This reach could also provide spawning habitat, although likely less abundant than gravel-dominated reaches below Dwinnell Dam and in Big Springs and Parks creeks. A flow release from Dwinnell Dam to mimic snowmelt runoff (April or May) would benefit the Nelson Ranch reach and all life history tactics utilizing this reach for rearing habitat for the reasons listed in Section 3.2.1. The Nelson Ranch reach could also provide adult over-summering and juvenile summer rearing habitat to restore Spring Chinook to the Shasta River.

### *Instream Flow Objectives*

- establish a flow threshold that enables fry and juvenile access into off-channel rearing areas during spring (March-May), and a range of flows that provide good rearing conditions in these off-channel areas;
- identify a range of flows that provides abundant habitat area for summer rearing in the mainstem channel for salmonid fry, juvenile Chinook and coho salmon, and steelhead 1+ and 2+ life stages;
- identify spring snowmelt hydrograph to (1) promote geomorphic functions, (2) promote recruitment of native riparian vegetation along the mainstem, and (3) stimulate downstream migration of salmonid fry and juveniles.

### *Non-Flow Restoration Objectives*

- manage or eliminate tail-water return flows;
- rehabilitate and protect channel morphology through riparian fencing;
- assess potential benefits of gravel augmentation to increase spawning habitat availability;

### **3.2.3 Middle Mainstem**

#### *Primary Life Stages and Habitat Functions Targeted through Instream Flow and Non-Flow Measures*

Restoring instream flows and removing barriers to allow adult migration through this reach in fall is a high priority. Spawning habitat may be available intermittently along the lower section of this reach (e.g., Little Shasta River to Yreka Creek) but would be a low priority relative to other spawning habitat. With restored instream flows, this reach could provide abundant and high quality juvenile rearing habitat through winter and into spring for Chinook and coho juveniles, and for steelhead 1+ and 2+ life stages. A flow release from Dwinnell Dam to mimic snowmelt runoff (April or May) would benefit this reach and the life history tactics utilizing this reach for the reasons listed in Section 4.2.1.

### *Instream Flow Objectives*

- establish a flow threshold that enables fry and juvenile access into off-channel rearing areas during spring (March-May), and a range of flows that provide good rearing conditions in these off-channel areas;
- identify spring snowmelt hydrograph to (1) promote geomorphic functions, (2) promote recruitment of native riparian vegetation along the mainstem, and (3) stimulate downstream migration of salmonid fry and juveniles.

### *Non-Flow Restoration Objectives*

- manage or eliminate tail-water return flows;
- rehabilitate and protect channel morphology through riparian fencing;

### **3.2.4 Shasta Canyon**

#### *Primary Life Stages and Habitat Functions Targeted through Instream Flow and Non-Flow Measures*

All life history tactics utilize the Shasta Canyon reach. This reach currently provides the highest abundance of salmonid spawning habitat and sustains Chinook salmon production. Restored instream flows in early fall (Sept 15-Oct 15) would ensure migration and spawning are not inhibited by low streamflows and consequent high water temperatures, or by flow fluctuations. Late fall and winter spawning flows appear adequate to support Chinook and coho spawning, but a habitat-flow

relationship should be established to verify and sustain spawning flows. Winter fry and juvenile rearing habitat also appears adequate for Chinook and coho salmon. Restored instream flows in the spring (April, into May, and occasionally into June in wetter water years) would provide abundant and high quality rearing habitat for late-juvenile and smolt life stages during spring emigration. Restored instream flows in the summer would provide rearing habitat for juvenile Chinook and coho salmon, and steelhead 1+ and 2+ life stages, but temperature criteria will dominate the determination of instream flow needs for salmonid rearing; habitat-flow relationships for summer rearing would be of secondary interest until summer water temperature conditions are addressed .

#### *Instream Flow Objectives*

- establish a streamflow threshold for providing “good” upstream migration, primarily targeting mid to late-September for Chinook migration and into December for Coho;
- establish habitat-flow relationship for salmonid spawning;
- establish a flow threshold that enables fry and juvenile access into side channel and off-channel rearing areas during spring (March-May) when the basin’s juveniles are migrating to the Klamath River, and a range of flows that provide good rearing conditions in these off-channel areas;
- establish habitat-flow relationship for summer rearing (June-Sept) in the mainstem channel for juvenile Chinook and coho salmon, and steelhead 1+ and 2+ life stages.

#### *Non-Flow Restoration Objectives*

- rehabilitate channel morphology through gravel augmentation;

### **3.2.5 Big Springs Creek**

#### *Primary Life Stages and Habitat Functions Targeted through Instream Flow and Non-Flow Measures*

The location of Big Springs Creek as tributary to the upper mainstem, the availability (through purchase) of year-round cold springs, the potential high productivity, and the multiple benefits to downstream reaches on the mainstem, makes this reach the highest recovery priority in the basin. Providing spawning habitat (possibly needing spawning gravel augmentation) in this reach would provide an alternative spawning reach to the mainstem reach below Dwinnell Dam and Parks Creek, thus reducing risk of catastrophic loss of spawning cohorts. Restoring instream flows would provide abundant and high quality salmonid fry and juvenile rearing habitat in Big Springs Creek year-around for Chinook and coho salmon, and steelhead 1+ and 2+ life stages.

#### *Instream Flow Objectives*

- establish habitat-flow relationship for salmonid spawning;
- establish a flow threshold that enables fry and juvenile access into off-channel rearing areas in Big Springs Creek during spring (March-May), and a range of flows that provide good rearing conditions in these off-channel areas;
- identify a range of flows that provides abundant habitat area for summer rearing in Big Springs Creek for salmonid fry, juvenile Chinook and coho salmon, and steelhead 1+ and 2+ life stages;

#### *Non-Flow Restoration Objectives*

- manage or eliminate tail-water return flow;
- rehabilitate and protect channel morphology through riparian fencing;
- assess potential benefits of gravel augmentation to increase spawning habitat availability;
- confirm that winter flow diversions (if any) don’t impact habitat;

### **3.2.6 Parks Creek**

#### *Primary Life Stages and Habitat Functions Targeted through Instream Flow and Non-Flow Measures*

Parks Creek offers similar potential for salmonid spawning and winter-spring rearing habitat as does the Dwinnell Reach. Restoring instream flows may offer the potential for abundant spawning and early fry rearing habitat that is needed to fully seed mainstem reaches where spawning habitat is more limited, but where cold summer rearing habitat may be available. Providing spawning habitat in this reach would provide an alternative spawning reach to the reach below Dwinnell Dam and Big Springs Creek, thus reducing risk of catastrophic loss of spawning cohorts. Instream flows in late-winter could increase fry rearing habitat. Instream flows in summer could increase juvenile salmonid rearing habitat, which is a potential limiting factor for salmonid recruitment. In addition, instream flows maintained downstream of the MWCD diversion may allow juvenile salmonids to access cold off-channel springs in summer. Finally, a flow bypass from the MWCD diversion in spring to mimic snowmelt runoff (April or May) would benefit Parks Creek and the life history tactics utilizing mainstem reaches below Parks Creek for rearing habitat for the reasons listed in Section 3.2.1. Parks Creek could also provide “engineered” access to the upper mainstem Shasta River above Lake Shastina.

#### *Instream Flow Objectives*

- establish habitat-flow relationship for salmonid spawning in the Foothills Reach from below I-5 to the MWCD diversion
- establish habitat-flow relationship for winter salmonid fry rearing, and for spring juvenile rearing through April, into May, and occasionally into June (in wetter water years);
- identify spring snowmelt hydrograph to (1) promote geomorphic functions, (2) promote recruitment of native riparian vegetation along the mainstem, and (3) stimulate downstream migration of salmonid fry and juveniles.

#### *Non-Flow Restoration Objectives*

- manage or eliminate tail-water return flows and start/end-of-irrigation-season rapid flow changes;
- assess habitat availability above MWCD diversion as summer refugia;
- rehabilitate channel morphology through channel reconstruction, riparian fencing, and gravel augmentation.

### **3.2.7 Little Shasta River**

#### *Primary Life Stages and Habitat Functions Targeted through Instream Flow and Non-Flow Measures*

The Little Shasta River provides opportunity for restoring several life history tactics not dependent on the mainstem. There is existing high quality habitat in the upper five miles between the Musgrave diversion and Dry Gulch that could sustain multiple life history tactics with spawning and year-around rearing habitat. Restoration of instream flows in late-winter could increase fry rearing habitat. Instream flows in summer could increase juvenile salmonid rearing habitat, which is a potential limiting factor for salmonid recruitment from this portion of the basin.



*Instream Flow Objectives*

- establish a flow threshold for providing “good” upstream migration, primarily targeting mid to late-September for Chinook migration, into December for Coho migration; and continuing through winter for steelhead migration;
- establish habitat-flow relationship for salmonid spawning in the Foothills Reach above the Musgrave diversion;
- establish habitat-flow relationship for winter salmonid fry rearing, and for spring juvenile rearing through April, into May, and occasionally into June (in wetter water years);
- establish a threshold for a flow release to mimic snowmelt runoff and provide “good” downstream rearing and migration conditions in spring for pre-smolts and smolts emigrating from headwaters reaches through to the mainstem, primarily during April and May;

*Non-Flow Restoration Objectives*

- manage or eliminate tail-water return flows;
- confirm fish passage from the Shasta River mainstem upstream to Dry Gulch (and possibly above);
- rehabilitate and protect channel morphology through riparian fencing;

**3.2.8 Yreka Creek**

*Primary Life Stages and Habitat Functions Targeted through Instream Flow and Non-Flow Measures*

Yreka Creek is perhaps the only tributary to the Shasta River that is not regulated for irrigation purposes. It is also likely the source for the majority of coarse sediment and spawning gravel recruitment to the Shasta River Canyon. There is flow regulation for domestic water supply purposes on Greenhorn Creek, which may also block delivery of sediment to Yreka Creek and eventually the Shasta River mainstem. With instream flows, there is potential for abundant, easily accessible, high quality spawning habitat and early fry rearing habitat, primarily for coho and steelhead, and secondarily for fall Chinook. Given the limited flow regulation that occurs, it is unknown if summer flows are adequate to provide suitable water temperatures to support summer rearing habitat. Restoration of the lower three miles of Yreka Creek riparian corridor could provide abundant high quality winter and spring rearing habitat for Chinook and coho salmon, and steelhead 1+ and 2+ life stages. Yreka Creek provides opportunity for additional life history tactics to increase population resiliency, and reduce risk of catastrophic population impacts.

*Instream Flow Objectives*

- establish fall flows for upstream migration;
- establish fall spawning flow requirements;

*Non-Flow Restoration Objectives*

- rehabilitate channel morphology through gravel augmentation;
- restore floodplain and floodway riparian corridor in the lower reach of Yreka Creek;
- restore instream flows and/or temperatures for spring, summer, and fall objectives;

### **3.3 Primary Assumptions of this Instream Flow Needs Methodology**

Several primary assumptions made in developing this methodology warrant explicit mention.

Assumption #1: There is a cumulative benefit of each individual increment of flow released in the Shasta River, as the flow propagates downstream through the mainstem and canyon (i.e., a quantity of water released/bypassed at a point of diversion benefits habitat there and downstream).

Assumption #2: While the Shasta River is recognized as a highly productive river, this factor cannot be expected to compensate for degraded or unsuitable habitat. The habitat requirements of the salmonid populations in the Shasta basin are no different from other watersheds, and good quality habitat is necessary to maintain and recover salmonid population abundance.

Assumption #3: In many locations within the Shasta River basin, summer water temperature is the primary factor controlling salmonid habitat suitability, not microhabitat area as defined by hydraulic variables. Until summer water temperature conditions are addressed in these locations, flow prescriptions targeting habitat area will not have the expected population response.

Assumption #4: The role of the Shasta Canyon is unique as an agent of rapid growth in spring (April, May, and June) when many life history tactics pass through the Canyon on their way to the Ocean. The increment of growth added while juvenile salmonids rear their way through the canyon is essential to increase survival rates during subsequent smolt and ocean entry phases.

Assumption #5: A basic assumption shared by most instream flow needs assessments, but still worthy of explicit mention, is that higher quality habitat is assumed to allow higher fish densities. Instream flow needs assessments build on this assumption by identifying flows that provide good quality habitat, and rely on the maxim: “if you build it, they will come”. However, there are no guarantees fish will immediately respond to the availability of good habitat. Population responses may require considerable time and patience.

## **4 INSTREAM FLOW ASSESSMENT METHODS AND RECOMMENDED APPLICATIONS**

### **4.1 Microhabitat Mapping**

An essential analytical tool for identifying instream flow needs is the field development of quantitative relationships between suitable microhabitat area and streamflow – called habitat-flow curves or habitat rating curves – for specific species and life stages in specific tributaries and mainstem reaches. The proposed analytical framework for evaluating instream flow needs will require individual habitat rating curves from many microhabitat locations, rather than single composite habitat rating curves as in traditional PHABSIM evaluations. Several field methodologies for measuring microhabitats at multiple streamflows were evaluated. Necessary attributes for a preferred field methodology were: (1) accuracy in identifying microhabitats under diverse hydraulic conditions, (2) repeatability, (3) capability to assess long channel sections economically, (4) adaptability for population modeling, (5) flexibility in weighting channel segments not mapped, and (6) transparency in data collection and interpretation. No one methodology was expected to outperform all others for evaluating the high priority life history tactics. The following methodologies were considered: microhabitat mapping, wetted perimeter, R2 Cross, Tennant, PHABSIM, and 2D hydrodynamic modeling. Refer to Appendix B for these evaluations.

#### ***4.1.1 Habitat Suitability Criteria***

Habitat suitability criteria (HSC) are the foundation for constructing credible habitat rating curves. They must define quantifiable hydraulic (depth and velocity), substrate, and cover (e.g., overhanging stream banks, submerged vegetation, and large wood) conditions favored by salmonids as highly suitable (= good) habitat. Many tributaries of the Shasta River presently have no rearing juvenile anadromous salmonids, or too few juveniles, to adequately characterize habitat utilization entirely by direct observation. Instead, three general information sources helped establish habitat suitability criteria for microhabitat mapping (Table 2): (1) direct and indirect observations of habitat utilization by CDFG and UC Davis researchers snorkeling the Shasta River mainstem and a few tributaries (Jeffres et al. 2008; Chesney 2006), (2) habitat suitability criteria developed by direct observation in the Klamath River and Trinity River basins (Hampton 1988; Naman et al. 2004; Hardin et al. 2005; Hardy et al. 2006), and (3) general habitat requirements of each salmonid species derived from field experience outside the Shasta River and the scientific literature. The HSC proposed for Chinook salmon, coho salmon, and steelhead in the Shasta River basin are listed in Table 2.

These proposed HSC will require refinement. For example, juvenile Chinook criteria were revised to exclude velocities between 0.0 to 0.5 ft/s to distinguish highly suitable juvenile Chinook habitat from coho habitat, as well as to exclude large homogenous areas of pool bodies with no cover and poor foraging. We recommend maintaining the velocity range up to 1.5 ft/s for juvenile Chinook. This range extends higher than velocity criteria developed from the Trinity River, but is similar to criteria developed from the Klamath River. The productivity of the Shasta River may allow suitable habitat with higher velocities than the Trinity River. Uncertainty remains regarding how to establish highly suitable HSC for these microhabitats: (1) suitable fry and juvenile salmonid rearing along the fringes but not in the interiors of dense clumps of emergent vegetation, (2) dense but patchy submerged vegetation in the mainstem and a few tributaries, (3) steep silt/clay banks with shallow overhangs which may provide highly suitable cover for juvenile coho, (4) the slack bodies of pools which met initial juvenile Chinook hydraulic criteria, but would offer poor rearing habitat quality, and (5) the importance of concentrated ‘hot-spots’ as rearing habitat (e.g., beaver ponds and spring seeps) for juvenile salmonids. More direct observation of microhabitat utilization by juvenile salmonids in

Table 2. Binary habitat suitability criteria developed from Hampton et al. (1988), Hardin et al. (2004) and Hardy et al. (2006), used to guide development of criteria recommended for use in the Shasta River basin.

Hampton (1988) from Trinity River				
Species	Life Stage	Depth (ft)	Velocity (ft/s)	Substrate/Cover
Chinook	Fry	0.4 - 2.2	0.0 - 0.7	
	Juvenile	0.7 - 4.0	0.0 - 1.0	
	Spawning	0.8 - 2.6	0.8 - 2.6	cobble 3-6"
Coho	Fry	0.6 - 1.8	0.0 - 0.7	
	Juvenile	0.8 - 3.0	0.0 - 1.1	
	Spawning	0.5 - 2.0	0.5 - 2.0	co-dominant substrates (large gravel, small cobble) 2-3"/3-6"
Steelhead	Fry	0.5 - 1.5	0.0 - 1.0	
	Juvenile	1.4 - 4.0	0.0 - 3.2	
	Spawning	0.5 - 2.0	0.4 - 2.8	co-dominant substrates (large gravel, small cobble) 2-3"/3-6"
Hardin 2005 and Hardy (2006) from Klamath River				
Species	Life Stage	Depth (ft)	Velocity (ft/s)	Substrate/Cover
Chinook	Fry	0.5 - 1.5	0.0 - 1.0	primarily non-emergent rooted aquatic vegetation, grasses, willows, sedges, within 1-2 ft of cover
	Juvenile	1.0 - 4.2	0.0 - 1.5	primarily non-emergent rooted aquatic vegetation, grasses, willows, sedges, within 1-2 ft of cover
	Spawning	<1.1	1.7 - 3.5	1-2"(.81);2-3"(1.0)/3-6"(.72)
Coho	Fry	0.5 - 1.7	0.1 - 0.7	primarily non-emergent rooted aquatic vegetation, grasses, sedges, filamentous algae
	Juvenile	0.9 - 3.8	0.1 - 0.7	used Chinook juv cover attributes within 1 ft of cover
	Spawning	not specified		
Steelhead	Fry	0.0 - 2.0	0.0 - 0.7	used Chinook fry cover attributes
	Juvenile	0.7 - 2.4	0.6 - 2.6	primarily grasses, sedge, mixed vegetation, boulders;
	Spawning	not specified		
Recommended for Shasta River				
Species	Life Stage	Depth (ft)	Velocity (ft/s)	Substrate/Cover
Chinook	Fry (<55 mm)	0.2 - 1.5	0.0 - 0.5	large gravel and cobble; vegetative cover
	Juvenile (>55mm)		0.5 - 1.5	
	Spawning	0.5 - 3.0	1.0 - 2.5	2-3"(1.0)/3-6"(.72)
Coho	Fry (<55 mm)	0.2 - 1.5	0.0 - 0.5	large gravel and cobble; vegetative cover
	Juvenile (>55mm)	<1.5	0.0 - 0.5	streambank, vegetation, or wood cover
	Spawning	0.5 - 3.0	1.0 - 2.5	1-2"(.81);2-3"(1.0)/3-6"(.72)
Steelhead	Fry (<55 mm)	0.2 - 1.5	0.0 - 0.5	large gravel and cobble; vegetative cover
	Juvenile (>55mm)		0.5 - 2.5	
	Spawning	0.5 - 3.0	1.0 - 2.5	1-2"(.81);2-3"(1.0)/3-6"(.72)

the mainstem and tributaries will be needed. A detailed assessment of cover types used by juvenile coho will help refine juvenile coho HSC. In the interim, we recommend including cover provided by stream banks, vegetation, or large wood in combination with hydraulic criteria to define highly suitable juvenile coho habitat.

Another refinement will be greater recognition of different HSC within species' life stages. For example, juvenile 2+ steelhead require deeper and faster habitat than 0+ and 1+ juveniles. Several steelhead life history tactics require mid- to upper tributary juvenile rearing, basically with a 2+ pre-smolt then migrating downstream. These tactics will be critical for sustaining small populations until downstream conditions improve. A similar rationale can be applied to Chinook juveniles. As Chinook juveniles grow, they gradually become better swimmers and therefore less obliged to remain along

the channel margins. Pre-smolt, migrating juveniles frequently utilize deep pool entrances to feed and use bubble curtains as cover. HSC for fry (<55 mm), small juveniles (55 mm to 100 mm), and large/pre-smolt juveniles (> 100 mm) would improve instream flow need evaluations for many life history tactics.

We provide two recommendations regarding HSC development. Concurrent with the implementation of the next phases of instream flow needs assessments, CDFG should begin developing habitat suitability for Chinook salmon fry and juveniles in the Shasta Canyon reach. Fish densities should be high enough to allow abundant fish observations there. This would help clarify salmonid use of vegetation cover types unique to the Shasta Canyon (and potentially apply to other reaches of the Shasta River), and provide a means of evaluating the transferability of the Klamath and Trinity river HSC referenced in this study. In addition, we suggest that CDFG and UC Davis researchers consider incorporating HSC data collection procedures into their direct observation studies, particularly for coho fry and juveniles in the Shasta River mainstem at the Nelson Ranch and at Big Springs Creek. Given the low abundances of coho fry and juveniles, these habitat utilization measurements would need to be considered preliminary, but the time required to obtain multiple independent HSC measurements requires that researchers begin to collect those data now.

#### ***4.1.2 Microhabitat Mapping: Where and How Much?***

An early decision in evaluating instream flow needs for a given tactic is where and how much channel reach to measure. Representative channel reaches logistically are easier to measure and interpret, once the data have been collected. However, future adaptive management will likely require population prediction. Habitat abundance estimates throughout each reach comprising a given life history tactic will be required in the modeling. Although an initial instream flow needs investigation can be accomplished without population modeling, this option should not be compromised by prior data collection limitations. The data demands of population modeling and those of instream flow needs evaluation should be compatible.

The temptation is strong to recommend a minimum (or range) of preferred channel lengths for microhabitat mapping. However, we observed from the pilot microhabitat mapping in the Little Shasta River and Shasta River Canyon that habitat occurs at different spatial scales for different species and life stages. Adhering to a fixed reach length for microhabitat mapping will undoubtedly under-sample some habitats and over-sample others. Juvenile coho rearing habitat was extremely spotty on the Little Shasta River sample reach, whereas juvenile Chinook habitat was abundant at lower baseflows. Shorter reaches can be measured to construct good Chinook juvenile habitat rating curves and assess reach-wide Chinook juvenile rearing habitat, than for juvenile coho rearing habitat needs. In other streams, such as Parks Creek and Yreka Creek, both juvenile coho and 2+ steelhead habitat will likely be highly patchy. Sampling intensities must be matched with these spatial realities.

A distinct advantage of microhabitat mapping over PHABSIM and 2D hydraulic modeling is its adaptability. Steep and coarse segments for much of the Shasta River Canyon are difficult to model, as are many side-channels and single debris jams offering highly suitable juvenile coho rearing habitat. Another significant advantage has emerged recently with the availability of highly accurate global positioning technology. Microhabitat mapping has heretofore required detailed basemaps typically obtained from low elevation photography. An aerial photograph magnified to approximately 1:20 or less (depending on stream size) generally provides the necessary scale for developing a good basemap for recording habitat polygons. Streams with dense overhead canopy often require additional effort (e.g., helium balloon photography) to produce acceptable images. GPS does not eliminate the need for aerial photographs, but will reduce polygon mapping error. An aerial photo basemap will still be extremely useful in mapping an entire 'representative' reach, but a portable GPS system would

facilitate microhabitat mapping for much longer sections of stream channels for measuring widely spaced and less common microhabitats for juvenile coho and 2+ steelhead as well as habitat in all prominent side-channels.

A first step in implementing microhabitat mapping will be conducting reconnaissance-level channel surveys for a given life history tactic. An important objective will be to identify geomorphic spatial scales in these surveys that will be critical for making reach-wide habitat extrapolations. Rather than relying on traditional mesohabitat units to stratify channels, hydraulic units provide a more geomorphically and ecologically grounded stratification strategy. A hydraulic unit is a relatively short reach of channel with a common hydraulic setting, identified from aerial photos or in the field by thalweg orientation. The most common hydraulic unit is a single channel bend. A representative reach should include approximately 6 to 8 hydraulic units. A typical meander, comprised of two channel bends and therefore two hydraulic units, will have a channel length often varying from 7 to 10 bankfull widths. Eight hydraulic units would require a mainstem segment length equivalent to roughly 40 bankfull widths. In the Little Shasta River valley bottom this would be roughly 1,600 ft long. The length of a representative reach initially targeted for microhabitat mapping can be scaled to watershed size using this approach.

Another early decision is the frequency of microhabitat measurement. A habitat-flow curve will need a minimum of 5 to 6 mapped streamflows, but could benefit from 7 to 10 mapped streamflows, to sufficiently capture each rating curve's shape. The specific targeted flows should be identified before initiating the mapping, as a guide to conducting the fieldwork. However, this assumes the channel remains the same year-round. Emergent and submergent vegetation goes through cyclical growth spurts and die-offs. Dense vegetation can dominate microhabitat availability and quality. Although not observed in WY 2008 and WY 2009, winter peak floods will scour rooted vegetation and could greatly alter plant dominance the following spring and summer (and likely longer). There is no simple remedy but to remain observant and adaptable. Quantification of microhabitat abundance in the upper mainstem's sinuous valley bottom may not be prudent given the cyclical dominance of emergent and submergent vegetation. Although emergent vegetation in the Shasta River Canyon is pervasive, the primary effect is along the active channel margin (which is year-round) and on the benches and floodplain. This can be managed by microhabitat mapping the active (baseflow) portion of the mainstem channel, but treat the benches and floodplains differently. A lower and upper streamflow threshold for highly suitable rearing habitat can be established without microhabitat mapping each eddy and scour lane that will change seasonally as the emergent vegetation grows. The valley bottom of tributaries (e.g., Little Shasta River) may require separate winter, late-spring, and summer habitat rating curves for those tactics with late-spring and/or over-summer juvenile rearing needs.

#### **4.1.3 Microhabitat Mapping: Doing it.**

High quality aerial photo basemaps are essential for microhabitat mapping. Examples of aerial photos with different scales and photo resolution are provided in Appendix B. Season, vegetation condition, and streamflow are important variables to consider when collecting aerial photographs. The basemap size and scale used during microhabitat mapping may be determined by individual mapper's preferences, but we've found that 11 x 17 in printed and laminated maps are the handiest size, and scales larger than 1 in = 25 ft are too small to capture the desired level of detail in habitat polygons. A five or ten foot scaled grid overlain and printed on basemaps is also useful. In many channel reaches, microhabitat mapping onto aerial photos can be complimented, or even replaced, by using Total-Station or GPS surveying to map habitat polygons.

A core team of field biologists must be formed prior to field mapping. The core mapping team should be professional fisheries scientists with field experience observing habitat utilization for one or more targeted species. The mapping team should conduct a field calibration session to orient everyone and adopt a single microhabitat mapping protocol best suited for each reach to be mapped. At least two core team biologists should be present at each microhabitat mapping event.

With aerial basemaps, well-defined microhabitat criteria, and a depth/velocity measuring device in hand, microhabitats can be delineated that meet the HSC requirements for each species and life stage being evaluated. The microhabitat polygon is then drawn onto the basemap using color pens. Alternatively the Total-Station or GPS survey techniques could be used to delineate the polygon boundaries. An important step in the microhabitat delineation process is determining how many points along the habitat polygon boundary are measured to define the polygon. Our recommendation is that enough points are measured to reduce error so that no more than 15% of the polygon is outside the hydraulic criteria or that an area no larger than 15% of the total polygon area is outside the polygon boundary. This process of detailed depth and velocity measurement is slow but necessary to preserve the repeatability of the method. Several hydraulic units should be mapped and then remapped at greater detail to quantify the mapping error in selected channel segments.

We do not recommend mapping hydraulic criteria and cover components separately and then combining them later in a computer application to define the microhabitat boundaries. This procedure potentially results in extraneous measurements where there is no habitat. Instead, core mappers must be able to “see” each polygon in the field as a specific microhabitat for a targeted species and life stage. According to our criteria (Table 2) there should therefore be a minimum of five sets of anadromous salmonid polygons (spawning, fry rearing, and juvenile Chinook, coho, and steelhead rearing), if habitat for each species and life stage is present. Given the potential confusion in drawing these lines, more than one set of basemaps may be required for each streamflow mapped.

During the microhabitat mapping, several key features of the study site should be delineated in addition to the microhabitat polygons. These include the wetted edge of the channel, the proximity of main channel flow to thresholds for flow accessing side channels or other lateral habitat features, and riffle crest thalweg depths in the mainstem and side-channels (if inundated)(described in Section 4.4 below). For each study site, several (at least 2 or 3) photo monitoring sites should be established, with panoramic photographs (described in Appendix B) taken at each monumented photo-point for each streamflow mapped. We also recommend mapping benthic macroinvertebrate habitat in riffles (using generalized criteria) and amphibian habitat.

The HSC will not be infallible. Invariably field biologists conducting the microhabitat mapping will encounter an area of channel that meets the defined criteria, but simply doesn't appear to be good habitat. Or conversely an area may not meet the defined criteria but nevertheless appears to be good habitat. In these situations, we recommend recording these polygons as a separate layer (e.g., a dashed instead of solid sharpie line of the appropriate color). In this way, these anomalous areas can later be included or excluded, and if too many such patches occur, the criteria may require refinement to include or exclude these areas, as the case may be.

Each laminated basemap sheet should be labeled with the field crew names, mapping date, estimated discharge (measured on-site or from nearby gage), and legend key. Completed basemaps should be archived as original data sheets (i.e., don't erase polygons and reuse basemaps).

#### **4.1.4 Constructing Habitat Rating Curves**

Once the fieldwork is complete, the mapped microhabitat polygons must be digitized from the aerial basemaps and compiled by species and life stages. Habitat rating curves can then be constructed for each species and life stage within each channel segment for a given life history tactic, with the X-axis = streamflow (cfs) and the Y-axis = habitat (ft<sup>2</sup>). Habitat rating curves can easily be developed for each nested spatial scale for a given life history tactic. The basic unit of measurement will be a habitat rating curve for each prominent microhabitat feature measured. This could mean a separate rating curve for a large pool's entrance, tail-out, point bar fringe, and the deep scoured portion of the pool (particularly if associated with LWD).

Microhabitat areas within study sites should be extrapolated to the reach scale based on the initial macro-scale mapping. We do not recommend using mesohabitat units as a basis for extrapolation; instead, extrapolation based on habitat density (microhabitat area per stream length) is preferred. If a sub-reach did not have a study site selected to represent that reach, then the study site with the most similar conditions should be used for extrapolation.

### **4.2 Identifying Thresholds of Abundant Instream Habitat**

At each of our three study sites – the Little Shasta River, the Shasta Canyon, and the Nelson Ranch we encountered habitat complexity too high for accurate quantification. We therefore set objectives for identifying flow thresholds above which specific, targeted instream habitat (or migration conditions) are met. This method requires evaluation of a range of streamflows, but does not require a habitat-flow curve or estimate of habitat area. The advantage of this method is that it allows a reach-wide evaluation to identify a specific instream flow need where habitat quantification is either infeasible or prohibitively labor-intensive. We identified at least four objectives at our study sites where this approach can be applied.

#### **4.2.1 Side-channel Features at the Little Shasta River**

In the bottomlands reach of the Little Shasta River, snowmelt floods during spring often exceeded the main channel capacity, and streamflow accessed side-channels and floodplains. This seasonal flood likely provided abundant habitat for many rearing life stages (fry, juvenile, pre-smolt) in off-channel locations. This habitat is difficult to quantify, however, because streamflow diversions have reduced the frequency of these flows.

Within our Little Shasta River study site we identified several side channels that could provide abundant habitat with seasonal streamflow (Figure B17). A study objective was to identify a specific flow threshold above which these channel features would be flowing. Identifying these thresholds requires either a stage-discharge relationship at each side-channel entrance, and/or photographs from monumented photopoints over a range of flows bracketing the threshold, along with gaged daily average discharge. We provide a photopoint example in Figure B12. We also noted in at least one example the side channel entrance had become aggraded, thus requiring higher stage (and discharge) to allow flow into the side-channel. In these cases it may be practical to mechanically lower the entrance threshold to allow more frequent inundation.

#### **4.2.2 Lateral Rearing Habitat Features in the Shasta Canyon**

The Shasta Canyon reach is a moderate gradient, bedrock-dominated reach with a single-thread main channel. We noted many features adjacent to the main channel such as side-channels and low-elevation floodplain benches that provide abundant rearing habitat when inundated. Available NAIP 2005 aerial photographs were used to map these features (Figure B18). Several of these sites were



then evaluated during this study to determine (1) what methods could be used to quantify habitat in these features, and (2) if flow thresholds could more easily be identified. Appendix B provides a summary of this investigation.

As with the Little Shasta River side-channel features, identifying thresholds of for flow access to off-channel features requires a stage-discharge relationship at each side-channel entrance, and/or photographs from monumented photopoints over a range of flows bracketing the threshold. A gaged daily average discharge is also needed. Along with this information, a qualitative evaluation of habitat quality at a subset (or all) of these features, from field observations and photographic interpretation, would help refine a determination of instream flow needs. At least one exception – the Salmon Heaven side channel – provides spawning habitat that should be quantified (i.e., a habitat-flow curve) by microhabitat mapping over a range of streamflows.

#### **4.2.3 Adult Salmonid Migration Through the Shasta Canyon**

In the Shasta River canyon, barriers to upstream migration may be caused by anthropogenic features such as diversion dams, natural features such as high-gradient riffles, transverse bars, and cascades (physical barriers), and by unsuitable water temperature (thermal barriers). Each physical barrier may be passable over a specific streamflows and should be evaluated independently to identify a flow threshold that provides passage. In addition, the cumulative effect of many individual barriers slowing the rate of upstream migration should be considered. We recommend identifying a single flow threshold that provides “good” passage conditions (not a “minimum” passage flow) for many or all potential barriers through the Shasta Canyon to the mouth of Yreka Creek. Migration flow thresholds should be plotted with X-axis = Longitudinal Distance from the Klamath River and Y-Axis = Discharge, to allow evaluation of cumulative passage longitudinally through the Shasta Canyon reach. We also recommend the riffle crest thalweg depth be measured in several sub-reaches of the Shasta Canyon, and plotted with discharge. This method is described below and in Appendix B.

#### **4.2.4 Shallow-water Rearing Habitats of the Nelson Ranch Reach**

UC Davis researchers investigating salmonid habitat use at the Nelson Ranch developed a site-specific habitat classification system (Jeffres et al. 2008). Their direct observations using snorkel surveys revealed steelhead fry utilization of abundant shallow-water habitat types along the river margins. This rearing behavior persisted from late-winter into early spring. Once irrigation season began on April 1, streamflow diversions caused the river stage to drop, forcing salmonid fry to relocate to other (potentially less abundant) rearing habitat. According to Jeffres et al. (2008) “...by June, aquatic macrophytes had become well established and juvenile steelhead had begun to utilize this productive and bioenergetically favorable habitat”. Given that April, May, and June are critical months for salmonid growth, the continued availability of abundant shallow-water rearing habitat is an important component in the life history of several salmonid tactics. Utilization of this habitat type would likely persist if it were available.

Quantifying habitat area (in ft<sup>2</sup>) in these shallow, highly variable features is less a priority than identifying flow (and stage) thresholds above which habitat is available to salmonids. We recommend an analysis using GIS mapping data and stage and discharge data collected by UC Davis researchers to identify a range of flows within which the shallow-water habitat is suitable for fry and early juvenile rearing life stages. This analysis would consist of mapping all shallow-water habitat features within several selected study sites, then implementing a similar approach described in Section 4.2.2 for the Shasta Canyon. This should include stage discharge relationships and photo monitoring at multiple sites, with qualitative estimates of habitat quality at each flow observed.

### **4.3 Demonstration Flow Assessment**

The Demonstration Flow Assessment (DFA) method has been described in several different forms (Annear et al. 2004; Railsback and Kadvaný 2008) to fit a variety of applications. In the Shasta River, DFA methods (using photo-monitoring) may be particularly useful where access to private lands is not available. We recommend application of panoramic photographs at monumented photo monitoring sites to (1) document streamflow and habitat conditions available when microhabitat is mapped to produce habitat-flow curves, (2) document when flow thresholds are exceeded, such as flow into backwater and side-channel features, inundation of cover features, or submersion of lateral spawning gravel patches or migratory passage barriers, and (3) provide visual props during discussions and presentations to stakeholders. For demonstration purposes, habitat polygons mapped onto rectified aerial basemaps can be transferred onto oblique panoramic photos to provide a good visual tool for discussing habitat areas and application of habitat criteria (Figure B11).

### **4.4 Riffle Crest Thalweg Depth**

If all streamflow was abruptly cut-off, a stream's pools would become isolated standing water separated by dewatered riffles. The water surface elevation of each pool would be determined by the immediate downstream riffle crest's thalweg elevation, where the 'thalweg' is the deepest spot on a channel cross section spanning the riffle crest. Fish biologists and geomorphologists define maximum pool depth at zero streamflow as the 'residual' maximum pool depth. During stream surveys, maximum pool depth can be measured independent of the ambient streamflow by subtracting streamflow depth at the downstream riffle crest from the maximum pool depth. Although an important stream monitoring tool, the riffle crest thalweg (RCT) has been under-appreciated, and therefore under-utilized, by geomorphologists and stream ecologists.

The riffle crest influences salmonid habitat in small streams by imposing a primary hydraulic control on water depths and velocities for most of the water year. During baseflows and higher receding storm flows, the riffle crest exerts hydraulic resistance, initiating a backwater effect on upstream pools, runs, and glides. Streamflows approaching the riffle crest must pass through the narrower and shallower riffle cross section. Only at peak flows is this backwater effect mostly drowned-out. However, bankfull channel width at the riffle crest tends to be narrower than elsewhere in a stream. So even at bankfull flows and higher, the riffle crest location can be hydraulically significant.

The hydraulic influence of the riffle crest, and the riffle crest's thalweg, should be incorporated into a process-based methodology for quantifying instream flow needs. One theoretical justification, and broad management goal, would be to prescribe a diversion rate that does not significantly diminish this key hydraulic function, and therefore, would sustain anadromous salmonid spawning and rearing habitat. The maximum change in stage at the riffle crest's thalweg that would not measurably impair anadromous salmonid habitat availability could be converted to a maximum allowable diversion rate.

Our preliminary finding is that the median riffle crest (RCT) depth is weakly, if at all, a function of drainage area, but more strongly a function primarily of streamflow (smaller grained alluvial channels have oblique point bars with shallower RCT depths). Although more data are needed to substantiate this observation, the median RCT depth can become an important rule-of-thumb method for evaluating instream flow needs when landowner access or time is limiting.

#### **4.5 Standard Setting Hydraulic Methods – Wetted Perimeter, R2 Cross, Tennant**

Hydraulic data (depth, velocity, slope, stage, discharge) collected at cross sections within mapping reaches is useful for understanding the effects of flow changes on aquatic habitat, especially in combination with microhabitat mapping, oblique panoramic photographs, or other data describing habitat availability or habitat use. Given the relative ease of calculating the wetted perimeter and the hydraulic variables used in R2 Cross (See Appendix B), application of these methods can provide additional quantitative information on instream flow needs estimated from other methods. We do not recommend using these methods as a primary approach to estimate instream flow needs or establish flow requirements in the Shasta River basin. These methods are not intended to provide flows protective of all species and life stages, nor are they intended to promote species recovery from low population levels.

However, given that these methods can rapidly identify a lower boundary of suitable hydraulic conditions, above which water depths and velocities begin to approach a range considered suitable for salmonid habitat, these methods could be used in combination with riffle crest thalweg depths (and other available data) to identify interim minimum baseflows, above which minimum functions such as fish passage over riffles, and spawning, may be provided. These rule-of-thumb estimates could serve until more detailed habitat quantification methods could be applied and instream flow needs for a broader range of habitat functions and life history tactics identified.

#### **4.6 Incremental Habitat-Modeling Methods (PHABSIM and 2D Modeling)**

This category of methods generally includes PHABSIM (1D) and 2-dimensional (2D) modeling approaches that combine hydraulic models with habitat suitability criteria to predict habitat flow relationships over a range of modeled flows. These two methods are the most widely used instream flow methods, with the 2D modeling approach recently gaining popularity in IFIM studies because of the spatially-explicit habitat output that allows validation studies to accompany instream flow needs estimates.

We do not recommend an IFIM habitat modeling approach for the Shasta River, for several reasons. First, we strongly support the more transparent and, in our view, more accurate microhabitat mapping approach to developing habitat-flow curves. The greater accuracy results from microhabitat mapping's requirement of observing and measuring pre-determined hydraulic variables and other habitat variables at each habitat polygon before it can be included in a habitat area estimate. Also, a 2-dimensional hydraulic model would be extremely challenging to calibrate in the Shasta River mainstem and Little Shasta River bottomlands reaches, where the spring-creek channel morphology and aquatic vegetation create highly complex hydraulic conditions. Second, we believe the method for obtaining a habitat-flow curve is of secondary importance to the analytical approach used once the desired curves are obtained. The analytical approach typically employed in IFIM studies (time-series analysis) loses the integrity of the annual hydrograph by relying on flow and habitat duration curves. This analytical approach also appears less transparent to non-technical audiences than the Number of Good Days approach we've developed. Finally, a hydraulic modeling approach may be much more expensive to implement, given the number of discrete reaches and multiple independent diversions that are distributed throughout the Shasta River basin.

With that perspective, however, we do not explicitly recommend against use of 2D modeling in explicit situations, or if the limitations of this approach can be balanced with other methods. The ability to input different criteria, update bed topography, and model a wider range of flows than may be feasible to microhabitat mapping are obvious strengths of a modeling approach. One useful application of 2D modeling may be in an assessment of spawning flow requirements in the

Shasta Canyon, in the mainstem Shasta River below Dwinnell Dam, and/or in Parks Creek below the MWCD Diversion, where the alluvial channel morphology of these reaches renders hydraulic modeling more feasible. Two-dimensional hydraulic modeling may be especially useful for assessing spawning gravel availability and the potential need for gravel augmentation in these reaches. Another application could be in combination with a redd-scour model to evaluate risk associated with location of redd construction from winter high flow scour.

## **5 ANALYTICAL APPROACH: THE UNIMPAIRED HYDROGRAPH AND NUMBER OF GOOD DAYS**

### **5.1 Unimpaired Hydrographs and Thermographs as Baseline for Quantifying Recovery**

An instream flow assessment needs a baseline for measuring the degree of attainable recovery. We suggest a reference baseline of historical hydrologic and thermal conditions for judging impacts and determining the extent of feasible recovery. Unimpaired flow is the natural flow in a stream without human alteration such as irrigation withdrawals, impoundments, or diversions. The unimpaired annual hydrograph is thus the unaltered annual flow pattern, commonly presented as a graph of annual daily average streamflow for each day of the water year. The fundamental assumption in relying on the unimpaired hydrograph is that it provide the impetus for processes that shaped and sustained the river's morphology, natural riparian vegetation patterns, and key salmonid habitat features and life history characteristics (among other functions). According to the National Research Council: "In the 1990's, a growing body of research emerged, directed at managing river health, or the ecological integrity of riverine systems...suggesting that a healthy aquatic ecosystem requires the intra- and inter-annual patterns of flow variation in the natural flow regime be considered" (Karr 1991, Frissell and Bayles 1996, Poff et al. 1997, Richter et al. 1997, USFWS and HVT 1999, Trush et al. 2000, NRC 2007).

In our proposed methodology, the baseline, or reference condition, would be defined by considering life history tactics, then reconstructing unregulated streamflow and temperature regimes at strategic locations where instream flow needs must be identified. We emphasize that the use of unimpaired streamflow and temperature conditions does not suggest the intention of recommending those conditions; the unimpaired hydrograph is simply a reference point against which instream flow needs are evaluated.

Because the earliest streamflow gages were installed after water development began in the Shasta basin, no flow records provide an accurate estimate of the unimpaired annual hydrograph. For purposes of demonstrating our analytical approach, we relied on available USGS gaging data and anecdotal information describing ungaged spring discharge to develop a set of unimpaired hydrographs for the mainstem Shasta River and for the Little Shasta River. For the Little Shasta River, we combined USGS 'Little Shasta River near Montague' gaging records (Station 11-516900) for the available period of record (1958-1978) with an assumed 12 cfs constant discharge from Evans Springs and Cold Springs. These hydrographs approximate unimpaired streamflow at the base of the foothills (Figure 8). For the mainstem Shasta River below the Little Shasta River confluence, representative annual hydrographs were constructed from USGS gaging records 'Shasta River near Edgewood' (Station 11-516750) for six water years (1959, 1963-1967), by summing the Shasta River at Edgewood, 10 cfs year-round discharge from Carrick Creek Springs, 125 cfs year-round discharge from Big Springs, the Little Shasta River near Montague, and 12 cfs year-round discharge from Evans and Cold Springs (Figure 9). These hydrographs thus represent unimpaired streamflow at and below the confluence of the Little Shasta River. They do not account for additional flow input from the ungaged Yreka, Willow, and Julian creek watersheds.

Baseline water temperature conditions are more problematic: no empirical unimpaired data are available. The Northcoast Regional Water Quality Control Board (Regional Board) and UC Davis researchers Mike Deas and Sarah Null have developed temperature models for the mainstem Shasta River and for tributary boundary conditions. These models were modified recently to estimate unimpaired water temperature conditions for the year 2001 (Deas and Null 2007, Null 2008, Null et

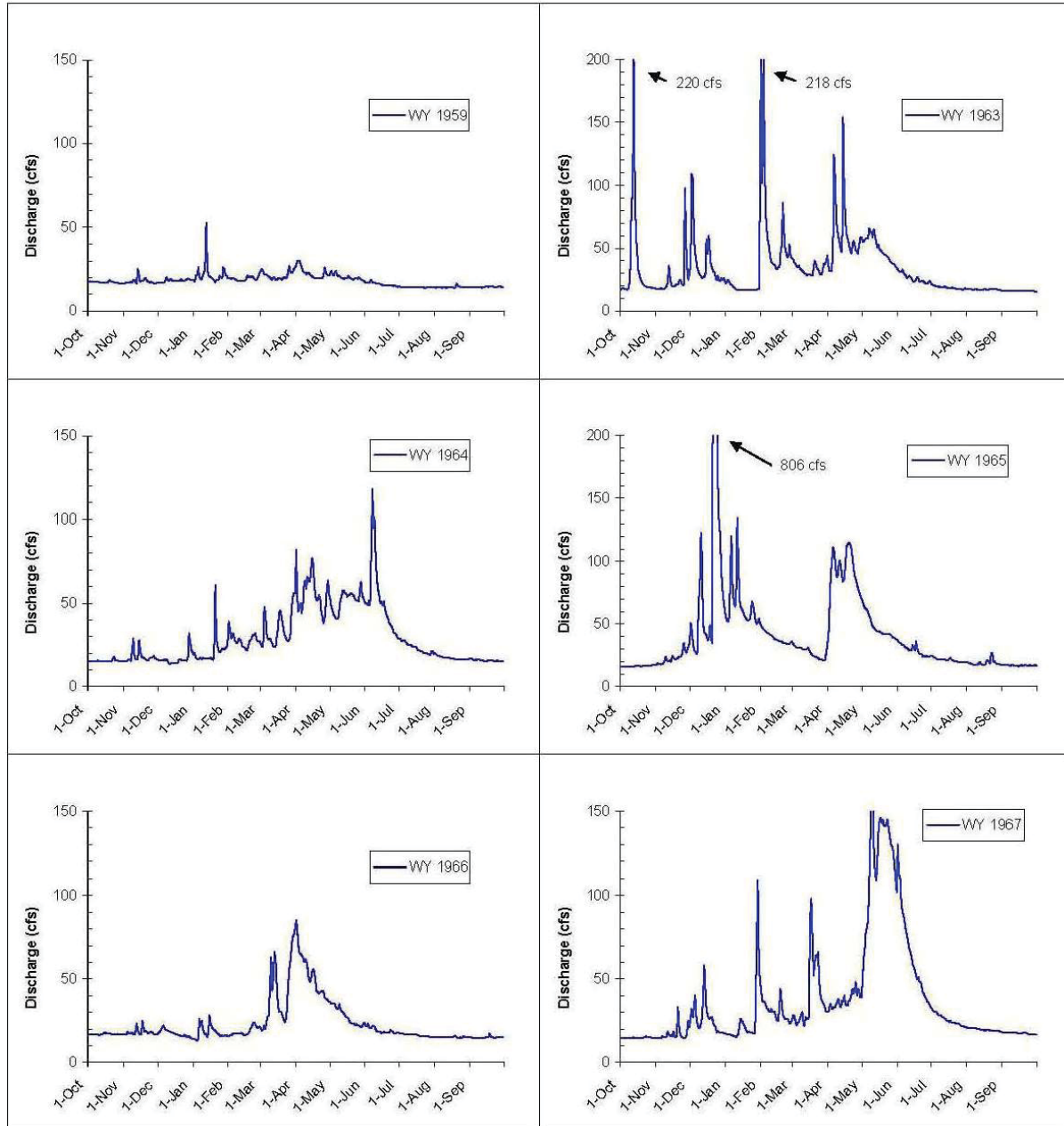


Figure 8. Annual hydrographs from USGS ‘Little Shasta River near Montague’ gage (11-516900) with a conservative 12 cfs daily average flow added to represent historical spring discharge from Evan Springs and Cold Springs located below the USGS Gage location. The annual hydrographs are a good approximation of historical unimpaired flows in the Little Shasta River Bottomlands reach. Common hydrograph components include spring-charged summer and winter baseflows, winter floods, and a spring snowmelt flood in April or May of most water years.

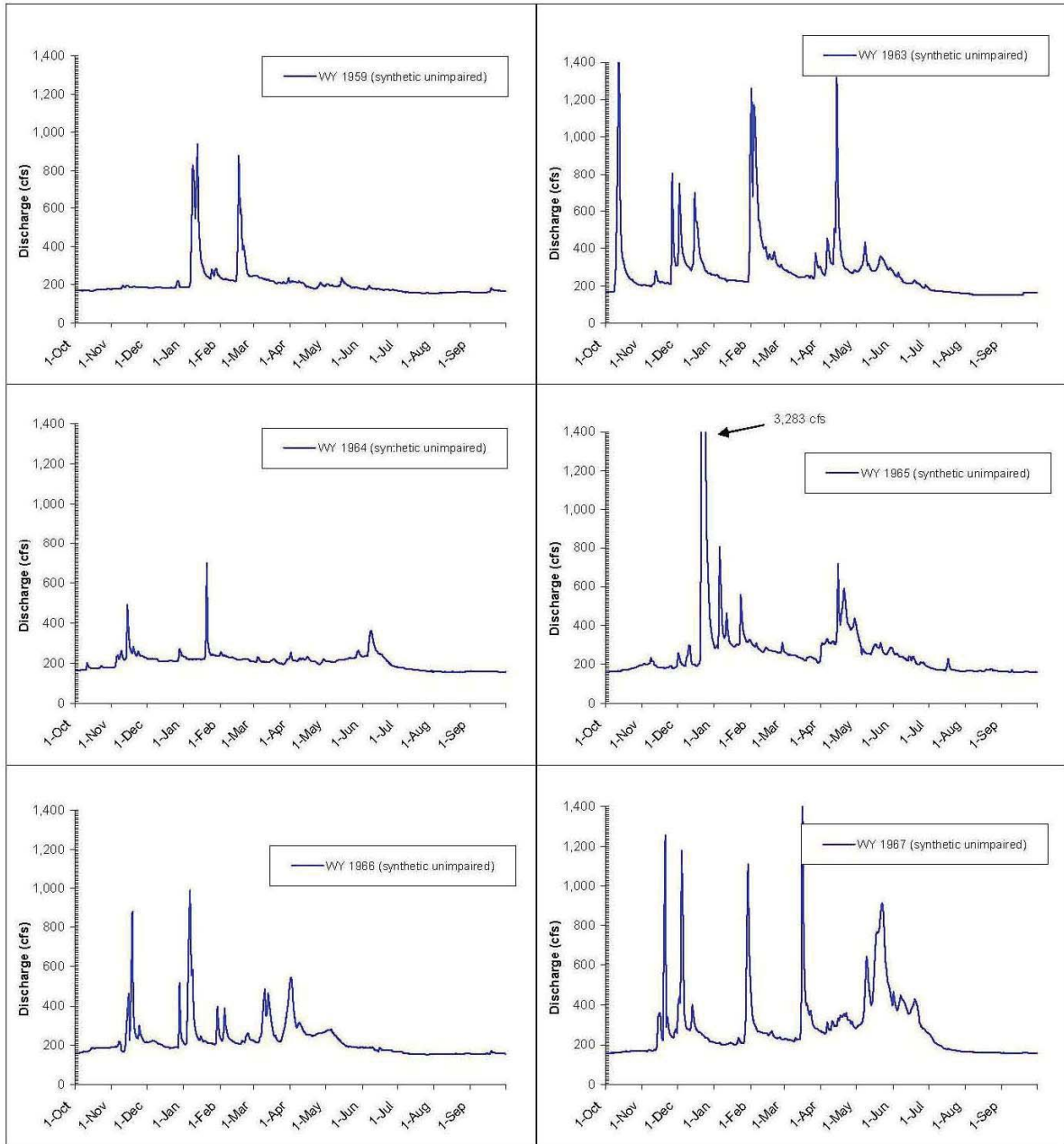


Figure 9. Annual hydrographs representing cumulative discharge for the Shasta River mainstem below the Little Shasta River confluence for the six water years of overlapping flowdata (1959, 1963-1967), including the USGS ‘Shasta River near Edgewood’ gage, 10 cfs discharge from Carrick Creek Springs, 125 cfs year-round discharge from Big Springs, the USGS ‘Little Shasta River near Montague’ gage, and 12 cfs year-round discharge for Evans and Cold springs. The annual hydrographs are a conservative approximation of historical unimpaired flows in the mainstem Shasta River, as several tributary inflows are not included.

al. 2009 in press). We obtained daily average unimpaired water temperature data from Sarah Null for three locations: the Shasta River mainstem at the Anderson Road Bridge, at the confluence with the Klamath River (mouth), and for the Little Shasta River at its confluence with the mainstem. We reviewed this data and decided against presenting this in our demonstrated analysis (below) because the data were from different water years. However, our analytical framework will require additional temperature modeling of unimpaired conditions paired with the capability of modeling alternative instream flow recommendations for numerous (e.g., at least 10) consecutive water years representing a range of water year types.

## 5.2 Number of Good Days (NGD)

### 5.2.1 Overview of Analysis

What seems urgently missing in how we quantify instream flow needs is not as much how we construct habitat-flow relationships, but rather what we do with them once constructed. Ecologically, habitat-flow relationships are abstract unless aligned with what an individual organism actually experiences day-to-day, and the cumulative consequence of those daily experiences among all individuals in the population. Annual hydrographs and annual thermographs, records of daily streamflow and temperature fluctuation, provide a way to bridge the abstract to real ecological consequences.

Instream flow needs for each life history tactic must address temporal and spatial constraints within the Shasta River basin. A key step in our analytical framework is replacing the Y-axis of the annual hydrograph (Q) and annual thermograph (T) with ecological variables pertinent to life history tactics, and ultimately to the number of returning adult salmon and steelhead. This Y-axis replacement can be accomplished by: (1) re-making the Y-axis into a biological variable that directly measures an organism's response (e.g., exchanging T for 'specific growth rate' on the Y-axis) and/or (2) establishing a threshold(s) for a new Y-axis that biologically defines a physical variable. Using annual hydrographs and thermographs, therefore, allows a day-to-day accounting of changing habitat availability, growth potential, fish passage, and even stream productivity (targeting abundant benthic macroinvertebrate riffle habitat). This accounting mechanism can be evaluated individually for a life history stage or collectively to assess instream flow needs for each tactic.

A simple modeling and accounting strategy is to count the number of good days (NGD) in which habitat requirements are met for a specific life history tactic. If the annual hydrograph and thermograph satisfy all specified thresholds defining each tactic's habitat requirements on a given day, then that day (in that year and in that channel reach) is counted a 'good day' for that tactic (Figure 10). This accounting strategy can be conducted for individual life stages, for the entire tactic's freshwater life cycle, and for many water year types. Thresholds must be established for 'good' habitat availability, thermal conditions, and stream productivity. Good habitat capacity is exceeding a minimum habitat area (ft<sup>2</sup>) threshold on any given day. Good habitat quality is staying within a suitable range in water temperatures (°F) favoring rapid growth. Good stream productivity is exceeding a threshold minimum riffle area (ft<sup>2</sup>) for good benthic macroinvertebrate habitat and staying within a threshold range of favorable water temperatures for rapid macroinvertebrate growth.

The fundamental 'unit' of measurement for an NGD analysis must be a stream's annual hydrographs and annual thermographs. The analytical framework maintains the integrity of each annual hydrograph throughout the analysis. For example, if we replace Q (on the hydrograph) with habitat abundance (using a streamflow-habitat rating curve), the resulting 'annual habigraph' (with 'day' still on the X-axis) preserves the sequence of daily average streamflows (though converted to ft<sup>2</sup> of habitat). Habitat-duration curves do not accomplish this and are thus not as useful.



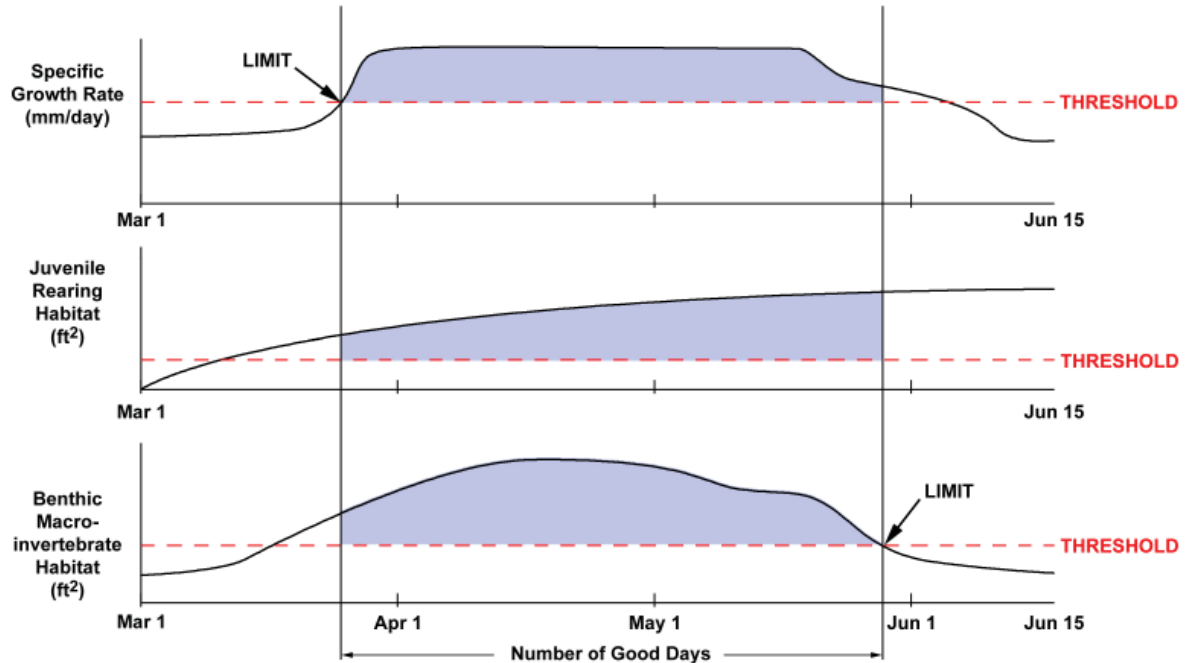


Figure 10. Illustration of analytical process for calculating Number of Good Days using three quantified variables and their associated thresholds: specific growth rate, juvenile rearing habitat area, and productive riffle habitat. This analytical process first quantifies each variable as a function of streamflow ( $Q$ ), then replaces  $Q$  on the Y-axis with ecological variables pertinent to specific life history stages. The Number of Good Days (NGDs) in which each targeted threshold for each variable are met, are counted.

An instream flow prescription would be expected to maintain, and generally increase, NGD within the time window of the life stage being assessed. An upper limit on NGD, establishing baseline performance, can be determined from unregulated annual hydrographs, then compared to present regulated instream flows and proposed instream flow needs.

Ideally all fish would encounter nothing but good days during their stay in the Shasta River basin. But even unimpaired annual hydrographs likely did not meet this expectation. The many successful life history tactics in the Shasta River basin are a testament to highly variable water years, in different regions of the basin that favored some tactics over others in any given water year. NGDs created from unregulated and regulated annual hydrographs and thermographs for each life history tactic will incorporate spatial and temporal variability into the instream flow needs assessment.

An important task in calculating NGD will be developing thresholds for good habitat capacity, quality, and productivity. Methods for quantifying fish and macroinvertebrate habitat abundance as a function of streamflow (habitat-flow curves) are diverse and all imperfect. NGD assessments can be done for representative reaches but would best be served by acquiring reach-wide habitat estimates for each tactic. Finding the methods best suited for the Shasta River basin required a study itself (Appendix B).

**5.2.2 Necessary Prerequisites for the NGD Analysis:**

1. Targeted species life history tactics with specific life history stages and life history stage periodicities assigned to each channel reach within each life history tactic.
2. Constructed habitat-flow curves for appropriate anadromous salmonid species and their life stages for inner mainstem and side-channels.
3. Constructed habitat-flow curves for benthic macroinvertebrates for the inner mainstem.
4. Riffle crest thalweg (RCT) surveys for each channel reach spanning a full range of streamflows for the instream flow needs evaluation, including paired measurements of the RCT controlling the mainstem channel water surface and adjacent side-channel entrance water surface.
5. At least ten continuous water years of annual hydrographs and thermographs for each channel reach of a life history tactic.

**5.2.3 Basic NGD Set-Up:**

1. Develop water year types by ranking annual yield totals.
2. Select a minimum of ten continuous water years for NGD analysis that includes the full range of water year types.
3. Construct unregulated and regulated annual hydrographs for each water year (want to include all time periods spanning all life history needs) using daily average streamflows.
4. Construct unregulated and regulated annual thermographs for each water year.
5. Assign water temperature thresholds for good, fair, poor, and bad growth/survival (may consider side-channels independently).
6. Construct unregulated and regulated annual habigraphs for each water year from the streamflow-habitat rating curves.
7. Assign habitat abundance thresholds to the streamflow-habitat rating curves for inner mainstem and side-channels.
8. Construct unregulated and regulated annual stage-o-graphs for each water year from the riffle crest surveys.
9. Assign RCT depth thresholds by species/life stage.
10. Define streamflow passage windows at identified/suspected migration barriers.

**5.2.4 Basic NGD Analysis:**

11. For each unregulated water year, compute the number of days within the specified time period that all thresholds for good habitat are met. For juvenile Chinook rearing, these thresholds will be high habitat capacity, good growth potential, and high stream productivity.
12. Repeat (11) for the present regulated condition as well as potential instream flow scenarios. Initially consider simplified instream flow scenarios that use diversion rate only, bypass flow only, and/or a combination of the two.
13. Compile NGD results from (11) and (12) by plotting NGD (Y-axis) against the instream flow prescription (X-axis) for each general prescription scenario.
14. Establish a threshold band for NGD. This step can be simple or extremely complex. 'Simple' identifies sharp changes in the plotted NGD results from (13) and 'complex' may require a population model or individual-based model.
15. Evaluate the sensitivity of NGD outcome to thresholds, basic life history assumptions, and measurement errors.
16. Report findings from the basic NGD analysis.

### ***5.2.5 Additional NGD Analyses:***

Beyond the analysis of NGD for individual life history tactics, several other analyses may be useful. First, in addition to evaluating single life history stages in NGD analyses, the relative success of individual cohorts can be followed through a linked NGD analysis. No additional computations would be necessary, but the results would be compiled and interpreted differently. For example, for how many cohorts has Chinook adult migration, followed by egg incubation, followed by fry rearing, followed by juvenile rearing, followed by smolt outmigration life stages all achieved 50% or more NGD's, thus qualifying as good Chinook freshwater cohort years (NGY's)? This statistic might be more compelling than simply NGD relative to the baseline.

Next, the NGDs experienced by an individual fish can be evaluated, based on different emergence timing. For example, if a Chinook fry emerged from the redd on February 1, then migrated downstream at a rate of 500 ft daily, how many good days would this fish encounter in a given WY before entering the Klamath River? If another fish emerged on February 2, how many NGDs would this fish encounter in a given WY? If a juvenile leaving Big Springs on May 1 experienced good conditions during its downstream migration to the Canyon, would a juvenile leaving May 2 also encounter good conditions throughout its downstream journey? May 3? This analysis quantifies the number of good (potentially successful, if not eaten on the way) juvenile migration departures. This approach can incorporate several channel reaches, or at least provide strong spatial/temporal context.

An NGD analysis can be paired with a growth model to identify a minimum attainable smolt size as 'good' using an analytical framework. This analysis thus attempts to quantify the ultimate X-Y graph, identifying flows that achieve the highest growth rates for specified increments of water (i.e., maximizing beneficial uses).

Finally, identifying instream flow needs that provide many good days is still not sufficient. In addition to computing NGD, we must also protect against poor or bad days, or in some cases lethal days (e.g., from a pulse of high temperature, or channel dewatering). The Number of Bad Days (NBD) may warrant more attention than NGD if options for releasing more instream flows are not available. The Number of Bad Days must distinguish chronic poor habitat conditions (i.e., sub-lethal, longer time-spans) from acute habitat degrading events exceeding fish tolerance limits ( i.e., lethal or causing emigration ). These two conditions have much different outcomes with regard to persistence of a specific life stage at a particular location.

### **5.3 Working Example of an NGD Analysis**

The NGD analytical framework emphasizes simplicity and transparency. To appreciate how it works, an example is helpful. The 'data' applied in this example were obtained, in part, from microhabitat mapping conducted at the Little Shasta River. Where habitat-flow curves were incomplete at higher flow ranges, we extended the curves using our professional judgment to create a plausible example.. This analysis is not intended to identify actual instream flow needs, but simply to demonstrate the analytical process of doing it.

Following Steps 2-7 outlined above (excluding temperature), the Little Shasta River valley bottom Chinook life history tactic was selected for our model analysis. Eleven annual hydrographs, from WY 1958 through WY 1968 for the Little Shasta River near Montague (USGS 11-516900) provided estimates of unregulated streamflows. The published USGS daily average data were modified by adding 12 cfs daily average flow to account for springs below the gaging station. Unimpaired temperature data were unavailable, so the NGD in this example was computed only relative to habitat abundance (i.e., a good day occurred when habitat abundance exceeded the threshold abundance for 'good' habitat capacity independent of water temperature). Habitat-flow curves for Chinook fry and

Chinook juveniles were approximated from the limited data available (Figure 11) for the mainstem channel and side-channels in the Little Shasta River microhabitat mapping reach. We estimated a threshold for abundant Chinook juvenile habitat of 8,000 ft<sup>2</sup> and for Chinook fry habitat of 2,000 ft<sup>2</sup>. Therefore, an NGD for Chinook juveniles occurred when the total ft<sup>2</sup> of habitat (inner mainstem habitat and side-channel habitat combined) exceeded 8,000 ft<sup>2</sup> each day between March 1 and May 31 in each water year. The annual hydrograph (solid black line) and habigraph (solid blue line) were plotted for the period January 1 to June 1 for one example Water Year: 1962 (Figure 12 upper chart). The Number of Days the habigraph exceeded the targeted habitat threshold were then summed for the time period (Figure 12 orange dotted line). This procedure is repeated for each water year using the 11 baseline unimpaired water years (Step 11 above). In the example provided (Figure 12 upper chart), the habitat area threshold was not met during a few intermittent baseflow days due to lower daily average flows, then for several consecutive days in early April when streamflows were high.

The next step in the analysis (Step 12) analyzed a simple scenario of fixed daily diversions, at 5 cfs increments. In this analysis, we applied the same diversion rate each day within the time period for fry and juvenile life stages, beginning with 5 cfs diversion, then 10 cfs diversion, etc. Annual habigraphs were generated at each diversion rate for eleven different water years (1958-68) for diversion rates from 5 to 50 cfs. An example of the NGD analysis using the same WY 1962, with 20 cfs diversion rate is presented in Figure 12 lower chart.

With NGD computed for each water year and for each diversion rate, results of this hypothetical NGD analysis were plotted in Figures 13 and 14. For Chinook fry, daily diversion rates greater than 10 cfs began to greatly decrease NGD in drier water years. In the wettest two years (WY 1965 and WY 1958) a sharp decline was not evident until approximately 20 cfs diversion. For Chinook juveniles, dry years were immediately impacted by a 5 cfs diversion whereas wetter years required substantially higher diversions. To reiterate, this analysis is based only on habitat area using curves extrapolated beyond our empirical data, for illustration purposes only. It is not intended as a meaningful analysis of diversion rates.

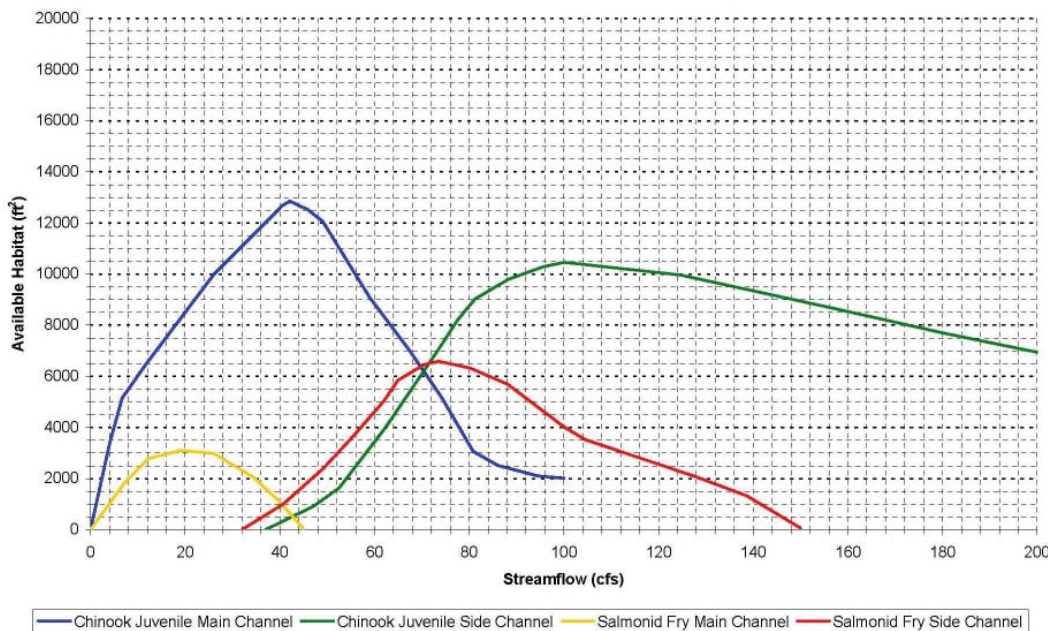


Figure 11. Hypothetical sketched Chinook fry and juvenile habitat rating curves for the Little Shasta River mainstem channel and side-channels in a 1,300 ft long reach at the Shasta Valley Wildlife Area.

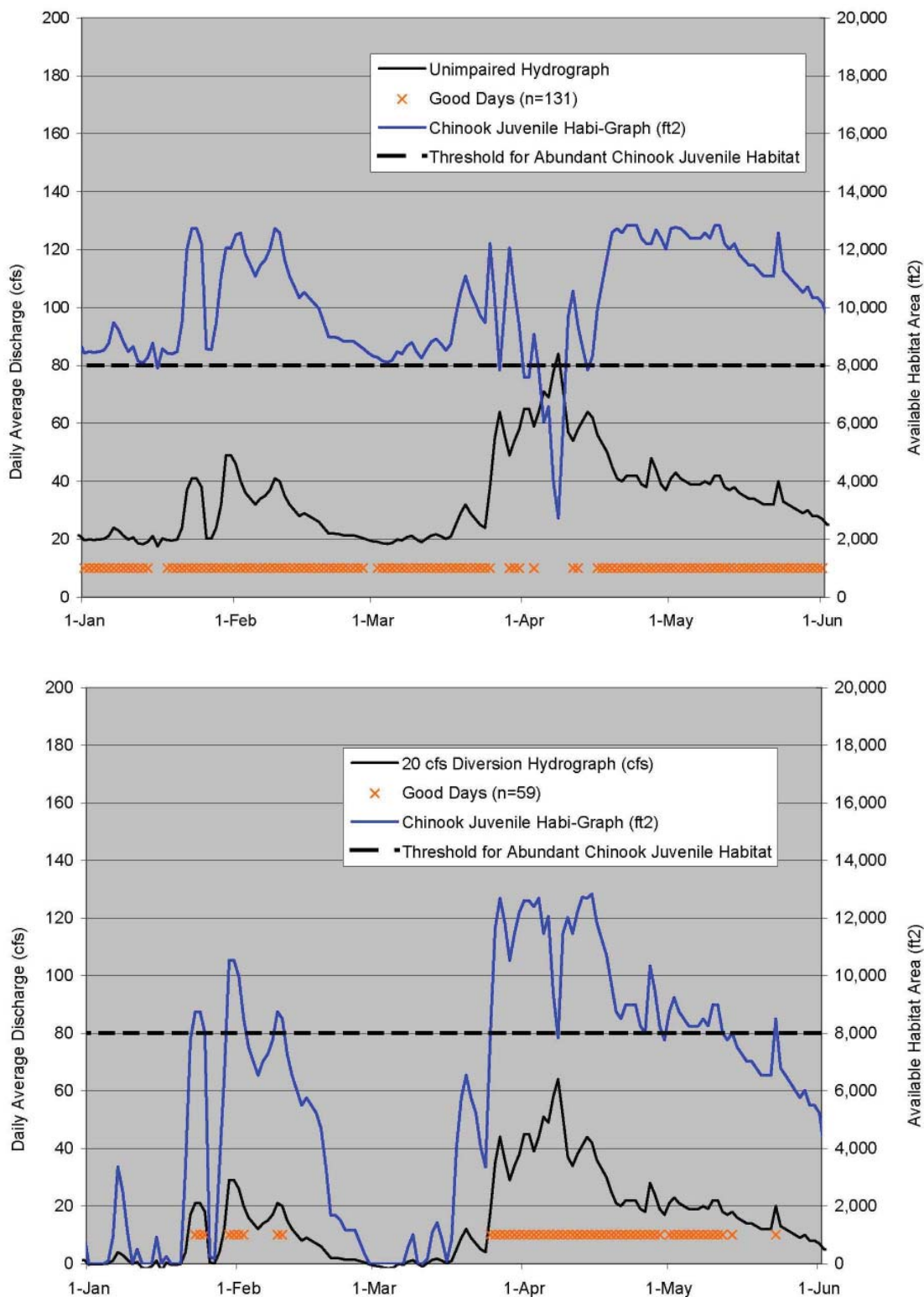


Figure 12. Example of a juvenile Chinook rearing habigraph for WY 1962 under unregulated streamflows (above), and at a diversion rate of 20 cfs (below). Good Days for rearing habitat occurred when habitat area exceeded a threshold estimated at 8,000 ft<sup>2</sup>.

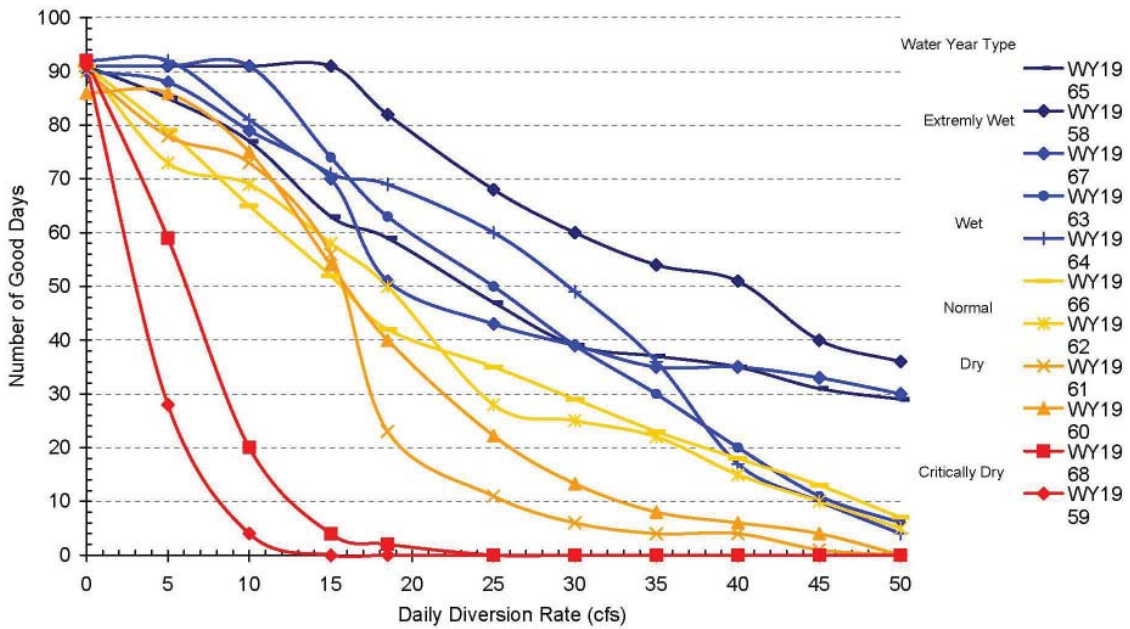


Figure 13. Hypothetical Number of Good Days (NGD) analysis for juvenile Chinook rearing habitat in the Little Shasta River. The NGD analysis was applied to 11 water years from the USGS ‘Little Shasta River near Montague’ gage’.

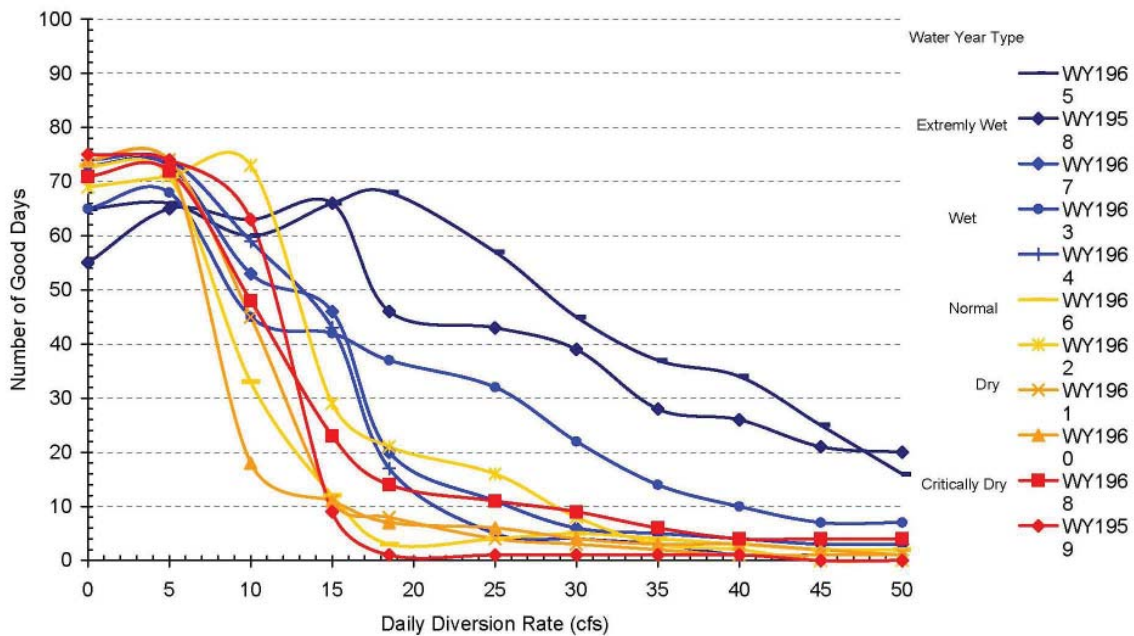


Figure 14. Hypothetical Number of Good Days (NGD) analysis for Chinook fry rearing habitat in the Little Shasta River. The NGD analysis was applied to 11 water years from the USGS ‘Little Shasta River near Montague’ gage’.

### ***5.3.1 Key Assumptions in the NGD Analysis***

The NGD analysis requires two key assumptions: identifying thresholds of abundant habitat area, temperatures, etc., and specifying how many good days are necessary for a successful life stage of a given life history tactic. There are at least two ways to specify habitat abundance thresholds from the field data: (1) on the original habitat rating curve, and (2) on the unregulated habigraph for each water year analyzed. Each way provides a unique perspective that could be justified, but (1) should be the preliminary favorite. A bell-shaped habitat rating curve with steep sides makes designating an upper and lower threshold for ‘abundant’ habitat easy. Less ideal shapes would make threshold designations more subjective. Adjusting lower/upper habitat abundance thresholds on habitat rating curves could drive a sensitivity analysis (i.e., is this subjectivity significant?). Another analytical strategy would be exploring (2). Using only unregulated annual hydrographs from a single water year type, e.g., Dry water years, a habitat threshold designating abundant habitat can be subjectively fit to each corresponding unregulated annual habigraph. The typical NGD for just Dry unregulated annual habigraphs could be used to establish a baseline for evaluating only Dry water years.

Population models, such as SALMOD, can estimate a range in habitat abundance providing robust population numbers. This range could serve as the habitat abundance threshold in the NGD analysis. However, SALMOD does not apply to steelhead. Another application of a population model would dovetail with the NGD analysis. If the NGD can be improved via instream flow releases, how many more NGDs would be enough to expect population recovery? A percentage improvement can be subjectively offered (e.g., a 10% NGD improvement), or a population model could forecast a threshold percentage improvement. Therefore, the two troublesome thresholds driving the NGD analysis could be addressed through population models.

A quantitative yet simple analytical alternative for designating a habitat threshold is the use of a minimum juvenile habitat area per individual, as could be adapted from Reeves et al. (1989) for coho salmon in Oregon and Washington. This would require (1) an estimated adult return, then working backwards through the life history (using general survival estimates for each life stage), then (2) an estimate of the number of juveniles and fry needed to achieve the adult population. A habitat area per juvenile and fry would give a total habitat area that could be used as a threshold in the NGD analysis. This rough approach could work well for 1+ coho and 2+ steelhead, two life stages that often limit adult return.

The second key assumption is identifying how many good days are necessary to sustain a particular life stage. At least two approaches are available to specify this: (1) the unimpaired habigraph and NGDs as a baseline, considering the range of variability over multiple water year types, and (2) modeling and monitoring specific growth rates to assure adequate seasonal growth and thus survival, and ultimately quantifying the size class distribution of juvenile and pre-smolt emigrants at specific locations in the basin.

## **6 INSTREAM FLOW NEEDS PROJECT IMPLEMENTATION**

### **6.1 Phase I: Develop Instream Flow Methods and Basin-wide Framework**

The Shasta River Instream Flow Methods Project and this Project Report provide the framework for proceeding into the implementation phase of an Instream Flow Needs project in the Shasta River basin. This Phase I study evaluated instream flow methods, and provided a basin-wide methodology for implementation in subsequent phases. The basin-wide approach recommended in this Report is intended to allow flexibility in implementation phases, by focusing on specific life history tactics, the associated tributary and mainstem reaches, and the instream flow needs objectives derived for each tactic and reach. This methodology may also be more suitable for implementation at a reach-scale small enough to address CDFG 1602 and 5937 permitting requirements.

### **6.2 Phase II: Implement Instream Flow Assessments**

A preliminary project scope has been developed for Phase II, to begin the implementation of instream flow needs assessments at two high priority reaches: the Shasta River Canyon and the Little Shasta River. Phase II will identify the appropriate life history tactics and habitat requirements, develop the unimpaired hydrographs and thermographs as a baseline for measuring the extent of feasible recovery. The project will identify migration, spawning, and rearing habitat needs, develop habitat-flow relationships for the appropriate life stages, then integrate this information with other habitat requirements (temperature, food resources, migration timing, etc.) to develop instream flow recommendations for these two Phase II reaches.

Given the importance of the upper mainstem Shasta River and its influence on streamflow and temperature conditions in the Shasta River Canyon, the Phase II project will need to coordinate with UC Davis and Northcoast Regional Water Quality Control Board researchers to incorporate their technical expertise and temperature modeling efforts into our eventual instream flow recommendations. Flow recommendations will be accompanied by explicit recovery targets (presented as hypotheses) and monitoring recommendations, that, when implemented along with revised instream flows, would test the effectiveness of streamflow recommendations and track salmonid recovery. Finally, given the high priority and high profile nature of this project, outreach efforts begun with the Phase I project should continue, including technical meetings and public workshops, coordination with landowners for property access, and final reports accessible to the public.

The following sections describe tasks proposed for Phase II.

#### **6.2.1 Task 1: Study Reach, Site Selection, and Aerial Photo Basemap**

The Shasta River Canyon and Little Shasta River could provide critical habitat for several freshwater salmonid life stages, including (a) spawning, incubation, and early fry rearing (b) summer/ fall juvenile rearing, (c) winter juvenile rearing, and (d) juvenile and smolt emigration. This task will identify representative study sites that could provide habitat for these life stages, and obtain a set of high resolution aerial photographs for use in habitat mapping and other field efforts. A reach-scale reconnaissance survey will be conducted on the Little Shasta River from Dry Gulch (approximately RM 15.5) downstream to the Shasta River confluence (RM 0), and on the mainstem Shasta River from Yreka Creek (RM 7.8) to the Klamath River. This survey will provide the basis for selecting study sites that adequately represent each stream reach.



### **6.2.2 Task 2: Develop Unimpaired and Regulated Hydrographs and Thermographs**

This task will use published flow data and hydrologic/thermal models to develop unimpaired and regulated daily average annual hydrographs and daily average, minimum, and maximum thermographs for a concurrent period of record (e.g., WY 1990 to 2008 if possible) that represents a range of water year types (e.g., wet years, drought periods, etc.). Alternatively, if unimpaired hydrographs and thermographs cannot feasibly be developed for a discrete period of record, then representative hydrographs and thermographs will be developed for up to five different water year types (e.g., Extremely Wet, Wet, Normal, Dry, and Critically Dry divided into 20% exceedence classes). These data will be used for quantifying a baseline of habitat availability under unimpaired conditions.

### **6.2.3 Task 3: Develop Habitat-Flow Relationships**

To sustain entire cohorts of salmonids, flow recommendations must provide adequate habitat area (measured in square feet of suitable habitat area) within stream reaches accessible to salmonids, with connectivity to reaches utilized by preceding and succeeding life stages. This task will employ several field-based empirical methods. Habitat mapping will apply habitat suitability criteria to quantify the area of available habitat over a range of streamflows for each targeted species and life stage. Mapping will be conducted during at least six flows at three or more study sites on each river. The product of habitat mapping is a set of flow-habitat curves for each targeted species and life stage. Habitat mapping (along with continuously recording dataloggers) will also identify flow thresholds above which desired habitat functions are met, such as (a) minimum flow thresholds providing juvenile and adult fish passage (i.e. connectivity), (b) a flow threshold that provides hydraulic complexity to maintain water quality (temperature, DO), nutrient cycles, and invertebrate drift, and (c) a flow threshold that inundates ephemeral habitat features such as gravel bars, floodplains, and side channels. Dataloggers will be deployed to estimate stage-discharge relationships, collect hydraulic (depth, velocity, slope, stage) data, and document peak flow events at key stream locations. High resolution panoramic photographs will be taken from monumented photopoints at each habitat-mapped flow for qualitative assessment of habitat at a range of flows (primarily for demonstration and outreach purposes).

### **6.2.4 Task 4: Identify Instream Flow Needs**

Instream flow evaluation requires a baseline for quantifying the degree of attainable reach-wide (and ultimately basin-wide) recovery. This task will employ a reference baseline of historical conditions, analyze alterations resulting from flow diversions, and evaluate options for feasible recovery. The reference condition is defined by reconstructing unregulated streamflow and temperature regimes (to the extent feasible and defensible), and then estimating the number of days in which habitat area thresholds and temperature targets are available during the relevant portion of the unregulated hydrograph. We will identify chronic and acute temperature thresholds (e.g., daily maximum, daily minimum, daily average, mean-weekly average temperature, mean-weekly maximum temperatures) from published literature (e.g., USEPA 2003, NCRWQCB 2006), then evaluate streamflow and temperature regimes that meet desired habitat conditions. Estimating the Number of Good Days attained under regulated hydrographs can then be compared to unimpaired conditions. The expected result of the project is to provide one or two sets of annual hydrographs for each water year type that would provide varying degrees of benefit to anadromous salmonid populations for each study site. The benefits of these hydrographs will be computed, compared, and contrasted with estimated unimpaired conditions and existing conditions.

## **7 ADAPTIVE MANAGEMENT AND MONITORING**

### **7.1 Establish Interim Streamflows and a Rigorous Adaptive Management Program**

The realm of instream flow studies occupies a unique position in aquatic ecology, because it is the pivotal junction between fisheries resource conservation and water consumption by humans. The scientific literature, both peer-reviewed and unpublished, is replete with studies investigating the effects of reduced flows on fish populations, most typically attempting to determine the “minimum flow required” to support those populations while maximizing flow diversions. Within this abundant literature, many studies have argued the validity, efficacy, and efficiency of instream flow methods, as well as the scientific framework that presumably would achieve the proper balance between water consumption and fishery protection.

In Castleberry et al. (1996), 12 workshop participants regarded as experts in the field of fisheries ecology, management, and instream flow studies concluded that “currently no scientifically defensible method exists for defining the instream flows needed to protect particular species of fish or aquatic ecosystems.” They suggest three fundamental rules, under the umbrella of adaptive management, be established as the basis of instream flow studies:

- Rule #1: set conservative interim instream flow standards that prescribe a reasonable annual hydrograph along with minimum flows;
- Rule #2: develop a robust monitoring program to evaluate interim flow requirements, treating prescribed flows as management experiments;
- Rule #3: establish a procedure for revising interim flows when new information suggests improved benefits.

We support this view, and suggest that an instream flow program targeting species recovery in the Shasta River must be designed and implemented concurrent with a rigorous adaptive management and monitoring program.

### **7.2 Establish Management Objectives**

A challenge to any recovery plan involving instream flow needs assessments is achieving agreement on management objectives. But just as instream assessments require a baseline (unimpaired conditions), they also require a target. Essential steps in the process of establishing management objectives include (1) prioritize which tactics are recoverable in the short term, then (2) set explicit, realistic juvenile and adult production goals for each tactic and for each species (Chinook, coho, steelhead). In lieu of an identified population target, we have assumed that recovery of the seventeen life history tactics listed in Appendix A, with annual survival of cohorts, a strong size-class distribution leading to good survival, recruitment, and eventually abundant annual adult escapement, will produce a viable (recovered) population. But we acknowledge the uncertainty in this assumption and the need for monitoring, confirmation or refutation, and adjustment of population targets. More specific population targets are needed.

To support management decisions and adaptive management, the Shasta River has one of the strongest and longest-running monitoring programs in the state. The Shasta River Fish Counting Facility tracks annual escapement of Chinook and coho salmon continuously since 1930, and now collect annual fry and juvenile production estimates at the weir near the mouth of the Shasta River. Recent expansion of monitoring in the upper mainstem reaches has included PIT-tagging of juvenile coho and steelhead, which will provide information on individual growth rates, migration patterns, and survival.

Eventually, with implementation of instream flows, validation of instream flow recommendations should be pursued by direct observation, by monitoring of juvenile and smolt size-class distributions (Figure 15), and by tracking seasonal growth rates through marked-recapture methods.

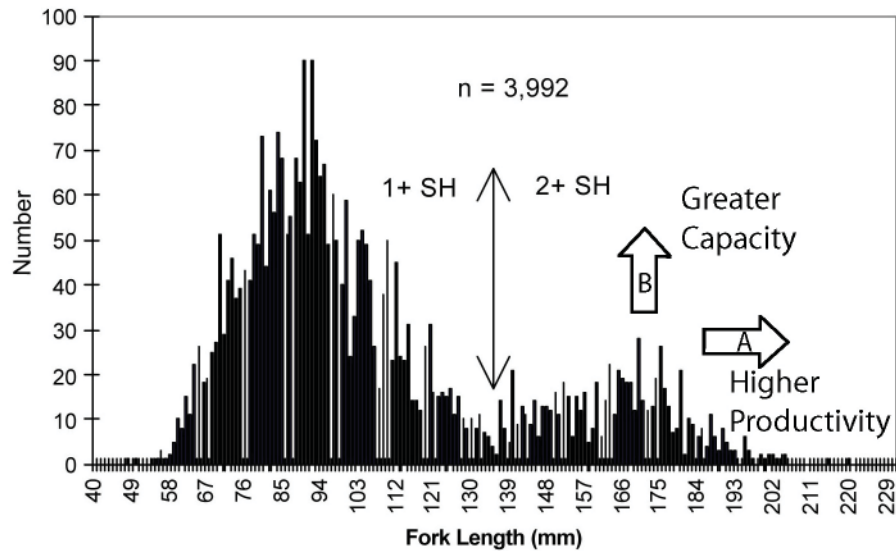


Figure 15. Typical size class distribution of steelhead smolts showing the idealized effects of restoration actions that increase habitat capacity and productivity. This distribution shows a clear break between 1-year old and 2-year old Steelhead (SH) at approximately 138 mm.

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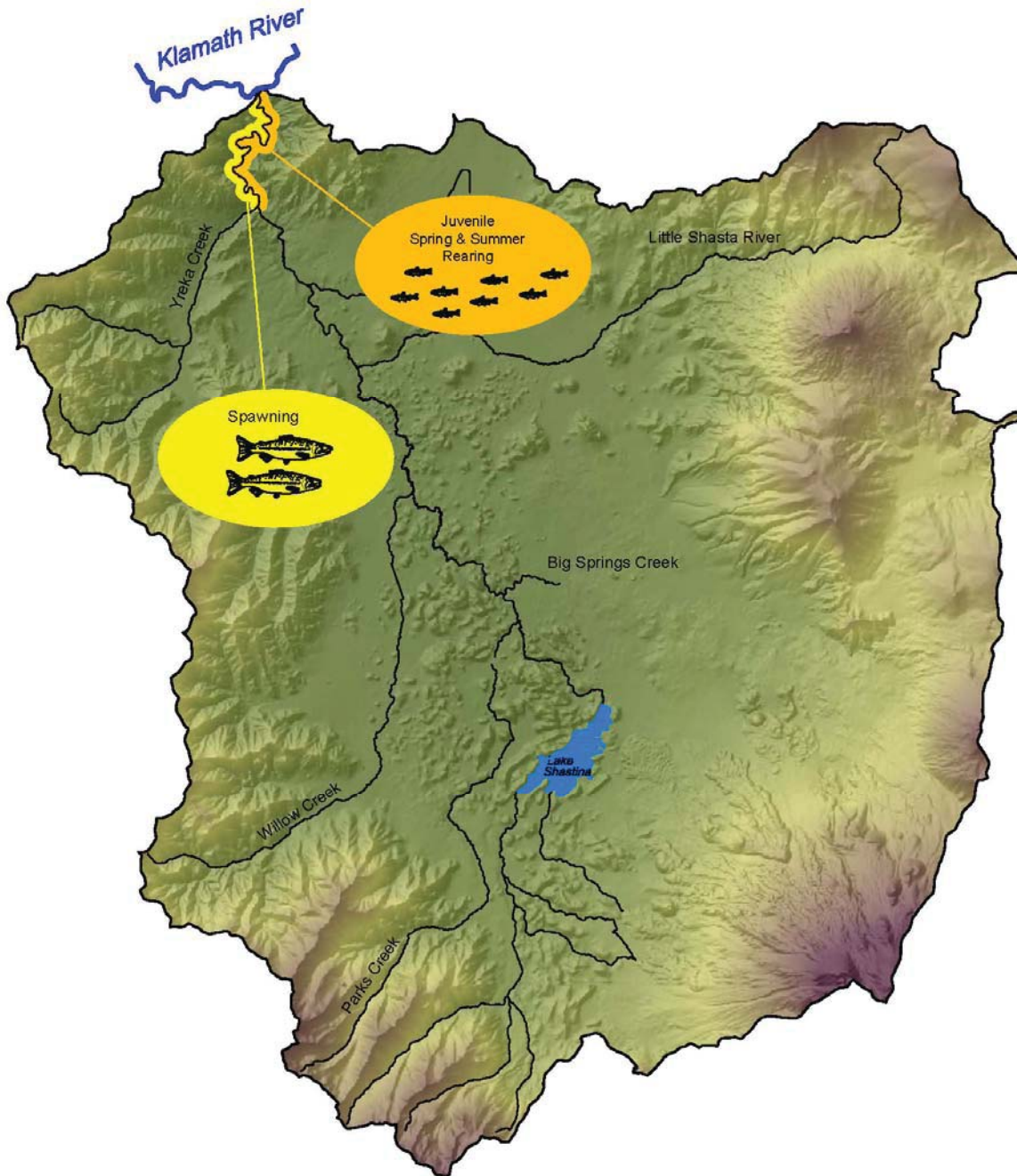


**9 APPENDIX A: SALMONID LIFE HISTORY TACTICS OF THE SHASTA RIVER BASIN**

Table A1. Preliminary ‘existing and recoverable’ life history tactics identified for the Shasta River basin.

Life History Tactics	Spawning - Incubation - Early Fry Rearing		Juvenile Spring - Summer Rearing		Juvenile Over-Winter Rearing		Presmolt - Smolt Emigration	
	Oct-Nov-Dec-Jan-Feb-Mar	Apr-May-Jun-Jul-Aug-Sept	Apr-May-Jun-Jul-Aug-Sept	Oct-Nov-Dec-Jan-Feb-Mar	Apr-May-Jun	Apr-May-Jun	Apr-May-Jun	
1 Fall Chinook Canyon 0+ Tactic		Canyon	0+ ENTER KLAMATH					
2 Fall Chinook Big Springs Complex 0+ Tactic		Big Springs Complex	0+ ENTER KLAMATH					
3 Coho Big Springs Complex 1+ Tactic		Big Springs Complex				Mainstem/Canyon		
4 Coho Big Springs Complex 0+ Tactic		Big Springs Complex	0+ ENTER KLAMATH					
5 Steelhead Big Springs Complex 1+ and 2+ Tactics		Big Springs Complex	(1 or 2 years)					
6 Steelhead Little Shasta River Headwaters 1+ Tactic		Little Shasta Headwaters	Little Shasta Foothills		Bottomlands	Mainstem/Canyon		
7 Steelhead Little Shasta River 2+ Tactic		Little Shasta Headwaters			Lower Shasta Mainstem (1 yr)	Mainstem/Canyon		
8 Coho Parks Creek Headwaters Tactic		Parks Headwaters				Mainstem/Canyon		
9 Coho Parks Creek Foothills/Bottomlands Tactic		Parks Headwaters	Parks Foothills			Mainstem/Canyon		
10 Coho Parks Creek Foothills/Big Springs Complex Tactic		Parks Foothills	Big Springs Complex			Mainstem/Canyon		
11 Coho Canyon Tactic		Canyon						
12 Coho Little Shasta River Foothills Tactic		Little Shasta Foothills				Little Shasta Bottomlands/ Mainstem/ Canyon		
13 Coho Little Shasta River Foothills/Bottomlands Tactic		Little Shasta Foothills			Little Shasta Bottomlands	Mainstem/Canyon		
14 Coho Little Shasta River Bottomlands Tactic		Little Shasta Foothills	Little Shasta Bottomlands			Mainstem/Canyon		
15 Fall Chinook Yearling Tactic		Canyon			0+ ENTER KLAMATH			
16 Coho Below Dwinell Tactic		Below Dwinell	Below Dwinell, Big Springs Complex			Mainstem/Canyon		
17 Spring Chinook Tactic		Below Dwinell, Big Springs Complex			0+ ENTER KLAMATH			

**9.1.1 Tactic 1: Fall Chinook Canyon 0+ Tactic**



Spawning - Incubation - Early Fry Rearing	Juvenile Spring - Summer Rearing	Juvenile Over-Winter Rearing	Presmolt - Smolt Emigration
Oct-Nov-Dec-Jan-Feb-Mar	Apr-May-Jun-Jul-Aug-Sept	Oct-Nov-Dec-Jan-Feb-Mar	Apr-May-Jun
Canyon	→ 0+ ENTER KLAMATH		

***Tactic 1: Fall Chinook Canyon 0+ Tactic***Description of life history tactic:

Fall Chinook are the most abundant salmonids currently in the Shasta River basin (CDFG 1997). Their “ocean-type” strategy allows an early exit from the Shasta River, and they rely on additional growth in the Klamath mainstem and estuary before entering the ocean. Snyder (1931) recognized this tactic from analysis of adult Chinook scales: “the individual from which it [scale] was taken, hatched from an egg deposited in the fall or early winter, passed down stream in time to arrive in the estuary in the following summer, remained in the estuary until growth... was complete, perhaps late fall, and then migrated to the sea.” The fall Chinook Canyon tactic utilizes the Canyon reach for its entire Shasta River life history, spawning in the fall, emerging in winter and early spring, and then emigrating to the Klamath between February and June. Fall Chinook begin arriving at the SRFCF in September, and peak in September and October of most years (Walsh and Hampton 2006). CDFG estimates most fall Chinook currently spawn in the lower 8 to 10 miles of the Shasta River. Additional spawning habitat utilized by other Chinook tactics is available upriver. Winter floods of 1,000 to 1,850 cfs (and occasionally higher) are common downstream of Yreka Creek and may occasionally scour Chinook redds. CDFG estimates the average 2001 to 2005 Chinook fry production from the Shasta River was 2.34 million annually (Chesney et al. 2007), and that over 89% of the total 0+ Chinook emigrated between mid-February and early April, potentially avoiding summer rearing and poor mainstem Klamath water quality. The contemporary peak emigration timing (April to May) may also correspond with abruptly reduced streamflows from irrigation diversions and concurrent increases in water temperatures, whereas historically, snowmelt floods ranged from 400 to 700 cfs persisted through April and May, and later in wetter years. Snowmelt runoff provided cold water, access to floodplain and side-channel rearing habitat, and highly productive invertebrate food resources. Historically, some Chinook juveniles probably remained in the Canyon reach through summer and emigrated as larger juveniles and smolts in the fall, winter, or following spring (i.e., other tactics).

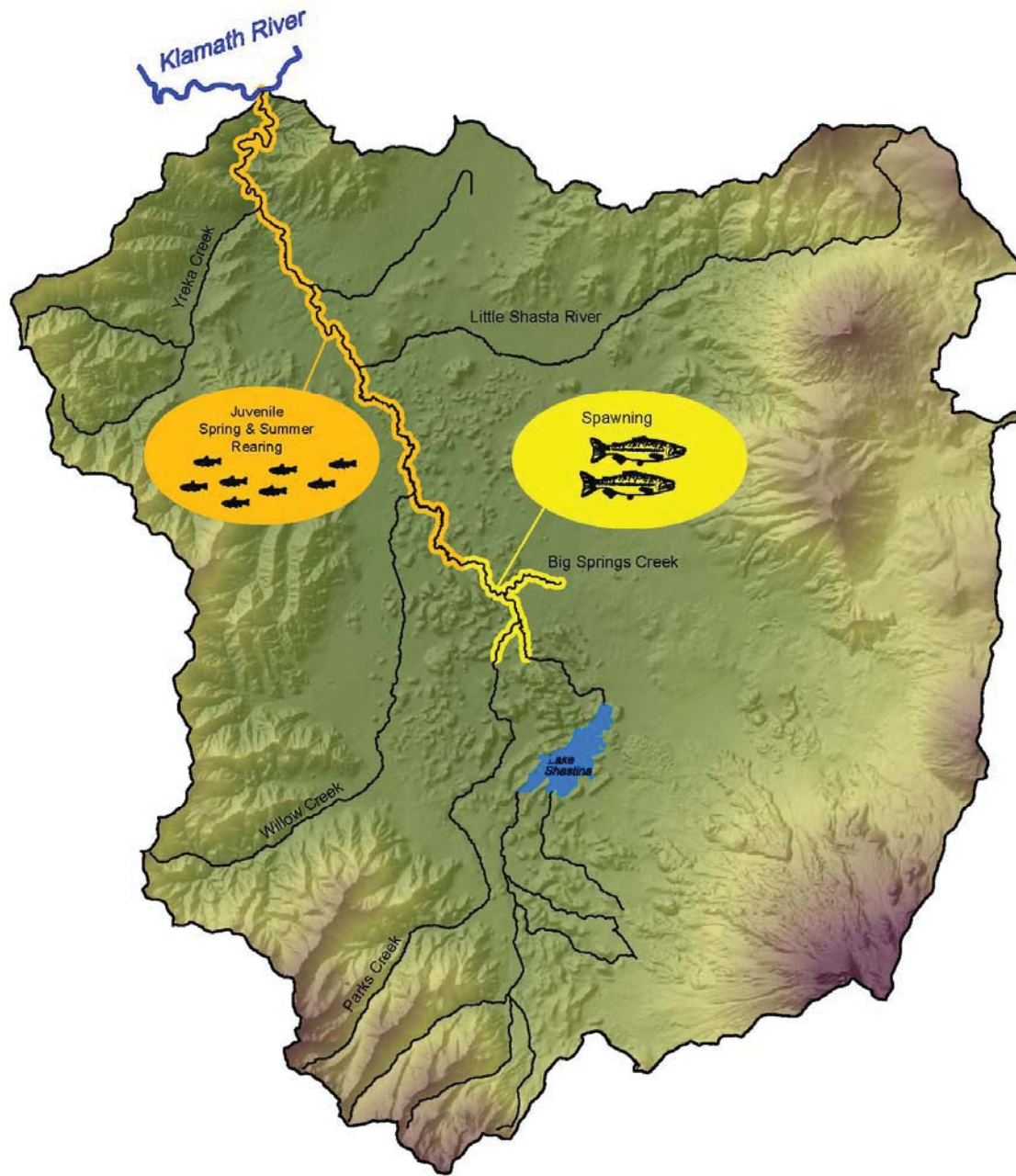
Current status of tactic and habitat conditions

Fall Chinook spawning habitat in the Canyon reach is heavily utilized (Walsh and Hampton 2006). Ricker (1997) suggests high levels of fines in spawning gravels may reduce fry emergence. Poor gravel supply to the canyon resulting from reduced winter floods below Dwinell Dam may limit spawning habitat quantity and quality (CDFG 2004 Coho Recovery Plan). Fry and juvenile rearing habitat appears abundant in the Canyon reach at typical winter/spring baseflows (200 to 300 cfs) that persist up until the irrigation season begins. But reduced spring flows, instead of the unimpaired snowmelt flows, reduces habitat abundance in backwaters, side channels, and floodplains of the Canyon reach. Water temperatures in spring also can approach or exceed the tolerable limits for juveniles, and may promote earlier than optimal emigration. Fry and juvenile growth and survival in the Klamath River are poorly understood, particularly given the effects of disease. Early emigration may potentially promote higher survival.

High priority data and information needs

- estimate of streamflow threshold that provides unrestricted upstream migration into and through the Canyon reach (applies to all Tactics henceforth);
- assessment of potential natural and anthropogenic migration barriers that impede or slow migration through the Canyon reach, their cumulative effects on migration over a range of flows, and estimate of streamflow threshold that provides unrestricted migration through the Canyon;
- relationship between streamflow and Chinook spawning habitat abundance in the Canyon reach in the range of 50-225 cfs;
- estimate of the current distribution and abundance of spawning gravels in the Shasta Canyon reach, including spawning gravel sources, transport rates and mobility, and assessment of the need for gravel augmentation to replenish coarse sediment supply and spawning gravel abundance;
- relationship between streamflow and Chinook fry and juvenile rearing habitat abundance in the Canyon reach, including habitat on floodplain and side channel features, in the range of 50-225 cfs (possibly higher range);
- assessment of the survival and recruitment of fry entering the mainstem Klamath in late winter and early spring, relative to juveniles and smolts entering the Klamath in late spring and early summer;
- estimates of Chinook fry growth rates (relative to water temperature) in the Canyon reach, compared to growth estimates in the mainstem Klamath River;
- relationship between size of Chinook smolts at ocean entry, and survival to adult returns to the Shasta River;
- comparison of unimpaired and impaired water temperature conditions in the Canyon reach in fall and spring; evaluation of the effects of elevated fall water temperatures on fecundity; evaluation of the effects of elevated spring water temperatures on fry growth rates and emigration;
- assessment of harvest management practices and potential impacts on early returning fall Chinook;
- role of Canyon salmon in providing for genetic mixing and re-colonization;

**9.1.2 Tactic 2: Fall Chinook Big Springs Complex 0+ Tactic**



Spawning - Incubation - Early Fry Rearing	Juvenile Spring - Summer Rearing	Juvenile Over-Winter Rearing	Presmolt - Smolt Emigration
Oct-Nov-Dec-Jan-Feb-Mar	Apr-May-Jun-Jul-Aug-Sept	Oct-Nov-Dec-Jan-Feb-Mar	Apr-May-Jun
Canyon	→	0+ ENTER KLAMATH	

***Tactic 2: Fall Chinook Big Springs Complex 0+ Tactic***Description of life history tactic:

The fall Chinook Big Springs Complex tactic is the second of two tactics that dominate contemporary fall Chinook runs (complementing the Shasta Canyon 0+ tactic). The Big Springs Complex tactic exhibits similar spawner migration timing up the Klamath and into the Shasta River. But given adequate streamflow and water temperatures, some fall Chinook continue their migration above the canyon to spawn. Mainstem barriers and high water temperatures may delay upstream migration in some years. Fall Chinook spawn in the mainstem Shasta River from approximately river mile 32 to Big Springs Creek, in lower Big Springs Creek, lower Parks Creek, and in the Shasta River upstream of Parks Creek (Chesney et al. 2007). These reaches cover approximately 13 river miles. Mainstem reaches above Dwinnell Dam likely supported this tactic historically. Fall Chinook eggs incubate through fall and into winter, and are likely less vulnerable to scour from winter floods than redds constructed in the Shasta Canyon reach because of the unconfined channel morphology and attenuated flood peaks below Dwinnell Dam. This tactic could buffer the Chinook population from threat of large winter floods. Fry emerge in late winter and spring, likely rear briefly near the spawning grounds, then slowly migrate downstream through the Middle and Lower Mainstem reaches, through the Canyon reach, and into the Klamath River. CDFG biologists estimate a large proportion of fall Chinook progeny from the Shasta Canyon leave the Shasta River by early April, whereas downstream migrants from the upper mainstem river arrive at the SRFCF through late spring (end of June). Emigrants from the Big Springs Complex are likely larger than Canyon progeny, but at present may be at greater risk of mortality due to Klamath River disease/parasite problems.

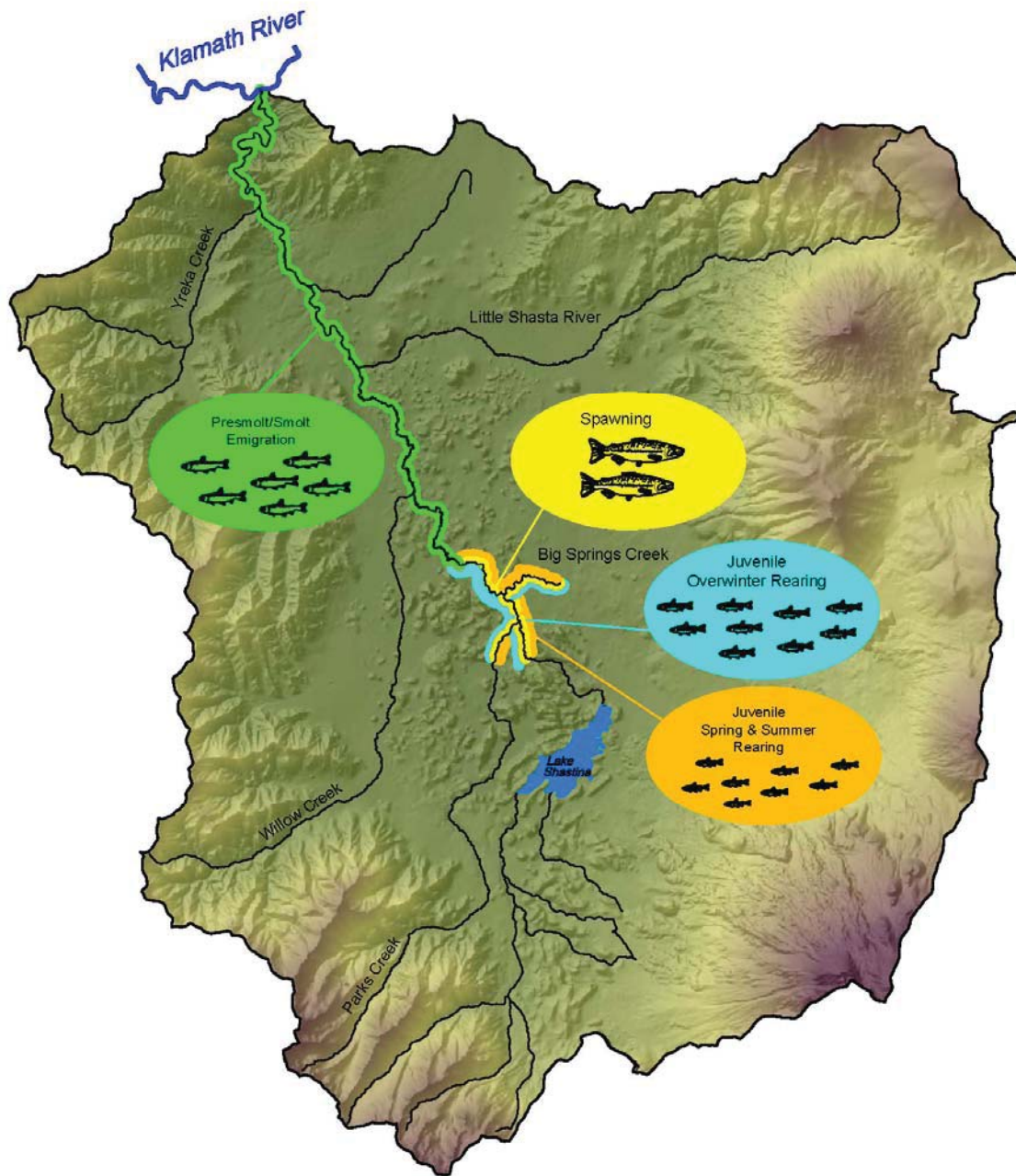
Current status of tactic and habitat conditions

Overall, given healthy habitat conditions in the mainstem Shasta and the Klamath River, this would be a highly productive tactic. This tactic appears to persist under contemporary conditions, at least for adult migration, spawning location and timing, and early emergent rearing in the general vicinity of the spawning grounds. However, irrigation diversions beginning April 1 may force Chinook fry to emigrate from the Big Springs Complex earlier than would be optimal, likely by early May. Given more suitable water temperatures and access to migrate upstream to find more favorable habitat, the rearing period for Chinook fry could extend later into spring and result in larger downstream migrants. However, delayed emigration to the Klamath River may increase the risk of mortality from disease and parasites.

High priority data and information needs

- assessment of potential natural and anthropogenic migration barriers that impede or slow migration to the Big Springs Complex, their cumulative effects on migration over a range of flows, and estimate of streamflow threshold that provides unrestricted migration to the Big Springs Complex;
- relationship between streamflow and Chinook spawning habitat abundance in the Big Springs Complex in the range of 50 to 225 cfs;
- estimate of the distribution and abundance of spawning gravels in the Big Springs Complex; assessment of spawning gravel sources, transport rates, and mobility; and assessment of the need for gravel augmentation to replenish coarse sediment supply and spawning gravel abundance below Dwinnell Dam;
- relationship between streamflow and Chinook fry and juvenile rearing habitat abundance in the Big Springs Complex in the range of 50 to 225 cfs (possibly higher range);
- estimates of Chinook fry rearing densities within suitable water temperature conditions;
- estimate of water temperature threshold or other environmental cues that encourage emigration of Chinook fry from the Big Springs Complex in spring;
- estimates of Chinook fry growth rates (relative to water temperature) in the Big Springs Complex, compared to growth estimates in the Canyon reach, and in the mainstem Klamath River;
- evaluation of existing and potential riparian vegetation coverage in the Big Springs Complex, and assessment of hydrograph components available to promote natural riparian vegetation recruitment;
- assessment of a minimum corridor width throughout the Big Springs Complex required to protect stream banks, floodplains, emergent wetland, and riparian vegetation;
- evaluation of geomorphic conditions, potential habitat availability, and actions required for restoration of channel morphology and salmonid habitat (particularly spawning) in the Dwinnell reach;
- evaluation of bank erosion and channel migration rates, and geomorphic processes maintaining channel confinement in the Below Dwinnell and Nelson reaches;
- evaluation of the relative importance of growth incurred during emigration down the mainstem Klamath River, and survival during ocean entry and eventual adult return;

***9.1.3 Tactic 3: Coho Big Springs Complex 1+ Tactic***



Spawning - Incubation - Early Fry Rearing	Juvenile Spring - Summer Rearing	Juvenile Over-Winter Rearing	Presmolt - Smolt Emigration
Oct-Nov-Dec-Jan-Feb-Mar	Apr-May-Jun-Jul-Aug-Sept	Oct-Nov-Dec-Jan-Feb-Mar	Apr-May-Jun
Big Springs Complex	→		Mainstem/Canyon

***Tactic 3: Coho Big Springs Complex 1+ Tactic***Description of life history tactic:

An important contemporary tactic for coho is utilization of the Big Springs Complex for spawning, spring and summer rearing, and over-winter rearing. Historically, extensive spawning habitat was available in the upper mainstem, Parks Creek, and Big Springs Creek, and the rearing capacity and productivity in the Shasta Big Springs Complex likely produced copious numbers of smolts. Presently, adults spawn in the mainstem from GID to above Parks Creek, in Big Springs Creek, and in Lower Parks Creek (Chesney et al. 2007). The extent of overlap in spawning habitat utilization among Chinook, coho, and steelhead in this reach is poorly understood. Habitat and channel morphology of the Shasta mainstem and Parks Creek were historically maintained by moderate winter floods and snowmelt runoff, but are now cut off from high flows by Dwinnell Dam. Big Springs has no flood component. Early emergent fry concentrate in the Big Springs Complex and utilize highly productive rearing habitat along stream margins, within dense beds of aquatic vegetation, and on submerged floodplain surfaces, all of which produce abundant food resources. As ambient conditions warm and the irrigation season begins, water temperatures in spring and early summer rise. Depending on rearing densities, some fry probably disperse both upstream and downstream in search of habitat (different tactics). Given suitable water temperatures, the Big Springs Complex would likely remain densely populated through summer and winter. The water surface elevation (not necessarily discharge) and water temperature appear to dominate habitat quality in these reaches; abundant food and cover appear well suited for coho rearing. Recent observations of densities and growth rates of juvenile steelhead rearing in these reaches suggest similar rearing conditions exist for coho, and this tactic could produce abundant and large 1+ presmolts and smolts by as early as March. Assuming that proportionally more adults return from larger smolts, this tactic would likely produce abundant adult coho salmon returns. Scattered pockets of water temperature refugia may support a few fish remaining through summer in the Big Springs Complex, although migratory access into these cold-water springs is problematic.

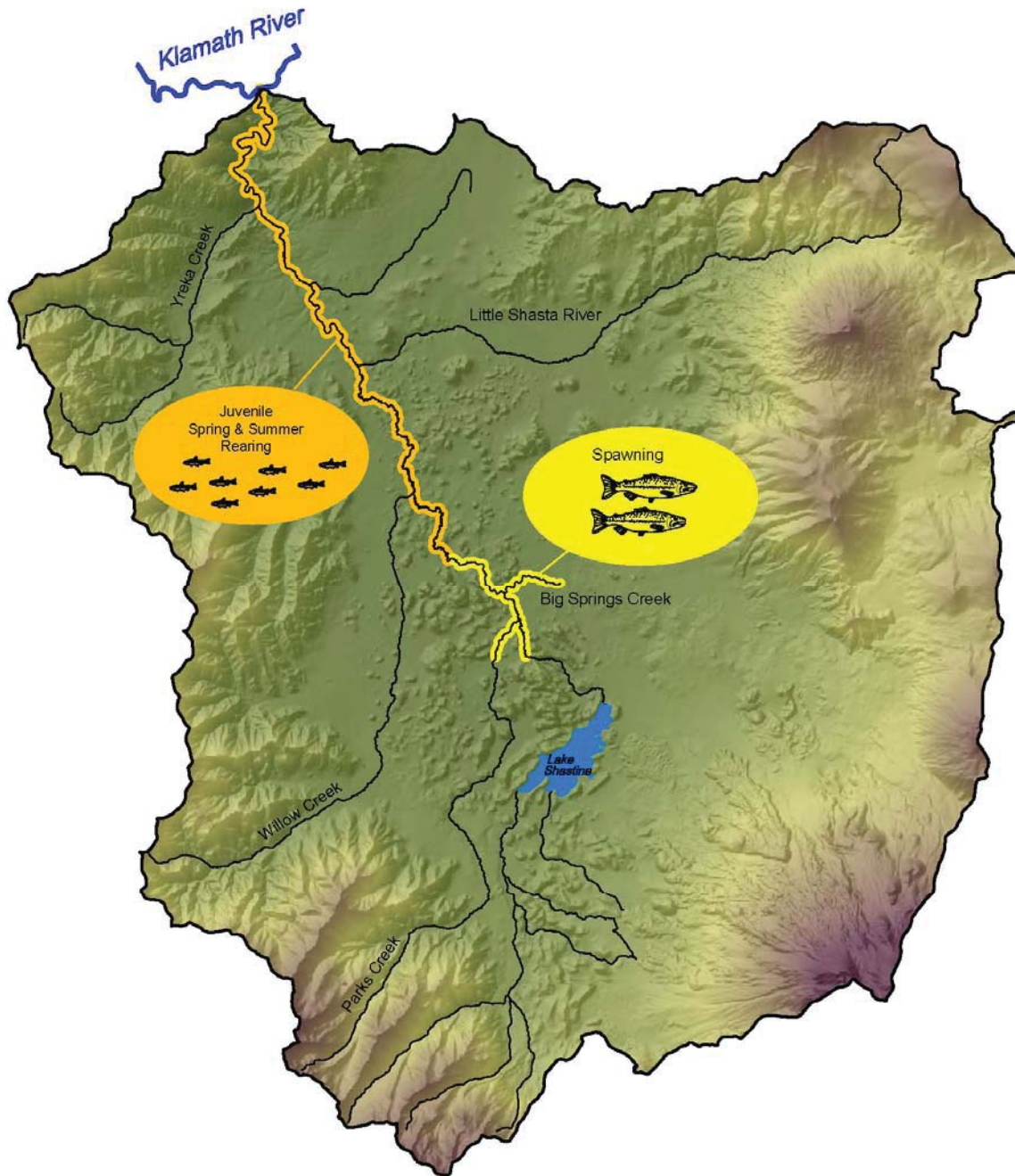
Current status of tactic and habitat conditions

Coho spawning likely occurs in isolated patches throughout the Big Springs Complex, given emergent fry have recently been observed in this area (Carson Jeffres pers. comm.). During the 2005 to 2007 spring/summer seasons, CDFG and UC Davis researchers conducted direct observations using snorkel surveys and operated a rotary screw trap near the downstream end of the Big Springs Complex on the Nelson Ranch. They observed coho rearing in the Big Springs Complex reaches until water temperatures in spring of most/all years exceed suitable ranges (~68 °F) for juvenile coho, which presumably force coho to emigrate or succumb to temperature induced mortality. The fate of these young-of-year emigrants is unknown. If water temperatures were suitable, other habitat requirements appear suitable, potentially allowing this coho tactic to thrive with modestly improved conditions.

High priority data and information needs

- assessment of potential natural and anthropogenic migration barriers that impede or slow migration to the Big Springs Complex, their cumulative effects on migration over a range of flows, and estimate of streamflow threshold that provides unrestricted migration to the Big Springs Complex;
- relationship between streamflow and Coho spawning habitat abundance in the Big Springs Complex in the range of 50-225 cfs;
- estimate of the distribution and abundance of spawning gravels in the Big Springs Complex; assessment of spawning gravel sources, transport rates, and mobility; and assessment of the need for gravel augmentation to replenish coarse sediment supply and spawning gravel abundance below Dwinnell Dam;
- relationship between streamflow and coho fry and juvenile spring and summer rearing habitat abundance, in the range of 50-225 cfs (possibly higher range) in the Big Springs Complex;
- estimate of water temperature threshold or other environmental cues that encourage emigration of Coho juveniles from the Big Springs Complex in spring;
- quantitative estimates of Coho fry and juvenile growth rates under different water temperature regimes;
- evaluation of existing and potential riparian vegetation coverage in the Big Springs Complex, and assessment of hydrograph components available to promote natural riparian vegetation recruitment;
- assessment of a minimum corridor width throughout the Big Springs Complex required to protect stream banks, floodplains, emergent wetland, and riparian vegetation;
- evaluation of geomorphic conditions, potential habitat availability, and actions required for restoration of channel morphology and salmonid habitat (particularly spawning) in the Dwinnell reach;
- evaluation of bank erosion and channel migration rates, and geomorphic processes maintaining channel confinement in the Below Dwinnell and Nelson reaches;
- evaluation of the relative importance of growth during emigration down the mainstem Klamath River, and survival following ocean entry and eventual adult return;
- estimate of the size class distribution of 0+ coho at ocean entry from scale and otolith analysis of returning adults;

***9.1.4 Tactic 4: Coho Big Springs Complex 0+ Tactic***



Spawning - Incubation - Early Fry Rearing	Juvenile Spring - Summer Rearing	Juvenile Over-Winter Rearing	Presmolt - Smolt Emigration
Oct-Nov-Dec-Jan-Feb-Mar	Apr-May-Jun-Jul-Aug-Sept	Oct-Nov-Dec-Jan-Feb-Mar	Apr-May-Jun
Big Springs Complex	→ 0+ ENTER KLAMATH		



***Tactic 4: Coho Big Springs Complex 0+ Tactic***Description of life history tactic:

In addition to the more typical coho life history pattern of 12 to 18 months of freshwater rearing, some coho salmon of the Shasta River exhibit a less commonly observed 0+ tactic. While there is no historical documentation of this tactic, the unique habitat conditions and spring-dominated hydrology of the mainstem Shasta appear to promote (and historically promoted) unusually high productivity that would have enabled a portion of the young-of-year cohort to emigrate their first year. Accelerated growth likely began with spawning: abundant discharge from Big Springs may have enabled adult coho to spawn earlier than in other Klamath River tributaries. Snyder (1931) observed “The time of arrival of salmon in the tributaries appears to differ markedly... and their degree of maturity varies also. For example, during the week beginning October 16 (1927), relatively small numbers of the [Chinook] held between the Klamathon racks were ripe. In Shasta River large numbers were actively spawning [likely Chinook], while many spent and a few dead fish were seen.” Egg incubation may also have been accelerated by relatively warmer spring-fed water temperatures. By early spring, snowmelt runoff provided abundant, high quality rearing habitat along stream margins, within dense beds of aquatic vegetation, and on submerged floodplain surfaces, all of which produce abundant food resources. As flows receded in summer, aquatic vegetation in the mainstem continued to provide substrate for food production and cover for juvenile coho rearing. Recent growth studies by CDFG and UC Davis researchers indicate that high summer growth rates in the Big Springs Complex may enable emigration and smolting as 0+ fish. Chesney et al. (2007) estimates approximately 870 0+ coho left the Shasta during the 2006 sampling period, representing 7.4% of juvenile coho emigrants. The 0+ emigration peaked in early June, six weeks later than the peak emigration of 1+ coho. But these juveniles were approaching 100 mm by mid to late June. Suitable water temperatures in this reach likely would allow rearing to extend through the summer, enabling juvenile coho to emigrate in the fall, grow their way downstream through the mainstem Shasta and Klamath rivers, smolt and enter the ocean at a large (130 to 140 mm) size.

Current status of tactic and habitat conditions

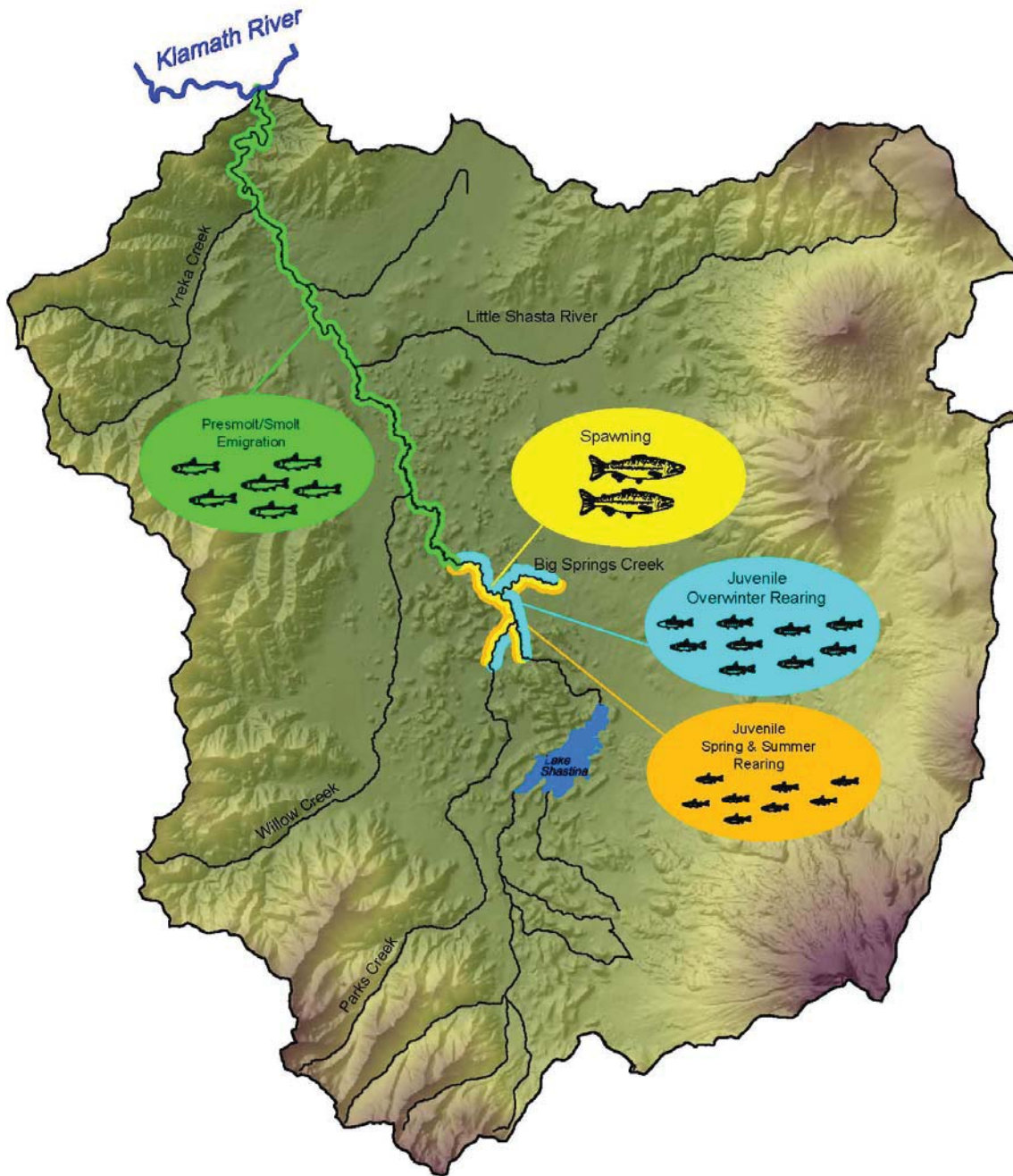
This tactic appears to persist under current partially-regulated streamflow conditions from adult migration and spawning through juvenile rearing into early summer. However, elevated water temperatures currently appears to force coho to emigrate from the Big Springs Complex by early June. The fate of 0+ coho rearing in the mainstem Klamath is unclear: they may rear in non-natal tributaries through the summer and fall, enter the ocean, or succumb to temperature-induced mortality. Although currently diminished, late-winter and spring baseflows still inundate small floodplains and stream edges along the mainstem, oxbow ponds with emergent wetland vegetation, and side channels. These features provide rearing habitat and high growth rates into spring (Carson Jeffres pers. comm.).

High priority data and information needs

[same data and information needs as Tactic #3]

- identification of anthropogenic sources of elevated water temperatures in the Big Springs Complex;
- estimate of water temperature threshold or other environmental cues that encourage emigration of 0+ Coho juveniles from the Big Springs Complex in spring;
- survival of 0+ coho in the Klamath River in June, July, August, September;
- evaluation of growth incurred during emigration down the mainstem Klamath River;
- estimate of the size class distribution of 0+ coho at ocean entry from scale and otolith analysis of returning adults;

***9.1.5 Tactic 5: Steelhead Big Springs Complex 1+ and 2+ Tactics***



Spawning - Incubation - Early Fry Rearing	Juvenile Spring - Summer Rearing	Juvenile Over-Winter Rearing	Presmolt - Smolt Emigration
Oct-Nov-Dec-Jan-Feb-Mar	Apr-May-Jun-Jul-Aug-Sept	Oct-Nov-Dec-Jan-Feb-Mar	Apr-May-Jun
Big Springs Complex	→ (1 or 2 years)	→	Mainstem/Canyon

***Tactic 5: Steelhead Big Springs Complex 1+ and 2+ Tactics***Description of life history tactic:

Without access to their ancestral spawning grounds higher in the watershed, winter steelhead utilizing Shasta River mainstem are constrained to the Big Springs Complex where their life stages overlap considerably with coho salmon. Microhabitat partitioning between these two sympatric species may be unique because of the spring creek morphology (absence of a pool-riffle morphology), and because aquatic plants provide spatial separation, abundant food, and thus less competition. Historically, the annual hydrograph was dominated by cold baseflows fed by springs, and a spring snowmelt. Winter steelhead entered the Shasta River beginning in October, and spawned between December and May. Steelhead spawning habitat was historically abundant in the upper watershed, particularly in the Shasta River and Parks Creek Headwaters reaches. In addition to successful Headwaters tactic, a Steelhead Big Springs Complex tactic would have been historically highly productive for both 1+ and 2+ life history tactics. CDFG and UC Davis researchers observed steelhead (primarily 0+ and 1+ fish) rearing on shallow, low velocity floodplain benches during spring. As stage dropped, juveniles moved to main channel habitat dominated by submerged aquatic macrophytes to rear through summer. Because of their ability to tolerate slightly warmer water temperatures, and preference for higher water velocities, summer rearing in the Big Springs Complex currently favors steelhead, whereas historically, juvenile coho may have been equally abundant. Recent research has shown that, despite water temperatures in the upper end of their suitability range, steelhead growth rates appear exceptionally high, indicating suitable hydraulic conditions (depth and velocity) and high food availability. Abundant food and slightly higher temperature tolerances may be the key to this tactic. Steelhead probably inhabit these reaches year-round for one season (1+ tactic) or two seasons (2+ tactic), although winter migration to other stream reaches cannot be ruled out. Following one or two years of rearing, juvenile steelhead emigrate through the lower mainstem reaches, the Shasta Canyon, and down the Klamath River.

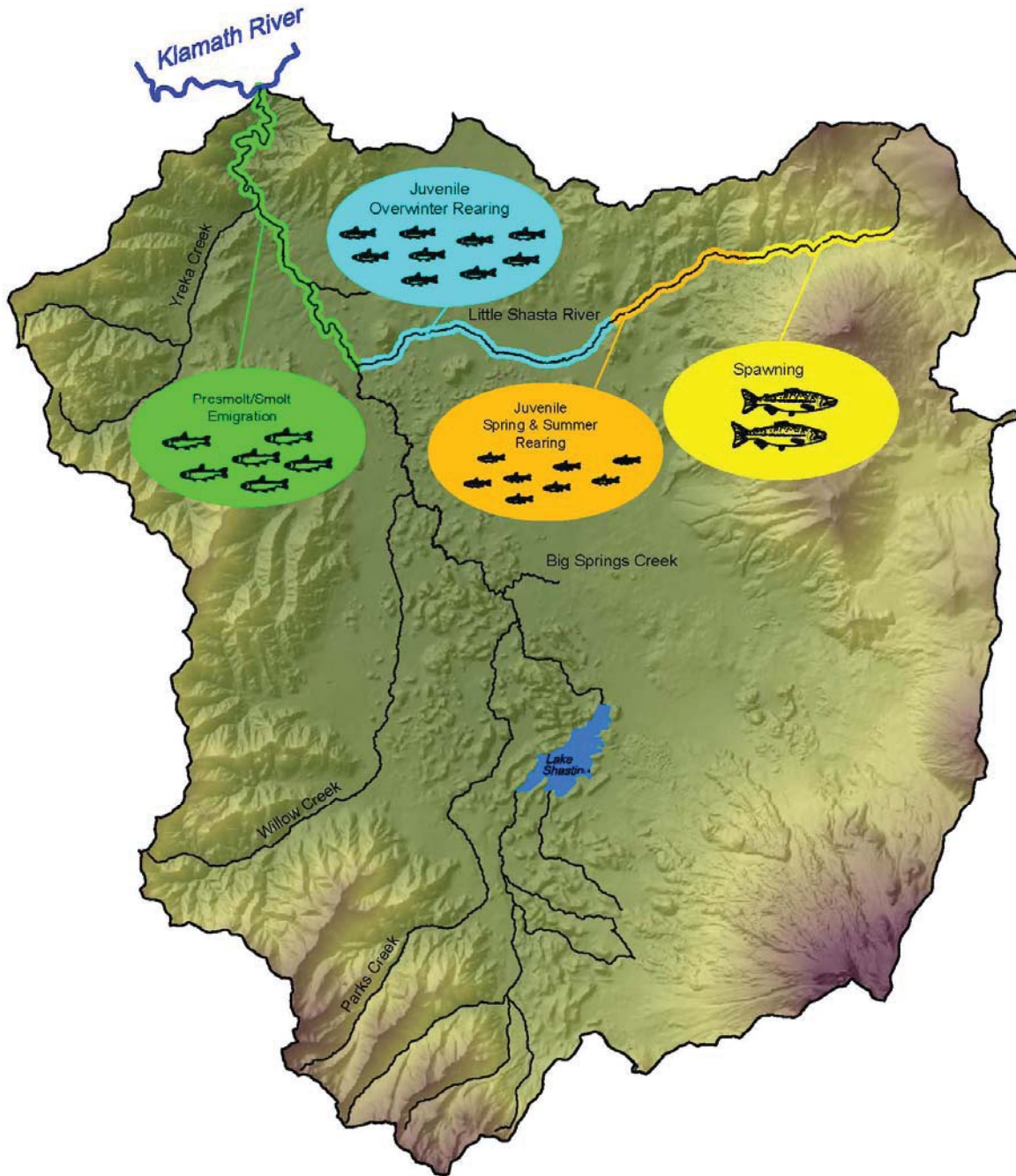
Current status of tactic and habitat conditions

Juvenile steelhead appear abundant in the Nelson reach where UC Davis researchers have been observing their rearing life history. Despite warm water temperatures during the summer months, habitat conditions appear suitable in the Big Springs Complex to sustain a steelhead life history tactic. While spawning is notoriously elusive, the presence of 0+ steelhead in spring strongly suggests that successful spawning occurs in the Big Springs Complex. Spawning habitat may still limit fry abundance, however. Emergence and early fry rearing occurs simultaneously with annual re-growth of dense aquatic macrophytes, which provides high quality rearing habitat. Peak emigration timing of 0+ steelhead generally occurs in May and June (Chesney et al 2007).

High priority data and information needs

- assessment of potential natural and anthropogenic migration barriers that impede or slow migration to the Big Springs Complex, their cumulative effects on migration over a range of flows, and estimate of streamflow threshold that provides unrestricted migration to the Big Springs Complex (for Summer steelhead);
- relationship between streamflow and steelhead spawning habitat abundance in the Big Springs Complex in the range of 50-225 cfs;
- estimate of the distribution and abundance of spawning gravels in the Big Springs Complex; assessment of spawning gravel sources, transport rates, and mobility; and assessment of the need for gravel augmentation to replenish coarse sediment supply and spawning gravel abundance below Dwinell Dam;
- relationship between streamflow and steelhead fry and juvenile spring and summer rearing habitat availability in the reach below Big Springs, in the range of approximately 50-225 cfs;
- estimates of fry and juvenile steelhead rearing densities within suitable water temperature conditions;
- empirical estimate of water temperature threshold that triggers emigration of juvenile steelhead from the Big Springs Complex in spring and summer;
- quantitative relationship between water temperature and juvenile steelhead growth rates;
- evaluation of existing and potential riparian vegetation coverage in the Big Springs Complex, and assessment of hydrograph components available to promote natural riparian vegetation recruitment;
- assessment of a minimum corridor width throughout the Big Springs Complex required to protect stream banks, floodplains, emergent wetland, and riparian vegetation;
- analysis of bank erosion and channel migration rates, and processes maintaining channel confinement in the Upper Mainstem and Nelson reaches;
- evaluation of geomorphic conditions, potential habitat availability, and actions required for restoration of channel morphology and salmonid habitat (particularly spawning) in the Dwinell reach;
- relative importance of growth incurred during mainstem rearing and timing of emigration to survival during emigration and ocean entry;

***9.1.6 Tactic 6: Steelhead Little Shasta River Headwaters 1+ Tactic***



Spawning - Incubation - Early Fry Rearing	Juvenile Spring - Summer Rearing	Juvenile Over-Winter Rearing	Presmolt - Smolt Emigration
Oct-Nov-Dec-Jan-Feb-Mar	Apr-May-Jun-Jul-Aug-Sept	Oct-Nov-Dec-Jan-Feb-Mar	Apr-May-Jun
Little Shasta Headwaters	Little Shasta Foothills	Bottomlands	Mainstem/Canyon

***Tactic 6: Steelhead Little Shasta River Headwaters 1+ Tactic***Description of life history tactic:

Steelhead exhibit the most complex life history traits of any Pacific salmonid: juveniles rear in the watershed for one, two, or more years before emigration, or can residualize in freshwater if downstream passage is not feasible, and adults exhibit iteroparity (return to sea after spawning). In the Shasta basin, steelhead also had an advantage over salmon of preferring spawning in higher gradient headwaters reaches (above contemporary diversions), accessed in fall and winter during higher baseflows and storm events (~50 to 200 cfs). This enabled fry and juveniles historically to rear where summer water temperatures remained cold, which then ensured their contemporary persistence. Steelhead can also thrive better in higher velocity streamflows, a requirement if overwintering in headwater streams. The Little Shasta River Headwaters 1+ tactic likely took advantage of these benefits, and was a primary steelhead tactic. Adults accessed as much as 10 miles of headwaters habitat above Dry Gulch to spawn. After emerging in spring in the Headwaters, steelhead fry began a slow descent into the Foothills reach where late spring and summer conditions provided the optimal balance between water temperatures conducive to rapid growth, and plentiful food resources stimulated by a moderate snowmelt runoff. Habitat conditions remained optimal in the Foothills reach for juvenile steelhead, and they remained through the fall and winter. By early to mid-spring, the 1+ steelhead cohort began a second slow downstream descent, through the valley bottom of the Little Shasta and Shasta mainstem, lasting 1 to 2.5 months before entering the Klamath river in mid April to early July, and measuring from ~140 to 180 mm mean fork length (Chesney et al.2007, Chart 14). This large size, with emigration timing allowing even additional growth in the Klamath mainstem and estuary before ocean entry, guaranteed a strong smolt-to-adult survival in many years.

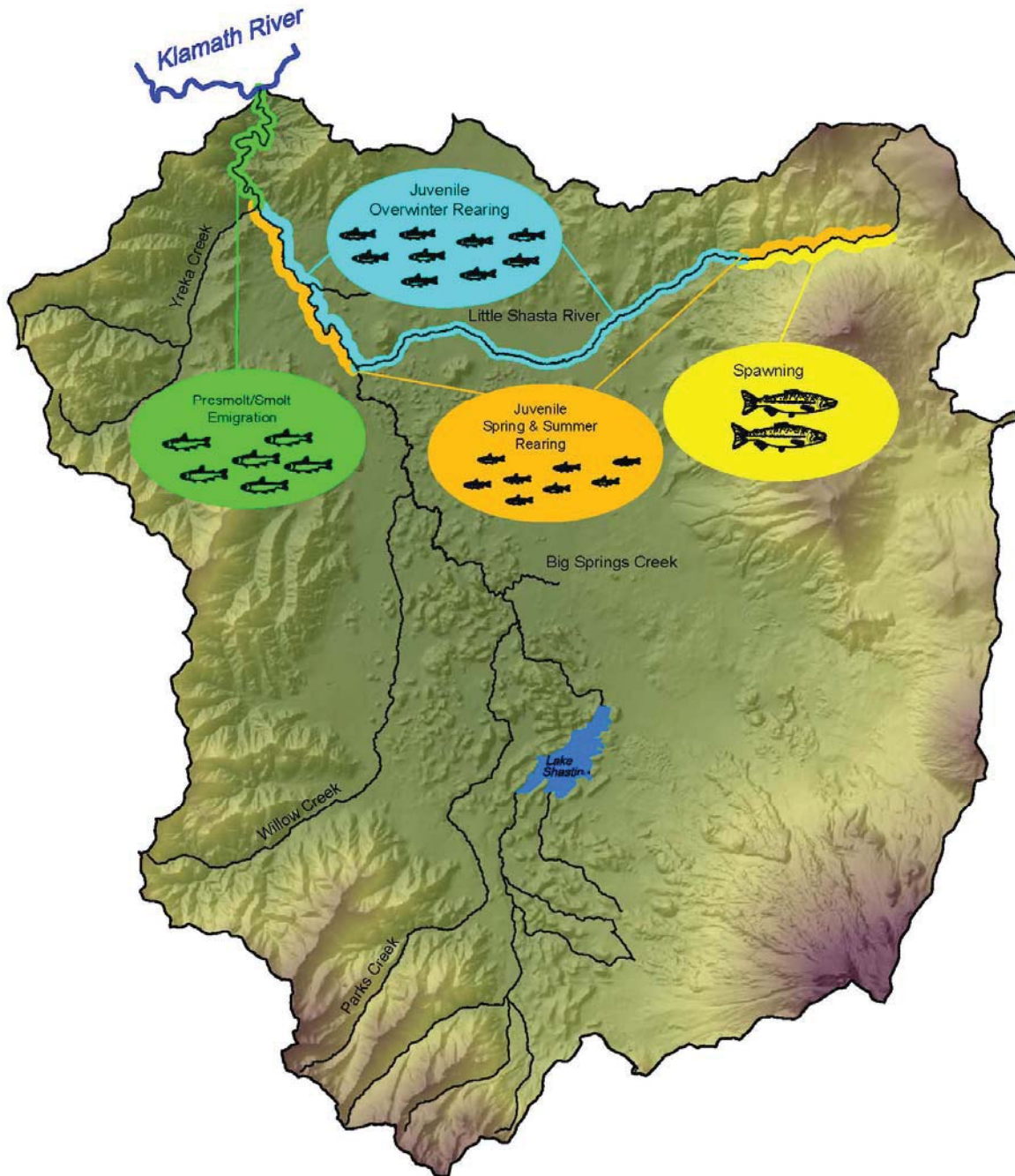
Current status of tactic and habitat conditions

Recent studies by CDFG and TNC indicate steelhead rear in the Nelson reach. Other mainstem or tributary reaches providing summer habitat are unknown. Juvenile steelhead have been observed in the Little Shasta River in limited sampling conducted by the CDFG Wildlife Area biologist (M. Farmer pers com). Suitable habitat appears available in the Headwaters reach to support spawning, early emergent rearing, and oversummering, although data are not available to confirm summer water temperature suitability. Summer and winter rearing may also be feasible in the Foothills reach and winter rearing habitat may also be available in the Bottomlands reach, although flows in this reach are more variable. Primary constraints on this tactic are adequate streamflows in fall during the adult migration period, summer rearing habitat capacity in the Foothills reach, and adequate streamflows for downstream migration in spring through the Shasta mainstem, Canyon, and Klamath River. Steelhead survival may also be affected by Klamath disease pathology. Despite the promise of this tactic, annual estimates of steelhead 1+ leaving the Shasta basin are considerably lower than the 0+ and 2+ estimates.

High priority data and information needs

- assessment of potential natural and anthropogenic migration barriers that impede or slow migration from the mainstem Shasta River confluence to the Little Shasta River Foothills and Headwaters reaches, their cumulative effects on migration over a range of flows, and estimate of streamflow threshold that provides unrestricted migration to these reaches;
- reach-scale survey of steelhead habitat availability from the mainstem Shasta River confluence to the Little Shasta River Foothills and Headwaters reaches, to determine (1) extent of spawning habitat, (2) extent of rearing habitat, and (3) location of natural and anthropogenic migratory barriers;
- relationship between streamflow and steelhead fry and juvenile winter rearing habitat availability in the Little Shasta River Foothills and Bottomlands reaches (below diversions), in the range of approximately 5-50 cfs;
- relationship between streamflow and ephemeral steelhead rearing habitat in side-channels and on floodplains in the Little Shasta River Bottomlands reach, or minimum flow threshold providing rearing habitat in these features;
- streamflow and water temperature data for the Headwaters and Foothills reaches;
- evaluation of existing and potential riparian vegetation coverage in the Foothills and Bottomlands reaches, and an assessment of hydrograph components available to promote natural riparian vegetation recruitment;
- assessment of a minimum corridor width throughout the Foothills and Bottomlands reaches required to protect stream banks, floodplains, emergent wetland, and riparian vegetation;
- estimate of timing and size class distribution of 1+ steelhead downstream migrants (if any) from the Little Shasta River to the mainstem Shasta River in spring;
- direct observation or e-fishing surveys in the Headwaters and Foothills reaches to determine presence/absence and age class distribution of steelhead juveniles;
- analysis of winter rearing habitat abundance and food availability in the Bottomlands reach following seasonal dewatering;

***9.1.7 Tactic 7: Steelhead Little Shasta River 2+ Tactic***



Spawning - Incubation - Early Fry Rearing	Juvenile Spring - Summer Rearing	Juvenile Over-Winter Rearing	Juvenile Spring - Summer Rearing	Juvenile Over-Winter Rearing	Presmolt - Smolt Emigration
Oct-Nov-Dec-Jan-Feb-Mar	Apr-May-Jun-Jul-Aug-Sept	Oct-Nov-Dec-Jan-Feb-Mar	Apr-May-Jun-Jul-Aug-Sept	Oct-Nov-Dec-Jan-Feb-Mar	Apr-May-Jun
Little Shasta Headwaters	→	Lower Shasta Mainstem	→	→	Mainstem/Canyon

***Tactic 7: Steelhead Little Shasta River 2+ Tactic***Description of life history tactic:

The steelhead 2+ life history tactic was likely a mainstay in the historic Shasta River steelhead population, because extended residence allowed fish to attain a larger size, which resulted in higher smolt-to-adult survival. The Little Shasta River (among several other tributaries in the basin) provided ideal conditions for a steelhead 2+ tactic. Able to ascend high into the watershed, steelhead spawned in the Little Shasta River Headwaters reach beginning in late fall and continuing late into winter (December to March). Eggs required 50 days to 80 days before the fry emerged in spring and early summer. Early emergent fry then distributed throughout the Headwaters reach and descended into the Foothills reach to rear through the spring and summer. The Headwaters reach had low summer baseflows (~15 to 25 cfs) but suitable water temperatures. Several different ages of rearing juveniles occupied the available rearing habitat, but densities were moderate to low. In winter, perhaps stimulated by winter flood conditions, juvenile steelhead descended through the Bottomlands reach and into the Shasta River mainstem, where winter rearing was good. These 1+ steelhead then remained in the mainstem to rear through an entire second year, becoming strongly territorial, piscivorous, and growing large as a result. By late winter and early spring (early by typical emigration timing), the 2+ steelhead began exiting the Shasta mainstem and Canyon into the Klamath River. Recent data (Chesney et al. 2007) indicate an extended emigration period for 2+ steelhead, beginning in mid-February and continuing through June. The 2+ steelhead were larger than the 1+ tactic, measuring (and increasing through their emigration) from ~160 to 200 mm mean fork length. An important variation on this tactic could have been for 1+ juveniles to rear in lower gradient reaches during winter, then return to colder Headwaters and Foothills reaches to rear in summer. Snowmelt runoff provided good rearing conditions through the Lower Mainstem and Shasta Canyon, and in the Klamath River.

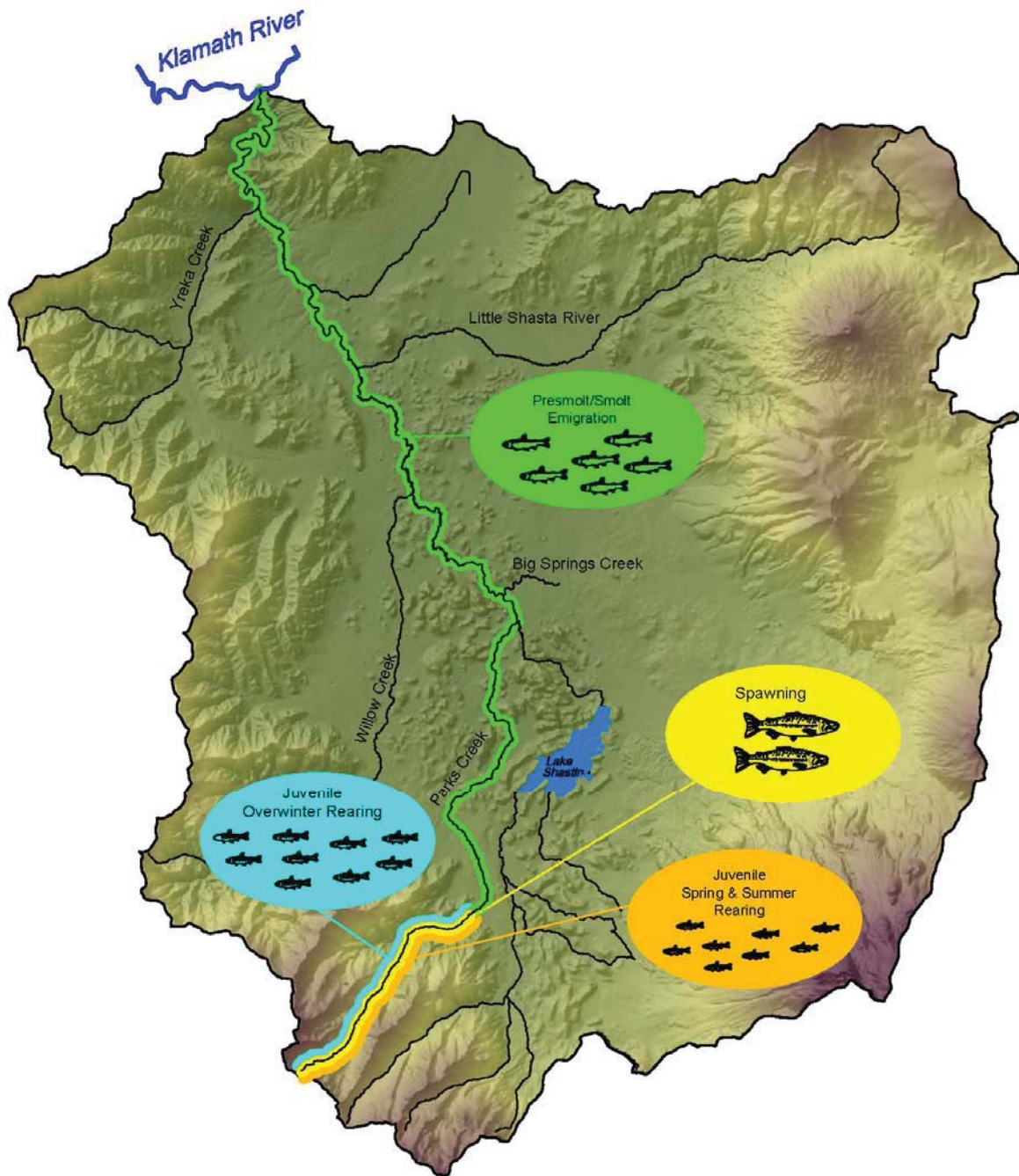
Current status of tactic and habitat conditions

Within the Shasta basin, the steelhead 2+ life history appears to be a dominant tactic. The 2006 CDFG outmigrant studies estimated 32,616 (40%) of steelhead migrants were 2+ fish (another 57% were 0+ migrants). CDFG hypothesizes that the high abundance of 2+ relative to 1+ steelhead may result from the Shasta functioning as a winter refugia for steelhead not of Shasta River origin (B. Chesney pers com). As with the steelhead 1+ tactic, suitable spawning habitat appears available in the Headwaters reach. Summer and winter rearing may also be feasible in the Foothills reach and winter rearing habitat may also be available in the Bottomlands reach. The primary constraints on this tactic are streamflows in fall during the adult migration period and summer rearing habitat in the Bottomlands and Lower Shasta mainstem.

High priority data and information needs

- assessment of potential natural and anthropogenic migration barriers that impede or slow migration from the mainstem Shasta River confluence to the Little Shasta River Foothills and Headwaters reaches, their cumulative effects on migration over a range of flows, and estimate of streamflow threshold that provides unrestricted migration to these reaches;
- reach-scale survey of steelhead habitat availability from the mainstem Shasta River confluence to the Little Shasta River Foothills and Headwaters reaches;
- relationship between streamflow and steelhead fry and juvenile winter rearing habitat availability in the Little Shasta River Foothills and Bottomlands reaches (below diversions), in the range of approximately 5 to 50 cfs;
- discharge providing suitable temperature and rearing habitat for steelhead 1+ and 2+ in the Bottomlands and Lower Mainstem reaches;
- streamflow and water temperature data for the Headwaters and Foothills reaches;
- evaluation of existing and potential riparian vegetation coverage in the Foothills and Bottomlands reaches, and an assessment of hydrograph components available to promote natural riparian vegetation recruitment;
- estimate of timing and size class distribution of 1+ steelhead downstream migrants (if any) from the Little Shasta River to the mainstem Shasta River in spring;
- direct observation or electrofishing surveys in the Headwaters and Foothills reaches to determine presence/absence and age class distribution of steelhead juveniles;
- analysis of winter rearing habitat abundance and food availability in the Bottomlands reach following seasonal dewatering;

**9.1.8 Tactic 8: Coho Parks Creek Headwaters Tactic**



Spawning - Incubation - Early Fry Rearing	Juvenile Spring - Summer Rearing	Juvenile Over-Winter Rearing	Presmolt - Smolt Emigration
Oct-Nov-Dec-Jan-Feb-Mar	Apr-May-Jun-Jul-Aug-Sept	Oct-Nov-Dec-Jan-Feb-Mar	Apr-May-Jun
Parks Headwaters		→	Mainstem/Canyon



***Tactic 8: Coho Parks Creek Headwaters Tactic***

Description of life history tactic:

Given a pool-riffle channel morphology, winter flood hydrology, and moderate spring snowmelt, the Parks Creek Headwaters tactic was probably more typical of coho salmon life histories throughout their distribution, and similar to other headwaters tactics in the Shasta and Scott basins. Seasonal runoff patterns in the Parks Headwaters reach were probably similar to the Shasta Headwaters reach as depicted in the Edgewood gage. This tactic utilized spawning habitat at the upper end of the coho salmon's stream elevation/gradient preference, where spawning gravel deposits were plentiful. Spawning higher in the watershed often depended on late fall and early winter freshets to allow upstream migration. Emerging from the gravels in spring, many fry remained in the Headwaters reach where cold water rearing habitat persisted through the spring and summer. Spring snowmelt brought a pulse of early season productivity, rapid growth, and some downstream dispersal of displaced fry. Rearing habitat would have depended on a healthy riparian canopy, deep pools, and complex physical structure to provide shade, cover, and suitable water temperatures. Summer rearing densities and growth rates were probably lower than in the mainstem. In dry years and at the lower elevations in the Foothills reach, summer rearing may have become unsuitable, or at least had extremely low habitat availability, with temperature refugia confined to deep pools. Stewart Springs and possibly other springs may have provided cold summer baseflows in the Headwaters reach. Winter rearing habitat probably depended on habitat areas with abundant instream cover or off-channel rearing as protection against winter floods, otherwise juveniles were forced to emigrate to lower gradient reaches. Productivity in the Headwater reach probably peaked in the spring during or after the snowmelt, which enabled rapid growth before emigration to the mainstem and Klamath River.

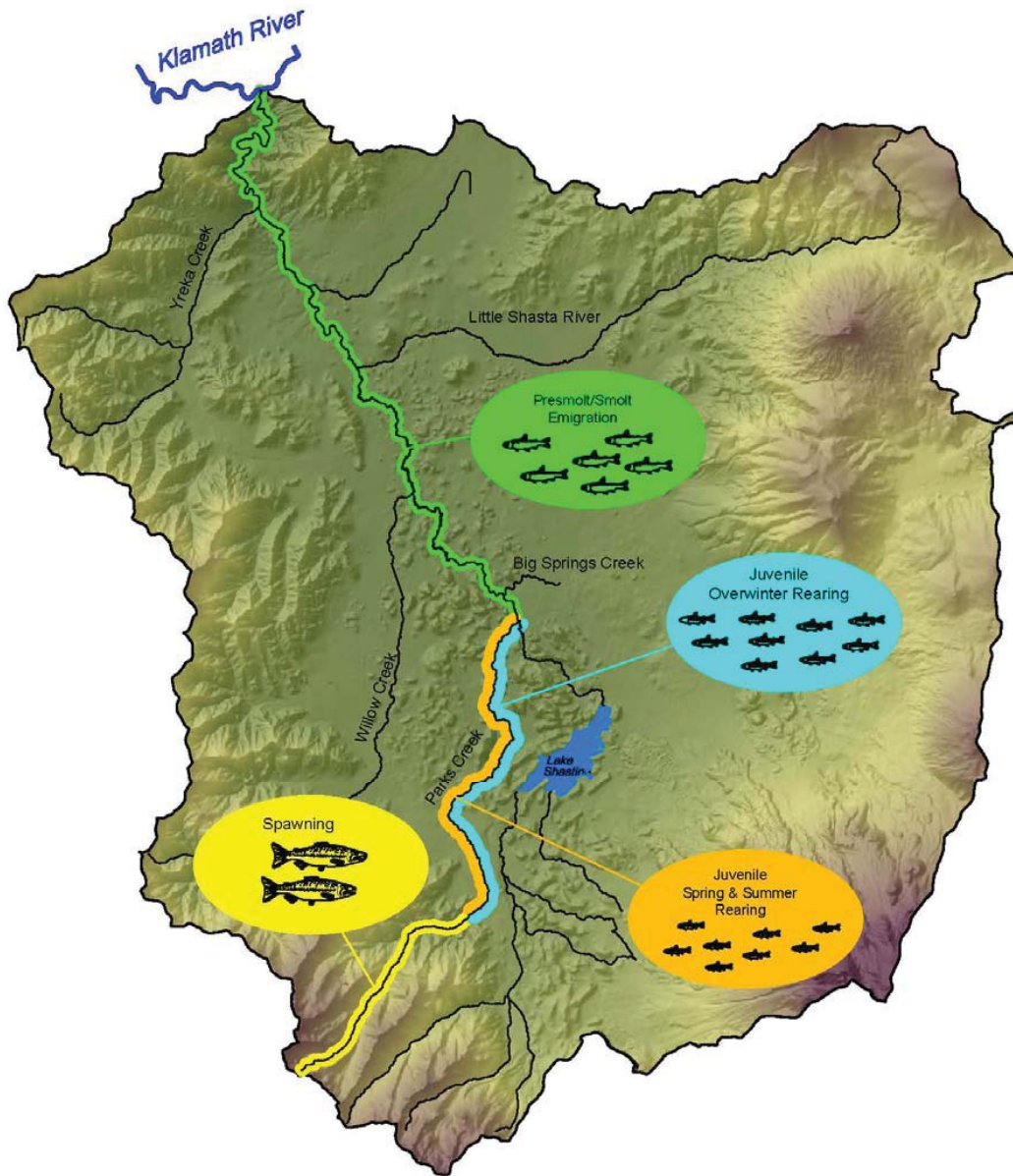
Current status of tactic and habitat conditions

The current status of this tactic is unknown. Streamflows in Parks Creek are diverted in summer for irrigation and in winter to fill Lake Shastina. Streamflow may not be sufficient in many years to allow upstream migration. Fry rearing habitat, juvenile spring/summer rearing habitat, and juvenile overwintering rearing habitat have not been documented in the Headwaters reach. The reach is currently not accessible to agency or private researchers. However, if flows were provided in the fall to allow adult migration to the Headwaters reach, then spawning habitat, fry rearing habitat, summer juvenile rearing habitat, and overwinter juvenile habitat could be available. Juveniles would then require adequate flows in spring to reach the mainstem Shasta River.

High priority data and information needs

- assessment of potential natural and anthropogenic migration barriers that impede or slow migration to Parks Creek Headwaters reach, their cumulative effects on migration over a range of flows, and estimate of streamflow threshold that provides unrestricted migration to Parks Creek Headwaters;
- reach-scale reconnaissance survey of coho spawning and rearing habitat in Parks Creek from the confluence to the historical limit of anadromy;
- direct observation or e-fishing surveys in the Headwaters reach to determine presence/absence and age class distribution of juvenile coho;
- estimate of streamflow threshold that provides unrestricted upstream coho migration to the Parks Creek Headwaters reach;
- estimate of the distribution and abundance of spawning gravels in Parks Creek;
- relationship between streamflow and coho spawning habitat abundance in Parks Creek Headwaters reach;
- relationship between streamflow and coho fry and juvenile summer and winter rearing habitat availability in Parks Creek Middle and Headwaters reaches;
- flow and water temperature data (above diversions) for Parks Headwaters reach;
- estimate of timing and size class distribution of downstream migrants from the Parks Creek to the mainstem Shasta River in spring;
- relationship between streamflow and ephemeral coho rearing habitat in side channels and on floodplains in the Parks Creek Bottomlands reach, or minimum flow threshold providing rearing habitat in these features;
- evaluation of the impacts of sediment transport into the Parks Creek diversion channel on the mainstem Parks Creek channel morphology.
- evaluation of existing and potential riparian vegetation coverage in Parks Creek Bottomlands reach, and assessment of hydrograph components available to promote natural riparian vegetation recruitment;
- assessment of a minimum corridor width throughout the Parks Creek Foothills and Bottomlands reach required to protect stream banks, floodplains, emergent wetland, and riparian vegetation;
- evaluation of geomorphic conditions, potential habitat availability, and actions required for restoration of channel morphology and salmonid habitat in the Parks Creek Foothills and Bottomlands reach;
- evaluation of bank erosion and channel migration rates, and geomorphic processes maintaining channel morphology in the Parks Creek Bottomlands reach;

***9.1.9 Tactic 9: Coho Parks Creek Foothills/Bottomlands Tactic***



Spawning - Incubation - Early Fry Rearing	Juvenile Spring - Summer Rearing	Juvenile Over-Winter Rearing	Presmolt - Smolt Emigration
Oct-Nov-Dec-Jan-Feb-Mar	Apr-May-Jun-Jul-Aug-Sept	Oct-Nov-Dec-Jan-Feb-Mar	Apr-May-Jun
Parks Headwaters	Parks Foothills	→ Mainstem/Canyon	

***Tactic 9: Coho Parks Creek Foothills/Bottomlands Tactic***Description of life history tactic:

The Parks Creek Foothills/Bottomlands tactic was probably a dominant historical coho tactic in Parks Creek, but is absent under present water management practices primarily because of lack of summer streamflows in Parks Creek. Seasonal runoff patterns in Parks Creek were probably similar to the Shasta River as depicted in the Edgewood gage, with spring-fed baseflows, moderate winter floods, and a distinct snowmelt hydrograph. Fall freshets and springs provided baseflows for adult migration. Spawning habitat was probably abundant and of high quality in the moderate gradient, alluvial Foothills reach. The early life history (migration, spawning, incubation, and early fry rearing) may have been indistinguishable from the Coho Headwaters tactic, but the two tactics diverged when many fry of both tactics redistributed in spring and summer to the lower-gradient Bottomlands reach. Upstream dispersal of fry and juveniles was likely a key feature of this tactic, allowing access to cold-water mainstem and spring habitat. In the Bottomlands reach, juvenile coho would have thrived. Historical summer rearing conditions based on cold summer flows in this reach have not been confirmed, but given the presence of an historical snowmelt, springs, and groundwater recharge, suitable rearing conditions were likely prevalent throughout the summer. In dry water years, streamflows and water temperatures may have become marginal if not entirely inhospitable, but most years likely provided abundant habitat. Historical conditions in the Parks Creek Bottomlands reach include the presence of ephemeral wetlands, beaver impoundments, and a meandering, low gradient stream channel, all contributing to rich, complex habitat. Once summer passed, temperatures cooled and coho remained in the Bottomlands to rear throughout the winter. If springs moderated winter water temperatures, fish could have continued rearing and growing. The following spring, juveniles were sufficiently large to emigrate to the mainstem Shasta River and Klamath River before and during the snowmelt runoff.

Current status of tactic and habitat conditions

This tactic is not present under current water management practices. Parks Creek flows are among the most regulated in the Shasta basin. Summer flow diversions dewater the channel for several months of the summer in most water years. Winter flow diversions to Lake Shastina have eliminated the winter baseflows, winter floods, and the spring snowmelt. In addition, fish passage is uncertain at the MID Diversion and the Cardoza obstruction. The channel morphology may also be heavily degraded from loss riparian habitat, cattle grazing, and other human activities.

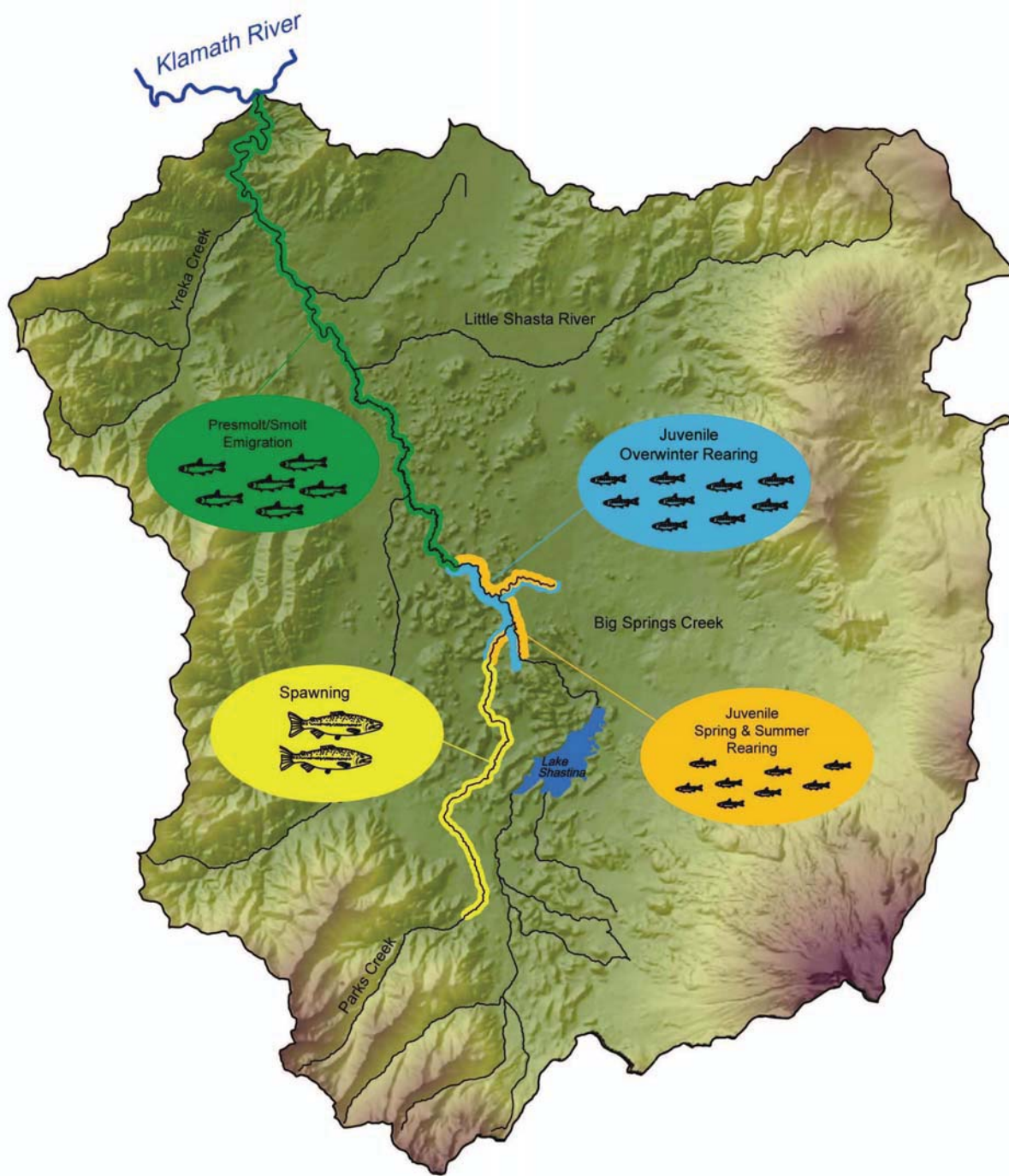
Overwinter rearing habitat may also be available in the Middle Parks and Headwaters reaches, but this is unconfirmed.

High priority data and information needs

[same data and information needs as Tactic #8]

- relationship between streamflow and coho fry and juvenile spring and summer rearing habitat abundance, in the Parks Creek Foothills and Bottomlands reaches;
- estimate of water temperature threshold or other environmental cues that encourage emigration of Coho juveniles from the Parks Creek Foothills and Bottomlands reaches in spring;
- evaluation of existing and potential riparian vegetation coverage in the Parks Creek Bottomlands reach, and assessment of hydrograph components available to promote natural riparian vegetation recruitment;
- assessment of a minimum corridor width throughout the Parks Creek Bottomlands reach required to protect stream banks, floodplains, emergent wetland, and riparian vegetation;

**9.1.10 Tactic 10: Coho Parks Creek Foothills and Big Springs Complex Tactic**



Spawning - Incubation - Early Fry Rearing	Juvenile Spring - Summer Rearing	Juvenile Over-Winter Rearing	Presmolt - Smolt Emigration
Oct-Nov-Dec-Jan-Feb-Mar	Apr-May-Jun-Jul-Aug-Sept	Oct-Nov-Dec-Jan-Feb-Mar	Apr-May-Jun

### ***Tactic 10: Coho Parks Creek Foothills and Big Springs Complex Tactic***

#### Description of life history tactic:

The mainstem Shasta River requires restoration of two critical habitat components to make several coho 1+ tactics thrive: adult access to abundant spawning habitat in fall, and cold water summer rearing habitat. Investigations conducted by the NCRWQCB (2006) and UC Davis researchers (Deas et al. 2004; Jeffres et al. 2008) at the TNC's Nelson Ranch indicate that suitable summer water temperatures in the Nelson Reach and more broadly throughout the Big Springs Complex are eminently attainable with modest increases in instream flow, riparian vegetation recover, and a robust tail-water management program. The Parks Creek Foothills could provide an abundant source of spawning habitat and thus abundant fry cohorts to seed summer rearing in the Big Springs Complex. There are as much as eight miles of potential spawning reach with moderate gradient, gravel-bedded channel, from below the I-5 Bridge upstream to the MWCD Diversion dam, and possibly upstream to the Edson-Foulke canal. Recent CDFG radio-tagging studies have tracked adult coho into Parks Creek (CDFG 2008). Winter flows are required to protect incubating eggs and newly emergent fry. Spring streamflows through April would also be required, with a well-timed flow release to mimic snowmelt runoff. These streamflow components would stimulate benthic invertebrate productivity and to allow fry to grow and redistribute to the mainstem and Big Springs Complex where high quality summer rearing habitat would be abundant. Upstream dispersal of fry and juveniles was likely a key feature of this tactic, allowing access to cold-water mainstem and spring habitat. Fry migration upstream to summer habitat above points of diversion might be an important consideration. With streamflow management, the Coho Parks Creek – Big Springs Complex tactic could produce a large and robust size-class of juvenile coho.

#### Current status of tactic and habitat conditions

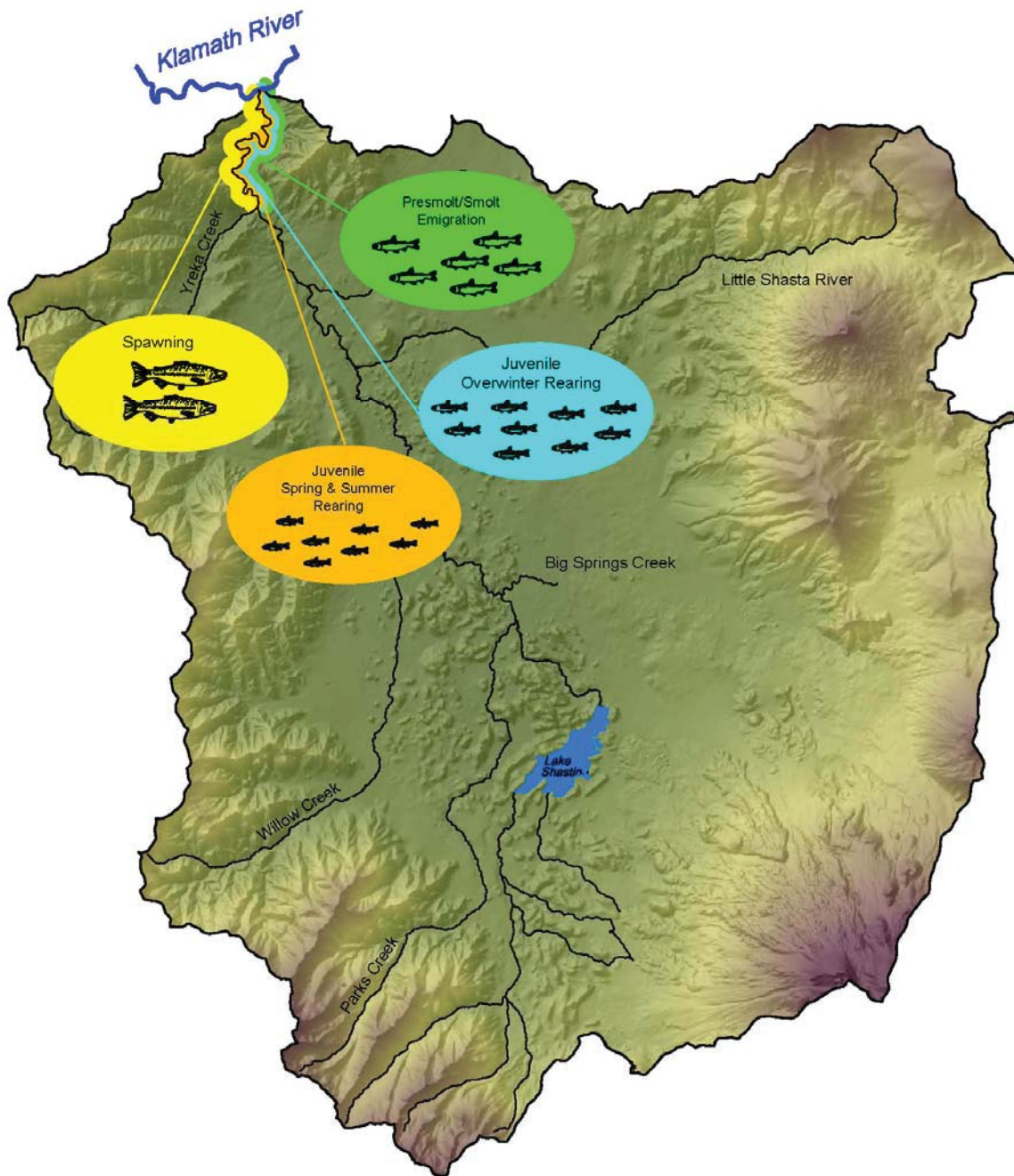
This tactic is not present under current water management practices. Parks Creek flows are among the most regulated in the Shasta basin. Summer flow diversions dewater the channel for several months of the summer in most water years. Winter flow diversions to Lake Shastina have eliminated the winter baseflows, winter floods, and the spring snowmelt. In addition, fish passage is uncertain at the MID Diversion and the Cardoza obstruction. The channel morphology may also be heavily degraded from loss riparian habitat, cattle grazing, and other human activities.

Overwinter rearing habitat may also be available in the Middle Parks and Headwaters reaches, but this is unconfirmed.

#### High priority data and information needs

- [same data and information needs as Tactic #8]
- relationship between streamflow and coho fry and juvenile spring and summer rearing habitat abundance, in the Parks Creek Foothills and Bottomlands reaches;
- estimate of water temperature threshold or other environmental cues that encourage emigration of Coho juveniles from the Parks Creek Foothills and Bottomlands reaches in spring;
- evaluation of existing and potential riparian vegetation coverage in the Parks Creek Bottomlands reach, and assessment of hydrograph components available to promote natural riparian vegetation recruitment;
- assessment of a minimum corridor width throughout the Parks Creek Bottomlands reach required to protect stream banks, floodplains, emergent wetland, and riparian vegetation;

**9.1.11 Tactic 11. Coho Canyon 1+ Tactic**



Spawning - Incubation - Early Fry Rearing	Juvenile Spring - Summer Rearing	Juvenile Over-Winter Rearing	Presmolt - Smolt Emigration
Oct-Nov-Dec-Jan-Feb-Mar	Apr-May-Jun-Jul-Aug-Sept	Oct-Nov-Dec-Jan-Feb-Mar	Apr-May-Jun
Canyon	→		

***Tactic 11: Coho Canyon 1+ Tactic***Description of life history tactic:

The Shasta Canyon reach, extending 7.8 miles from Yreka Creek to the Klamath confluence, was perhaps the most challenging reach of the Shasta Basin within which to produce a coho smolt. With the combined unimpaired hydrograph of all the headwaters, tributaries, and springs, the coho of this tactic first competed with the huge historical Chinook runs that dominated the mainstem, and were immediately at a competitive disadvantage by spawning later, emerging later, and generally preferring lower velocity water and abundant cover for rearing. Incubating eggs and early emergent fry were also vulnerable to scour and downstream displacement by winter storm peaks in December through March. Abundant habitat appears available in the Canyon for early emergent fry to escape at least moderate winter floods. And while the snowmelt runoff in April and May produced abundant juvenile rearing habitat, young-of-year coho that survived the winter were subjected to waves of displaced fry and juveniles from upstream reaches, and presmolts and smolts emigrating through the Canyon. Many of the progeny of Canyon spawners may have joined the chorus of winter and spring early-immigrant fish (these fry emigrated to the Klamath River where their survival is currently speculative). Then came the summer season and warm water temperatures, possibly the warmest in the basin given this reach's location at the bottom of the watershed. Upstream dispersal of fry and juveniles was likely an important feature of this tactic, allowing access to cold-water mainstem and tributary habitat. Finally, there appears to have been abundant juvenile steelhead rearing habitat in the canyon, though predation on young-of-year coho fry could have been substantial. Nevertheless, habitat was available in the Shasta Canyon for all life stages of coho, and some likely persevered to emigrate to the Klamath River.

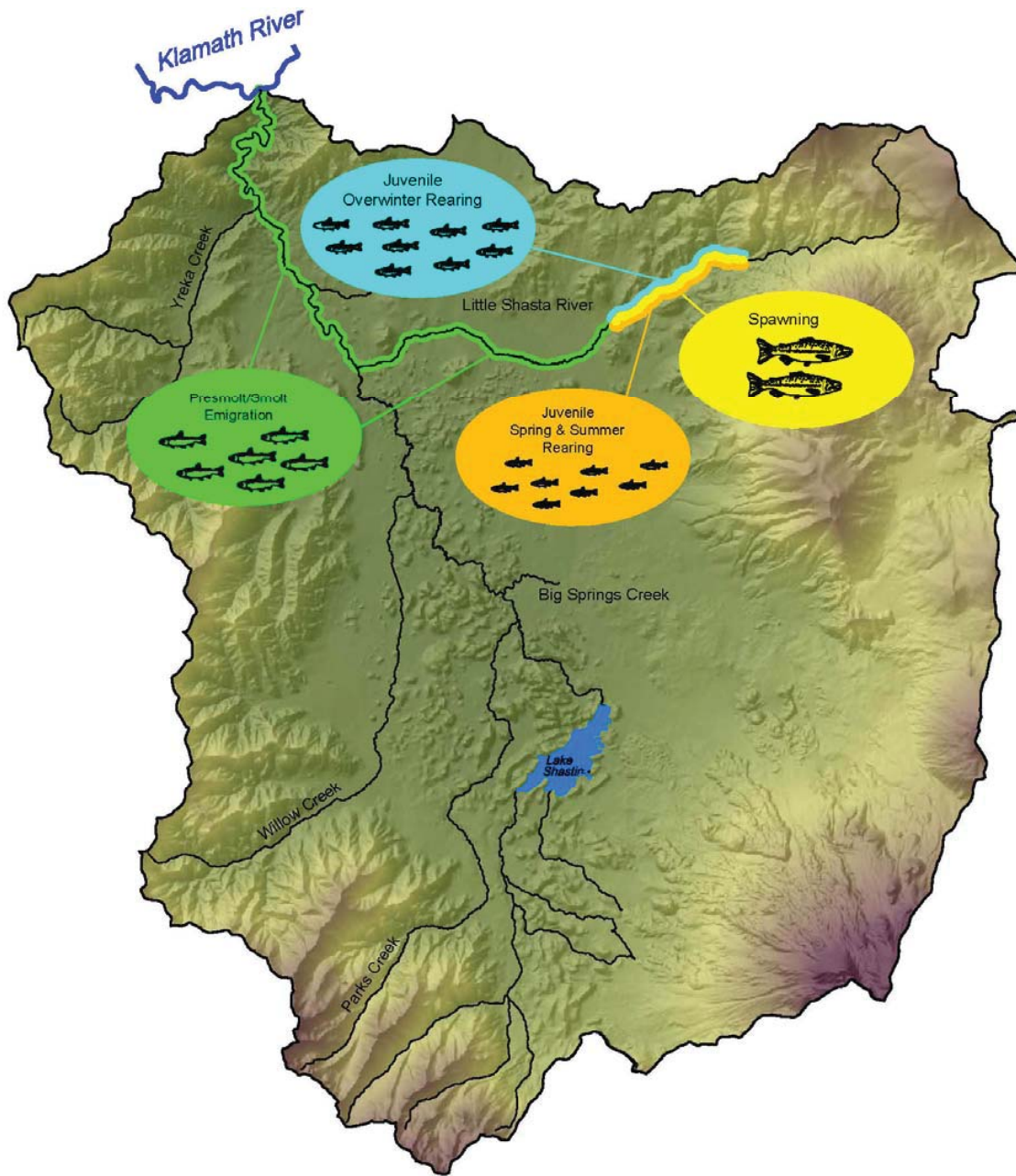
Current status of tactic and habitat conditions

Anecdotal observations and radio-tracking studies by CDFG have identified adult coho spawning in the Canyon. CDFG biologists estimate that currently approximately half of all coho spawning occurs in the Canyon (Chesney et al. 2007). This tactic may be one of only a few contemporary tactics still producing fry and juveniles that reach the Klamath River. Adult passage is likely not an issue, nor is the availability of spawning habitat at the low contemporary escapements. Rearing habitat remains suitable until water management practices cumulatively reduce instream flows, and water temperatures become unsuitable in all years. Because the Dewey Smith Obstruction appears impassable to juvenile upstream migration, fry are assumed to migrate to the Klamath where their survival is currently speculative. Agency and tribal biologists have observed coho rearing in cold-water refugia in Klamath tributaries, many of which are assumed to be non-natal juveniles.

High priority data and information needs

- relationship between streamflow and coho spawning habitat availability in the Canyon reach;
- relationship between streamflow and coho fry and juvenile spring rearing habitat availability in the Canyon reach;
- evaluation of the effects of spring and summer water temperatures on fry growth rates and emigration;
- estimate of the current distribution and abundance of spawning gravels in the Shasta Canyon reach, including spawning gravel sources, transport rates and mobility, and assessment of the need for gravel augmentation to replenish coarse sediment supply and spawning gravel abundance;
- estimate of coho fry and juvenile rearing habitat area on floodplain and in side-channel features in the Canyon reach, and streamflow threshold for providing access to those rearing sites;
- relationship between size and timing at Klamath or ocean entry, and survival-to-recruitment;
- evaluation of the fate of early emergent fry entering the mainstem Klamath in late winter and early spring;
- estimate of the size class distribution of Canyon Tactic 0+ coho emigrating from the canyon in May-June relative to the overall size class distribution of 0+, particularly comparing to sizes of 0+ emigrating from Big Springs Complex;
- the role of Shasta Canyon as winter rearing area for out-of-basin coho;
- the role of Shasta Canyon in genetic mixing (both coho and Chinook) and re-colonization due to poorly imprinted early outmigrants from canyon rearing elsewhere. (maybe this goes elsewhere);
- evaluation of impacts of Higgs hydro, Smith hydro and Smith O&C dams on fish passage, bypass flows, screening etc.

***9.1.12 Tactic 12: Coho Little Shasta River Foothills Tactic***



Spawning - Incubation - Early Fry Rearing	Juvenile Spring - Summer Rearing	Juvenile Over-Winter Rearing	Presmolt - Smolt Emigration
Oct-Nov-Dec-Jan-Feb-Mar	Apr-May-Jun-Jul-Aug-Sept	Oct-Nov-Dec-Jan-Feb-Mar	Apr-May-Jun
Little Shasta Foothills			Little Shasta Bottomlands/ Mainstem/ Canyon



***Tactic 12: Coho Little Shasta River Foothills Tactic***Description of life history tactic:

The Little Shasta River unimpaired hydrograph was nearly as ideal a hydrograph as could be provided for salmonids – consistent year-round baseflows augmented by local cold-water springs, and a modest snowmelt that annually inundated highly productive rearing areas (floodplains, side channels, beaver ponds). Additionally, the Little Shasta has a relatively benign winter high flow regime (as depicted in the historical gaging records) and the potential for high winter survival. For coho salmon, the 5.6 mile long Little Shasta River Foothills reach from Dry Gulch to the Blair Hart Diversion provided high quality spawning and rearing habitat. The reach had a moderate gradient, gravel-bedded alluvial morphology, abundant deep pools for juvenile coho rearing, undercut banks and accumulations of woody debris, and a dense riparian and mixed conifer canopy. The elevation, channel morphology, riparian canopy, and cold mountain runoff combined to sustain high quality coho rearing habitat throughout the year, for most or all water year types, even dry years. Additional production for this tactic may have occurred farther upstream in the Headwaters reach above a natural waterfall at the confluence of Dry Gulch that may have been passable by adult coho. As with other tributary tactics, juveniles could overwinter in the Foothills reach, or disperse in the fall to seek over-wintering habitat elsewhere, presumably in the lower-gradient Upstream dispersal of fry and juveniles may also have allowed seasonal redispersal into favorable habitat. In spring, presmolts and smolts depended on adequate streamflows through at least late-April or mid-May to emigrate through the Bottomlands reach where good rearing habitat conditions were strongly streamflow dependent. Longer sustained rearing would increase smolt output.

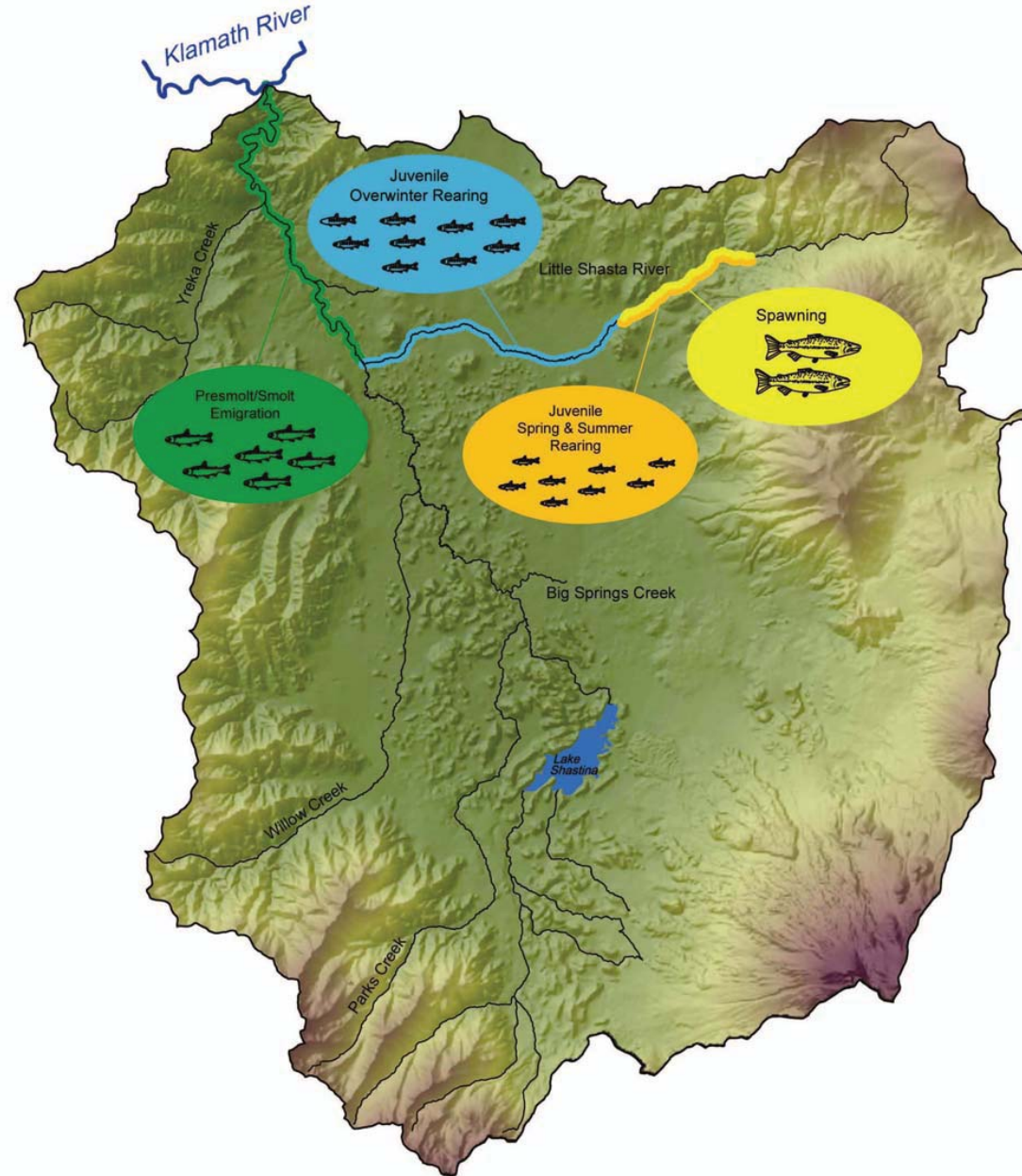
Current status of tactic and habitat conditions

The Little Shasta River presents the ideal opportunity to augment life history diversity for Chinook, coho, and steelhead populations as a way to hedge against unforeseen constraints in other reaches or tributaries. The Little Shasta River is relatively isolated from the rest of the basin, habitat is available for all life stages of all three salmonid species, and only moderate streamflows would be required to sustain high quality year-round rearing habitat. The Little Shasta Foothills reach (above the Musgrave/Hart Diversions) is presently not easily accessible to agency or private researchers. Currently, streamflows are inadequate to encourage upstream migration, particularly early in the fall for Chinook. Passage through the Foothills reach is uncertain. The Dry Gulch Falls may be impassable at low flows, or at least discourages migration. Spawning habitat may be abundant in the Foothills reach and above, but has not been investigated. Spring and summer rearing habitat is also not confirmed but is presumed suitable to at least moderate rearing densities and growth rates. Spring downstream migration may be hampered by flow diversions. During the irrigation season, the Bottomlands reach has unsuitably high summer water temperatures or is dewatered.

High priority data and information needs

- estimate of streamflow threshold that provides unrestricted upstream coho migration to the Little Shasta River Headwaters reach;
- reach-scale survey of coho habitat availability from the mainstem Shasta River confluence to the Little Shasta River Headwaters reach (approximately Dry Gulch), to determine (1) extent of spawning habitat, (2) extent of rearing habitat, and (3) location of natural and anthropogenic migratory barriers;
- relationship between streamflow and coho fry and juvenile summer rearing habitat availability in the Little Shasta River Headwaters reach, in the range of approximately 5-50 cfs;
- flow and water temperature data for Little Shasta Headwaters and Foothills reaches;
- analysis of existing and potential riparian vegetation coverage in the Foothills;
- assessment of current impaired streamflow conditions and their effect on riparian vegetation recruitment, seed release timing (phenology) of primary woody riparian species, and assessment of streamflow magnitude and timing that may promote natural regeneration of riparian vegetation;
- estimate of streamflow threshold that provides unrestricted upstream migration into the Headwaters reach;
- relationship between streamflow and ephemeral coho rearing habitat in side channels and on floodplains in the Little Shasta River Bottomlands reach, or minimum flow threshold providing rearing habitat in these features;
- estimate of streamflow threshold that provides coho rearing habitat in side channels and on floodplains in the Little Shasta River Bottomlands reach;
- direct observation or e-fishing surveys in the Headwaters reach to determine presence/absence and age class distribution of juvenile coho;

***9.1.13 Tactic 13: Coho Little Shasta River Foothill – Bottomlands Tactic***



Spawning - Incubation - Early Fry Rearing	Juvenile Spring - Summer Rearing	Juvenile Over-Winter Rearing	Presmolt - Smolt Emigration
Oct-Nov-Dec-Jan-Feb-Mar	Apr-May-Jun-Jul-Aug-Sept	Oct-Nov-Dec-Jan-Feb-Mar	Apr-May-Jun
Little Shasta River Foothills	→	Little Shasta River Bottomlands	Mainstem/Canyon

***Tactic 13: Coho Little Shasta River Foothills– Bottomlands Tactic***

Description of life history tactic:

The near-term recovery of coho salmon in the Shasta River basin will require utilizing any available cold-water habitat for summer rearing. Several Little Shasta River tactics propose to take advantage of potentially the best remaining year-around habitat in the Little Shasta River, in the Foothills reach above the Musgrave Diversion. This reach provides at least five miles of spawning habitat and summer cold-water rearing habitat. The primary instream flow need is to restore baseflows in the fall to allow adult migration upstream to the Foothills reach. Spawning habitat is presumed to be abundant enough to fully seed this reach with emergent fry. The reach has a riparian canopy, a gravel-cobble bed, and likely has abundant large wood providing good rearing habitat conditions during summer. Fry that remain to rear in the Foothills reach would then be available to migrate into winter rearing habitat in the Bottomland reach below the Hart Diversion downstream to the confluence with the mainstem Shasta River. High quality winter rearing in this reach could be provided through winter and into spring. Spring streamflows through April would also be required in the Bottomlands reach, with a well-timed flow release to mimic snowmelt runoff. These streamflow components would stimulate benthic invertebrate productivity and to allow fry to grow and redistribute to the mainstem and canyon, continue juvenile rearing and growth until large enough to smolt. Because irrigation season begins March 1 on the Little Shasta River, both March and April would be important months for providing juvenile rearing habitat in the Bottomlands reach. Springtime streamflows should enable fry and juvenile migration both upstream (fry dispersal to upstream reaches if spawned below diversions) and downstream (juvenile and pre-smolt emigration to high quality rearing habitat in the Bottomlands reach and in the Shasta River mainstem and canyon reaches).

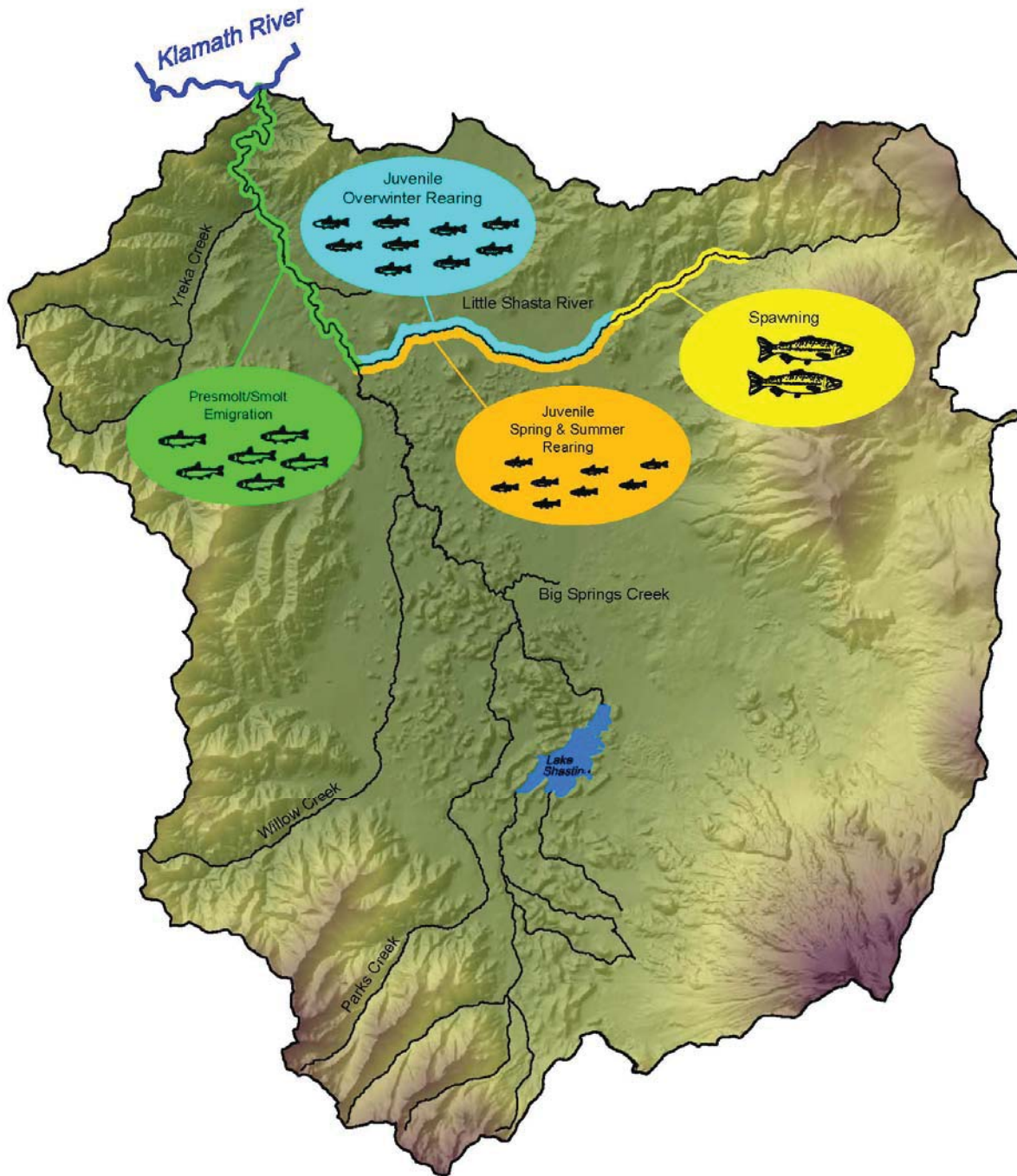
Current status of tactic and habitat conditions

Currently, streamflows are inadequate to encourage upstream migration into the Little Shasta Foothills reach (above the Musgrave/Hart Diversions), particularly early in the fall for Chinook. Passage through the Foothills reach is uncertain. The Dry Gulch Falls may be impassable at low flows, or at least discourages migration. Spawning habitat may be abundant in the Foothills reach and above, but has not been investigated. Spring and summer rearing habitat is also not confirmed but is presumed suitable to at least moderate rearing densities and growth rates. Spring downstream migration may be hampered by flow diversions. During the irrigation season, the Bottomlands reach has unsuitably high summer water temperatures or is dewatered.

High priority data and information needs

[same data and information needs as Tactic #12]

***9.1.14 Tactic 14: Coho Little Shasta River Bottomlands Tactic***



<b>Spawning - Incubation - Early Fry Rearing</b>	<b>Juvenile Spring - Summer Rearing</b>	<b>Juvenile Over-Winter Rearing</b>	<b>Presmolt - Smolt Emigration</b>
Oct-Nov-Dec-Jan-Feb-Mar	Apr-May-Jun-Jul-Aug-Sept	Oct-Nov-Dec-Jan-Feb-Mar	Apr-May-Jun

***Tactic 14: Coho Little Shasta River Bottomlands Tactic***

Description of life history tactic:

With the exception of a reach mimicking the canyon, the Little Shasta River is appropriately named, having good habitat conditions analogous to the mainstem but on a smaller scale. The winter flood and spring snowmelt hydrographs were present but much smaller compared to the mainstem. The year-round baseflows from local springs resembled the mainstem. Productivity of the Little Shasta Foothills reach, and especially of the Bottomlands reach, was likely extremely high. The Bottomlands tactic would have accessed the Little Shasta River Headwaters reach for spawning and rearing life stages, but was different from the Headwaters tactic because fry and juveniles migrated to the Bottomlands reach throughout the spring and summer and found abundant, high quality habitat in the 11.8 miles of this low-gradient reach. This tactic probably far outperformed the Headwaters tactic of smolt production because of the habitat quality in the Bottomlands reach. As in the mainstem Shasta River, the Little Shasta River probably historically maintained suitable water temperatures throughout the summer, abundant food from aquatic macrophytes and emergent vegetation (cattail and bulrush), and extensive rearing capacity in spring and summer from snowmelt-flooded floodplains, side channels, beaver ponds, and high quality habitat in the Little Shasta mainstem. Growth rates and fish densities would have been high through spring, summer, and into fall. With such optimal habitat conditions, juvenile coho would have remained in this reach through the winter, where habitat capacity and overwinter survival would have continued to be high. Upstream dispersal of fry and juveniles may also have allowed access to cold-water habitat in the Headwaters reach. This tactic historically benefited from a snowmelt runoff of ~50 to 100 cfs sustained flows in April and May in most years. By May, coho smolts of the Bottomlands tactic would have been large enough to emigrate to the mainstem and Klamath river, and the Pacific Ocean.

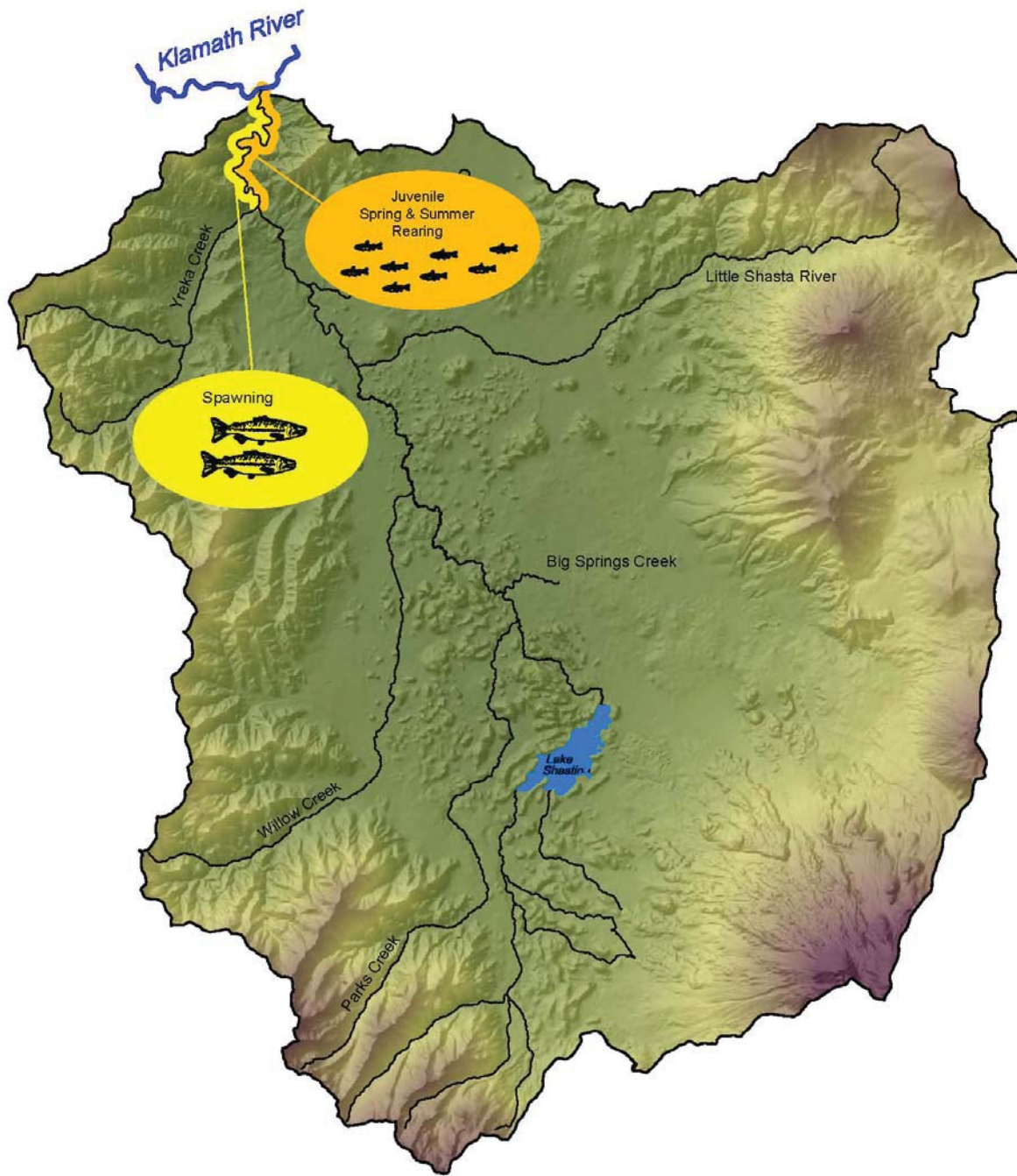
Current status of tactic and habitat conditions

Although juvenile coho have been captured in the Little Shasta River sporadically in recent years (Mike Farmer pers. comm.), habitat in the Foothills and Bottomlands reaches is not available consistently to sustain a coho tactic. Streamflows appear inadequate (frequently no flows) in the fall and winter of most/all years to promote upstream migration. Adult passage through the Bottomlands reach is also uncertain. If suitable late-summer and fall streamflows were available, adequate streamflows and spawning habitat in the Foothills reach could provide abundant spawning. However, flow diversions for irrigation beginning in early spring appear to diminish habitat in the Bottomlands, and water temperatures become unsuitable by mid-summer before the reach becomes completely dry.

High priority data and information needs

- reach-scale survey of coho habitat availability from the mainstem Shasta River confluence to the Little Shasta River Headwaters reach (approximately to Dry Gulch), to determine (1) extent of spawning habitat, (2) extent of rearing habitat, and (3) location of natural and anthropogenic migratory barriers;
- relationship between streamflow and coho fry and juvenile summer rearing habitat availability in the Little Shasta River Foothills and Bottomlands reaches, in the range of approximately 5 to 50 cfs;
- flow and water temperature data for Little Shasta Foothills and Bottomlands reaches;
- water temperature data for Little Shasta Foothills and Bottomlands reaches;
- estimate of water temperature threshold or other environmental cues that encourage emigration of Coho juveniles from the Big Springs Complex in spring;
- analysis of existing and potential riparian vegetation coverage in the Bottomlands;
- relationship between streamflow and ephemeral coho rearing habitat in side channels and on floodplains in the Little Shasta River Bottomlands reach, or minimum flow threshold providing rearing habitat in these features;
- direct observation or efishing surveys in the Foothills and Bottomlands reach, and/or downstream migrant trapping data at the mouth of the Little Shasta River, to determine presence/absence and age class distribution of juvenile coho;

**9.1.15 Tactic 15: Fall Chinook Yearling Tactic**



Spawning - Incubation - Early Fry Rearing	Juvenile Spring - Summer Rearing	Juvenile Over-Winter Rearing	Presmolt - Smolt Emigration
Oct-Nov-Dec-Jan-Feb-Mar	Apr-May-Jun-Jul-Aug-Sept	Oct-Nov-Dec-Jan-Feb-Mar	Apr-May-Jun
Canyon	→	0+ ENTER KLAMATH	

***Tactic 15: Fall Chinook Yearling Tactic***Description of life history tactic:

A large proportion of the fall Chinook run utilizes the 7.8 mile Shasta Canyon reach for their entire Shasta River life history, spawning in the fall, emerging in late winter and spring, then emigrating to the Klamath beginning in February and continuing through June (DWR 1986, Walsh and Hampton 2006). The unimpaired snowmelt runoff likely ranged as high as 400 to 800 cfs in the Canyon during April and May, which may have optimized fry rearing habitat suitability in the Canyon by inundating floodplain and side-channels. CDFG estimates the average 2001-2005 Chinook production from the Shasta River was 2.34 million fry (Chesney et al. 2007), and that over 89% of the total 0+ Chinook emigrated as emergent fry between mid-February and early April. The peak Chinook emigration timing (March through April) may therefore correspond to reduced flows in the spring (from irrigation diversions) and increased water temperatures, which prompts most Chinook produced from redds in the Canyon (the Chinook Canyon tactic) to emigrate as emergent fry (Chesney et al. 2007). However, given the uncertainty of survival as a small Chinook fry in the Klamath River, an important life history variation for Chinook salmon was to remain in the benevolent mainstem Shasta River at least through the summer for additional growth. Snyder (1931) noted abundant Chinook fry in seine hauls in the lower Klamath River in late September 1920 and explained that “It would appear from what has been discovered at or near the mouth of the river that a pronounced emigration of young salmon occurs in the late summer and early fall.” The Fall Chinook Yearling tactic in the Shasta Canyon was probably sustained by cold summer baseflows that allowed a portion of the cohort to rear through the summer, gain additional size/weight, then emigrate when Klamath mainstem temperatures cooled in fall. Smolt-to-adult survival of fall Chinook may be enhanced by growth rate and size at ocean entry. Progeny of most fall Chinook spawners would benefit from higher spring flows and improved rearing habitat conditions (the Chinook Canyon tactic), and progeny of late-fall spawned Chinook and smaller individuals of the cohort may benefit from extended rearing by remaining through the summer (the Chinook Yearling Tactic). Late fall emigration would also reduce risk of mortality from disease in the Klamath River.

Current status of tactic and habitat conditions

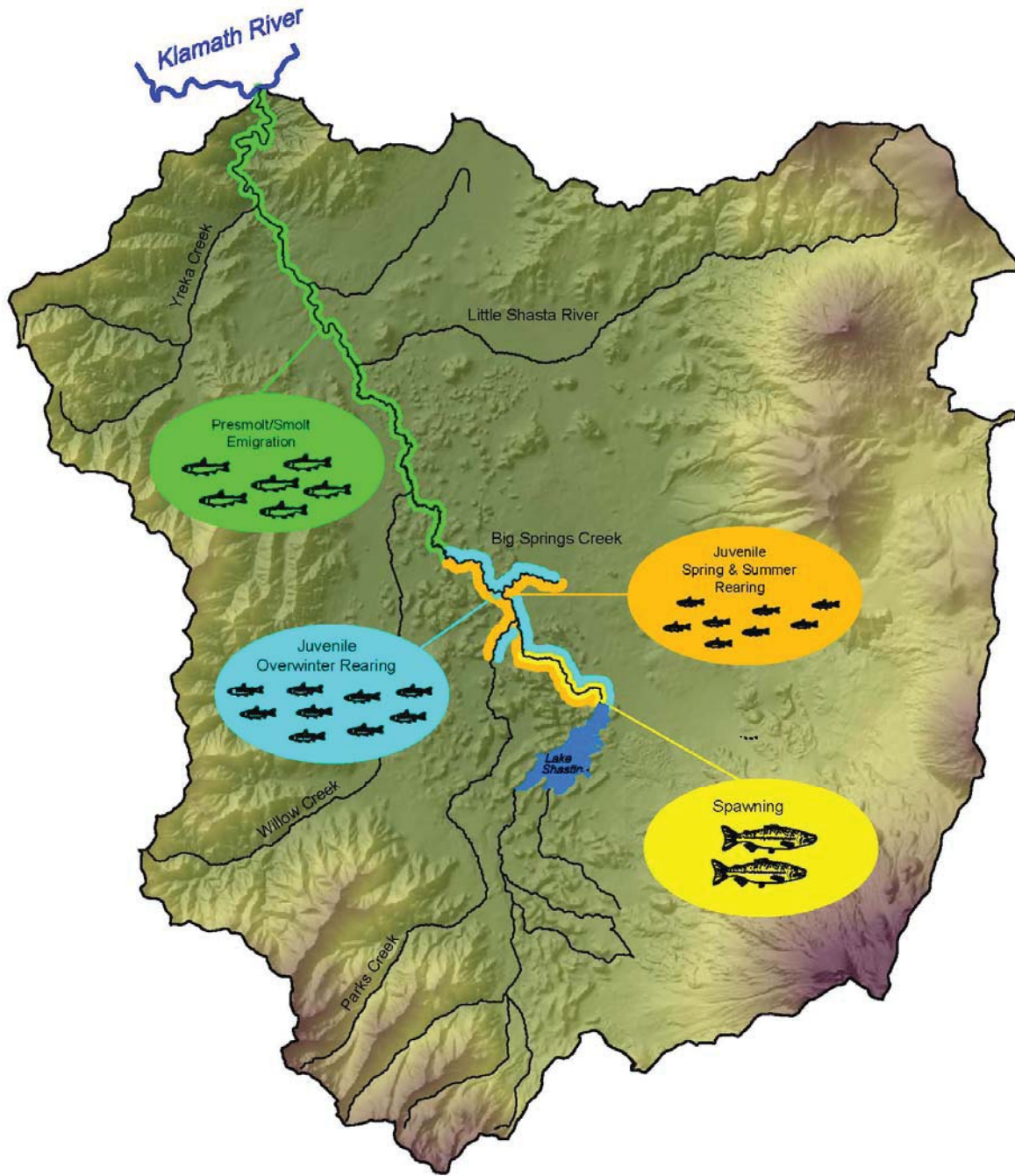
CDFG studies have documented a substantial loss of suitable rearing habitat in the lower Shasta River as a result of water management operations. Elevated water temperatures in early spring may force most or all Chinook fry to emigrate before the low summer flow period. Given suitable summer baseflow and water temperature conditions, fry and juvenile Chinook rearing habitat would be abundant in the Canyon reach. Currently, survival of emergent fry Chinook entering the Klamath River is unknown, but elevated water temperatures, low summer flows, and high infection of juvenile Chinook by myxozoan parasites (Nichols and Foott 2005, from Chesney et al. 2007) indicate survival may be low. The risk of infection from parasites appears to increase later in the season, after most Chinook outmigrants leave the Shasta. The predominance of salmon following this tactic in the Shasta may indicate that early outmigration is beneficial, when late outmigration has a high risk of mortality. The yearling tactic may not be beneficial under contemporary Klamath River summer conditions.

High priority data and information needs

[same data and information needs as Tactic #1]

- relationship between size at Klamath or ocean entry, timing of entry to Klamath, and survival to recruitment;
- distribution and abundance of juvenile Chinook summer rearing habitat in the Big Springs Complex (and possibly in a restored Dwinnell reach);
- water temperature threshold that encourages extended residency in the Shasta River mainstem, and location/prevalence of cold water refugia along the mainstem.

***9.1.16 Tactic 16: Coho Below Dwinnell Tactic***



Spawning - Incubation - Early Fry Rearing	Juvenile Spring - Summer Rearing	Juvenile Over-Winter Rearing	Presmolt - Smolt Emigration
Oct-Nov-Dec-Jan-Feb-Mar	Apr-May-Jun-Jul-Aug-Sept	Oct-Nov-Dec-Jan-Feb-Mar	Apr-May-Jun
Below Dwinnell	Below Dwinnell, Big Springs Complex	→	Mainstem/Canyon



***Tactic 16: Coho Below Dwinnell Tactic***

Description of life history tactic:

This tactic is similar to the Big Springs Complex coho 1+ tactic, but incorporates the 6.9 mile long section of mainstem Shasta River below Dwinnell Dam downstream to the Big Springs confluence. This reach may have been one of the few reaches capable of providing habitat for all the freshwater life stages: spawning, incubation and early emergent fry rearing, summer rearing, winter rearing, and even pre-smolt rearing before the cohort began migrating to the Klamath River and the Pacific Ocean. Given the increase in stream gradient through the Nelson reach and the Below Dwinnell reach, spawning gravels may have been (and still may be) abundant in this reach. However, since construction of Dwinnell Dam in 1928, spawning habitat is degraded by the blockage of sediment supplied to this reach from above Dwinnell Dam, and from the loss of winter floods that historically maintained the channel morphology and habitat characteristics. As with other tactics that utilized spawning reaches for fry rearing, some fry remained within these same reaches, while some fry were forced to emigrate to find suitable habitat in other areas because of high fry rearing densities within the spawning grounds. Fry that remained could have reared throughout this reach an entire year under historical conditions. Upon emigrating in the spring, this tactic, like many others, would have benefited from the excellent rearing conditions afforded in the mainstem Shasta River, the Klamath River mainstem, and estuary.

Current status of tactic and habitat conditions

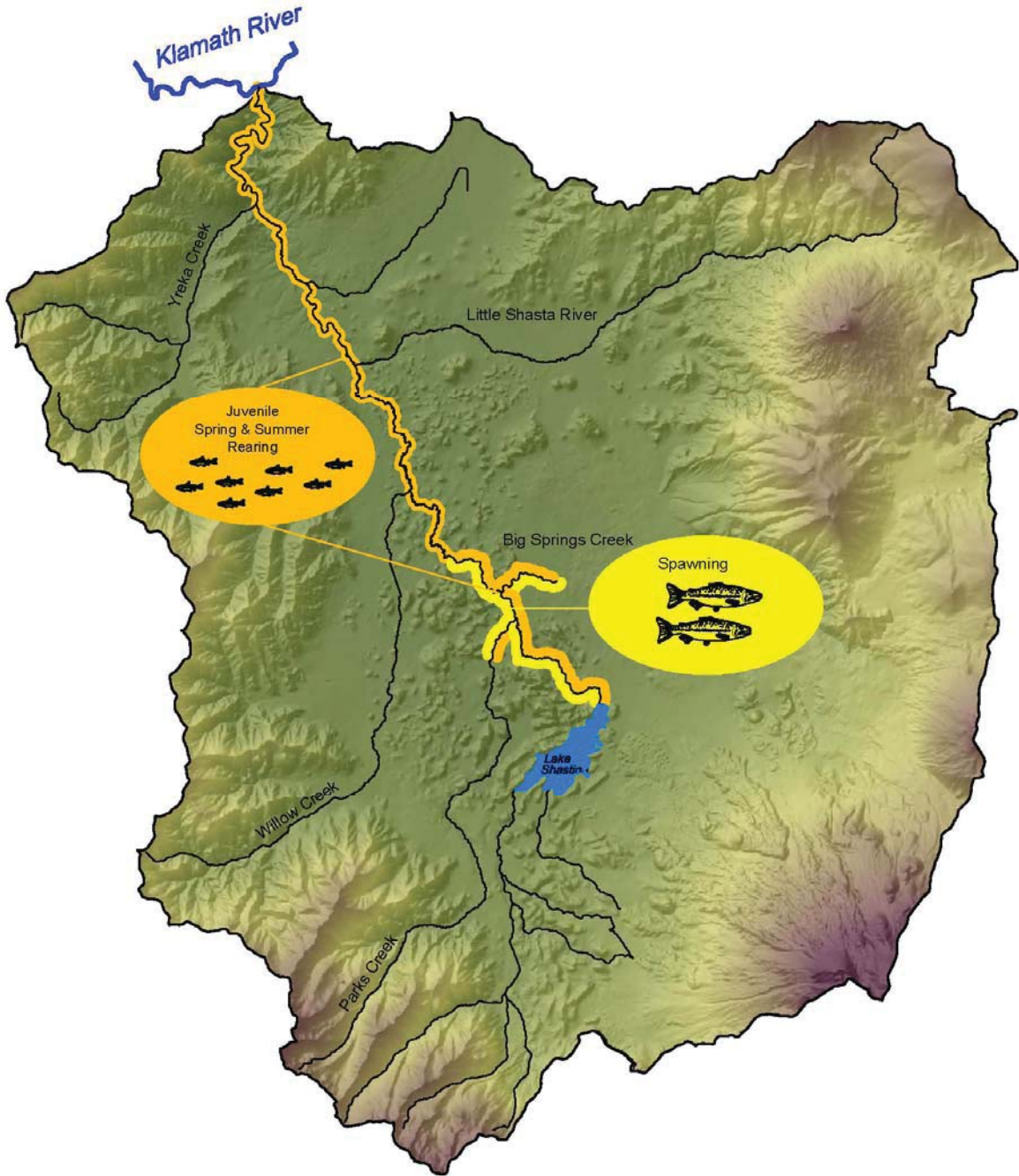
During the irrigation season, the reach below Dwinnell Dam has unsuitably high water temperatures and low baseflows that cannot sustain spawning or rearing habitats. Conditions of early emergence rearing habitat, juvenile spring/summer rearing habitat, and juvenile overwintering rearing habitat have not been well-documented. Based on what is known, spawning and rearing could occur if streamflows were available below the dam. However, high quality cold water releases from Dwinnell Dam may be problematic, given potential water quality issues in Lake Shastina (Vignola and Deas 2005). Providing cold baseflows during irrigation season (April 1-October 1) in the Below Dwinnell reach would require that local springs near the dam be allowed to feed the mainstem, perhaps augmenting small releases of Lake Shastina water when water quality conditions are not severe. Water diversion rights could be offset by water delivery from Dwinnell Dam. The quantity of flow of these springs is unknown. This type of water transfer would not only benefit the Below Dwinnell reach, but would also improve temperature and flow conditions in the Nelson Ranch reach and conditions farther downstream.

High priority data and information needs

[same data and information needs as Tactic #3]

- relationship between streamflow and Coho spawning habitat abundance in the Below Dwinnell in the range of 50 to 225 cfs;
- estimate of the distribution and abundance of spawning gravels, and assessment of spawning gravel quality in the Below Dwinnell reach; preparation of gravel maintenance plans in the Below Dwinnell reach;
- location of springs, groundwater seepage, and other sources of coldwater summer rearing habitat refugia in the Below Dwinnell reach;
- mapping to determine extent of existing riparian vegetation, identification of plant stand types, evaluation of age-class structure, and location of geomorphic surfaces capable of supporting riparian vegetation recovery;
- feasible riparian vegetation recovery options, including experimentation with snowmelt flood releases to promote riparian plant seedling germination, initiation, and survival to recruitment; and riparian planting experimentation;

**9.1.17 Tactic 17: Spring Chinook Mainstem Tactic**



Spawning - Incubation - Early Fry Rearing	Juvenile Spring - Summer Rearing	Juvenile Over-Winter Rearing	Presmolt - Smolt Emigration
Oct-Nov-Dec-Jan-Feb-Mar	Apr-May-Jun-Jul-Aug-Sept	Oct-Nov-Dec-Jan-Feb-Mar	Apr-May-Jun
Below Dwinnell, Big Springs Complex	→	0+ ENTER KLAMATH	

***Tactic 17: Spring Chinook Mainstem Tactic***Description of life history tactic:

The spring Chinook salmon was more accurately an entire life history strategy rather than a tactic, and they likely occupied the entire watershed that was historically available to anadromous salmonids. But it is described in this context to highlight the breadth of life history diversity sustained by historic flow and habitat conditions in the Shasta River. The Spring Chinook were likely the dominant historical life history strategy. Snyder (1931) documented the spring Chinook from anecdotal evidence and from records of the commercial catch in the estuary in 1918-20, and is quoted to say “They [spring Chinook] formerly came to the Shasta River in great numbers, an old resident referring to it as the best spawning tributary of the Klamath River.” Snyder also quoted R.D. Hume’s description of the Klamath River: “In 1850 in this river during the running season, salmon were so plentiful, according to the reports of the early settlers, that in fording the stream it was with difficulty that they could induce their horses to make the attempt, on account of the river being alive with the finny tribe. At the present time the main run, which were the spring salmon, is practically extinct...” Wales (1951) concluded his analysis of the Shasta River Chinook salmon with the assertion that “... it is my belief that a very large part of the former king salmon run in the Shasta River was spring run fish. Actually I believe that only about 8% of the run was fall run”. The spring Chinook began entering the Klamath in late March, peaked in April and May “during its flood height of very cold water, and pass up stream under the same conditions” (Snyder 1931), and waned by mid-June. Adults were smaller in size than fall run Chinook, were sexually immature, and lacked spawning colors. Snyder (1931) put their arrival in the Shasta River in June and early July where they held until becoming sexually mature to spawn at about the same time as the fall Chinook. Spring Chinook likely shared life history characteristics of the fall Chinook in terms of spawning location and habitat suitabilities, incubation and emergence timing, fry and juvenile rearing, and emigration timing. There is no specific documentation of their habitat utilization within the Shasta River basin differentiated from the fall Chinook. Wales (1951) stated “we have no records to show what part of the spawning run of kings used the river and tributaries above the dam but it is known that this area was important.” Snyder attributed the depletion of the spring Chinook to “construction of dams on the mainstem Klamath River...mining operations, overfishing both in the river and at sea, irrigation and other causes...”.

Current status of tactic and habitat conditions

Spring Chinook were extirpated from the Shasta River at least by the early 1900’s, but still persist in the Trinity and Salmon rivers. Assuming they historically concentrated in the Shasta mainstem reaches where cold water temperatures persisted throughout the summer (the Foothills, Below Dwinnell, Nelson Ranch, and Middle Shasta River reaches), their recovery to the Shasta basin is imminently feasible. Summer water temperatures in the Shasta River currently are not suitable to sustain oversummering adult Chinook. But given favorable water temperatures in summer and fall in the Shasta mainstem, habitat in the reaches below Dwinnell Dam appears to be suitable for the remainder of their life stages.

High priority data and information needs

- restoring the spring Chinook tactic to the Shasta River should be a high priority for salmonid recovery in the basin, but the data and information needs are beyond the scope of this plan.

## **10 APPENDIX B: INSTREAM FLOW FIELD METHODS**

### **10.1 Habitat Mapping**

A central currency of *incremental* instream flow methods is the habitat-flow curve. This curve describes a relationship between stream discharge and area of physical habitat (measured as ft<sup>2</sup>) available for salmonids. Incremental modeling approaches (e.g. PHABSIM) integrate hydraulic models with habitat criteria to produce a habitat-flow curve. Habitat mapping uses binary criteria to develop empirical habitat-flow relationships by mapping habitat on aerial photo basemaps (or using surveying equipment) over a range of flows.

Several practitioners are exploring alternative approaches to habitat mapping (McBain and Trush, 2004; Stillwater Sciences 2006 and 2007; Chamberlain et al. 2007; Hunter et al. 2008). Each method shares a common theme of employing a set of binary hydraulic criteria (depth and velocity) and habitat qualifiers (substrate, cover types, distance to cover) to delineate patches of salmonid habitat in the stream channel for the species and life stages of interest, then tracing the patch onto laminated aerial photo basemaps or using surveying equipment to map the patch. Habitat polygons are later digitized using AutoCAD or ARC-GIS computer software to calculate the area of each habitat patch. The total area is then summed for each streamflow to produce a habitat-flow curve. Mapping methods differ primarily in the degree to which habitat patch boundaries are determined by strict adherence to measured variables. Patches of channel that meet the specified criteria are either always designated as habitat (strict criteria mapping methods) or may be judged poorer quality and not designated as habitat. Various habitat mapping methods are described in Annear et al. (2004) and on the Hydropower Reform Coalition webpage at <http://www.hydroreform.org/hydroguide>.

Habitat mapping was conceived as a less expensive and potentially more accurate alternative to modeling, and this concept was tested on the Oak Grove Fork of the Clackamas River to support instream flow recommendations for the Portland General Electric (PGE) FERC relicensing process (McBain and Trush 2004). Criteria were used as guidelines for identifying available habitat, and were based on values from the scientific literature for each species and life stage selected for analysis. Binary criteria with suitability above 0.5 were selected. Numerous hydraulic measurements were made at each habitat polygon identified. One important feature of this mapping effort was that a selected group of fisheries scientists jointly mapped a single set of polygons for each streamflow. The resulting habitat-flow curves achieved a high degree of internal consistency that was recognized as a more valuable asset than other methods that may have achieved greater precision.

Railsback and Kadvaný (2008) use the Oak Grove Fork habitat mapping study as a case study in their publication, but refer to the approach as Demonstration Flow Assessment (DFA). We continue to describe this method as habitat mapping since it results in spatially explicit habitat areas and a habitat-flow curve, and is therefore more quantitative than traditional DFA methods (Annear et al. 2004). The resulting habitat maps also quantify habitat in ft<sup>2</sup> (instead of WUA) that is useful to individual or population models, and allow validation of habitat use through direct observation.

#### **10.1.1 Precision and Accuracy in Habitat Mapping**

Habitat mapping has been criticized for lacking precision (i.e., reproducibility) because some applications may allow variability in how trained biologists exercise professional judgment to identify habitat polygon boundaries, instead of relying exclusively on measurable criteria. In their summary of the Oak Grove Fork study, Railsback and Kadvaný (2008) state: “In practice, all decision models and analyses depend on professional judgment... Instead of describing alternative instream flow methods as subjective versus quantitative, it is more useful to see them as having different balances

between the effort they require and the amount of useful information they provide.” Railsback and Kadvaný (2008) assert that all methods used to develop habitat-flow curves are *estimation methods*, and no method can guarantee the elimination of bias (Lichtenstein et al. 1982; Morgan and Henrion 1990, from Railsback and Kadvaný 2008), whether in the selection of variables used in a modeling approach, selection of cross section or study site placement, or in the interpretation of results.

Acknowledging that accuracy and precision are important considerations for any scientific study, we identified four general sources of error associated with habitat mapping:

1. selection or development of habitat suitability criteria (error in accuracy);
2. locating the criteria variables in the stream channel (error in precision);
3. translating those located points onto a map or computer (error in precision);
4. extrapolating curves from study site to river reach scales, without quantifying reach-wide habitat variability (error in accuracy);

Note: Precise (from Wikipedia) means “exact, as in performance, execution, or amount. “In physical science it means “repeatable, reliable, getting the same measurement each time.” Accurate means “capable of providing a correct reading or measurement.” In physical science it means ‘correct’. A measurement is accurate if it correctly reflects the size of the thing being measured.

The first source of error, associated with selecting or developing habitat suitability criteria is, in our view, the most critical type of error. Application of criteria that are not a good representation of actual habitat utilization will lead to inaccurate habitat-flow curves. This is a potentially significant source of error common to all methods that utilize habitat criteria. Other issues associated with conventional habitat suitability criteria have been described in the scientific literature (e.g., correlation among habitat variables, the requirement of estimating habitat variables in a fully seeded system, and the assumption that higher quality habitat supports higher density of fish, among others) (also see Bovee 1986, Bovee et al. 1998) and are not discussed here.

The second error is the crux of the lack-of-precision issue associated with habitat mapping. Habitat mapping methods that employ criteria as general guidelines that are tempered with professional judgment are likely less reproducible, because different professionals may interpret ‘what is habitat’ in different ways based on their own set of experiences. If mapping methods adhere strictly to measured criteria to identify habitat area boundaries, then this error is avoided and the method is presumably rendered more precise. The counter-argument to this approach is the challenge of relying on a select few quantitative criteria to delineate suitable habitat

The third source of error, translating habitat boundary points onto a map or into digital format, is essentially a technical issue. This source of error can be overcome either by obtaining higher resolution aerial photographs to map habitat in the field (i.e., increasing the practitioner’s ability to visually identify reference points on the aerial photo), or by using 3-dimensional survey techniques such as a total-station or GPS equipment.

The fourth source of error is also fundamental to instream flow needs assessments. This source of error results from reliance on precision in measurement at the site scale at the expense of the accuracy in assessing habitat variability over longer reach scales. For example, mapping methods may strictly adhere to measured criteria to identify habitat boundaries, and thus achieve a high level of precision. But the effort required to attain this precision is often achieved at the expense of a broader reach-wide assessment to quantify habitat variability over larger spatial scales. Error associated with extrapolation from study site to reach scale is rarely addressed in instream flow modeling or criteria

mapping approaches. However, habitat mapping may improve the accuracy of the resulting habitat curves because they incorporate longer sections of stream or river and thus quantify variability in habitat. This improvement in accuracy may outweigh the potential loss of precision resulting from less strict adherence to hydraulic criteria.

### ***10.1.2 Little Shasta River Habitat Flow Curves***

The two objectives of our habitat mapping were to (1) determine if habitat mapping method could produce reasonable habitat-flow curves for the Little Shasta River, and (2) determine if this method met standards for reproducibility acceptable to our Technical Advisory Committee. We targeted mapping “good” habitat for salmonids. We identified an interim set of habitat suitability criteria for the Shasta River basin, relying on the available expertise of several researchers in the Shasta River watershed, while also referencing criteria collected from other California and Oregon rivers. We developed hydraulic habitat criteria for salmonid fry; Chinook, coho, and steelhead juvenile rearing stages; and salmonid spawning (Table B1).

Our first objective was to map habitat over a range of streamflows and develop a habitat-flow curve. We mapped habitat for four life stages within a 1,300 ft reach of the Little Shasta River at the Shasta Valley Wildlife Area (Figure B1), at five different flows ranging from 6.7 cfs to 26.3 cfs. We also mapped a floodplain debris line from an overbank event on January 4, 2008 that was evident in our Little Shasta River streamflow gage (Figure B2). Habitat polygons were drawn onto 11x17 inch laminated aerial photographs at a scale of 1in = 15ft. Biologist used a Transparent Velocity Headrod (Fonstad et al. 2005) to estimate water depths and velocities. Discharge was measured for each mapping event at our gage using a Rickly Hydrologics Price AA current meter and standard USGS methods (Buchanan and Somers 1969). Once the field mapping was complete, the polygons were digitized in AutoCAD and habitat area was quantified and plotted (Figure B3). On occasions when more than one biologist mapped habitat on the same day, habitat areas were computed as the average of all mappers.

We produced a habitat-flow curve for the lower range of discharge values of interest (Figure B3). However, water diversions and dry water year conditions prevented us from capturing streamflows higher than 26 cfs. Since habitat mapping began in March 2008, flows in the Little Shasta River exceeded 20 cfs on only two days (May 29-30, 2008), and mapping crews were not able to mobilize to map these flows. Our preliminary habitat-flow curve was intended for demonstration purposes only, and ultimately will require additional points to complete the curve. Our mapping efforts were informative in several aspects. First, juvenile Chinook had the broadest criteria – a velocity range

*Table B1. Preliminary hydraulic habitat criteria applied at the Little Shasta River study site.*

Species	Life Stage	Depth (ft)	Mean Column Velocity (ft/s)
Chinook	Fry	0.1 – 1.5	0.0 - 0.5
	Juvenile		0.0 - 1.5
	Spawning	0.5 - 3.0	0.5 - 2.5
Coho	Fry	0.1 – 1.5	0.0 - 0.5
	Juvenile		0.0 – 0.5
	Spawning	0.5 – 3.0	0.5 - 2.5
Steelhead	Fry	0.1 – 1.5	0.0 - 0.5
	Juvenile		0.5 - 2.5
	Spawning	0.5 – 3.0	0.5 - 2.5

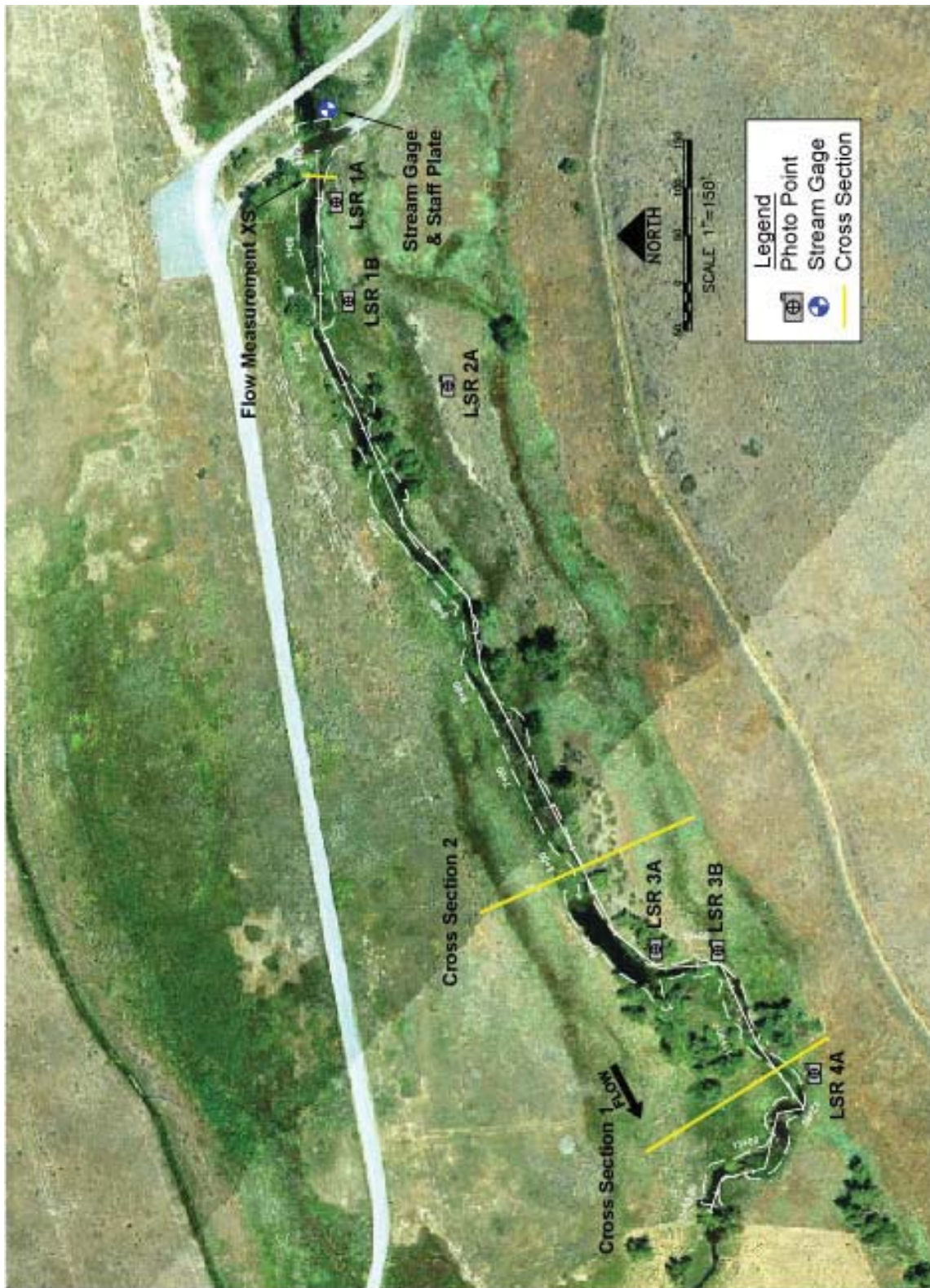


Figure B1. Little Shasta River habitat mapping site at the Shasta Valley Wildlife Area.



Figure B2a. Example of habitat polygons for salmonid fry, juvenile Chinook, coho, and steelhead mapped on March 17, 2008 at 12 cfs.





Figure B2b. Example of habitat polygons for salmonid fry, juvenile Chinook, coho, and steelhead mapped on March 17, 2008 at 12 cfs.



Figure B2c. Example of habitat polygons for salmonid fry, juvenile Chinook, coho, and steelhead mapped on March 17, 2008 at 12 cfs.

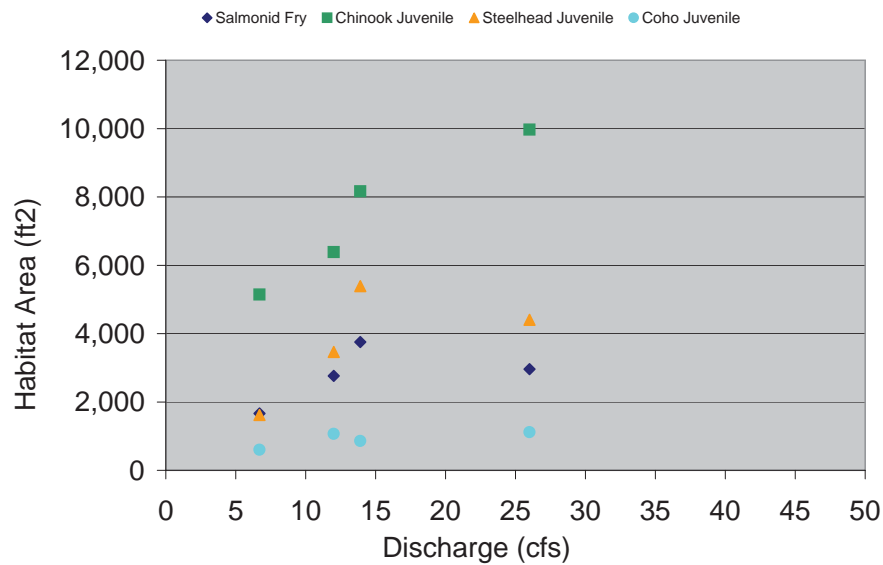


Figure B3. Habitat rating curve developed at the Little Shasta River over a range of available flows from March 2008 to February 2009.

of 0.0-1.5 ft/s and no depth limitation – and resulted with the most abundant habitat. These criteria, however, were inclusive of large patches of slow-moving water, primarily in the body and tail of pools, that was deemed to be very poor quality habitat. Several mappers included these areas while others did not; the result was a large difference in habitat area among mappers (Figure B4 a and b). Juvenile coho, in contrast, prefer deep, low velocity patches associated with cover, which were very restrictive criteria in our study reach. Because instream “object cover” (not bank cover) was generally lacking in this reach, our mapping team identified little habitat for juvenile coho, and the available habitat varied only slightly over the range of flows mapped. However, our reconnaissance-level observations of the Little Shasta River upstream and downstream of our study site indicated that coho habitat is highly unevenly distributed. We observed “hot-spots”: backwater areas, large beaver ponds, side channels and other features that would provide more abundant coho rearing habitat than was identified in our study site. Juvenile steelhead habitat depended strongly on the presence of higher velocity water and shear zones, which generally increased with flow as discharge increased up to 26 cfs. Finally, the salmonid fry habitat area increased with discharge. We attribute this to the trapezoidal channel morphology in this reach that provided relatively deep habitat units even at low flows, with only shallow-slow habitat patches becoming available as flow increased and inundated small lateral benches along the stream margin.

Two features in the Little Shasta River challenged our habitat mapping. Dense stands of bulrush/cattails lining portions of the channel banks or completely spanning riffles might be good rearing habitat for fry/juvenile coho and Chinook salmon (Figure B5). Hydraulic complexity within a single stand could be extreme: from 3 ft to 5 ft wide patches completely still adjacent to 1 ft wide fast-flowing lanes with velocities exceeding 3 ft/s (in riffles). Depth was almost meaningless within these patches as a habitat determinant. A juvenile Chinook salmon could be in 4 ft of water yet be within 0.2 ft of the water’s surface while hovering over a suspended floor of matted bull rush stems only 0.4 ft from the water’s surface. There were no juvenile fish to observe, but many of these microhabitat settings, especially where the stands spanned riffles (i.e., with local slope), appeared highly acceptable as good fry rearing habitat. Along channel banks of long low gradient pools/runs, these stands did not appear ideal as habitat. Only at the transition from open water to dense stems, comprising up to a few

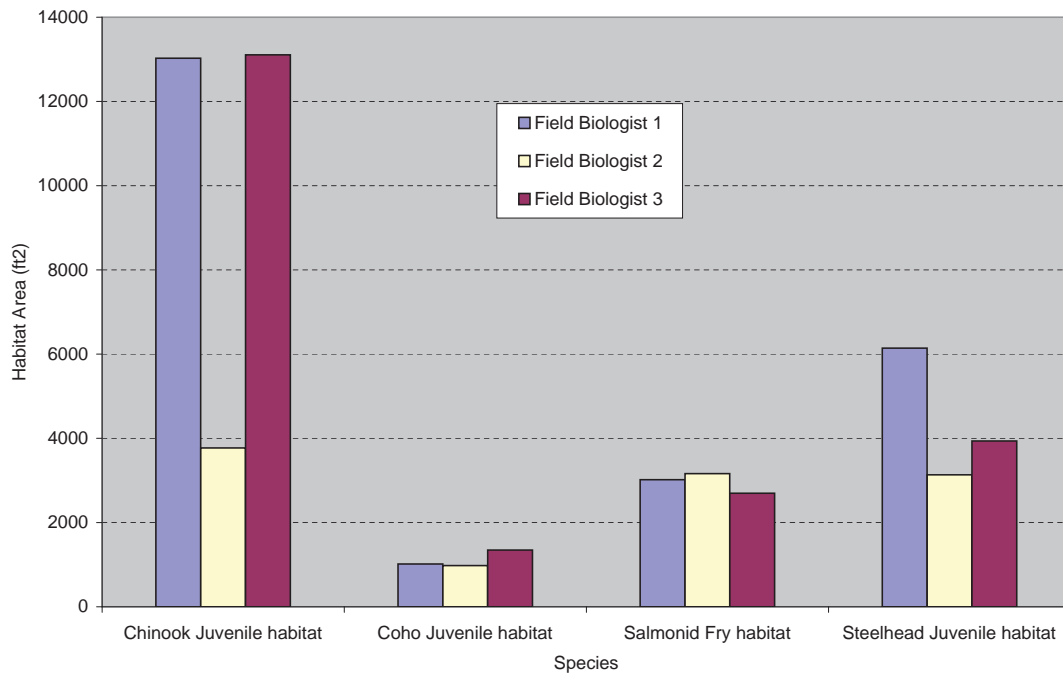
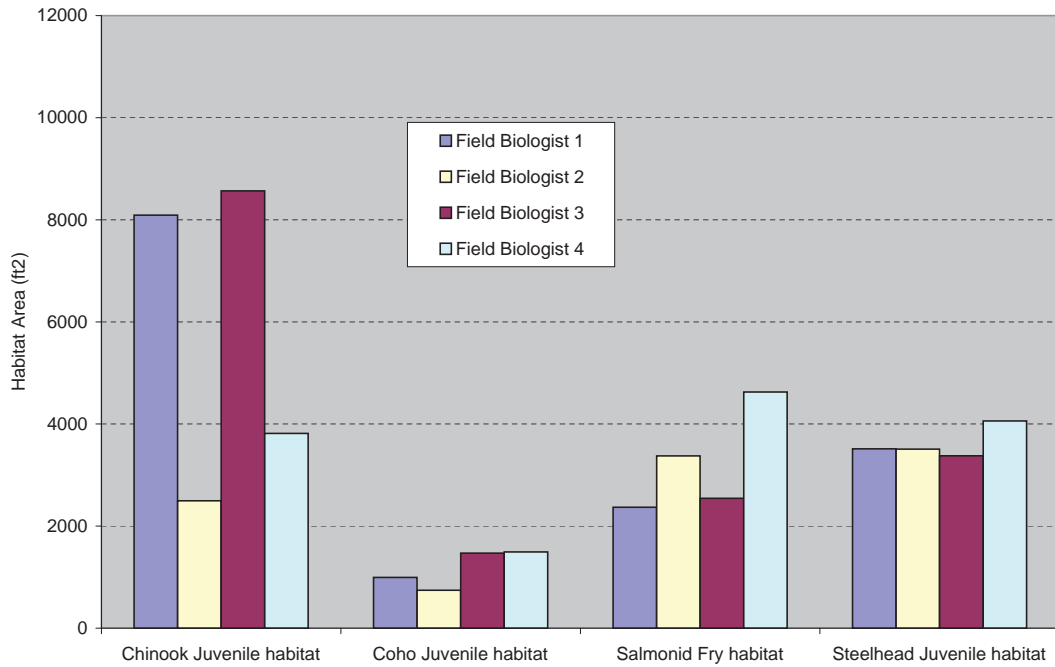


Figure B4a and b. Results of 'precision mapping' conducted on March 17, 2008 at 12 cfs (top) and March 18, 2008 at 26 cfs (bottom) with 4 and 3 independent mappers at the Little Shasta River study site.



*Figure B5. Clumps of cattail spanning the Little Shasta River channel.*

feet, did juvenile habitat appear plausibly good. Whether habitat mapping, PHABSIM, or 2D hydrodynamic modeling is used, this habitat issue must still be confronted. These stands are ephemeral as well, less prominent as winter progresses and flows batter down the cattail. The other feature was clay stream banks. Surprisingly, most of the clay banks only had narrow overhangs, typically less than 0.5 ft, rather than deep recesses. Coho juveniles might use these shallow overhangs as rearing habitat, with water depths ranging from 2 ft to 6 ft (or more) deep offering minor cover.

### **10.1.3 Precision Mapping**

Our second objective was to evaluate how similarly or differently a group of experienced professional biologists perceive salmonid rearing habitat, given a set of general hydraulic criteria as guidelines. Our technical advisory committee recognized that habitat mapping by group effort, as was done on the Oak Grove Fork, was not practical given the basin-wide data needs. We therefore sought to determine if different fisheries biologists could independently map habitat and develop flow-habitat curves that resembled each other reasonably well, in terms of both the quantity and location of mapped polygons. During two flow events (3/17/08 at 11.9 cfs and 3/18/09 at 26.3 cfs) biologists mapped habitat for each four life stage along our 1,300 ft study reach. Prior to mapping habitat, we reviewed data and information describing salmonid habitat utilization in the Shasta River basin, and developed our set of habitat criteria. We then walked a portion of the Little Shasta River together, discussing how we would apply the habitat criteria, and identifying which patches of river would be mapped as habitat for each of the four life stages. Finally, after this first-round of “training”, we set out on our own and mapped the 1,300 ft study reach.

The data from this mapping event were evaluated both in terms of how well individual habitat area estimates compared, and in how well individual mapper’s habitat polygons matched one other. Total habitat areas compared favorably for salmonid fry, coho, and steelhead life stages, but poorly for juvenile Chinook (Figure B4 a and b). As discussed above, the broad criteria used to define juvenile Chinook habitat resulted in a greater degree of interpretation and thus variation in the areas mapped as Chinook habitat. Pools provided the velocity and depth conditions but little cover or hydraulic complexity.

When we examined individual habitat polygons closely, the results showed a mix of good and bad overlap. The upstream and downstream ends of the project reach had better resolution in the aerial photo basemaps, and mapping precision thus appeared better in these sections (Figure B6 a-d). The middle section had poorer resolution due to large trees and shadows that made locating exact points in the channel more challenging.

Our conclusions are as follows:

- much more information gathered from direct observation (and other methods) is needed to describe the microhabitat utilized by juvenile salmonids in the Shasta River basin; descriptions of habitat utilization provided by several of our technical team members is the best information available, but there is still a high degree of uncertainty regarding the use of specific microhabitat types, such as (1) the dense clumps of cattail and bulrush in the Little Shasta River channel (which we suspect may be used by fry and juvenile coho), (2) steep mud banks that may or may not provide cover suitable for juvenile coho rearing habitat, (3) the large pool bodies that met our juvenile Chinook hydraulic criteria, but about which we still questioned its quality, and (4) just where would juvenile coho rear in the Little Shasta River within the typical bottomland channel configuration;
- our need to proceed with instream flow needs assessments in the meantime requires that we establish an interim set of habitat criteria for use in habitat mapping; our initial set of hydraulic criteria performed well, but should be refined as follows: (1) juvenile Chinook velocity range should be 0.5-1.5 ft/s, thus distinguishing it from juvenile coho habitat and excluding large homogenous areas of pool bodies; (2) juvenile coho habitat should include a depth criteria of <2 ft; (3) a reach-wide reconnaissance assessment of available cover could provide a set of cover criteria for better defining juvenile coho habitat; and (4) longer reaches could be surveyed just for juvenile coho rearing, to identify more widely distributed “hot-spots” of coho rearing habitat;
- high quality aerial photo images are essential tools in habitat mapping; the best resolution achievable from airplane-based photography may serve the purpose for the larger mainstem reaches, but may not be adequate in the smaller, densely vegetated channel types such as the Little Shasta River bottomlands; additionally, a set of high resolution aerial photographs for the entire mainstem from Dwinnell Dam to the mouth, and in several miles-long reaches of tributaries is essential to provide the flexibility in selecting study reaches; aerial photo coverage should overlap the LiDAR data recently obtained for the Shasta River mainstem and tributaries;
- a single fishery biologist mapping habitat will likely produce a habitat-flow curve that is both internally consistent and similar in overall shape as curves produced by other biologists; however, the magnitudes of different biologist’s curves may differ;
- during initial phases of habitat-flow assessments in the Shasta River and tributaries, habitat mapping methods that demonstrate precision in identifying habitat polygons will be more successful in achieving project goals of technical soundness and transparency, even though their application in broader river or stream reaches, while desirable, may be more limited;
- the disparity apparent among different biologists’ interpretation of salmonid rearing habitat showed that mapping methods that do not employ strict use of habitat criteria in identifying habitat will not achieve the desired level of precision in producing habitat-flow curves that is needed in the Shasta River basin;

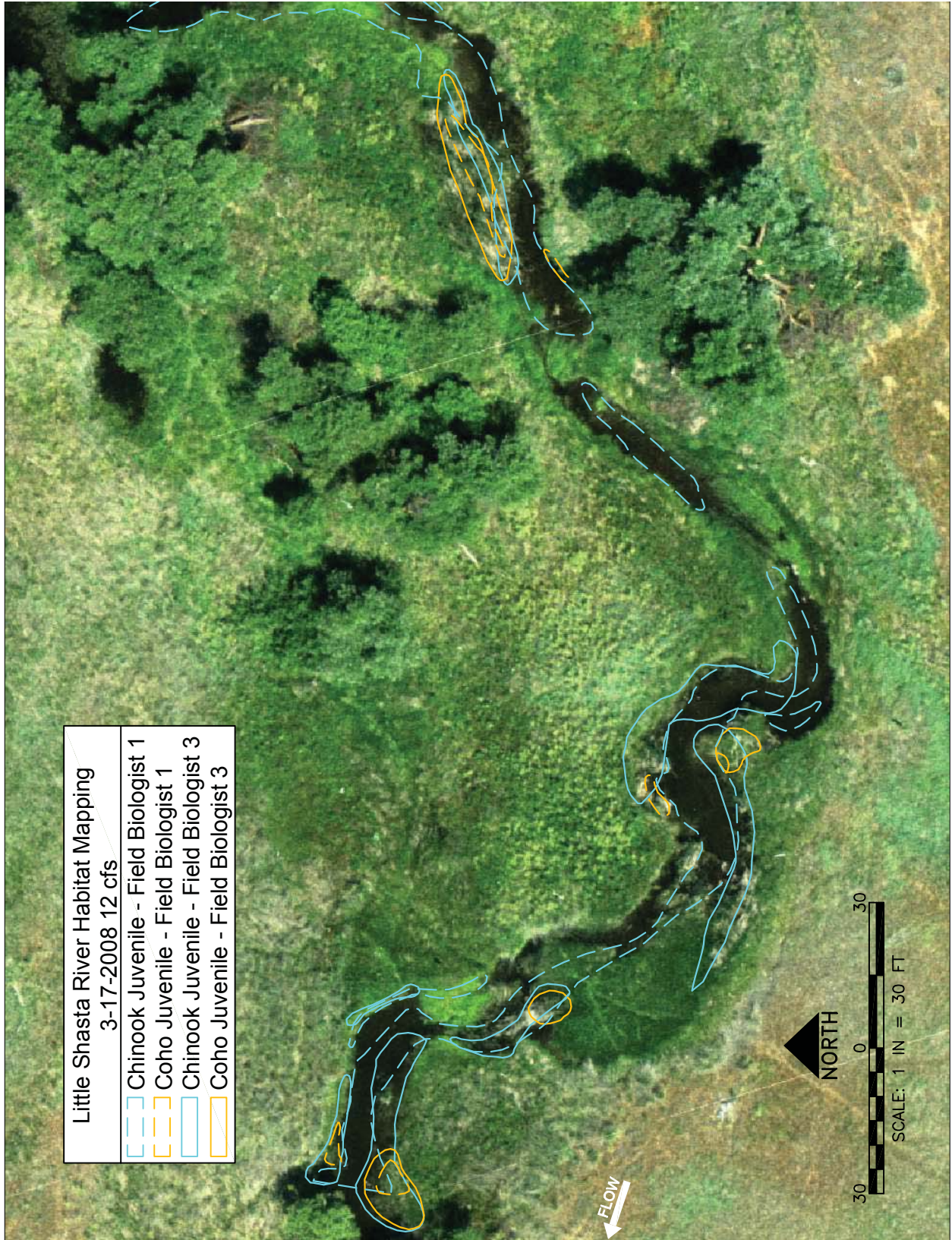


Figure B6a. Comparison of habitat polygons mapped by different biologists during precisions mapping trials at the Little Shasta River study site.

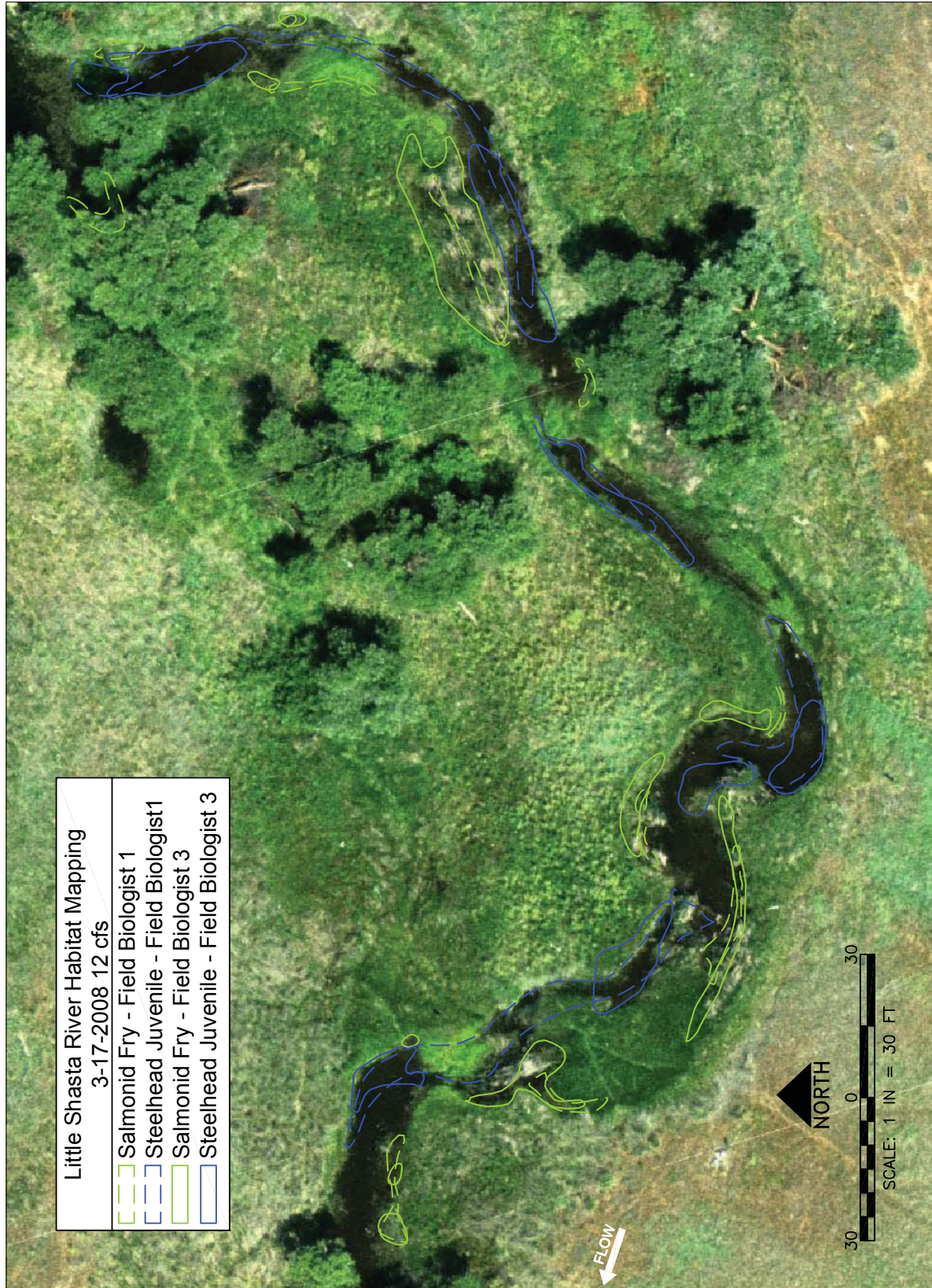


Figure B6b. Comparison of habitat polygons mapped by different biologists during precisions mapping trials at the Little Shasta River study site.



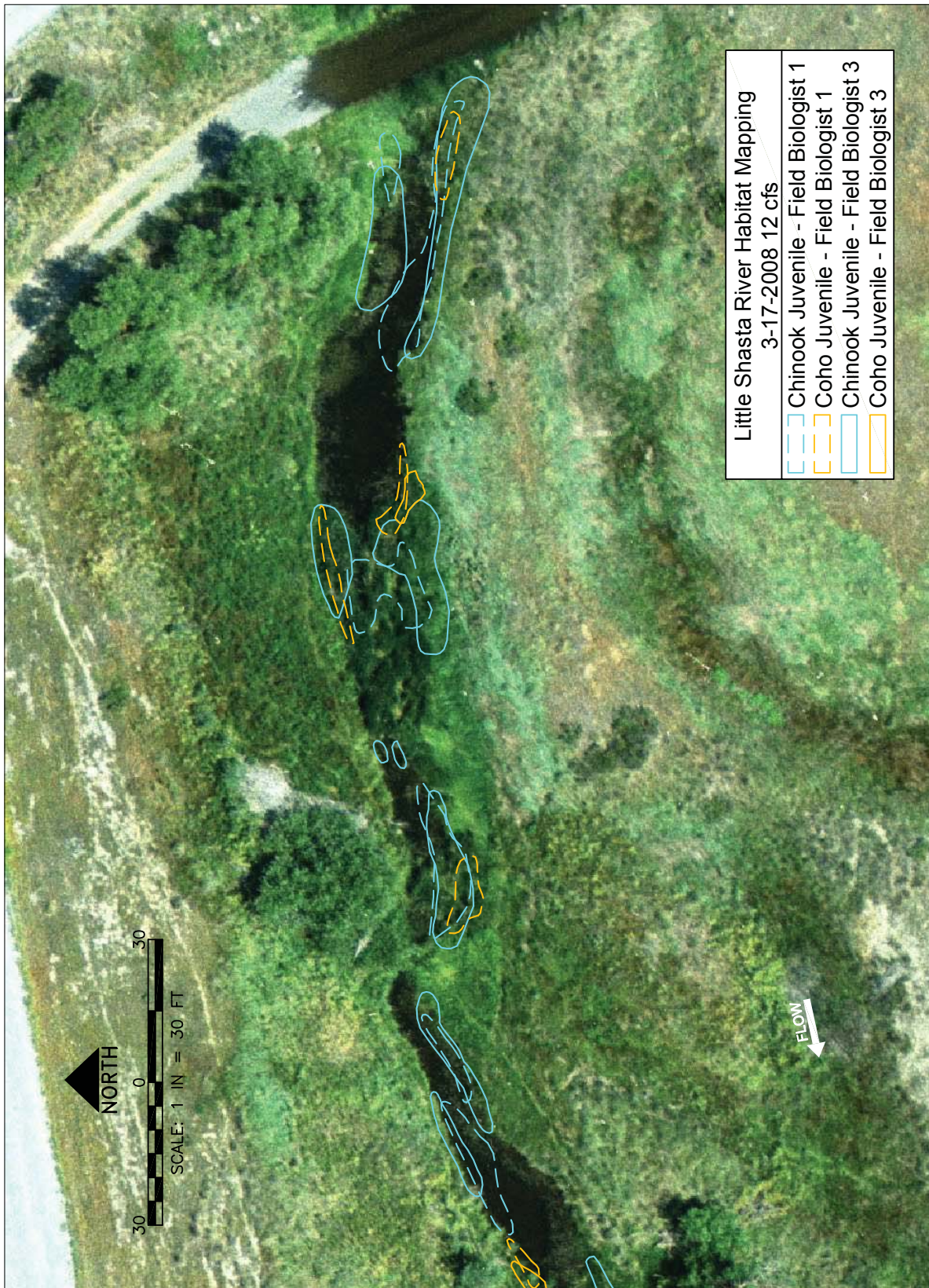


Figure B6c. Comparison of habitat polygons mapped by different biologists during precisions mapping trials at the Little Shasta River study site.

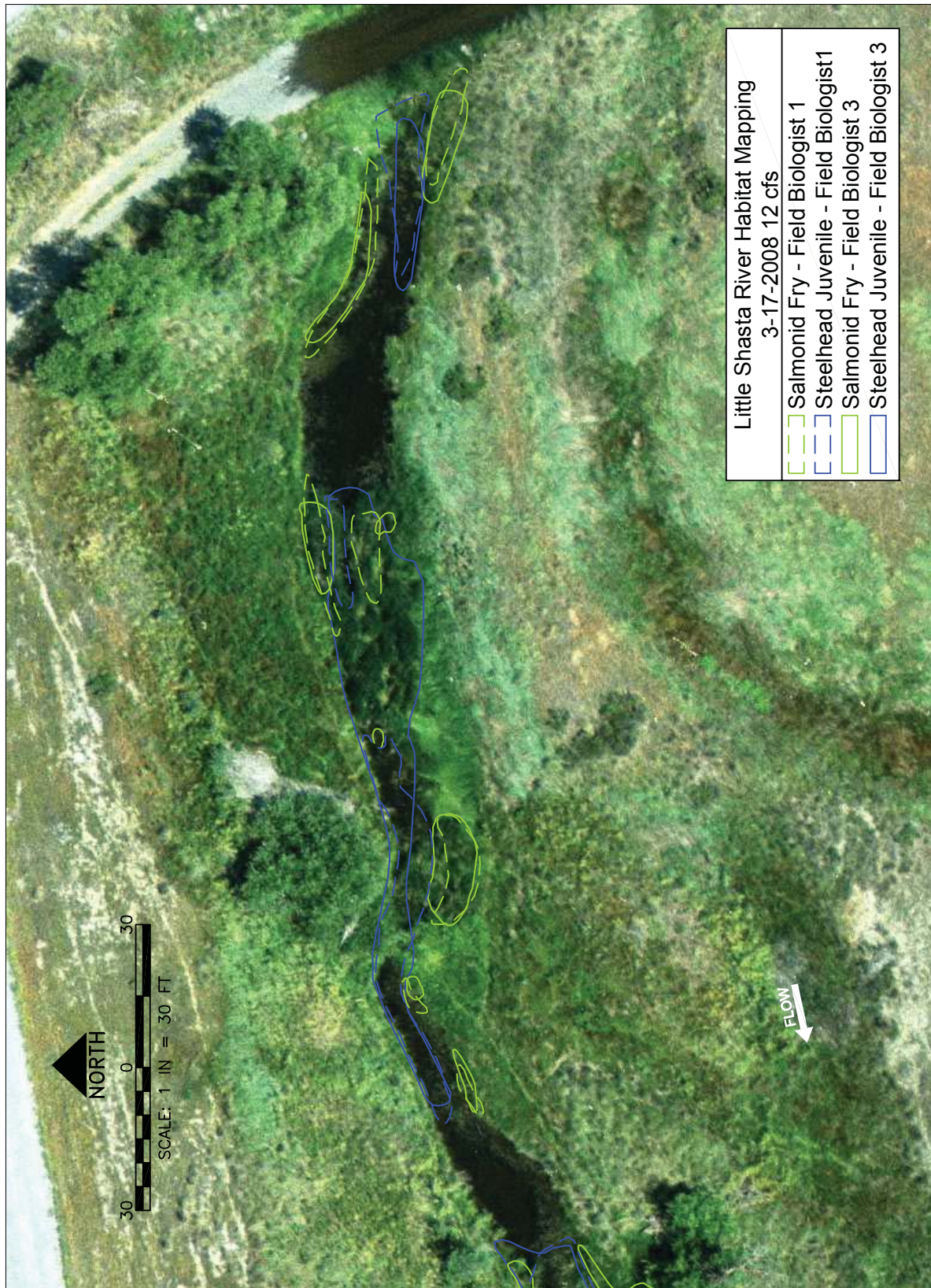


Figure B6d. Comparison of habitat polygons mapped by different biologists during precisions mapping trials at the Little Shasta River study site.

We believe the effort required to implement habitat mapping is an appropriate level of effort to obtain a habitat-flow curve, which is only one piece in the analytical process of determining instream flow needs. We also recognize that habitat mapping long sections of stream or river may be critical to improving the *accuracy* of habitat-flow curves (perhaps at the expense of some precision) because practitioners are able to quantify habitat variability over long river reaches [refer to family of curves].

#### **10.1.4 GPS Mapping Methods**

The Type-2 (locating the criteria variables in the stream channel) and Type-3 errors (translating those located points onto a map or computer) discussed above were both described as errors in precision. Both these types of errors can be substantially reduced using GPS equipment and digital velocity meters. Using these methods, criteria are measured in the field using a Marsh – McBirney style flow meter (velocity) and top setting wading rod (depth). Habitat polygons are mapped using a Trimble GeoXH GPS receiver and digital range finder compass. This methodology requires at least two field personnel, one to measure the habitat criteria and determine habitat polygon location a second to operate the GPS, Tablet PC, and range finder compass. The Trimble GeoXH GPS receiver with Zephyr Antennae is capable of producing sub-decimeter real-time positioning (high precision). Once the stream scientist measuring habitat criteria identifies the habitat boundary location in the stream, a GPS point is collected at that location using the rangefinder compass. This point is then visible on the Tablet PC (using Terrasync Pro software) using aerial photo imagery as a back drop, and the operator can determine if the point's location is correct or not. The GPS point is then "attributed" with habitat type, depth, and velocity measurement values. Once all points determining the habitat units are mapped, they are brought into GIS software to delineate habitat polygons, from which habitat area is then calculated.

Despite there being some disadvantages to using GPS technology in habitat mapping (e.g., reliance on satellite coverage), mapping with a GPS achieves a high level of precision, and results in spatially referenced data that allows assessment of relative habitat position and changes in habitat over time. The method is also often faster than other methods.

#### **10.1.5 Aerial Photo Basemap Quality**

Habitat mapping must rely on the highest quality aerial basemap images attainable balanced with the mapping area extent and thus cost to produce them. We have implemented three different aerial photo techniques to produce habitat mapping basemaps and provide examples of those images with habitat mapping polygons where they were available: (1) low-altitude aerial photo flight from airplane, targeting a scale of approximately 1:1200 and pixel resolution of about 0.125 inches (Figure B7); (2) ground-based helium balloon photography with digital camera mount; this requires installation and survey of control points for photo orthorectification (Figures B8 and B9); and (3) self-propelled, radio-controlled model airplane with digital camera mount and GPS capability; this does not require ground-surveyed control points, but requires GPS satellite contact (Figure B10);

### **10.2 Demonstration Flow Assessment**

We employed Demonstration Flow Assessment (DFA) methods (Annear et al. 2004; Railsback and Kadwany 2008) that rely on high quality panoramic photographs at fixed photo-monitoring points taken over a broad range of streamflows. Panoramic photographs used in DFA methods must have high pixel resolution, a good lens for optical quality, and use a polarizing filter to reduce light reflection off the water. Panoramic photographs are used to (1) document streamflow and habitat conditions available when each streamflow is mapped to produce habitat-flow curves, (2) document when flow thresholds are exceeded, such as flow into backwater and side-channel features, inundation

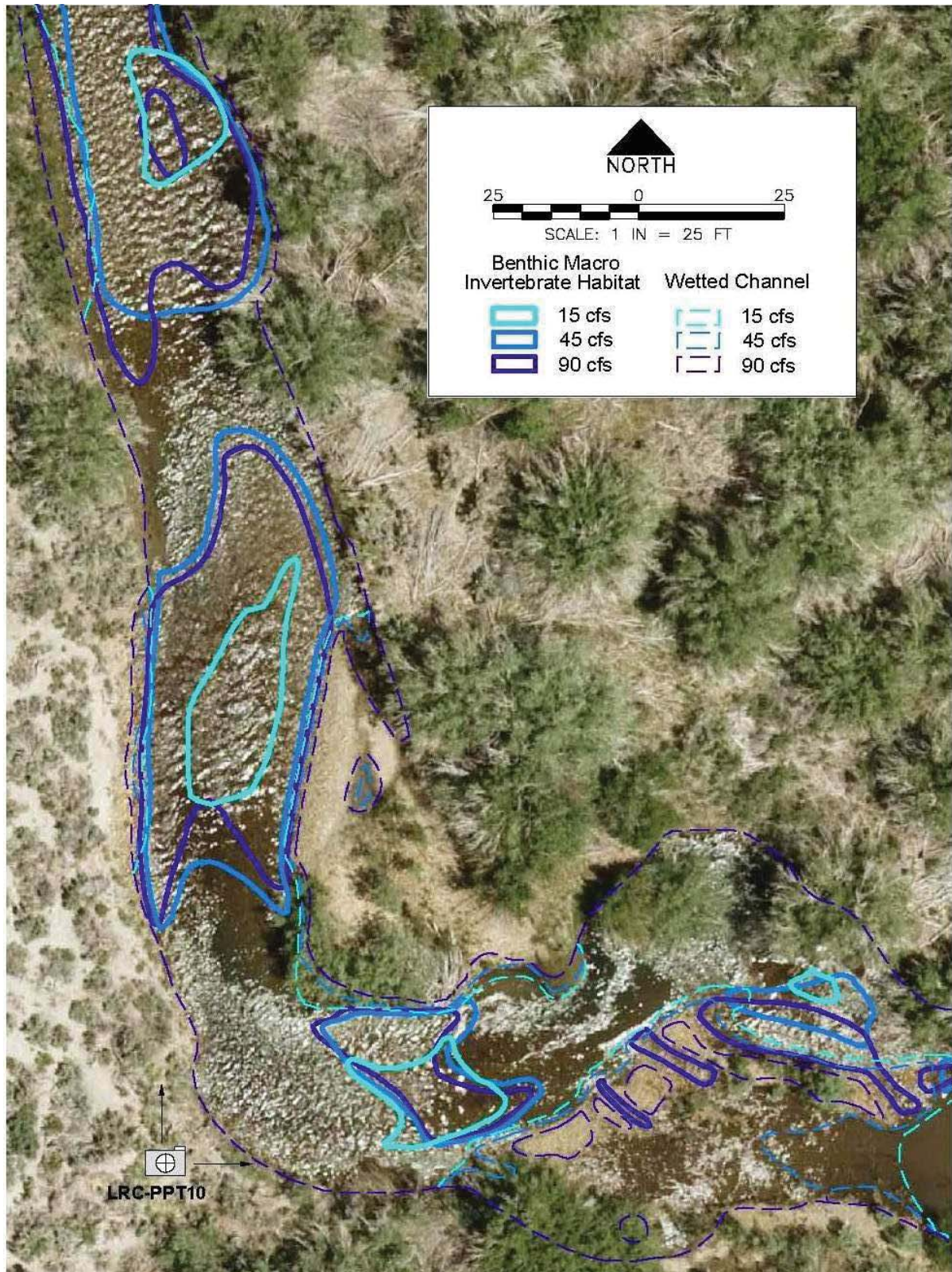


Figure B7. Example of aerial photo obtained from low-altitude airplane flight for Rush Creek, used to map benthic macroinvertebrate habitat in August 2008.

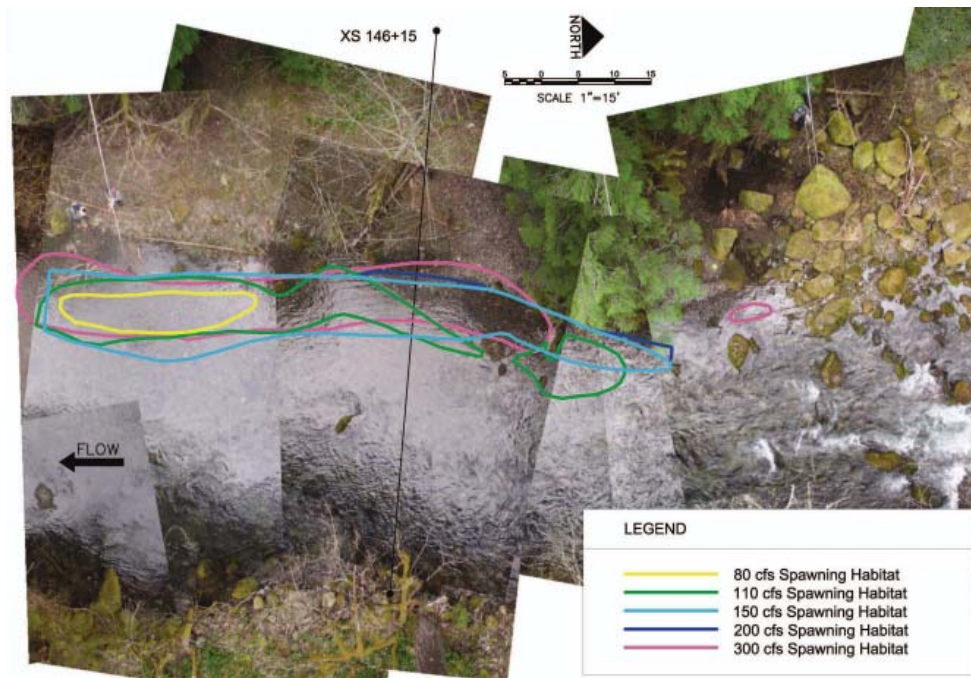


Figure B8. Example of helium balloon photo basemap prepared by McBain and Trush for habitat mapping on the Oak Grove Fork of the Clackamas River in 2005.

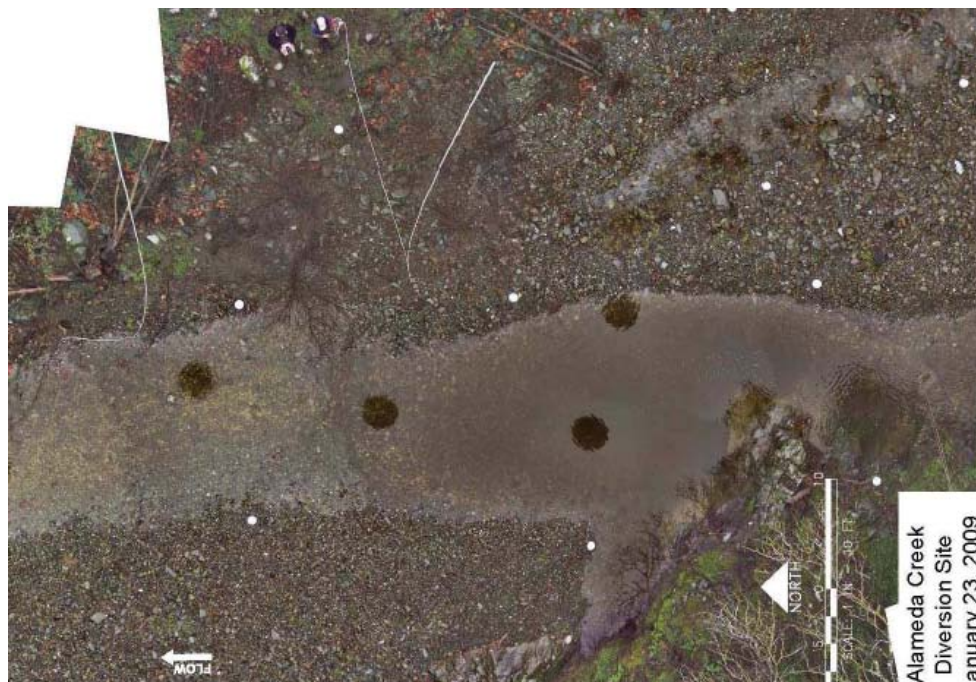


Figure B9. Example of helium balloon photo basemap prepared by McBain and Trush for habitat mapping on Alameda Creek planned for spring 2009.



*Figure B10. Example of remote control airplane photo basemap prepared by Brian Powell of McBain and Trush.*

of cover features, or submersion of lateral spawning gravel patches or migratory passage barriers, and (3) provide visual props during discussions and presentations to stakeholders. For demonstration purposes, habitat polygons mapped onto rectified aerial basemaps can be transferred onto oblique photos to provide a good visual tool for discussing habitat areas and application of habitat criteria (Figure B11).

At other project sites (e.g., Rocky Gulch, Humboldt Bay; Rush Creek, Mono Basin) we have used time-lapse cameras mounted temporarily at a site to collect photographs at fixed time intervals (hourly, daily, etc.). The optics and panoramic capability of the time-lapse cameras are somewhat limited, but this method can provide very useful photographic data. We used time-lapse cameras to photograph peak flow releases and snowmelt recession over a 60 day period on Rush Creek in the Mono Basin during the 2008 snowmelt runoff. A bridge construction site on Rocky Gulch in Humboldt Bay was photographed hourly over a span of several weeks, and a short (5 minute) movie produced to show the construction sequence.

### **10.2.1 Little Shasta River DFA**

We established six permanent photo-monitoring points at the Little Shasta River study site (Figure B1; Table B2), and collected photos during each habitat mapping event, and during several other site visits. An example is provided of photopoint LSR-3A (Figure B12a and B12b) showing the right bank backwater and side-channel at 12 cfs and 26 cfs that was monitored to identify a threshold for flow down the side-channel. Photo-monitoring at the Little Shasta River study site was used to document:

- Streamflow and habitat conditions during each habitat mapping event, and during irrigation season low-flow conditions;
- Thresholds for flow inundating backwater features and accessing side-channels that provide rearing habitat during higher streamflows;

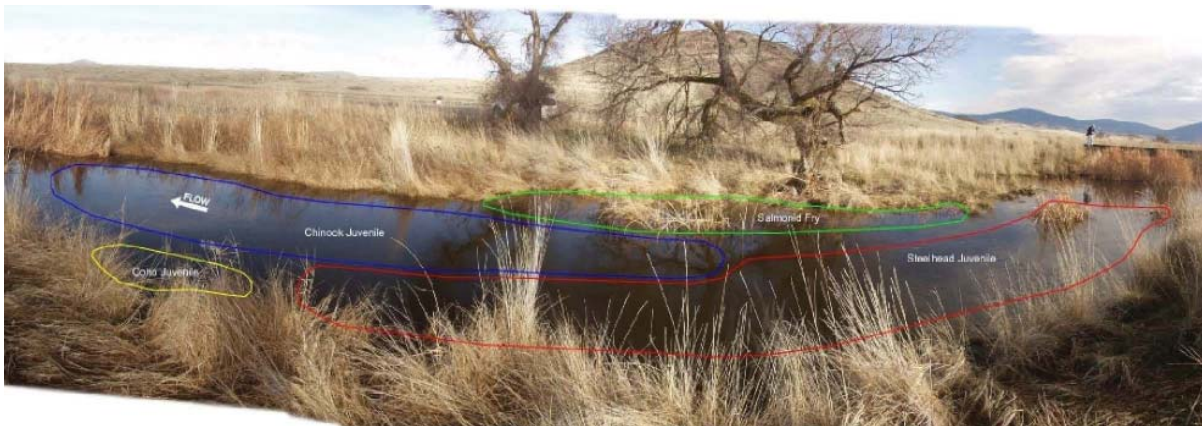


Figure B11. Example of panoramic photo with habitat mapping polygons overlain onto oblique photo to demonstrate habitat area locations.

- Migratory passage at a beaver dam (although only one discharge was monitored);
- The panoramic photographs collected at the Little Shasta River are primarily useful for supporting more quantitative data collected by habitat mapping and RCT depth measurements. We used several images during PAC meetings and presentations to describe those methods.
- Regarding the use of photo-monitoring to identify adult migration issues, we did not have opportunity to photograph a range of flows at the beaver dam (Figure 13) at the Shasta Valley Wildlife Area to determine if adult passage is impeded, and if so, what a flow threshold might be that would allow passage. Empirical evidence (i.e., presence of adult spawners in the reaches upstream of the beaver dam) suggests it is occasionally/intermittently passable at flows that occur sporadically in the fall. A key recommendation would be to first conduct a reconnaissance-level assessment of the entire Little Shasta River from the mainstem confluence to the Dry Creek cascades, identify all potential barriers to upstream migration, then determine if closer monitoring is required. Obviously extremely low flows common in the early fall (through October and into November) caused by irrigation diversions are an impediment to upstream migration.

### **10.2.2 Shasta Canyon DFA**

At the Shasta Canyon we established 17 photo-monitoring points, concentrated at two different study reaches: the Salmon Heaven reach and the Hudson Road Reach (Table B2). Several more photo-points can be established in the Shasta Canyon reach, especially using good vantage points along Hwy 263. Photo-monitoring in the Shasta Canyon was used to document:

- Migratory passage at different flow conditions at several potential barriers, including three cascades (primarily as an example of the DFA method, since these cascades are likely not barriers to migration at streamflows typically prevalent during the spawning season) and at the Dewey-Smith concrete dam structure at the head of the Shasta Canyon;
- thresholds for flow into side channels;
- thresholds for inundating spawning gravel deposits in lateral features that are likely available for spawning at the higher end of discharge range;
- streamflow conditions at spawning habitat sites

The Shasta Canyon has a high channel gradient and prominent boulder and bedrock morphology. Combined with extremely low streamflows that persist through the irrigation season well into fall, there is strong potential that low flows are a barrier to upstream migration for adult salmon

Table B2. Photopoint monitoring database.

PhotoPoint #	Stream Reach	Description and Location	# Images	Landscape/ Portrait	Camera FL (mm)	Discharge (cfs) at USGS Shasta River near Yreka (Stn 11-517500)											
						10/24/2007	12/2/2007	1/17/2008	3/18/2008	4/1/2008	9/5/2008	9/30/2008	10/2/2008	10/16/2008	2/18/2009		
						155	173	208	224	196	23	46	92	120	187		
SH0A	Upper Shasta Canyon	1 shot of Dewey Smith diversion structure, through gap in trees, from road at marker	1	landscape	25												
SH1A	Webb above Salmon Heaven	1 shot of potential spawning gravel in RB eddy among bedrock, from road at paint mark	1	landscape	25	x	x										
SH1B	Webb above Salmon Heaven	1 shot of potential spawning gravel in LB opposite T-Wood configuration on RB Canyon wall, from road	1	landscape	25	x	x										
SH1C	Webb above Salmon Heaven	2 shot pan of possible passage barrier at Railroad configuration on RB Canyon wall, from road	2	landscape	25	x	x										
SH1D	Webb above Salmon Heaven	7 shot pan of RNPV-RIF-P L sequence and RB side channel rearing habitat from upstream end of Salmon Heaven where canyon narrows with verticle walls, from rock promontory 15 ft below road	6	portrait	15	x	(2 parts)										
SH2A	Salmon Heaven	1 shot looking upstream showing mainstem and side channel entrances, from gravel bar	1	landscape	18	x				x							
SH2B	Salmon Heaven	1 or 2 shots of spawning patch downstream of rock weir at thermograph, from LB	2	portrait	18						x						
SH3A	BLM below Salmon Heaven	7-8 shot pan of LB rearing habitat on floodplain, from road	8	portrait	25	x	x			x							
SH3B	BLM below Salmon Heaven	5 shot pan of LB rearing habitat on floodplain, from rock promontory 30 ft below road	5	portrait	15	x	x			x							
SH3C	BLM below Salmon Heaven	3-4 shot pan of pool-tail and pool above LB rearing floodplain, from road adjacent pool-tail	4	portrait	25	x	x			x							
SH3D	BLM below Salmon Heaven	1 shot pan of SH3 reach, from road adjacent pool head aiming at upper point of medial bar	1	landscape	13	x	x			x							
SH4A	End Shasta Road	1 shot of possible passage barrier at Cascade at end of Old Shasta Rd, from dirt berm by pullout	1	landscape	18	x	x			x							
HR1A	Hudson Road South	1 shot of possible passage barrier at Cascade at south end of Hudson Rd, ~200 ft from look in road that goes up hill, from road aiming at middle of three in-line boulders	1	landscape	25	x											
HR2A	Hudson Road South	1 shot of spawning reach at DWR Site WS15A with RB snag and lg boulder in bank, from road	1	landscape	15	x											
HR3A	Hudson Road Middle	1 shot of possible passage barrier at Cascade at 90 bend in middle section of Hudson Rd, from slab rock jutting into channel	1	landscape	15	x											
HR3B	Hudson Road Middle	3 shot pan of possible passage barrier at cascade, from road in middle of cascade	3	land-port-port	15	x											
HR4A	Hudson Road North	1 shot of spawning reach at DWR Site WS12A with RB mature alder, from road at downstream end of spawning patch	1	landscape	15	x											
LSR1A	Little Shasta River	5 shot pan of first "unit" downstream of SWVA gravel ford below bridge, from top of terrace on RB	5	portrait	15		x										
LSR1B	Little Shasta River	5 shot pan of second "unit" downstream of gravel ford, from top of terrace on RB	5	portrait	15		x										
LSR2A	Little Shasta River	1 shot of deep pool at stn 3+35 with OG willow and MWD on RB	1	landscape	25			x									
LSR2B	Little Shasta River	6 shot pan at stn 9+38 from LB, of left 90-bend with lg pool (upstream), RB side channel entrance, and breaking to LB riffle-run	6	portrait	15			x									
LSR3B	Little Shasta River	6 shot pan at stn 10+10 from LB of right 90-bend promontory with meandering STH section	6	portrait	15			x									
LSR4A	Little Shasta River	5 shot pan at stn 11+84 up on LB hillside at "X" rock, with LB perched side channel entrance and meanders	3	portrait	15			x									





*Figure B12. Little Shasta River photo-monitoring point LSR 3A taken on March 17, 2008 at 12 cfs (above) and on March 18, 2008 at 26 cfs. Note the flow exceeding the threshold and flowing down right bank side channel at 26 cfs.*

(particularly the first arriving Chinook spawners). The Shasta Canyon also has the luxury of many vantage points along the Old Shasta Road, Hudson Road, and Hwy 263, where photo-monitoring would be quite useful. We established five photo-monitoring points and collected photos over a range of streamflows at these sites. None of these sites would likely be considered a passage barrier at the lowest unimpaired baseflows (e.g., 100-140 cfs), but irrigation diversions result in fall baseflows as low as 10-20 cfs. Two pairs of our photo-monitoring images are presented as examples, one at the Dewey-Smith obstruction near the head of the canyon (Figure B14); the other is a natural cascade along Hudson Road at RM 1.8 (Figure B15).

Our conclusion is that adult fish passage is readily identifiable for the features common in the Shasta Canyon reach, particularly if accompanied by measurements of Riffle Crest Thalweg depths (discussed in Section 7.4 below). The effort required to qualitatively assess numerous sites using photo-monitoring and DFA methods outweighs the added information from more intensive measurement.



*Figure B13. Beaver dam spanning the entire channel width on the Little Shasta River.*

### **10.1 Thresholds of Abundant Instream Habitat**

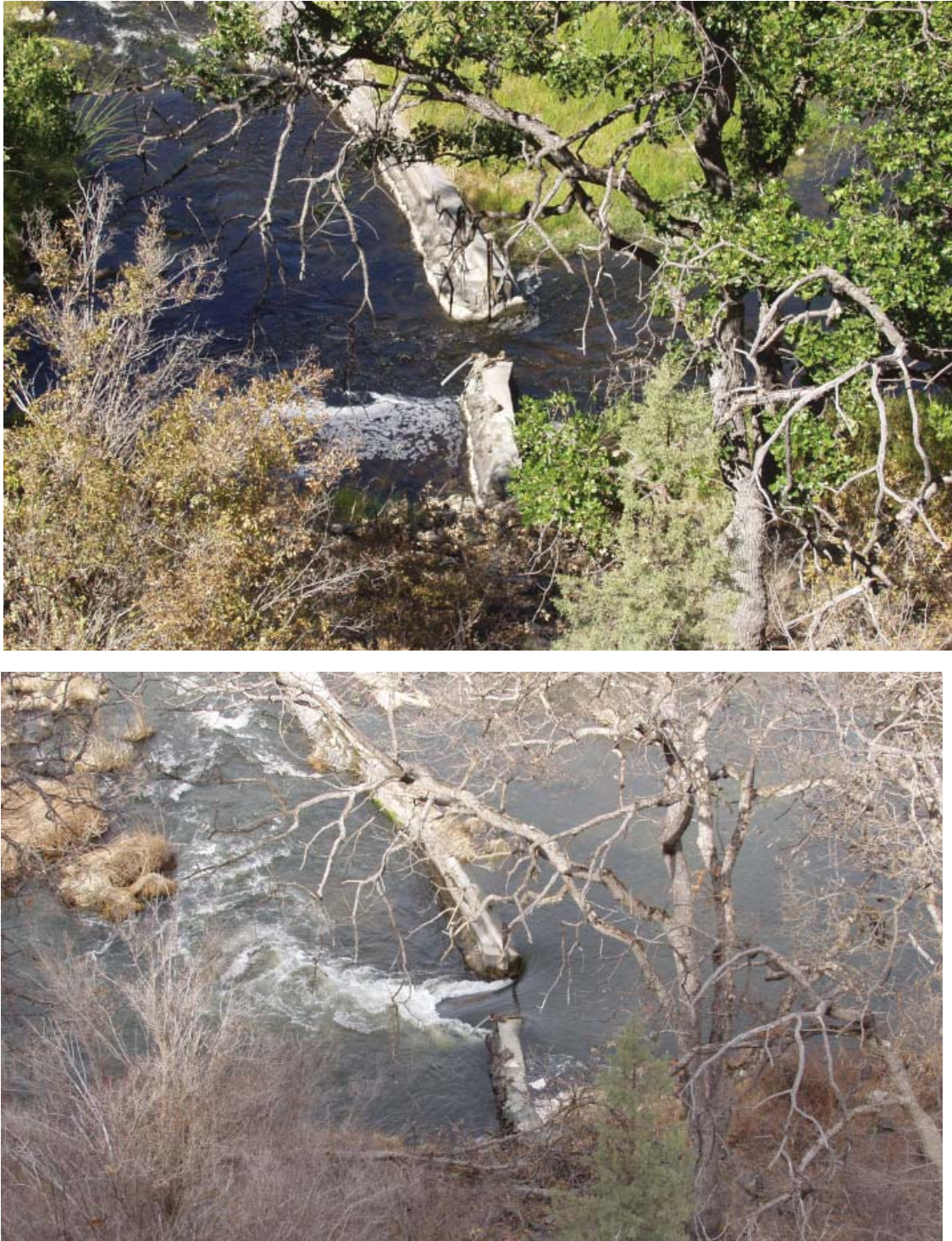
Side channels and off-channel features (which we call “lateral rearing features”) can provide high quality rearing habitat, typically over a range of moderate to high streamflows. In contrast to main-channel rearing habitat that is quantifiable within short reaches over a wide range of flows, lateral rearing features typically require quantification over longer river reaches and provide available habitat during shorter, more ephemeral timeframes. Habitat-flow curves are required for assessing habitat availability at low baseflow ranges in the mainstem channels; lateral rearing features may require only identifying a streamflow threshold that begins to provide habitat, accompanied by an estimated range of streamflows in which habitat is available. In other words, a habitat –flow curve is not essential, just an estimate of the range of flows that provide habitat (e.g., Figure B16).

#### **10.3.1 Little Shasta River**

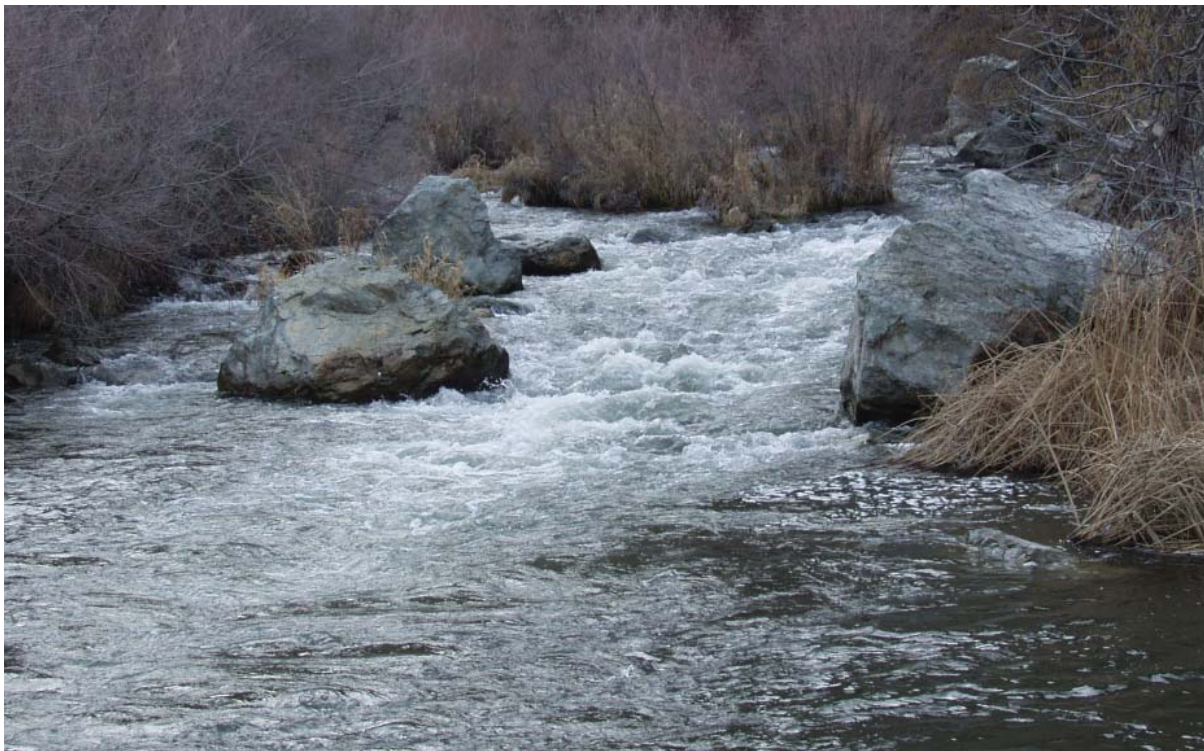
We identified three lateral rearing features along the Little Shasta River at the Shasta Valley Wildlife Area (Figure B17). The flow event of January 2008 accessed two of these features. The debris line remaining from this high flow event was mapped on March 17, 2008 (Figure B2). We surveyed the thalweg profile at the entrance to a side channel, noting that a berm had formed at the side-channel entrance; a stage-discharge relationship and simple mechanical excavation of this berm would allow lower streamflows to inundate this feature and provide habitat over a broader range of flows.

#### **10.3.2 Shasta Canyon**

Chinook spawning and rearing are key life history stages requiring abundant habitat in the Canyon. The Shasta River Canyon has a highly conducive channel morphology because of many side-channels and benches. The Canyon reach has suitable rearing habitat concentrated within the main channel over a broad range of low baseflows (e.g., 50-200 cfs), assuming temperature requirements are met. The steeper gradient and bedrock exposure in the canyon reach cause an increase in flow velocities that reduce rearing habitat suitability within the “inner channel” as discharge increases (e.g., above 15-200 cfs). We observed what is likely a critical transition at this intermediate range of flows in



*Figure B14. 'Dewey Smith' low-head concrete dam located at the head of the Shasta Canyon, taken on September 5, 2008 at 23 cfs (above) and on February 18, 2009 at 187 cfs (below).*



*Figure B15. Cascade along Hudson Road (RM 1.8) taken on September 5, 2008 at 23 cfs (above) and on February 18, 2009 at 187 cfs (below).*

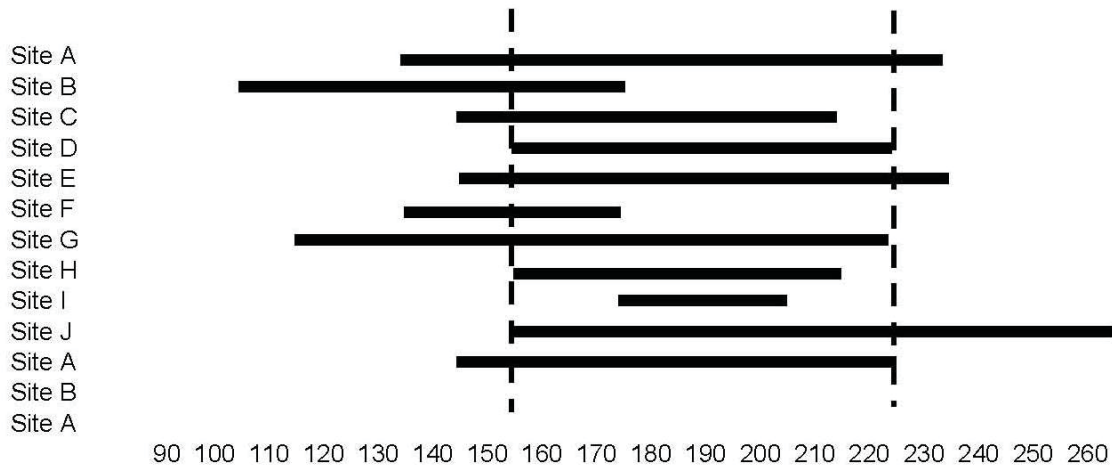


Figure B16. Conceptual diagram identifying an approximate range over which a particular lateral rearing feature could provide salmonid rearing habitat, using multiple sites to focus on a discharge range that inundates a majority of features.

which rearing habitat availability moves laterally onto shallow gravel and bedrock bars, among patches of bulrush and emergent aquatic vegetation, and into the distinct Salmon Heaven side channel (the only known true side channel feature in the canyon reach). This lateral rearing habitat may be of higher quality (i.e., better hydraulics, food resources) and critically important during pre-smolt emigration in April and May.

To demonstrate the method of identifying flow thresholds that provide available rearing habitat, we used the 2005 NAIP aerial photographs and aerial photos taken in our study, to map all identifiable lateral rearing features in the canyon reach from the I-5 Bridge to the Klamath River confluence (Figure B18). There are more features than were identifiable in our poorer quality basemaps, and this mapping will require more formal implementation in the next phase of flow studies. We selected three of these features for monitoring habitat availability: the Salmon Heaven side-channel and two floodplain features near Salmon Heaven (Figure B19).

Lateral Feature #1 is a very prominent rearing feature, located ~2,000 downstream of the Salmon Heaven side-channel (Figure B19). This feature was monitored using DFA methods to determine if we could use photo-monitoring to estimate discharge that bracketed available rearing habitat within this lateral feature. This method would therefore require (1) an estimate of discharge (available from the USGS Yreka gage), (2) a set of high quality panoramic photos from several vantage points, and (3) a judgment of the quality of rearing habitat available across the lateral feature or a YES-NO decision about habitat availability. We collected photos on nine dates at discharges of 155, 173, 224, 196, 23, 187, 46, 92, and 12 cfs (Table B3). An example is provided to demonstrate the utility of the images and the data interpretable from them.

On April 1, 2008, we mapped fry and juvenile rearing habitat at this feature (Figure B20) to (1) determine the feasibility of conducting detailed habitat mapping within multiple lateral rearing features, (2) portray the spatial distribution of rearing habitat within this site, and (3) to quantify available habitat at a single flow. At a discharge of 196 cfs, rearing habitat was abundant for all four life stages of salmonids considered in our study. Juvenile passage visually determined to be good, both into, through, and out of the site (i.e., no stranding risk). From this trial mapping event, we determined that application of habitat mapping methods that adhere to strict measurement of criteria

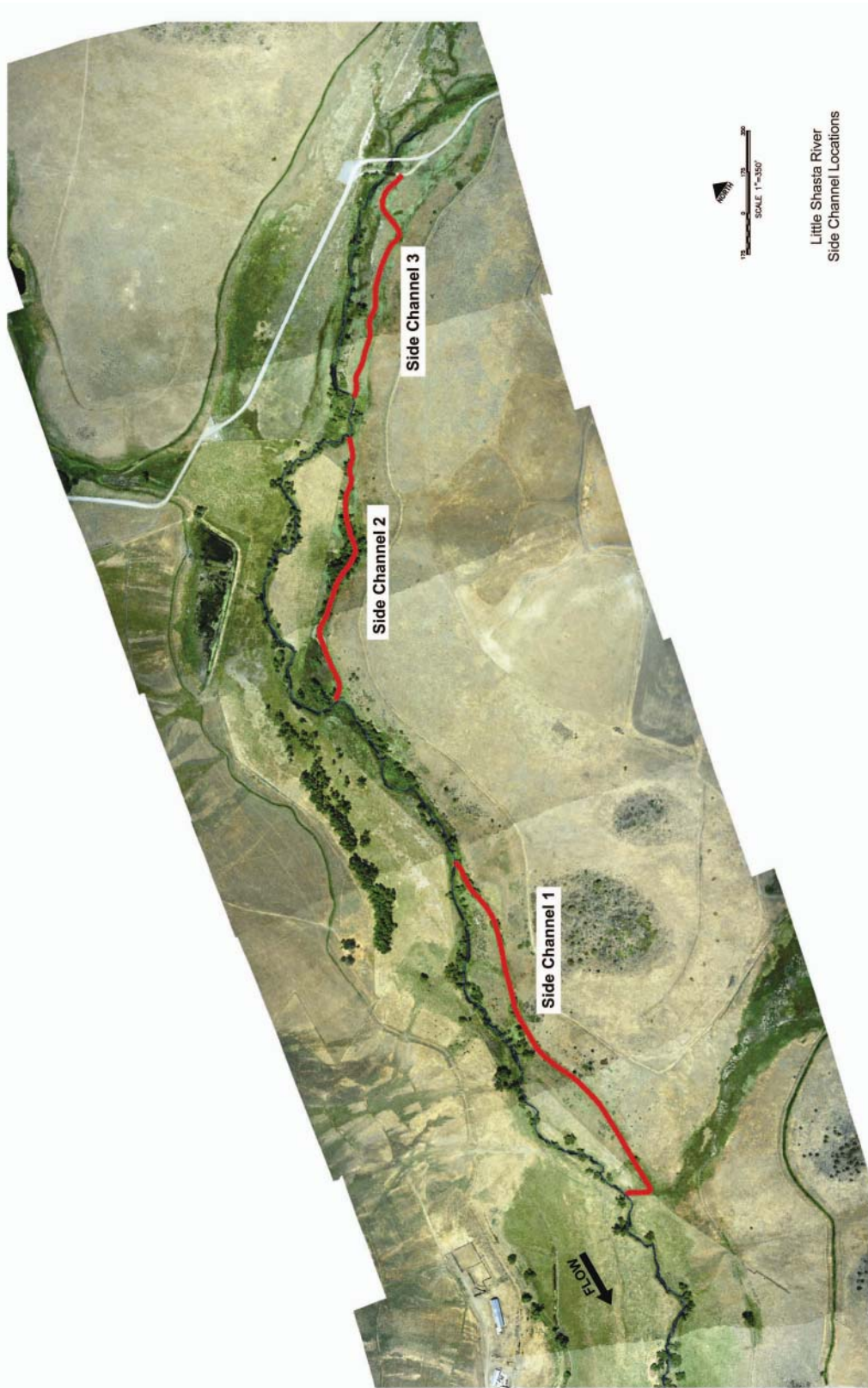


Figure B17. Site map of the Little Shasta River on the Shasta Valley Wildlife Area showing prominent side channel features that would provide valuable rearing habitat seasonally at high flows (e.g., 50-200 cfs).

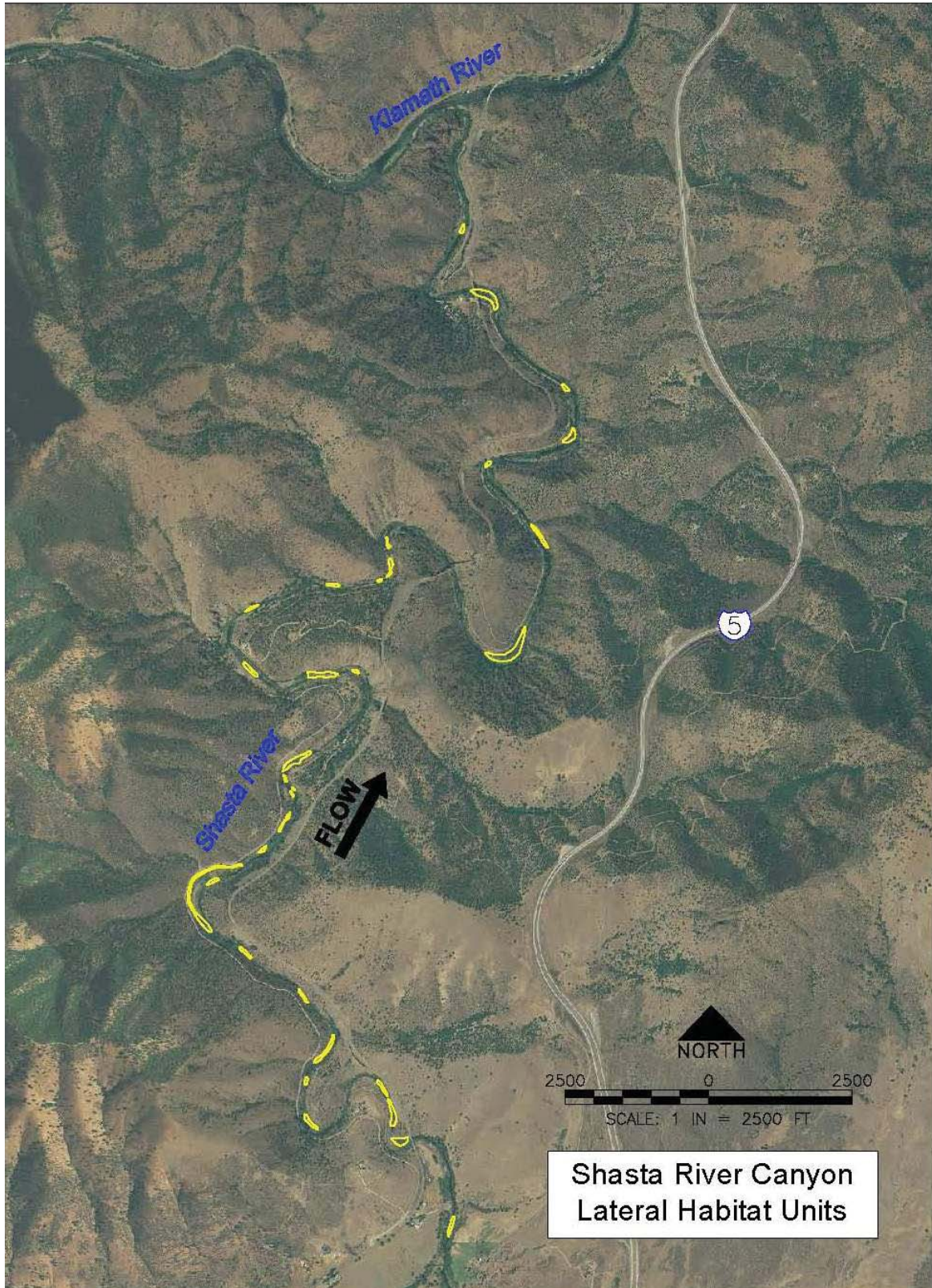


Figure B18. Lateral rearing features in the Shasta Canyon from I-5 Bridge down to the Klamath River confluence, mapped on the 2005 NAIP images (in the office) to estimate a potential number of lateral features.

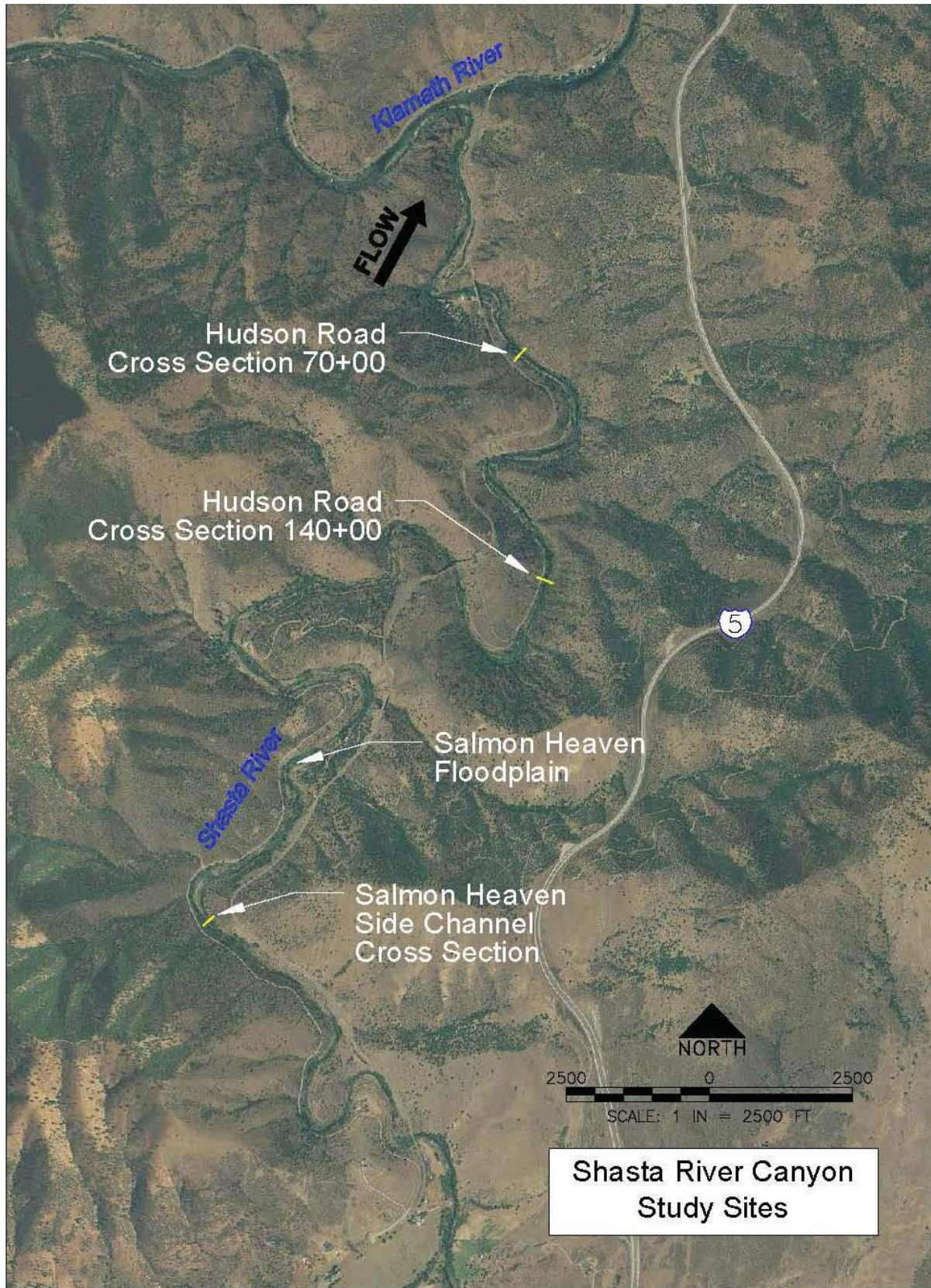


Figure B19. Shasta Canyon Study Sites (figure still under construction).



*Table B3. Observations of available habitat at the Salmon Heaven lateral rearing feature made from photo-monitoring over a wide range of flows. The flow threshold range is highlighted in gray.*

Date	Discharge at USGS Yreka Gage	Habitat Observations
9-5-08	23	vegetation density obscures open water areas; no apparent velocity through site, only small patches of standing water;
9-30-08	46	thick vegetation overgrown throughout site; open water areas not readily visible; observable areas have poor habitat (no velocity);
10-2-08	92	downstream half of site not obscured by alders has small area of inundated habitat, visible water patches has some apparent velocity to begin to provide habitat;
10-16-08	120	much greater area visibly inundated; this may be the <u>beginning</u> of threshold for abundant habitat at this feature;
10-24-07	155	vegetation is becoming dormant and it is less difficult to see flow through the site; there appears to be much more standing water and beginning to be more flow velocity through small riffles;
4-1-2008	196	with exception of large bedrock exposures, the entire lateral rearing feature is inundated with abundant flow through the site; habitat was mapped at this flow using depth/velocity criteria, and was abundant for salmonid fry, juvenile Chinook and steelhead; coho fry habitat (dependent on cover) was less abundant;
3-18-08	224	similar to 196 cfs, the entire feature is inundated and flow through the site is strong; this may be considered a peak in habitat area for salmonid fry and juvenile Chinook and coho; higher flows would provide higher velocities more suitable to juvenile steelhead;

to identify polygon boundaries would be infeasible over the range of flows of interest and at multiple lateral rearing sites. However, in reviewing the series of seven panoramic photos on computer with potential for zooming into the photo, the information attainable from aerials is adequate to bracket a range of flows in which suitable rearing habitat is likely available. Our estimate of this range is from above 120+cfs peaking at 196 cfs for fry, juvenile Chinook and coho, and peaking above 224 cfs for juvenile steelhead (especially 2+ life stage). A 200 cfs flow at the USGS Yreka gage is approximately a 56% exceedence flow using our unimpaired synthetic data (Figure 9). It is unlikely we could obtain an estimate of available habitat area across the entire site using this set of panoramic photos, because too much of the site was obscured at the height of the summer vegetation growing season. Habitat mapping is our recommended methodology for developing habitat-flow relationships in Canyon reaches. However, these side-channels and benches, many of which were essentially boulder fields grown-over with extremely dense emergent aquatic vegetation, may be too complex for habitat mapping or any other traditional habitat quantification methods.

Lateral Feature #2 was the Salmon Heaven side-channel, described in the following paragraph. Lateral Rearing Feature #3 was monitored using DFA methods (photo-monitoring) and is not discussed in detail here.



Figure B20. Habitat mapped at Shasta Canyon Salmon Heaven floodplain.

Data collected at the Salmon Heaven (SH) side-channel included photo-monitoring to identify a threshold flow that begins to provide spawning habitat, measurement of available spawning habitat during two discharges, and riffle crest thalweg depth measurement (discussed in Section 7.4 below). Spawning habitat was quantified in the SH side-channel on 10-25-07 and 2-18-09, at main channel discharges of 154 cfs and 187 cfs, respectively (Table B4). The side channel discharge was estimated during both mapping events. Both discharges provided suitable spawning habitat, but the slightly higher flow appeared to exceed a depth threshold and provided much more abundant spawning habitat in the side-channel. Our spawning area estimates lacked some precision because there was no aerial photo basemap available for the side channel. Polygons were estimated based on field-measured width and length of a round or elliptical polygon, and dimensions were recorded in a fieldbook. Mapping spawning habitat over a broader range of streamflows is recommended during future implementation phases. If more precise quantification of spawning (or rearing) habitat is deemed warranted in this unique feature, helium balloon photography should be considered.

*Table B4. Spawning habitat area estimates and riffle crest thalweg depths measured at the Salmon Heaven Side Channel site.*

Date	USGS Yreka Q (cfs)	Salmon Heaven Q (cfs)	Spawning Habitat Area (ft <sup>2</sup> )	Median Riffle Crest Thalweg (ft)	Minimum Riffle Crest Thalweg (ft)
10-25-07	154	20	1,834		
2-18-09	187	12	850	0.8	0.5

#### 10.4 Riffle Crest Thalweg for Estimating Thresholds for Migration

We have begun implementing a method previously applied in our Rush Creek (Mono Basin) instream flow study, measuring the thalweg depth (deepest point on cross section) at each riffle crest (the Riffle Crest Thalweg or ‘RCT’) along the study reach. This point is assumed the deepest point of the shallowest cross section and thus the limiter depth through which a migrating fish would be required to pass. In Rush Creek, we mapped the RCT depth at five flow releases to evaluate adult brown trout passage during summer and winter baseflow periods. The RCT measured values were ranked and plotted for each flow independently (Figure B21). This method is also being considered for use in the SWRCB AB2121 policy recommendations developed by Trout Unlimited. With the ranked RCT depths, the median or minimum depth can be selected for evaluating fish passage. The method is relatively quick and easy to apply and appears robust enough for use in evaluating fish passage at different flows. The method can also be applied to much longer reaches (on the order of stream miles) to capture variability in thalweg depths over a range of flows. We’re also investigating a metric based on the frequency of RCT’s below the median RCT, which may be useful in evaluating cumulative passage impedance caused by multiple shallow riffle crest depths.

We mapped the RCT depths along the Salmon Heaven side channel at a single discharge (187 cfs main channel; 12 cfs side channel), ranked and plotted the depths (Figure B22).

#### 10.5 Standard Setting Hydraulic Methods – Wetted Perimeter and R2 Cross

Standard setting instream flow methods use a single, fixed rule to establish minimum flow requirements (Annear et al. 2004). According to Annear et al. (2004), single transect hydraulic-based habitat methods are intended to “identify flows sufficient to provide a minimum or basic survival level of fish hydraulic habitat.” These methods are thus not intended to protect all components of salmonid habitat, nor promote the recovery of species from low population levels.

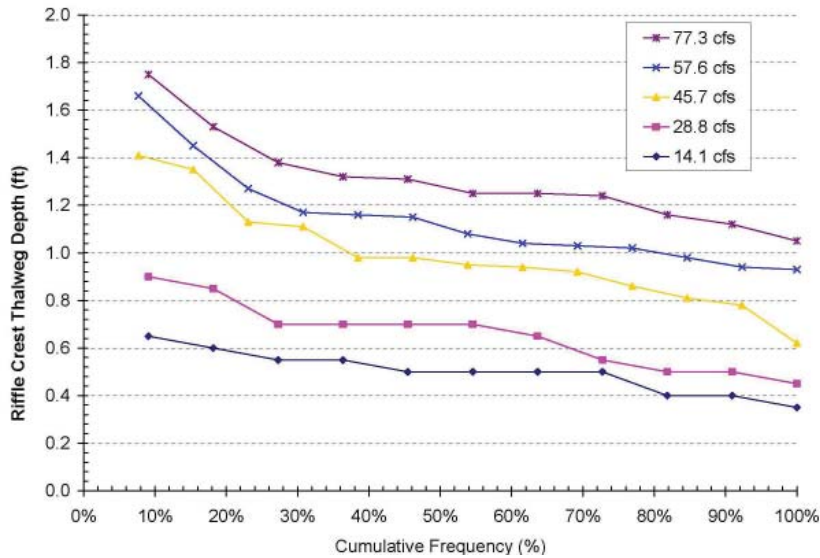


Figure B21. Riffle Crest thalweg depths measures in Rush Creek, Mono Basin, in August 2008 at five flow releases.

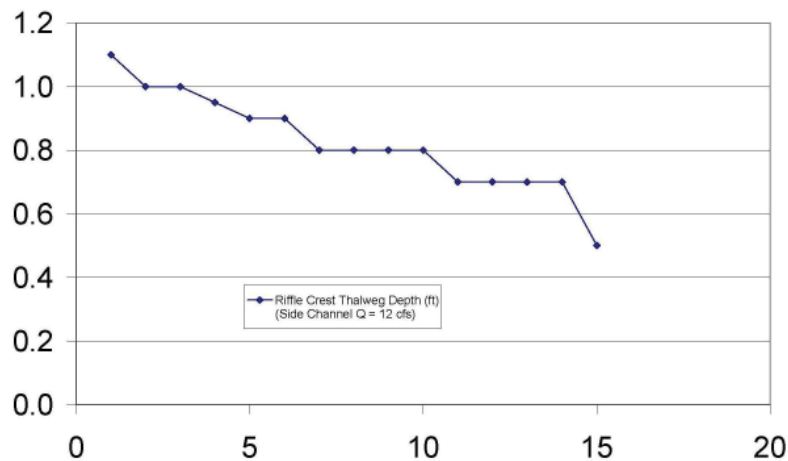


Figure B22. Riffle Crest thalweg depths measured in the Shasta Canyon Salmon Heaven side channel on February 18, 2009. Side channel discharge was 12 cfs.

We applied two transect-based standard setting methods, the Wetted Perimeter method and R2 Cross, at two cross sections established in the Shasta Canyon along Hudson Road. We used these methods to evaluate a flow range providing suitable spawning habitat. Wetted perimeter is the length of wetted channel between the left bank and right bank edges of the water surface. The method is applied to riffles, and assumes that there is a direct relationship between the wetted perimeter in riffles and fish habitat (Annear and Conder 1984). The method relies on a plot of wetted perimeter versus discharge, and identifies transitions (inflection points) or the maximum curvature in the wetted perimeter curve. The inflection point or point of maximum curvature is identified from the curve, and used to compute the associated discharge at that point on the curve. This discharge is then assumed to be protective of a range of aquatic habitat values. Appropriate riffles for the application of the wetted perimeter method must extend across the entire channel and maintain hydraulic control over a range of low to moderate flows.

R2 Cross is commonly applied in many Rocky Mountain states to provide rapid and rudimentary estimates of instream baseflow needs (Nehring 1979, Espergren 1998). The method assumes that a flow that maintains habitat in riffles is sufficient to provide habitat in pools and runs. Those flows would presumably also be sufficient to provide habitat for most life stages of fish, and the aquatic invertebrates that the fish feed on. Estimated channel top-width at bankfull discharge, depth, velocity, and percent wetted bankfull perimeter are used as the criteria in selecting an appropriate flow (Table B5).

Cross section topography and hydraulic data were collected at two riffle cross sections installed in the Shasta Canyon along Hudson Road. Both cross sections traversed riffles with easily identifiable spawning habitat, and several salmonid redds were observed within these riffles in fall of 2008 and 2009. Each cross section was surveyed with engineer’s level, and equipped with a Global WL16 pressure transducer and datalogger. Staff gages were installed on the cross sections and at approximately 50 ft upstream and downstream of the cross section to obtain water surface elevation estimates for slope and Mannings *n* calculations. Between October 24, 2007 and October 16, 2008, at least five stage, discharge, and slope measurements were collected over a range of streamflows from 23 cfs to 196 cfs. This flow range was assumed to bracket the lower end of a spawning habitat-flow curve. The bankfull channel width was estimated, although field evidence of channel-forming flows was sparse and unimpaired peak flow data were not available for estimating bankfull discharge. Data for the Wetted Perimeter and R2 Cross methods are summarized in Table B6.

The wetted perimeter was plotted with discharge for each cross section over the range of flows monitored (Figure B23). The Wetted Perimeter method targets the point of maximum curvature in the wetted perimeter-discharge plot, i.e., the point where the curve transitions from steep ascension to flattened curve. This inflection point occurred at a minimum streamflow of approximately 60 cfs.

The R2 Cross recommendations are based on maintaining three hydraulic criteria, average depth, average velocity, and % wetted perimeter across the cross sections (Table XX). Assuming a bankfull channel width greater than 60 ft, flow values where the R2 Cross criteria are exceeded are highlighted in Table B6. At XS70+00, all three criteria were met when flows exceeded 123 cfs; at XS 140+00, all three criteria were met when flows exceeded 99 cfs.

*Table B5. Criteria used to determine minimum flow requirements using R2 CROSS single transect method. Row in italics used for the Shasta River.*

Bankfull top width	Average depth	Percent wetted perimeter	Average velocity
1 ft - 20 ft	0.2 ft	50%	1.0 ft/s
21 ft - 40 ft	0.2 ft - 0.4 ft	50%	1.0 ft/s
41 ft - 60 ft	0.4 ft - 0.6 ft	50% - 60%	1.0 ft/s
61 ft - 100 ft	0.6 ft - 1.0 ft	>70%	1.0 ft/s

Table B6. Hydraulic data collected at the Shasta Canyon Hudson Road sites used for evaluating the Wetted Perimeter and R2 Cross methods.

Station 70+00							
Date	Discharge (cfs)	Width (ft)	Average Depth (ft)	Average Velocity (ft/s)	Percent XS Meeting Spawning Criteria		XS 70+00 WP
					Depth	Velocity	
10/24/2007	155	73.4	1.44	1.68	75%	60%	61.07
10/16/2008	123	58.5	1.55	1.18	86%	63%	58.86
10/2/2008	99	57.4	1.32	0.94	82%	56%	58.41
9/24/2008	45	52.7	0.95	0.53	69%	23%	56.71
9/5/2008	23	40.2	0.79	0.45	62%	0%	50.94

station 140+00							
Date	Discharge (cfs)	Width (ft)	Average Depth (ft)	Average Velocity (ft/s)	Percent XS Meeting Spawning Criteria		XS 140+00 WP
					Depth	Velocity	
10/24/2007	155	58.5	1.79	1.81	92%	84%	66.4
10/16/2008	123	59.8	1.5	1.1	94%	61%	61.9
10/2/2008	99	58.6	1.3	1	89%	65%	60.9
9/24/2008	45	51	0.9	0.6	84%	31%	56.6

To place these flow estimates in a more meaningful context, we compared them to other available data describing suitable spawning habitat.

- Using spawning criteria developed by our TAC (Table B1), we examined the percentage of each transect that exceeded our hydraulic criteria. Similar to the R2 Cross estimates, at flows above 99 cfs a majority of depth/velocity stations exceeded the criteria.
- We plotted fall Chinook salmon spawning habitat curves obtained from a 1983 unpublished PHABSIM study conducted by Thomas R. Payne and Associates in the Shasta Canyon (Figure B24) for the Chris Difani Project. These curves indicated the most abundant spawning habitat occurred in the range of approximately 80-180 cfs.
- We analyzed the CDFG Shasta River Fish Counting Facility washback data (spawned-out carcasses recovered at the SRFCF) for Chinook and Coho salmon for WY’s 2001 to 2006, by comparing the washback data to daily average flows at the USGS Yreka gage. Each spawning season generally had several single washbacks arrive at the SRFCF before days in which multiple washbacks occurred. We assumed (1) multiple washbacks indicated spawning was in “full swing”, and (2) several days would transpire between redd site selection and initiation of spawning, and the appearance of a carcass at the SRFCF. Although there is a strong inherent bias in the flow data at the October 1 end of irrigation season (Figure B25), there nevertheless appeared to be a threshold in which discharge that consistently exceeded approximately 110-130 cfs produced multiple washbacks several (7-10) days later. The strongest indicator of this relationship was the WY 2006 data in which higher post-irrigation flows appeared earlier than other water years, and the onset of spawning appeared earlier (Table B7).

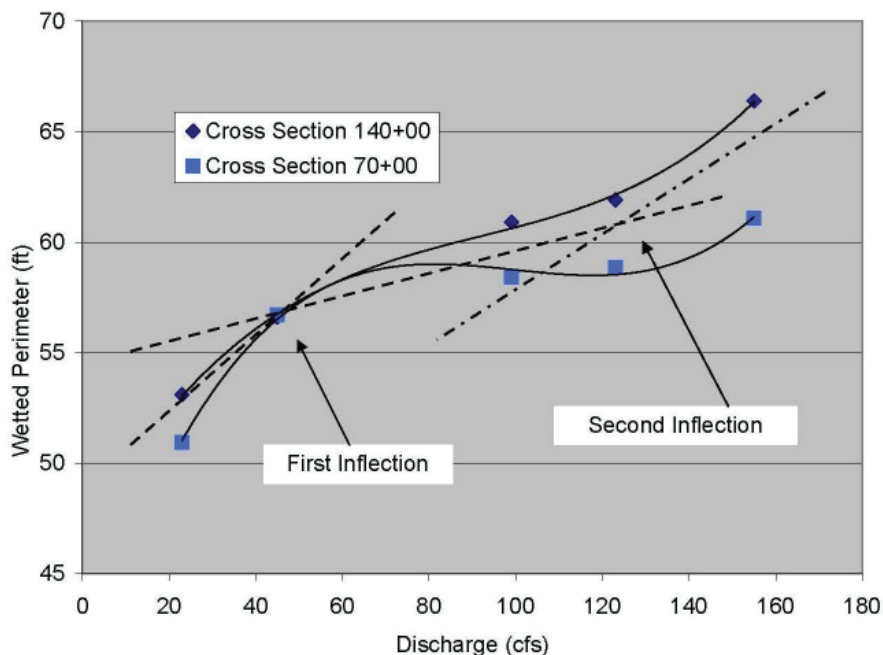


Figure B23. Wetted perimeter vs. discharge plotted for two cross sections monitored in the lower Shasta Canyon along Hudson Road. Polynomial trendlines (solid lines) were fitted to each set of points to define a curve and the inflection points. The dotted lines were placed to indicate major inflection points in the curves. Based on the channel geometry, two major inflection points occurred in the range of flows monitored.

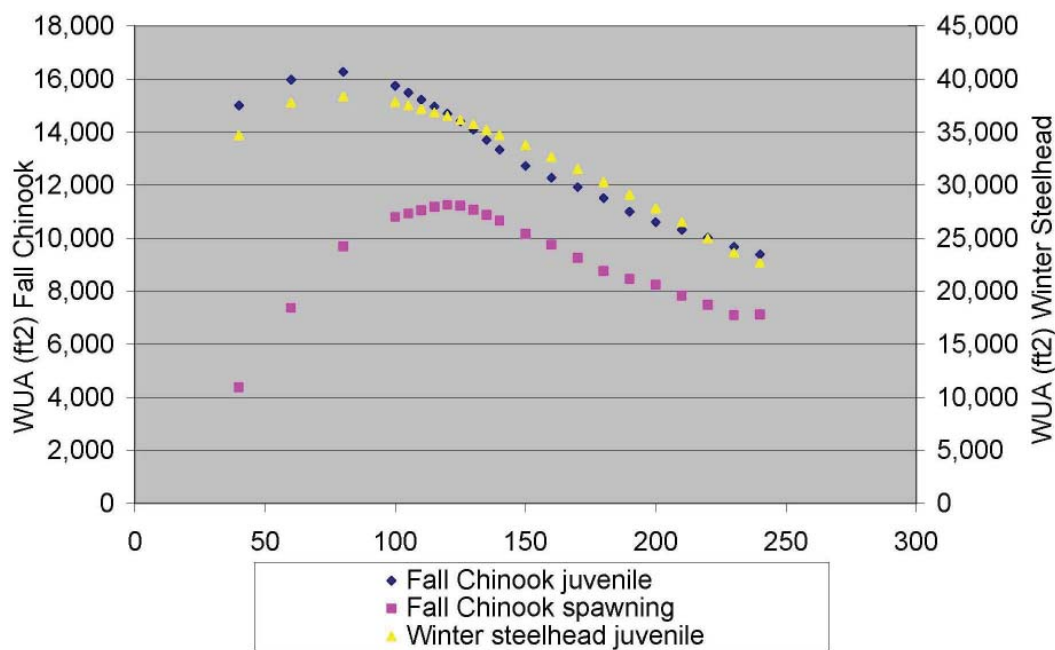


Figure B24. Weighted Usable Area (WUA) vs. discharge curves obtained from a 1983 PHABSIM two-flow analysis conducted by Thomas R. Payne and Associates for Mr. Chris Difani in the Shasta River Canyon.

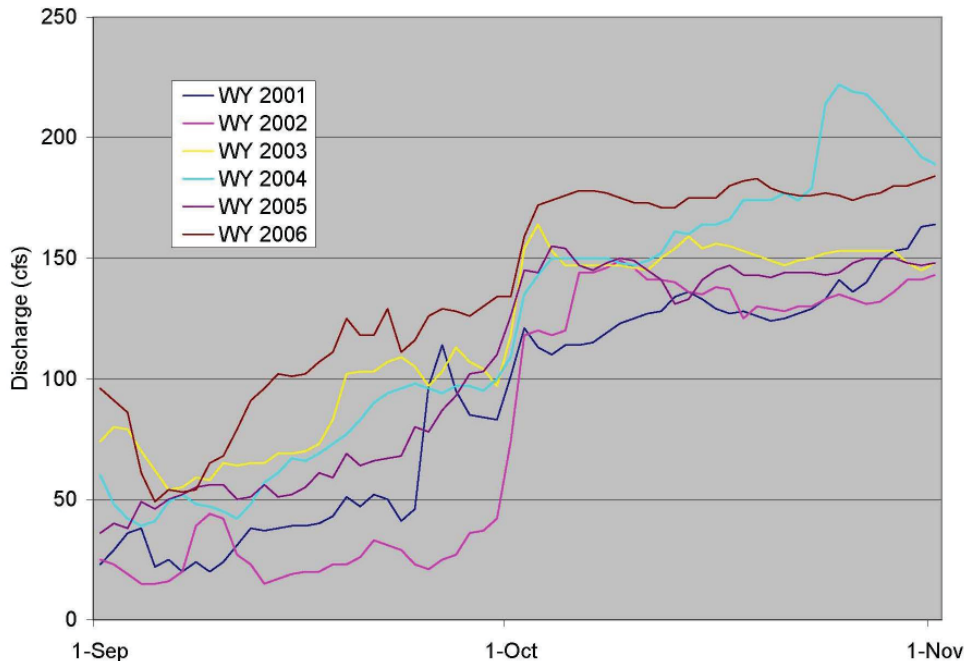


Figure B25. Daily average flows for September and October from the USGS ‘Shasta River near Yreka’ gage (11-517500) for water years 2001 to 2006. Flows increase substantially each year when the primary diversion season (for irrigation) ends on October 1.

These data collectively indicate a lower threshold for spawning flows beginning at approximately 80 cfs, becoming hydraulically “good” (i.e., high suitability) at approximately 120 cfs, and continuing through at least 180 cfs. The PHABSIM curves indicate the upper range of suitable spawning may exceed 240 cfs, based on hydraulic variables. The estimate of 60 cfs obtained from the Wetted Perimeter method is therefore much lower than these estimates, whereas the R2 Cross estimate of approximate 123 cfs (with all three criteria met) fits within this observed range.

The discharge-wetted perimeter plots presented a second inflection point (Figure B23), at approximately the 123 cfs observations. This second inflection may be useful for the following reason: the first (steeper) segment of the discharge-wetted perimeter curve (0-60 cfs) represents a proportionally higher increase in wetted perimeter with each increment of discharge, i.e., the wetted cross section is widening. The second (flatter) segment of the curve (60-120 cfs) thus represents a proportionally slower increase in wetted perimeter with each increment of discharge, i.e., the wetted cross section is becoming faster. Within the 60-120 cfs range, streamflow thus appears to be attaining hydraulic conditions favorable to spawning. The right half of this flat section of the wetted perimeter curve could therefore be used to indicate a flow range at which hydraulic conditions begin to become suitable.

Overall, these standard setting methods may provide useful hydraulic information to describe salmonid habitat, especially when evaluated in context with other information. However, neither method should be used independently to establish flow requirements that would be expected to be protective of all life stages and habitat types. The R2 Cross method states that maintaining hydraulic parameters at “adequate levels” would maintain habitat for “most life stages of fish and aquatic invertebrates” (Nehring 1979), but do not define “adequate” nor which life stages’ habitats are not maintained. Hardy et al. (2003) acknowledge “there are no validation studies in which the prescribed levels of instream flow at the magnitudes selected using R2 Cross have provided adequate levels of protection to the aquatic resources over extended periods of time.”



Table B7. Daily average discharge from the USGS ‘Shasta River near Yreka’ gage (11-517500) for WYs 2001-06 for September and October. The first day in which multiple salmon carcasses were recovered (highlighted in gray) at the Shasta River Fish Counting Facility was assumed to indicate start of spawning season, and generally occurred after streamflows remained above approximately 120 cfs (highlighted in orange).

Date	WY 2001	WY 2002	WY 2003	WY 2004	WY 2005	WY 2006
<b>Fall Chinook Escapement</b>	<b>11,093</b>	<b>6,818</b>	<b>4,289</b>	<b>962</b>	<b>2,129</b>	<b>2,184</b>
9/1	23	25	74	60	36	96
9/2	29	23	80	48	40	91
9/3	36	19	79	42	38	86
9/4	38	15	70	39	49	61
9/5	22	15	62	41	46	49
9/6	25	16	54	49	50	54
9/7	20	20	55	52	52	53
9/8	24	39	59	48	55	54
9/9	20	44	58	47	56	65
9/10	24	42	65	45	56	68
9/11	31	27	64	42	50	79
9/12	38	23	65	48	51	91
9/13	37	15	65	57	56	96
9/14	38	17	69	61	51	102
9/15	39	19	69	67	52	101
9/16	39	20	70	66	55	102
9/17	40	20	73	69	61	107
9/18	43	23	83	73	59	111
9/19	51	23	102	77	69	125
9/20	47	26	103	83	64	118
9/21	52	33	103	90	66	118
9/22	50	31	107	94	67	129
9/23	41	29	109	96	68	111
9/24	46	23	105	98	80	116
9/25	97	21	97	96	78	126
9/26	114	25	103	94	87	129
9/27	95	27	113	97	93	128
9/28	85	36	107	97	102	126
9/29	84	37	104	95	103	130
9/30	83	42	97	100	110	134
10/1	101	74	118	109	126	134
10/2	121	118	154	135	145	159
10/3	113	120	164	143	144	172
10/4	110	118	153	150	155	174
10/5	114	120	147	150	154	176
10/6	114	144	147	150	147	178
10/7	115	144	147	150	145	178
10/8	119	146	147	150	148	177
10/9	123	149	147	148	150	175
10/10	125	146	146	147	149	173
10/11	127	141	145	149	145	173
10/12	128	141	150	152	141	171
10/13	134	140	154	161	131	171
10/14	136	136	159	160	133	175
10/15	133	135	154	164	141	175
10/16	129	138	156	164	145	175
10/17	127	137	155	166	147	180
10/18	128	125	153	174	143	182
10/19	126	130	151	174	143	183
10/20	124	129	149	174	142	179
10/21	125	128	147	177	144	177
10/22	127	130	149	174	144	176
10/23	129	130	150	179	144	176
10/24	133	133	152	214	143	177
10/25	141	135	153	222	144	176
10/26	136	133	153	219	148	174
10/27	140	131	153	218	150	176
10/28	149	132	153	212	150	177
10/29	153	136	153	205	150	180
10/30	154	141	148	199	148	180
10/31	163	141	145	192	147	182

## 10.6 The Tennant Method

The Tennant Method is an office based method based on maintaining a pre-defined percentage of mean annual flow (Tennant 1976). For a gaged stream, the unimpaired mean annual flow is computed, and estimates of summer baseflow are computed as a percentage of the mean annual flow. “Good” habitat is considered 40% of mean annual flow, “Fair or Degrading” habitat is considered 30% of the mean annual flow, and “Poor or Minimum” is considered 10% of the mean annual flow. For ungaged streams, mean annual flow needs to be estimated.

We were not able to obtain published streamflow records of unimpaired flows for the Shasta River mainstem. Our analyses of streamflow data developed estimates of unimpaired daily average annual hydrographs for the six water years in which the USGS Shasta River near Edgewood and Little Shasta River near Montague published records overlapped (1959, 1963-67). These data were used to estimate the mean annual flow at our three study sites in the Shasta River basin: the Nelson Ranch, Little Shasta River, and the Shasta Canyon (Table B8). The mean annual flow estimates were conservative estimates and did not include several tributaries such as Willow and Julian creeks, and Yreka Creek, for which no streamflow data were available. Application of the Tennant Method in the Shasta River basin is also problematic because of the unique spring hydrology in the mainstem and in the Little Shasta River, which historically provided year-around cold baseflows.

The flow estimate for Good Habitat obtained for the Little Shasta River (7.2 cfs) corresponds to relatively low habitat abundance on the habitat-flow curve (Figure B3) developed from microhabitat mapping. Applying this flow estimate to summer rearing conditions in the Little Shasta River would also need to consider temperature suitability; for winter rearing conditions, this flow could be considered a minimum baseflow estimate that begins to be protective of rearing habitat availability for the four species/life states we assessed. Similar conclusions would apply for the Shasta Canyon site for summer and winter rearing habitat. The estimate of Good Habitat obtained for the Shasta Canyon does, however, correspond with the threshold for spawning habitat discussed in Section 10.5 above. We do not have any habitat data with which to compare the Tennant Method estimate for the Nelson Ranch site.

*Table B8. Estimated mean annual discharge and resultant minimum streamflow estimates obtained by applying the Tennant Method at each of our study sites, for different targeted habitat conditions.*

Study Site Location	Estimated mean annual flow	Good Habitat (40%)	Fair or Degrading Habitat (30%)	Poor or Minimum Habitat (10%)
The Nelson Ranch	215 cfs	86 cfs	64 cfs	21 cfs
Shasta Canyon	246 cfs	98 cfs	74 cfs	25 cfs
Little Shasta River at SVWA	18 cfs	7.2 cfs	5.4 cfs	1.8 cfs

## **11 APPENDIX C: STREAMFLOW AND WATER TEMPERATURE DATA**

The following streamflow data are available on DVD:

- USGS Shasta River near Edgewood
- USGS Shasta River near Montague
- USGS Shasta River near Yreka
- USGS Little Shasta River near Montague
- Gaging data collected at the Little Shasta River Shasta Valley Wildlife Area during this project are also provided on DVD

The following water temperature data are available on DVD

- Onset ProV2 hourly temperature data for Shasta River Canyon Salmon Heaven site, taken in mainstem and side channel
- Hourly water temperature data for the Little Shasta River collected by Mike Farmer of CDFG Shasta Valley Wildlife Area for three sites Upper, Bridge, Lower on the Wildlife Area property.

**12 APPENDIX D: PHOTO-MONITORING IMAGES**

Photo-monitoring images listed in Table B3 are available on DVD.