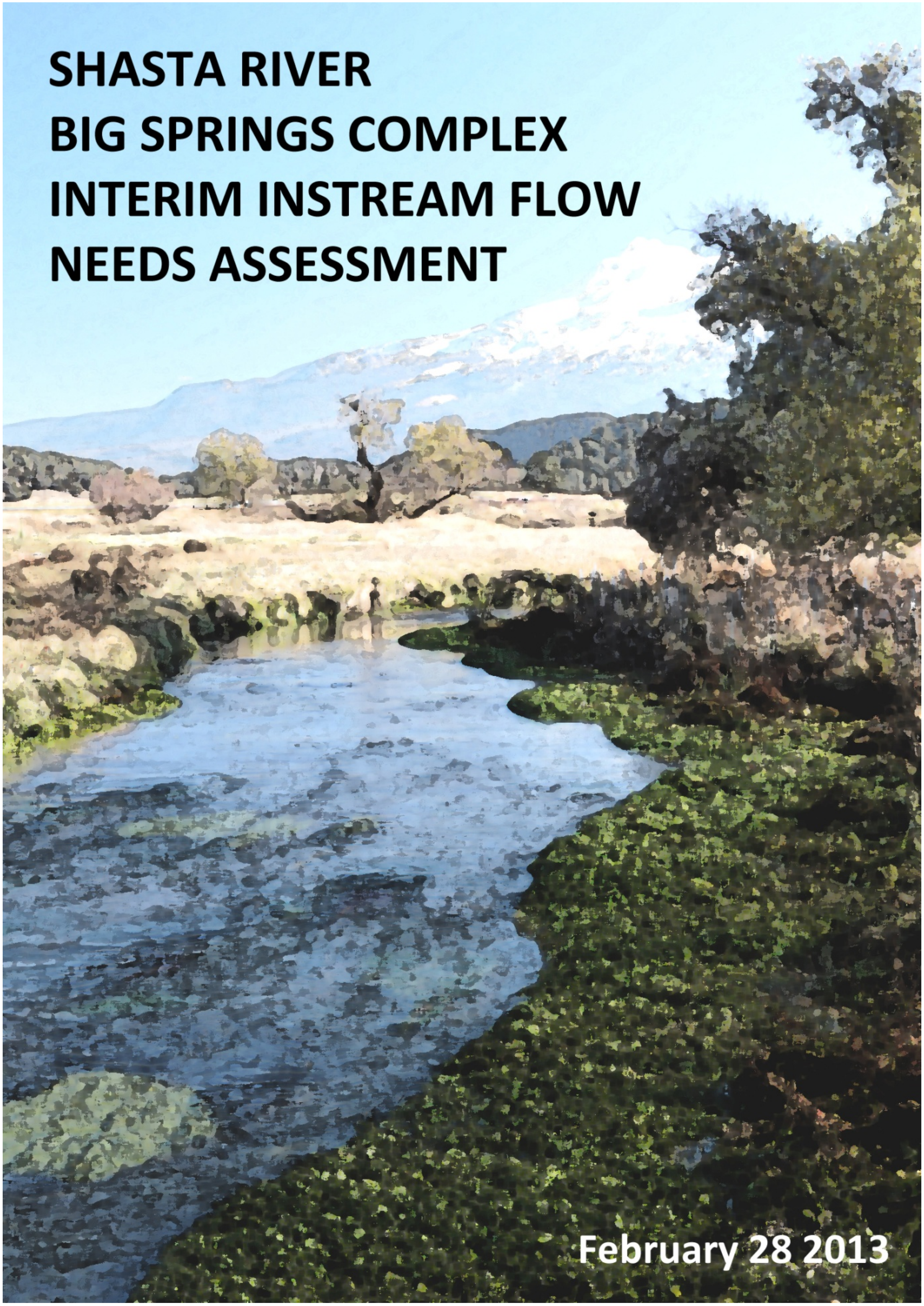
SHASTA RIVER
BIG SPRINGS COMPLEX
INTERIM INSTREAM FLOW
NEEDS ASSESSMENT



February 28 2013

SHASTA RIVER BIG SPRINGS COMPLEX INTERIM INSTREAM FLOW NEEDS ASSESSMENT

Prepared by:

MCBAIN & TRUSH, INC.

DEPARTMENT OF ENVIRONMENTAL RESOURCES ENGINEERING
HUMBOLDT STATE UNIVERSITY

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OCEAN PROTECTION COUNCIL
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LIST OF ACRONYMS USED IN THIS REPORT

BMI Benthic Macroinvertebrate

CDFW California Department of Fish and Wildlife

CESA California Endangered Species Act

DA Drainage Area

DHM Direct Habitat Mapping

FESA Federal Endangered Species Act

HEC-RAS Hydrologic Engineering Centers River Analysis System

HIG Hole in the Ground

HSU Humboldt State University

HHT Hydraulic Habitat Threshold

IFN Instream Flow Need

LHT Life History Tactic

LPC Lower Parks Creek

M&T McBain & Trush, Inc.

MWCD Montague Water Conservation District

NMFS National Marine Fisheries Service

OPC Ocean Protection Council

PHABSIM Physical Habitat Simulation System

$\mathbf{Q_{AVE}}$ Mean Annual Discharge

$\mathbf{Q_{MIN}}$ Minimum Flow

RCT Riffle Crest Thalweg Depth

mRCT Median Riffle Crest Thalweg Depth

RCT90 90th Percentile Riffle Crest Thalweg Depth

SONCC ESU Southern Oregon – Northern California Coast Evolutionarily Significant Unit

SWRCB State Water Resources Control Board

TM Thompson Method

TNC The Nature Conservancy

TWG Technical Work Group

UPC Upper Parks Creek

WP Wetted Perimeter

WY Water Year

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1 INTRODUCTION

The Shasta River in Northern California, which is a tributary to the Klamath River, supports populations of fall-run Chinook salmon (*Oncorhynchus tshawytscha*), coho salmon (*O. kisutch*), and steelhead trout (*O. mykiss*). The Shasta River was one of the most productive tributaries in the Klamath Basin, with annual adult escapements reported from early twentieth century in the high tens of thousands of Chinook salmon, thousands of coho salmon, and approaching ten thousand steelhead trout (Jong 1994, Snyder 1931). Over the past several decades, these fish populations have declined throughout the Klamath Basin, including the Shasta River, Table 1 (Deas et al. 2004).

Table 1. Native fishes of the Shasta River with their primary life-history strategy, i.e. resident(R) or anadromous (A), and their present ecological status indicated (adapted from Deas et al. 2004).

Name	Scientific Name	Life History	Status in Shasta River
Pacific lamprey	*Lampetra tridentate*	A	Common but probably declining
Klamath River lamprey	*Lampetra similis*	R	Not known
Klamath River speckled dace	*Rhinichthys osculus klamathensis*	R	Abundant, widespread
Klamath small scale sucker	*Catostomus rimiculus*	R	Common, widespread
Lower Klamath marbled sculpin	*C. klamathensis polyporus*	R	Common
Coho salmon	*Oncorhynchus kisutch*	A	Uncommon, declining
Chinook salmon	*Oncorhynchus tshawytscha*		
Fall run		A	Declining, low compared to historic numbers
Spring run		A	Extirpated
Steelhead trout (rainbow trout)	*Oncorhynchus mykiss*	A,R	
Winter run		A	Common but declining
Summer run		A	Extirpated

In 1997, the National Marine Fisheries Service (NMFS) listed the coho salmon Southern Oregon – Northern California Coast Evolutionarily Significant Unit (SONCC ESU) as threatened under the Federal Endangered Species Act (FESA) of 1973. In 2005, coho salmon ranging from San Francisco to the Oregon border were listed as threatened under the California Endangered Species Act (CESA).

As a result, the California Department of Fish and Wildlife (CDFW) began investigating instream flow needs (IFNs) for Shasta River salmonids in 2006. Their goal was to develop basin-wide instream flows pursuant to Fish and Game Code Sections 1603, 5901, and 5937, which have identified instream flow studies as a high priority action for the recovery and protection of coho salmon (CDFW 2004, 2009), Chinook salmon, and steelhead trout populations in the Shasta River (CDFW 1997; SRCRMP 1997). CDFW, California Trout (CalTrout), and McBain & Trush, Inc. (M&T), with assistance from UC Davis researchers and several landowners in the Shasta Basin, explored the applicability of different habitat quantification methods in addressing IFNs for high priority life-history tactics (LHTs) throughout the Shasta Basin (M&T 2009).

Beginning in 2009, CDFW and its project partners (Ocean Protection Council (OPC), Humboldt State University (HSU) Department of Environmental Resources Engineering, and McBain & Trush, Inc.) initiated investigations to determine *interim* IFNs for a portion of the upper Shasta River referenced as the Big Springs Complex and IFNs for portion of the lower Shasta River referenced as the Shasta River Canyon (Figure 1). Interim IFNs for the Big Springs Complex are investigated in this report. Funding was provided by the Ocean Protection Council through a Grant Agreement with the Humboldt State University (HSU) Foundation. Principal Investigators are Dr. Margaret Lang, Professor of the HSU Environmental Resources Engineering Department, and Dr. William Trush of McBain and Trush, Inc. The project is overseen by CDFW Water Branch staff and CDFW Region 1 staff environmental scientists. The Shasta River Instream Flow Program Technical Work Group (TWG) coordinates project activities.

1.1 Defining 'Interim' and 'Minimum' Instream Flow Needs

An IFN study identifies components of the natural flow regime, including the magnitude, frequency, timing, rate of change, and duration of streamflows, that are necessary to sustain organisms in a healthy aquatic ecosystem. A widely accepted IFN goal is to identify the most important components of the annual streamflow regimes that are necessary to collectively recover natural ecological processes affecting fish habitat, riparian vegetation, stream-channel morphology, and valley/floodplain morphology, rather than prescribe minimum baseflows only, which has been a common water management approach in past decades (Hill et al. 1991; Poff et al. 1997; Trush et al. 2000; Bunn and Arthington 2002; Postel and Richter 2003; Annear et al. 2004; Poff et al. 2010). Because IFN studies typically are multi-year efforts, *interim* instream flow recommendations completed on a seasonal or annual basis can precede final IFN findings (Castleberry et al. 1996; Annear et al. 2004). These interim IFNs can provide CDFW with quantitative recommendations for the streamflow provisions that are necessary for addressing agricultural diversions in Streambed Alteration Agreements without the expense of a multi-year IFN study.

The phrase 'fish in good condition' is a central component of California Fish and Game Code's Section 5937 statute (Branch 2008) and provides a qualitative objective for prescribing a *minimum* instream flow. At least three cases in California have applied Section 5937: (1) Cal Trout v. State Water Resources Control Board (SWRCB) in the Mono Lake hearings, (2) the Putah Creek Water Cases, and (3) the San Joaquin River litigation. CDFW biologist Darrell Wong testified before the SWRCB in the Mono Lake hearings, stating:

> *The instream flows necessary to keep fish in good condition include those which will maintain a self-sustaining population of desirably sized adult fish which are in good physical condition. The fish populations should contain good numbers of different age classes; and habitats for these age classes should not be limiting. The ecological health of a stream will determine if the fish are to be kept in good condition (Verbal Testimony, 1993, State Water Resources Control Board).*

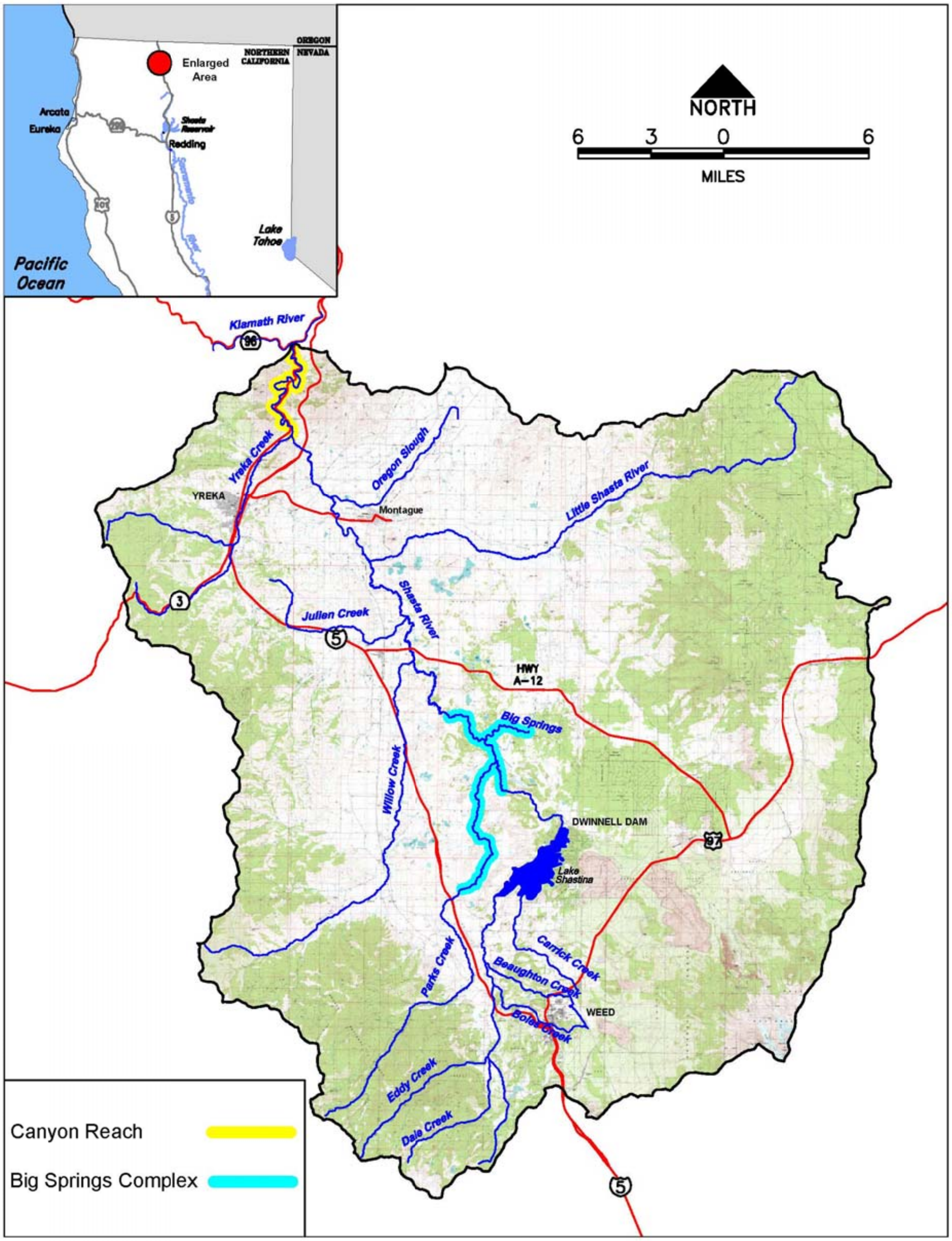


Figure 1. The Shasta Basin, Big Springs Complex and Shasta Canyon, Siskiyou County, CA.

Moyle et al. (1998) also interpreted 'good condition' by distinguishing three tiers of fish health: individual, population, and community:

> Tier No. 1. Individual. Individual fish should (1) have a healthy body conformation; (2) be relatively free of diseases, parasites, and lesions; (3) have reasonable growth rates for the region; and (4) respond in an appropriate manner to stimuli (e.g., predator avoidance).
>
> Tier No. 2. Population. A fish population should (1) contain multiple age-classes of fish, (2) exhibit a viable population size, and (3) be composed of healthy individuals. Because a viable population size is difficult to define, Moyle et al. (1998) used two criteria, including both habitat availability for all life history stages and the requirement that all habitats have a sufficiently broad distribution to sustain the species indefinitely, barring unexpected stream-wide catastrophes.
>
> Tier No. 3. Community. A fish community in good health is: (1) dominated by coevolved species, (2) predictably structured as indicated by limited niche overlap among the species and by multiple trophic levels, (3) resilient in recovering from extreme events, (4) persistent in species membership through time, and (5) replicated geographically. In short, a dynamic fish assemblage that will predictably occupy a defined range of environmental conditions.

The Big Springs Complex IFN study estimates the instream flows necessary to achieve Tier No.1 by determining suitable physical and thermal habitat conditions that must be provided by minimum instream flows to keep individual fish at specific life stages in good condition. Although habitat conditions provided by these minimum IFNs are intended to maintain *individual* fish in good condition, the recommended flows are not designed to meet the needs of riparian vegetation, geomorphic processes, or river-wide productivity. These interim flow recommendations also may not necessarily succeed at recovering fish populations.

Recovery of fish populations in the Shasta Basin will require more than meeting these Tier No.1 minimums. Addressing population-level (Tier No.2) and community-level (Tier No.3) requirements are both essential to achieving basin-wide recovery of salmonid species. While citing Dr. Moyle's tiers in administrative proceedings (Branch 2005), CDFW does not have procedural guidelines for determining intra-annual streamflow schedules necessary to accomplish all three tiers. NMFS (Williams et al. 2008) describes a framework for assessing coho salmon population viability to define when the SONCC ESU becomes naturally self-sustaining with a low risk of extinction and can therefore be de-listed. NMFS provides two numeric targets for coho salmon recovery, including both (1) a depensation threshold for the Shasta River of 531 adult fish, and (2) a low-risk, annual spawner abundance estimate of 10,600 fish.[1] Achieving NMFS's population viability goal in the Shasta basin in a reasonable timeframe will require meeting both Tier No.2 and Tier No.3 IFNs.

In summary, this IFN study recommends interim minimum instream flows to maintain native fish in good ecological condition, with a focus on several high priority life-history tactics that have been determined to be essential for population recovery within the Big Springs Complex. However, these minimum instream flows will not meet all Tier No.2 and Tier No.3 instream flow needs and therefore should not be expected to totally recover anadromous salmonid populations in the Shasta Basin. A future IFN study will be needed. The goal of future studies should not be to refine Tier No.1 interim streamflows recommended in this report, but to specifically quantify Tier No.2 and Tier No.3 IFNs including evaluation of floodplain habitat (Poff et al. 2010).

[1] At very low numerical densities, fish populations can experience a reduction in per capita growth rate with declining abundance, a phenomenon referred to as 'depensation.' This process occurs as a result of a variety of mechanisms, including both failure to find mates and therefore reduced probability of fertilization and failure to saturate predator populations, and this results in a negative feedback loop that accelerates population decline.

2 SALMONID HABITAT OBJECTIVES

2.1 Introduction

Our study focused both on the mainstem of the Shasta River extending from Dwinnell Dam downstream to Hwy A-12 and on the two primary tributaries of this reach, Parks Creek and Big Springs Creek (Figure 1). This region of the Shasta Basin, which is referred to as the Big Springs Complex (Figure 2), contains numerous springs with constant year-around streamflows of cold water, ranging between 11 ºC and 13 ºC when they emerge from the ground (Deas and Null 2007; Chesney et al. 2009). Reaches and sub-reaches examined within the Big Springs Complex were selected by the TWG (Table 2). Our study addresses interim instream flow needs for four freshwater life stages of Chinook and coho salmon, including: adult salmon migration and spawning (Section 2.2) winter incubation and fry rearing (Section 2.3), spring juvenile rearing, river productivity and smolt outmigration (Section 2.4), and summer juvenile salmonid rearing (Section 2.5). The IFN magnitudes and durations which maintain these four life stages in good condition will support multiple high priority life-history tactics identified for the Chinook salmon, coho salmon and steelhead trout populations originating within the Big Springs Complex (M&T 2009).

IFNs for steelhead trout life history needs are not estimated in this report because minimum instream flows recommended to meet Chinook and coho life history needs are considered adequate to meet steelhead freshwater life history needs as well. Thermal requirements that are protective of Chinook and coho salmon are generally protective of steelhead (Carter 2005, NCRWQCB 2006, Moyle et al. 2008). In addition, *minimum* habitat suitability criteria (specifically depth, velocity and substrate) for Chinook and coho adult spawning and juvenile rearing habitat either bracket or equal those for steelhead (Hampton et al. 1997). With the exception of spawning, life history periodicities for Chinook and coho also bracket those for steelhead. Steelhead spawning occurs from December to the end of March (Moyle et al. 2008) and overlaps the end of the salmon spawning period (September through December) and the entire winter juvenile rearing period (January through March) for Chinook and coho. Therefore we compared IFNs for winter juvenile rearing to IFNs for spawning habitat throughout the steelhead spawning period to ensure that adequate flow was provided to meet the minimum needs for spawning steelhead.

2.2 Objectives for Adult Salmon Migration and Spawning (September 7 through December 31)

Chinook salmon migration and spawning typically occurs from September through December. Coho salmon migration begins later than September, typically from mid-October through December. The mainstem reach of the Shasta River located just downstream of Parks Creek, Big Springs Creek, and the Shasta River from Big Springs Creek (i.e., Reach No.3 to No.5 in Figure 2 and Table 2) downstream to Grenada Irrigation District are identified as high priority reaches for Chinook salmon spawning (Deas et al. 2004; Jeffres et al. 2008, 2010; Chesney et al. 2009). Adult coho salmon migration and spawning are high priorities in the mainstem Shasta River extending from Clear Springs downstream to Big Springs Creek, in Parks Creek downstream of Interstate 5 (I-5), and along the entire length of Big Springs Creek (Jeffres et al. 2010). The objectives for migration and spawning IFNs are to provide access to spawning destinations and suitable spawning conditions for migrating adult salmon within the Big Springs Complex.

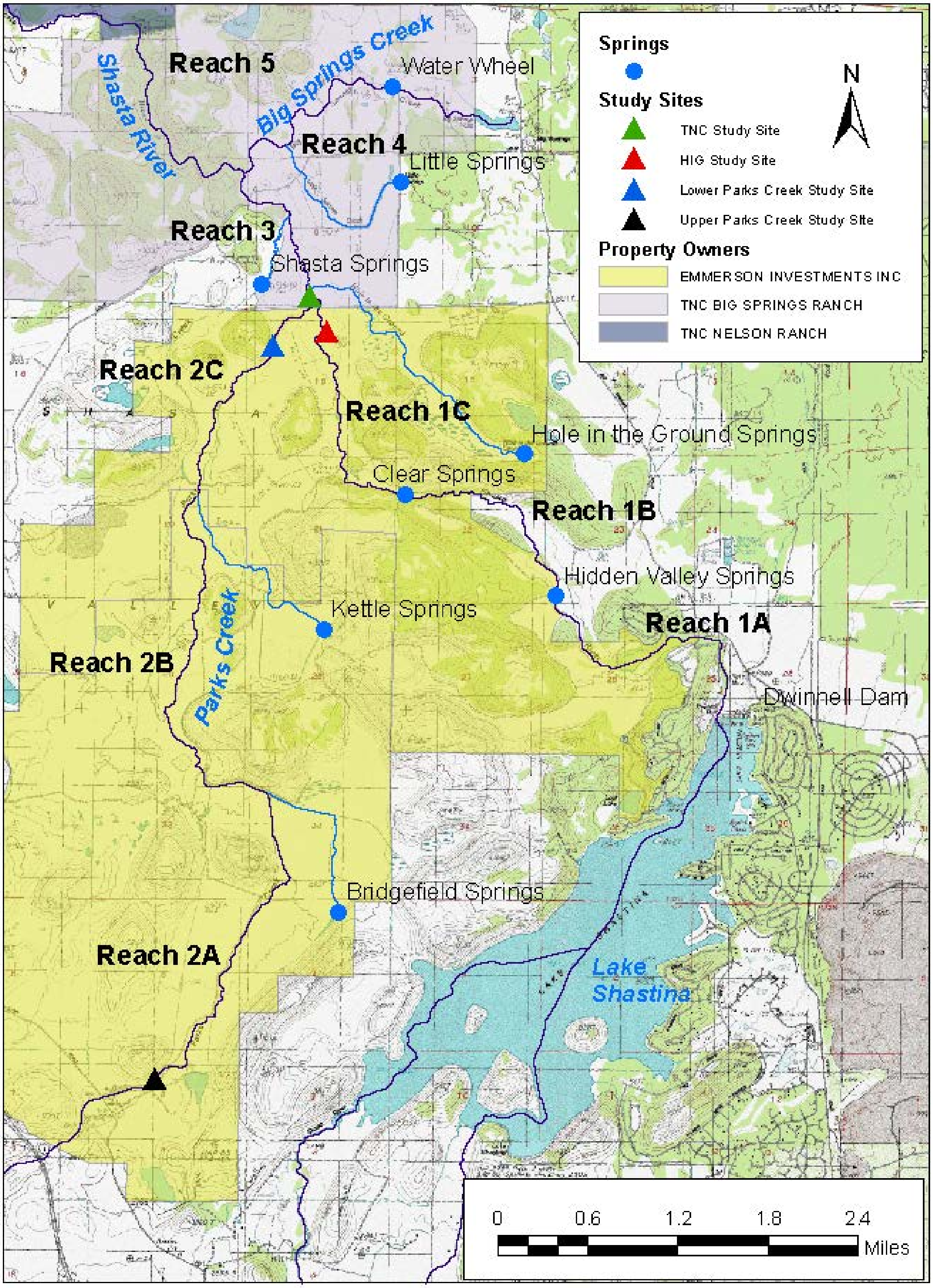


Figure 2. Reaches, sub-reaches, and study sites in the Big Springs Complex

Table 2. Location of channel reaches (numbered 1 through 5), sub-reaches (assigned letters a-c), and prominent springs within the Shasta River Big Springs Complex.

Reach	Reach or Spring Location	River Mile (mi)	Reach Length (mi)	Estimated Spring Discharge (cfs)	Water Temperature (^{o}C)
No.1	**Shasta River from Dwinnell Dam to Parks Creek**	40.6-34.9	5.7	NA	NA
1a	Dwinnell Dam to Rogenbuck Springs	40.6-38.2	2.4	NA	NA
	Hidden Valley Springs	*38.2*	*NA*	*1.2*	*13.9*
1b	Hidden Valley Springs to Clear Springs	37.2-37.0	1.2	NA	NA
	Clear Springs	*37.0*	*NA*	*2.5*	*13.6*
1c	Clear Springs to Parks Creek	37.0-34.9	2.1	NA	NA
No.2	**Parks Creek from 1-5 to Shasta River**	8.2-0.0	8.2	NA	NA
2a	1-5 to Bridgefield Springs	8.2-5.2	2.8	NA	NA
	Bridgefield Springs	*5.2*	*NA*	*3.2*	*13.5*
2b	Bridgefield Springs to Kettle Springs	5.2-1.8	3.4	NA	NA
	Black Meadow Springs		*4.6*	*0.8*	*13.5*
	Kettle Springs		*1.8*	*7.0*	*13.5*
2c	Kettle Springs to Shasta River	1.8-0.0	1.8	NA	NA
No.3	**Shasta River from Parks Creek to Big Springs Creek**	34.9-33.7	1.2	NA	NA
3a	Parks Creek to Hole in the Ground Springs	34.9-34.5	0.4	NA	NA
	Hole in the Ground Springs	*34.5*	*NA*	*4.0*	*~13*
3b	Hole in the Ground Springs to Big Springs	34.5-33.7	0.8	NA	NA
No.4	**Big Springs Creek**	2.2-0.0	2.2	89	11.6
	Little Springs	*0.7*	*NA*	*7.0*	*13*
No.5	**Shasta River from Big Springs Creek to Highway A12**	33.7-25.5	8.2	NA	NA
		Total	**16.5**	**114.7**	

2.3 Objectives for Winter Incubation and Fry Rearing (January 1 through March 31)

Between January and the end of March, salmon egg incubation, emergence and fry rearing are the priority IFNs in the Big Springs Complex. Reaches identified as key winter-rearing habitats include the upper mainstem Shasta River beginning from at least Clear Springs and extending downstream through the entire mainstem Shasta River, Parks Creek from at least I-5 downstream to the confluence with the Shasta River, and Big Springs Creek (based on Chesney et al. 2009). Winter rearing instream flows should be managed to ensure that egg incubation, emergence and fry rearing are widely available throughout the Shasta Big Springs Complex. In addition high quality juvenile rearing habitat, and adequate fish passage depths for fry and juveniles to redistribute freely is also critical (Chesney et al. 2009). Streamflows from winter storm events that either bypass the Montague Water Conservation District (MWCD) diversion structure on Parks Creek or spill from Dwinnell Dam (Figure 2) during the winter rearing period could potentially benefit juvenile salmonids by providing access to off-channel habitat in floodplains along Parks Creek and the mainstem Shasta River downstream of Parks Creek. Off-channel habitats can provide nutrients for the juvenile salmonids as well as refuge from the stress of high flows (Rosenfeld et al. 2008).

2.4 Objectives for Spring Juvenile Rearing, River Productivity and Smolt Outmigration (April 1 through June 15)

April through mid-June is a critical period for accelerating salmonid growth and development (McCormick and Saunders 1987). As air and water temperatures rise and daylight lengthens, biological productivity of the stream ecosystem increases, first in lower trophic levels (algal growth, then benthic macroinvertebrates), then rippling shortly afterwards through consumer populations (i.e., higher up the food web), including rearing salmonids (Hynes 1970). Improved growth at these early life stages translates into better health and greater survival in subsequent freshwater and ocean life stages (Hume and Parkinson 1988; Ward and Slaney 1988; Ward et al. 1989; Hayes et al. 2008). During the spring rearing season, realizing the Shasta River mainstem's productive potential may be as, or even more important to recover anadromous salmonid populations than prioritizing greater mainstem physical habitat capacity. Productivity can be increased by balancing water temperatures, food availability, and physical rearing habitat capacity.

In the unimpaired annual hydrograph (Section Figure 6), the predictable spring snowmelt pulse likely increased habitat capacity and invigorated the mainstem's productive potential. Physical habitat capacity likely increased through both the creation of more hydraulic complexity within the mainstem channel (than occurred at lower baseflows) and the provision of greater, longer duration streamflows to connect off-channel features hydraulically, such as scour channels and floodplains, with the mainstem channel. The spring snowmelt pulse also likely contributed to benthic invertebrate productivity by maintaining cooler water temperatures into late spring or early summer as well as by expanding riffles for greater and more productive benthic macroinvertebrate (BMI) habitat. Jeffres et al. (2008) measured aquatic macroinvertebrate drift rates in the Big Springs Complex that were approximately four times greater in April-June (with higher streamflow and cooler water temperatures) than in July-September (with low streamflows and warmer water temperatures).

No single minimum streamflow provision can accomplish all these complex hydrological and biological functions equally (Postel 2003), and thus multiple processes must be considered in developing interim IFNs for the spring snowmelt period. As a result, we focused on three hydraulic indicators of juvenile rearing habitat abundance and quality.

- First we mapped the area of substrates suitable to support BMI in riffles for each study site, using substrate criteria established in M&T (2010). In most gravel bed streams, the highest densities of BMI, and specifically the highest density of species that are important food sources for juvenile salmonids, occur in riffles (Logan and Brooker 1983). While herbivorous invertebrates associated with the aquatic macrophyte growth (such as *Amphipoda* species) are a key part of the food web on the Shasta river (Jeffres et al. 2010), these species tend to be less sensitive to instream flow needs than the gravel-based EPT taxa which dominate the riffle substrate during the winter and early spring (Merritt and Cummins 1996). Therefore we used depth, velocity and substrate criteria to develop habitat rating curves for gravel dependent BMI species. Depth and velocity thresholds for BMI habitat where established from Gore et al. (2001), Giger (1973), and Kennedy (1967). Because only three habitat mapping data points were available to construct a streamflow-BMI habitat rating curve (see Section 0) we used the mapped data points to estimate the streamflow at which 70% of the suitable riffle substrate area met depth and velocity criteria for BMI. This threshold was only used as a preliminary analytical measure of the instream flows that would protect a productive stream ecosystem to support juvenile salmonid growth and smolt outmigration.

- Second we identified a cross-sectional velocity threshold in pools capable of providing high quality habitat for older juveniles and smolts (see Section 3.2.5). Pool velocity thresholds were established based observations from Giger (1973) who noted that 90% of observed coho juveniles rearing in pools occurred wherever velocities ranged between 0.3 ft/sec and 0.7 ft/sec (Giger 1973).
- Third we used a reconnaissance level evaluation of bench inundation (see Section 3.2.6). Bench inundation provides shelter/cover and food for all juvenile salmonid life stages (fry, small and large juveniles, and smolts), thus contributing to improved habitat capacity and stream productivity. The minimum streamflow that initiated bench inundation was determined using either a rating curve at monitored cross sections or photographic documentation of bench inundation at known streamflows.

The objectives of the River Productivity and Smolt Outmigration IFN are to (1) provide abundant mainstem rearing habitat and passage for pre-smolts and smolts during their downstream migration, (2) stimulate BMI productivity to provide high quality food resources for immediate consumption as well as later during summer rearing, and (3) offset irrigation diversions beginning on, or soon after, April 1 from abruptly reducing rearing habitat availability and quality. Instream flows which satisfy the three hydraulic indicator criteria described above between April and mid-June throughout the Big Springs Complex are an interim measure to meet the objectives the River Productivity and Smolt Outmigration IFN.

2.5 Objective for Summer Juvenile Salmonid Rearing (June 16 through September 6)

Summer juvenile salmonid rearing habitat quality largely depends on the presence of suitable water temperatures, which are typically in the range of 15° to 20° C depending on species (Moyle 2002, Sullivan et al. 2000). A more detailed review of thermal requirement for rearing salmonids is included in the interim water temperature assessment, Section 5. As in most northern California rivers and streams, unimpaired streamflows in the Shasta River during the summer rearing season were the lowest intra-annual flows as a result of climate patterns in the region (Gasith and Resh 1999). However, the Shasta River offset the effects of low summer baseflows with abundant cold-water springs that created local pockets of cold-water rearing habitat which historically provided highly productive summer rearing habitat.

Juvenile rearing during the summer irrigation season is considered a primary constraint on coho salmon population recovery in the Shasta River (NRC 2003, CDFW 2004, Chesney et al. 2009). Chesney et al. (2009) established study sites on the Shasta River during the 2008 summer rearing season from the Nature Conservancy's (TNC) Nelson Ranch to Clear Springs on Emmerson Investment Inc.'s Hole in the Ground (HIG) Ranch (corresponding to Reach No.1, No.3, and No.5 of our study area, Figure 2 and Table 2). Furthermore, the Chesney et al. (2009) study documents early-spring habitat availability and habitat use by rearing coho salmon within the Shasta River mainstem reaches beginning in April 2008 and extending until warm temperature conditions forced these fishes to migrate. Temperature increases in the mainstem forced displacement from all but three of their study sites located downstream of Clear Springs. During our study period, the summer rearing season provided juvenile salmonid rearing habitat both in sparse, isolated pockets in short reaches downstream of Clear Springs, Kettle Springs, Big Springs, and in small cold water seeps along the mainstem.

The objective of IFNs for over-summer rearing habitat is to protect cold-water temperature refugia at and downstream from spring sources. If suitable mainstem temperatures cannot be maintained during the summer period, IFNs are intended to provide minimal aquatic habitat in the mainstem channels and access to off channel rearing habitat in spring creeks. Based on our understanding of the influence of spring creeks on summer habitat (Chesney et al 2009, Jeffres et al. 2009, Null et al. 2010), priority reaches for over-summer rearing habitat are Parks Creek downstream of Kettle Springs and Bridgefield/Black Meadow springs as far downstream as temperature analysis indicate (Section 5). In the mainstem Shasta River priority reaches for over-summer juvenile rearing habitat are from Clear Springs downstream past the confluence with Big Springs Creek and in Big Springs Creek. If favorable temperature conditions cannot be maintained above Clear Springs due to warm-water releases occurring from Dwinnell Dam, then a high priority would be to prevent warm-water releases from adversely affecting cold water flowing into the mainstem from Clear Springs, Parks Creek, Kettle Springs, Hole-in-the-Ground Springs, and Big Springs (Figure 2). In addition, given favorable juvenile salmonid rearing conditions observed in Big Springs Creek and the mainstem Shasta River below Big Springs Creek in both 2009 and 2010 (Jeffres et al. 2010), reaches No.4, and No.5 (Figure 2, Table 2) should receive a high recovery priority targeting over-summer rearing habitat.

3 METHODS FOR IDENTIFYING MINIMUM INSTREAM FLOW NEEDS

Minimum IFNs were investigated in five reaches within the Big Springs Complex (Table 2) to provide suitable interim recommendations under the timeframe and budget allotted. Analytical strategies for quantifying IFNs were applied in progressive stages of increasing specificity and quantification. The ultimate use for the recommended minimum IFNs will be to prescribe instream flows for those LHTs considered most responsive for basinwide salmonid population recovery. Although these minimum IFNs are only meant to address Tier No. 1 objectives, they nevertheless will be an important step toward recovery.

Stage No.1: Regional regression models by both Swift (1976, 1979) and Hatfield and Bruce (2000) were employed to estimate regionally appropriate IFNs for anadromous salmonid spawning and rearing. Both of these models rely on two independent variables, i.e., mean annual discharge (Q_{AVE}) and drainage area (DA).

Stage No.2: R2 Cross and Wetted Perimeter standard setting methods (Nehring 1979; Espergren 1996, 1998) were monitored at four study sites, with three study-site visits allotted from mid-May to late-August in WY2010. These standard setting methods added scientific refinement through site-specific measurement that the Stage No.1 analysis lacked.

Stage No.3: Direct Habitat Mapping (M&T 2009), riffle crest thalweg surveys, bench inundation analyses and hydraulic habitat threshold evaluations were applied to the Big Springs Complex to establish a quantitative connection between streamflow and salmonid habitat needs that the Stage No. 2 methods could not. Stage No.3 methods provided a field-based check on predicted IFNs from Stage No.1 and Stage No. 2 and were expected to more reliably identify IFNs for the Big Springs Complex.

Stage No.4: An interim assessment of the streamflow-water temperature relationship in the Big Springs Complex was completed to estimate if the recommended IFNs for the late-spring through early-autumn period (from Stage No.1 – No.3 methods) satisfy identified water-temperature criteria, especially for summer rearing of juvenile salmonids. When appropriate the recommended minimum IFNs were modified based on the results of the interim water temperature assessment.

3.1 Instream Flow Need Study Sites in the Big Springs Complex

Five channel reaches were selected in the Big Springs Complex for instream flow evaluation by the Technical Work Group (TWG), sub-reaches were delineated based on the location of spring inflows, and four study sites were selected to evaluate IFNs for high priority LHTs (Table 2). Reach No.1 had the Hole-in-the-Ground study site (HIG), located on the mainstem Shasta River 1,500 ft upstream of the confluence with Parks Creek (Figure 2). Reach No.2 had two study sites, one on Upper Parks Creek (UPC) located 2,000 ft downstream of Slough Bridge and the other on Lower Parks Creek (LPC) 4,300 ft upstream of the confluence with the Shasta River. Reach No.3 had one study site with TNC as the landowner (TNC), located within the first 1,000 ft downstream of the confluence of the Shasta River and Parks Creek. There were no instream flow study sites in Reach No.4 or No.5. Instead, several years of intensive field investigations by TNC and UC Davis researchers at TNC's Nelson Ranch and Shasta Big Springs Ranch provided most of the information for assessing IFNs.

3.2 Methods for Quantifying Minimum Instream Flow Needs

3.2.1 Regional Regression Models

Hatfield and Bruce (2000) compiled data from 127 PHABSIM studies throughout Washington, Oregon, and California. They first identified the single flow that maximized the PHABSIM index of microhabitat, termed the "optimum flow", which is the calculated peak of the streamflow-habitat weighted usable area (WUA) curve from the PHABSIM model. They then developed regression relationships for optimum spawning and rearing flows with mean annual discharge (Q_{AVE}) and latitude/longitude coordinates. We applied their regional regression equations based on mean annual discharge and latitude/longitude (from Hatfield and Bruce 2000), for Chinook salmon, steelhead trout, and all species pooled to compute minimum IFNs for spawning and juvenile rearing (0).

Regional regression methods are intended to be used as a planning tool, not as the sole or determining factor in an interim IFN assessment as they incorporate considerable statistical and ecological uncertainty (Hatfield and Bruce 2000). In addition, the concept of "optimum flow" (as the calculated peak of the streamflow-habitat WUA curve), is frequently criticized because it does not consider the feasibility of resulting flow regimes (Waddle 2006), interactions between multiple species, life stages and other variables that influence the state of the ecosystem (Ahmadi-Nedushan et al. 2006) or the importance of providing habitat over a range of flows (i.e. integrating the WUA curve). In this study, regional regression methods are used as the first stage in the IFN analysis to estimate regionally appropriate IFNs for anadromous salmonid spawning and rearing.

The regression equations developed based on Hatfield and Bruce (2000) are as follows:

<u>Chinook Salmon</u>

Spawning $-51.710 + 0.682*\log_e(Q_{AVE}) + 11.042*\log_e(\text{longitude})$ (1)

Fry $-3.794 + 1.246*\log_e(Q_{AVE})$ (2)

Juvenile $-0.998 + 0.939*\log_e(Q_{AVE})$ (3)

<u>Steelhead Trout</u>

Spawning $-33.064 + 0.618*\log_e(Q_{AVE}) + 7.260*\log_e(\text{longitude})$ (4)

Fry $-0.838 + 0.815*\log_e(Q_{AVE})$ (5)

Juvenile $-8.482 + 0.593*\log_e(Q_{AVE}) + 2.555*\log_e(\text{latitude})$ (6)

<u>All Species Pooled</u>

Spawning $-12.392 + 0.660*\log_e(Q_{AVE}) + 1.336*\log_e(\text{latitude}) + 1.774\log_e(\text{longitude})$ (7)

Fry $-6.392 + 0.812*\log_e(Q_{AVE}) + 1.4749*\log_e(\text{latitude})$ (8)

Juvenile $-6.119 + 0.679*\log_e(Q_{AVE}) + 1.771*\log_e(\text{latitude})$ (9)

These equations estimate the optimum flow for the species and life stage indicated. Log_e is 2.718 and Q_{AVE} is mean annual discharge (cfs) computed at the upstream end of the reach (e.g., at Dwinnell Dam on the Shasta River and at I-5 on Parks Creek; see Figure 2).

Swift (1979) used binary criteria to map spawning habitat, then plotted wetted perimeter to identify a preferred discharge for rearing habitat for five salmonid species inhabiting 84 channel reaches within 28 streams throughout the state of Washington. Specifically, Swift (1976) states:

> *The preferred discharge for rearing, or the discharge that provides the maximum wetted area of the streambed, is determined from the relationship between the average wetted perimeter [of four cross sections surveyed in each of 28 reaches] and the discharge at the study reach. The preferred rearing discharge is selected at the center point of greatest curvature in the wetted perimeter-discharge relationship.*

Furthermore, Swift (1976) developed regression relationships based on DA and Q_{AVE} to predict 'optimal' spawning and rearing flows, and the equations from Figures 10, 11, and 12 in that paper, for Chinook spawning, coho spawning, and salmon rearing, respectively, are as follows:

Chinook Spawning (Q_{cc}) $4.22((Q_{AVE})^{0.747}) \pm 39\%SE$ (10)

Coho Spawning (Q_{sc}) $2.13((Q_{AVE}))^{0.771}) \pm 45\%SE$ (11)

Salmon Rearing (Q_r) $0.686((Q_{AVE}))^{0.824}) \pm 53\%SE$ (12)

Where Q_{AVE} is computed at the point of diversion, SE is the mean standard error, Q_{cc} is the "average of the stream discharges preferred by spawning Chinook salmon", Q_{sc} is the "average of the stream discharges preferred by spawning coho salmon", and Q_r is the "stream discharge preferred by salmon for rearing" (Swift 1979).

These regional regression equations were applied to the Shasta River Big Springs Complex using both Q_{AVE} and DA estimated for five locations in the Shasta Basin (Table 3) as follows:

- <u>Reach No.1:</u> the Shasta River near Edgewood CA USGS gage (Sta. No. 11516750) has a DA of 70.3 mi^2 for the Shasta River upstream of Dwinnell Reservoir. The Edgewood station is located at 2,900 ft elevation. Q_{AVE} was obtained from Deas and Null (2007). DA at the HIG study site is 128.3 mi^2.This location excludes Carrick Creek, which provides a steady, year-round spring-fed flow of approximately 8.5 cfs, and thus does not contribute to typical snowmelt runoff.
- <u>Reach No.2:</u> Parks Creek approximately where it crosses I-5 has a DA of 36.0 mi^2 based on USGS topographic maps. This location is at 2,900 ft elevation. Q_{AVE} was obtained from Deas and Null (2007). DA at the UPC study site is 36.2 mi^2; DA at the LPC study site is 49.7 mi^2.
- <u>Reach No.3:</u> the Shasta River at the TNC study site (just downstream from the confluence with Parks Creek) is 178.0 mi^2. DA at the TNC study site was obtained by adding DAs for Reach No.1 and No.2. Q_{AVE} was obtained from Deas and Null (2007). Note this computation excludes considerable land area in the eastern portion of the watershed, contributing little or no surface streamflow to the Shasta River.
- <u>Little Shasta River</u>: the Little Shasta River near Montague CA USGS gage (Sta. No. 11516900) has a DA of 48.2 mi^2. This station is located at 3,280 ft elevation. Q_{AVE} was obtained from Deas and Null (2007).
- <u>Shasta River nr Yreka</u>: the DA of 793 mi^2 was obtained from the USGS Shasta River near Yreka CA gage (Sta. No. 11517500). This station is located at 2000 ft elevation. This DA includes considerable area in the eastern portion of the watershed that yields minor or no surface streamflow to the Shasta River.

Table 3. Mean annual discharge (Q_{AVE}) and drainage area (DA) used in regional regression computations to estimate salmonid spawning and rearing instream flows.

Shasta River Tributaries	INDEPENDENT VARIABLES				
	Drainage Area (mi^2)	Mean Annual Discharge (cfs)	Unit Runoff (cfs/mi^2)	Latitude (decimal degrees)	Longitude (decimal degrees)
Shasta River at Dwinnell (USGS Edgewood gage)	70.3	80	1.14	41.54	122.37
Upper Parks Creek (UPC) study site at I-5	36.0	62	1.71	41.50	122.46
Lower Parks Creek (LPC) study site	49.7	85	1.71	41.56	122.44
Hole in the Ground (HIG) study site	128.3	146	1.14	41.56	122.43
TNC study site	178.0	142	0.80	41.58	122.43
Little Shasta River at USGS gage	48.2	61	1.27	41.70	122.53
Shasta River nr Yreka CA	793.0	298	0.38	41.58	122.43

Both regional regression methods were intended to identify streamflows providing the best possible ecological conditions. Rantz (1964), Swift (1976, 1979), and Hatfield and Bruce (2000) define the optimum flow as the single flow providing the most spawning habitat. Swift (1979) comments that:

> *Redds near the center of a stream are more likely to be disturbed by high autumn and winter flows than those nearer the edges. Greater discharges during spawning may increase survival by shifting the spawnable area toward the edges even though the total area spawnable is reduced.*

Therefore, the streamflows providing the most habitat space may not necessarily provide the best habitat. Hatfield and Bruce (2000) qualify use of their optimum flow concept by stating that “it represents only the maximum value of an index for habitat and ignores vital ecological processes.”

3.2.2 Two Standard Setting Methods: Wetted Perimeter and R2 Cross

Two standard setting methods, WP and R2 Cross, were employed within pool riffle unites at each study site (Figure 3). The WP of a cross section is the length of wetted channel bed between left and right bank edges of the water surface. The WP method, applied to riffles, relies on there being a direct quantitative relationship between the WP (measured in ft) in riffles and juvenile rearing habitat (Annear and Conder 1984) and/or BMI food production (Bell 1973, Swift 1976). The WP method plots WP versus streamflow to identify a “breakpoint” adopted by CDFW (2011), at the curve’s maximum curvature described by Swift (1979): “the preferred rearing discharge is selected at the center point of the greatest curvature in the WP-discharge relationship.” The streamflow at this breakpoint is thus the estimated minimum instream flow. Riffles suitable for WP application must extend across the entire channel and maintain hydraulic control at baseflows. Each riffle cross section had a WP-streamflow curve that was used qualitatively to identify the maximum breakpoint using visual inspection of the figures produced (Figure 4).

CDFW (2011) ascribes the following protectiveness by the WP method:

> *The primary assumption with the method is that the flow represented by the breakpoint will protect aquatic life in food producing riffle habitats at a level sufficient to maintain an existing fish population at an acceptable level of production (Annear et al. 1995). It is further assumed that protection of riffle habitats will confer a minimal level of protection to deeper water habitats such as runs and pools (Stalnaker et al. 1995), although perhaps to a lesser degree than for riffles.*

CDFW (2011) cautions that the WP method should be restricted to "use on streams with well-defined riffle and pool sequences, and with cross sections that are wide, shallow, and relatively rectangular." Within the Big Springs Complex, the UPC and TNC study sites best met these restrictions. The LPG and HIG study sites were not used as they did not meet the CDFW restrictions. In addition, it is noted that there is inherent variability in identifying the breakpoint of a wetted perimeter curve (Gipple and Stewardson 1998). Therefore these interim IFNs are not meant to replace more standard approaches for defining Tier No.2 IFNs, including DHM mapping and PHABSIM analyses.

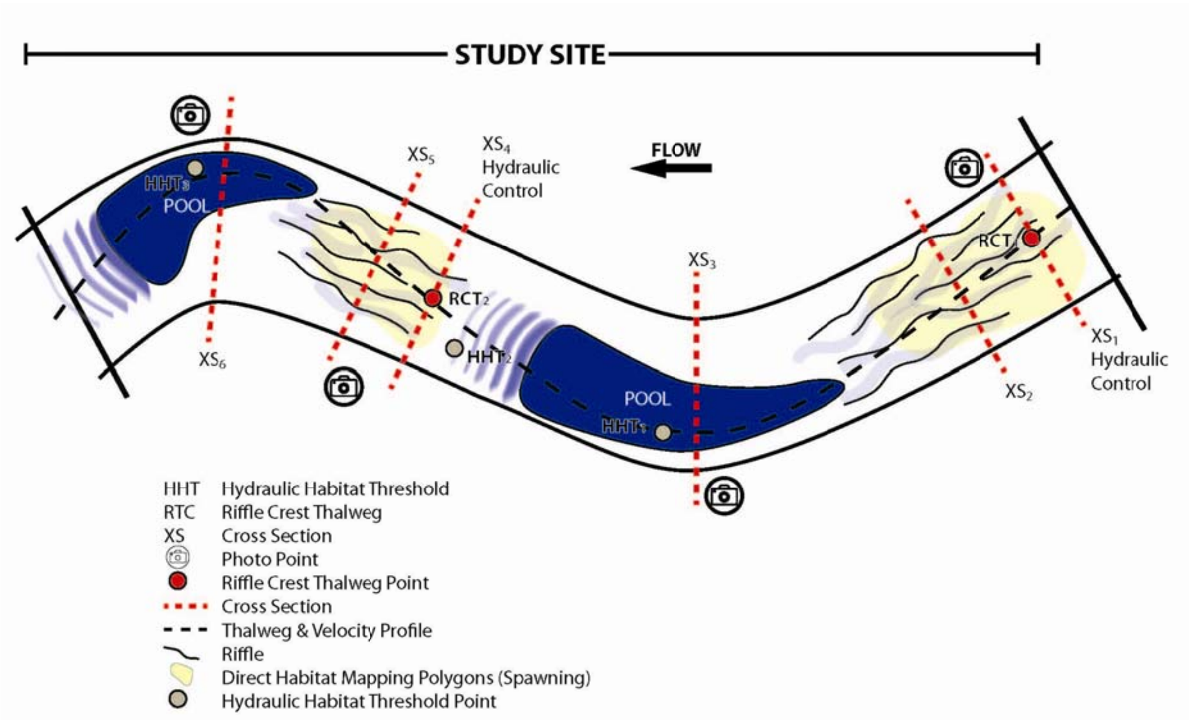


Figure 3. Idealized study site configuration for employing standard-setting methods, HEC-RAS modeling, and Direct Habitat Mapping (DHM).

Although not originally considered, the WP -streamflow curves were re-assessed based on CDFW's use of the "incipient asymptotic" streamflow threshold in addition to the breakpoint streamflow threshold (Figure 4). CDFW (2011) explains:

> *While the breakpoint flow may correspond to a less-than-desired level of habitat protection in some cases, a greater level of protection for aquatic resources can still be obtained using the wetted perimeter method for determining minimum flows. For example, the incipient flow at which wetted perimeter reaches an asymptote should provide a level of protection that is more consistent with maintaining habitat conditions to support a typical density of juvenile steelhead occupying a mosaic of feeding territories (sensu Kalleberg 1958) in a given habitat area. Assuming a*

roughly rectangular channel morphology, the incipient asymptotic flow should minimally provide a fully wetted stream channel, or nearly so. While this flow condition is likely below that associated with a maximum measure of habitat quality and quantity for juvenile steelhead – for example, maximum useable area from a PHABSIM study – it should be more protective for both aquatic macroinvertebrate and salmonid production than the lower breakpoint flow.

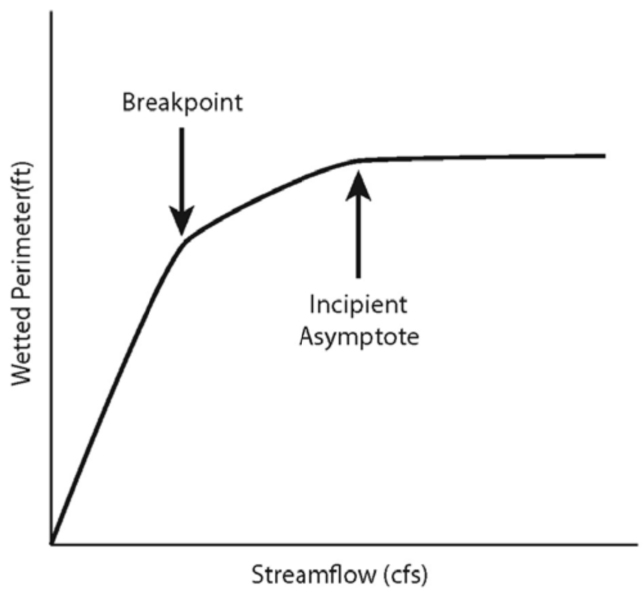


Figure 4. Wetted perimeter method of selecting the 'Incipient Asymptote' verses the 'Breakpoint' to achieve a more desirable level of habitat protection (CDFW 2011).

A second standard-setting method, R2 Cross, is commonly applied in many Rocky Mountain states to provide reconnaissance-level estimates of minimum instream flow needs (Nehring 1979, Espegren and Merriman 1995, Espegren 1996). The R2 Cross method identifies a minimum instream flow meeting specific depth and velocity threshold criteria in riffles as a hydraulic indicator for providing sufficient salmonid rearing habitat in pools and runs. Estimated channel top-width, average cross section depth, and velocity criteria are used in estimating a minimum instream flow (0). For the R2 Cross method, a 0.3 ft average cross-section depth criterion had a 21 ft to 40 ft wide channel (0) at the HIG, LPC, and UPC study sites in Reach No.1 and No.2; a 0.4 ft depth criterion had a 41 ft to 60 ft wide channel (Table 4) at the TNC study site in Reach No.3. A minimum threshold velocity criterion of 1.0 ft/s was applied to all study site cross sections analyzed.

Minimum instream flow needs were estimated for riffle cross sections at all the study sites using WP and R2 Cross. As a result of the narrow sampling timeframe of the study, the hydraulic geometry of riffle cross sections had to be modeled rather than measured directly. The US Army Corp of Engineers Hydrologic Engineering Center's River Analysis System (HEC-RAS), a 1-D, steady/unsteady flow model, was used to simulate the water-surface profile for each study site's riffle and to estimate hydraulic threshold parameters required for application of the R2 Cross method.

Table 4. Hydraulic criteria for determining minimum instream flows using the R2 Cross single transect method (adapted from Nehring 1979).

Bankfull Width (ft)	Average cross section Depth (ft)	Average cross section Velocity (ft/s)
1 -20	0.2	1.0
21 – 40	0.2 – 0.4	1.0
41 – 60	0.4 – 0.6	1.0
61 – 100	0.6 – 1.0	1.0

3.2.3 Direct Habitat Mapping

almonid spawning habitat and productive BMI riffle habitat were mapped at study sites to begin developing relationships (i.e., rating curves) between streamflow and habitat area. DHM used the Trimble GeoXH GPS Receiver and a Marsh McBirney Flo-Mate® electromagnetic velocity meter attached to a top-set wading rod. The output of this method was a streamflow-habitat rating curve. Sites ranged from 460 ft long at the TNC study site to 240 ft long at the HIG study site. DHM followed methods outlined in McBain and Trush (2009) and applied habitat suitability criteria (Table 5).

Table 5. Summary of depth and velocity criteria for mapping salmonid spawning habitat and productive benthic macroinvertebrate (BMI) riffle habitat. Spawning criteria were developed by a Technical Work Group (TWC) for the Shasta River Instream Flow Methods project; BMI criteria were developed for a Mono Basin instream flow study (M&T 2010); spawning substrate size requirements for the D_{50}^{*} are from Bjornn and Reiser (1991).

Species	Depth (ft)	Velocity (ft/s)	D50 Substrate (mm)*
Chinook salmon	>0.5	0.5 – 2.5	13 - 102
Coho salmon	>0.5	0.5 – 2.5	13 - 102
Steelhead trout	>0.5	0.5 – 2.5	6 - 102
BMI	$>D_{50}^{*}$	>1.5	32 - 256

*The D_{50} represents the median coarse sediment size for a particle distribution within the area being evaluated.

Six or more streamflows are typically used to plot streamflow-habitat rating curves. However, DHM of only three flows could be collected for this project. Therefore the following approach was used to identify upper and lower bounds (i.e., a high and low streamflow providing no habitat based on the depth/velocity criteria) and ceiling (i.e. maximum possible area of physical habitat within the study site) of each streamflow-habitat rating curve for a typical pool tail:

1. The streamflow was characterized as too low to provide spawning habitat when the riffle crest thalweg depth fell below the minimum habitat depth criterion (0.5 ft), (i.e., the entire spawning patch would then be *depth-limited).* RCT depth thresholds where estimated from RCT-depth streamflow relationship at each study site
2. The streamflow was characterized as too high when the most upstream location of spawnable gravel (for pool tails, where the pool tail begins to ramp upward towards the riffle crest) exceeded the maximum velocity (2.5 ft/s), (i.e., the entire spawning patch would then be *velocity-limited).* Velocity thresholds were estimated from the HEC-RAS models calibrated to each study site.
3. The maximum quantity of spawning habitat was limited by the mapped area (ft^2) of suitable spawning gravel between riffle crest and the pool tail.

The provisions for describing both the depth and velocity limitations provided an upper and lower streamflow threshold which book ended the streamflow-habitat rating curves. In addition, maximum quantity of available spawning gravel provided a ceiling for the curve. Using these three boundaries together with the three mapped streamflow habitat data points, a streamflow spawning habitat rating curve was fit by eye for each mapped spawning site (Figure 5). Since these streamflow-habitat rating curves were not developed from a typical number and distribution of data points, they were used as supporting analytical measures, rather than the sole deterministic element for quantifying IFNs.

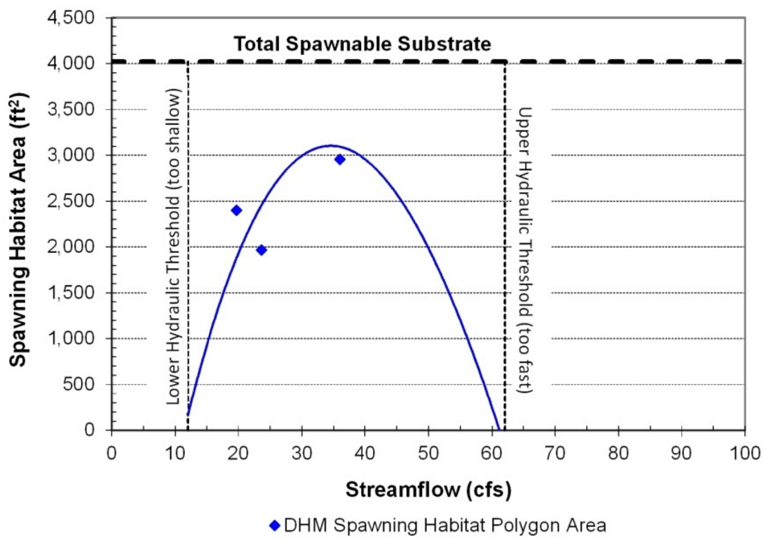


Figure 5. Example of our approach for estimating habitat rating curves given insufficient data for establishing traditional streamflow-habitat rating curves.

3.2.4 Riffle Crest Thalweg Depth (RCT), Median Riffle Crest Thalweg Depth (mRCT) and 90th Percentile Riffle Crest Thalweg (RCT90)

Riffle crest thalweg depths (RCTs), generally the shallowest riffle thalweg depth, were measured for all riffles within a study site, as well as immediately upstream and/or downstream of a study site (to increase sample size). The riffle crest is a hydraulic control, determining water surface elevation in the pool upstream of the riffle crest and influencing hydraulic variables (e.g., depth and velocity) upstream and downstream that in turn affect habitat availability for anadromous fish. The RCT defines the "residual" pool depth. The shallowest location for fish passage, tracing the deepest route through a riffle, generally is at the riffle-crest thalweg. At each riffle crest, only one depth measurement at the thalweg was taken. Because the RCT will vary along the stream channel for a given streamflow, data for several riffle crests were collected at each study site and the median was calculated. The median riffle crest thalweg depth (mRCT) for each surveyed channel reach was used to evaluate adult salmon and steelhead upstream passage and downstream smolt passage (Figure 3). Original mRCT threshold criteria for acceptable passage streamflows were:

- Minimum IFN for adult salmonid upstream migration was the streamflow providing 0.8 ft mRCT for coho salmon and steelhead trout and 1.0 ft for Chinook salmon.
- Minimum IFN for juvenile salmonid downstream migration was the streamflow providing 0.4 ft mRCT.

By surveying mRCTs over a wide range of streamflows, a reach-specific quantitative relationship between streamflow and mRCT was made. Streamflows meeting these threshold depth criteria for acceptable passage became the estimated minimum IFNs for this life stage. However, other life-stage specific IFNs required greater streamflows (e.g., physical rearing habitat for juvenile salmonids) than those required to produce an mRCT of 0.4 ft. Therefore, the mRCT > 0.4 ft threshold did not determine the IFNs identified in this report.

The Thompson Method (TM), which has often been used to evaluate potential riffle migration barriers, employs the criteria that passage is not impeded if the depth/velocity requirements are met over 25% of the wetted stream width or a continuous 10% of the wetted stream width (Thompson 1972). The TM depth criterion for Chinook adult passage is 0.8 ft and 0.6 ft for coho salmon and steelhead trout. mRCTs and the TM are closely inter-related. Typical cross-slopes for cross sections located at the riffle crest thalweg ranged from 2% to 4%. In a symmetrical 30 ft long riffle crest cross section with a streamflow producing a thalweg depth of 1.0 ft, the water depth of 5 ft on either side of the thalweg would be 0.85 ft (applying a cross-slope of 3%, for a contiguous 1/3 of the cross section length (i.e., 10 ft/30 ft). Using the TM, a 10% contiguous segment of the cross section must equal or exceed the threshold depth of 0.8 ft for Chinook and 0.6 ft for steelhead and coho. An mRCT threshold of 1.0 ft for Chinook prescribes comparable passage protection with the TM. However, there is one difference between their applications. The TM generally is applied only to those riffles, the shallower riffles, considered a potential problem, not the "median" riffle. Surveyed mRCTs, for a given study site and streamflow, were ranked to not only estimate the mRCT, but to estimate the exceedence probability of shallower values (e.g., the mRCT90 where 90% of the values are deeper). Threshold criteria can then be applied using the mRCT90 to evaluate salmonid passage potential in shallower riffles.

3.2.5 Hydraulic Habitat Thresholds

Juvenile and adult salmonid habitats are a function of local hydraulics. For example, a streamflow providing a depth of 0.8 ft at the riffle crest thalweg has created an hydraulic environment offering minimal adult coho salmon passage (e.g., the depth of a typical adult coho plus a 0.10 ft freeboard from the channel bed's surface). Unfortunately, channel hydraulics are difficult to measure and even more difficult to evaluate biologically and ecologically. PHABSIM and DHM essentially attempt this task directly by using suitability criteria for key physical variables to evaluate/quantify whether the hydraulic setting at any given streamflow and channel location can be considered habitat. For developing interim Big Springs Complex IFNs, a simpler methodological approach was needed.

The desire to quantify relationships between streamflow and habitat using simple field methods is not new. Giger (1973) recommends a generalized hydraulic approach:

> *The Fish Commission of Oregon studies summer requirements of juvenile coho* [sic] *salmon in a series of streams, to aid in predicting coho production by means of summer flow levels and to improve and justify the setting of summer streamflow minimums (Pearson, Conover, and Sams 1970). From their investigations they felt that there were two workable approaches to the determination of optimum streamflows for coho salmon, one using pool velocity and the other riffle velocity and area as criteria.*

In this "pool velocity" approach, it was observed that 90% of observed coho juveniles rearing in pools occurred wherever velocities ranged between 0.3 ft/sec and 0.7 ft/sec (Giger 1973). Rearing conditions were expected to improve with higher pool velocity, and 0.7 ft/sec was selected as a preferred velocity for abundant rearing habitat. The method, then, consisted of estimating average pool velocity at variable streamflows. A threshold streamflow for "optimal habitat" was the streamflow at which average velocity just exceeded 0.7 ft/sec.

In the "riffle velocity and area" approach, field observations and measurements of BMI were used to identify minimum average velocities and depths that promote BMI biomass in riffles. Provided velocities through pools are not excessive, a favorable streamflow creating riffles for high BMI production and physical juvenile salmonid rearing habitat should result in good juvenile salmonid growth. Giger (1973) notes that peak BMI production in riffles occurred at velocities near 2 ft/sec. High BMI productivity, therefore, would be expected at streamflows that create abundant riffles near this velocity threshold.

Simple indicators of desirable hydraulic conditions, called Hydraulic Habitat Thresholds (HHTs), were adopted for evaluating Big Springs Complex IFNs. In this approach, HHTs were assessed at a single point, for a cross section, along a longitudinal profile, or as an inundation surface to identify IFNs for each salmonid life stage, including adult migration, spawning, juvenile and smolt rearing, and smolt outmigration, as well as for productive BMI riffle habitats. Hydraulic settings characterized by many physical variables included depth, velocity, shear zones, incipient bench inundation, and WP.

There are two general types of HHTs:

- Preference HHTs rely on field-measured preferences for the desired hydraulic setting in assessing an IFN. For example, the 0.8 ft RCT for adult coho passage just covers the back of an adult coho with a 0.1 ft spacing (freeboard) from the channelbed's surface (Figure 3).
- Index HHTs indirectly measure IFNs. CDFW's (2011) WP method relies on the breakpoint of the streamflow-WP curve to identify a minimum streamflow providing BMI riffle habitat without actually having a physical variable(s) quantifying BMI riffle habitat (Figure 4).

In our investigation, preference HHTs were used to assess IFNs for adult passage and spawning habitat availability and index HHTs were used to assess IFNs for juvenile/smolt rearing habitat in pools and riffles, as well as productive BMI riffle habitat. Streamflows meeting the following HHTs for juvenile salmonid rearing habitat were used in assessing minimum IFNs: (1) a pool cross-sectional average velocity should exceed 0.5 ft/sec and (2) a riffle cross-sectional average velocity should exceed 1.0 ft/sec. A third HHT was used in evaluating minimum IFNs for large juvenile/smolt outmigration habitat: a pool or run's average column velocity through the deepest portion of the thalweg profile should exceed 1.5 ft/sec for a smolt minimum habitat IFN and should exceed 0.5 ft/sec for a juvenile minimum habitat IFN. All these HHTs are simple hydraulic indicators of a considerably more complex hydraulic environment spanning an entire pool or riffle. The riffle HHT exceeding 1.0 ft/sec does not consider velocities higher than 1.0 ft/sec to be preferred by juveniles, but rather that these higher velocities improve the hydraulic diversity of the overall streambed.

Juvenile pool/riffle HHT's were considered as general guidelines. However, HHTs were not meant to replace more standard approaches for defining Tier No.2 IFNs, including DHM mapping and PHABSIM analyses, but instead provide more insight from field-derived measurements under our limited sampling intensity and timeframe. No simple indicator satisfies all conditions encountered on the stream. Wide, deep pools will require significantly higher streamflows to achieve a cross-sectional average velocity of 0.5 ft/sec in their deepest regions than most other pools. None of these "big" pools were within the study sites, and there were insufficient resources to sample a few of them outside the actual study site boundaries (e.g., there was a big pool a short distance upstream of the HIG study site where a few measurements were made). As streamflows rise, more of the pool will exceed the average 0.5 ft/sec velocity threshold, yet each pool will approach a unique threshold differently.

3.2.6 Bench Inundation Threshold

Bench inundation provides shelter/cover and food for all juvenile salmonid life stages (fry, small and large juveniles, and smolts), thus contributing to improved habitat capacity and stream productivity (Rosenfeld et al. 2008). The objective of the bench inundation threshold was to identify a minimum streamflow that would initiate bench inundation, using either a rating curve at monitored cross sections or direct observation of documented photographs. Bench inundation is a key part of the River Productivity and Smolt Outmigration IFN.

3.3 Study Site Monitoring

Four study sites were established in Reach No.1 to No.3 of the Big Springs Complex. Field data were collected during three separate field visits in May, June, and August of 2010. Limited field data were collected in Reach No.4 or No.5 specifically for this study (see Sections 0 and 6.5). Thus, field data and observations from other studies were incorporated into our recommendations for these reaches. Each study site included at least two pool-riffle sequences (i.e., an entire meander wavelength consisting of two habitat units). Study sites had the following nine-step data collection procedure:

3.3.1 Cross Sections

Cross sections were established along each study site, with two cross sections traversing the riffle crest (hydraulic control), two traversing pool units, and two traversing each riffle, for a total of four riffle cross sections per study site (Figure 3). These cross sections were surveyed to a common reference pin at an arbitrary elevation and bed topography was surveyed in each case. Furthermore, each cross section had a stage pin for recording stage height during each field visit.

3.3.2 Water Level and Temperature Data Logger

A Hobo® U20 Water Level and Temperature Data Logger (U20-001-01) was installed on the farthest downstream cross section at each study site to collect stage height data (i.e., water depth) and water temperature. A single pressure transducer was installed at the TNC study site for recording ambient air pressure in order to account for atmospheric variability, which was assumed to be constant at all the sites throughout the study. Data from this air-pressure transducer were used to adjust all the water-level transducers such that only the variability in water-surface elevation was represented in the data.

3.3.3 Water Depth and Mean Column Velocity

Water depth and mean column velocity were measured at one foot increments across each cross section during three discharges in the field study period. Substrate and vegetation conditions were noted at each vertical station.

3.3.4 Longitudinal Profile

A longitudinal profile was surveyed at three streamflows observed during the field study period, using a Trimble GeoXH GPS unit to record coordinates (California State Plane NAD83, Zone 1), with water depth and mean column velocity measured at selected stations on the profile.

3.3.5 Riffle Crest Thalweg

Where possible RCT depth was measured at ten or more riffles within each study site during each field visit and the mRCT was computed for each streamflow surveyed. In some cases as few as 5 RCT depths were available in a reach.

3.3.6 Streamflow

Streamflow was measured at each study site during each field visit, using a 4 ft top-set wading rod, Price AA or Pygmy velocity meter, and Aquacalc data logger following standard USGS discharge measurement procedures (Harrelson et al. 1994).

3.3.7 Direct Habitat Mapping (DHM)

DHM was conducted for salmonid spawning habitat and BMI habitat during each field visit, following habitat mapping procedures described in M&T (2009) and in the Big Springs Complex Interim IFNs – Final Draft. The Trimble GPS unit was used to map habitat polygon boundaries and compute habitat area. A best-fit habitat-streamflow rating-curve was plotted for each polygon in the study reach from the three empirical data points and as a composite rating curve for the whole reach for BMI riffle habitat.

3.3.8 Hydraulic Modeling

HEC-RAS models were calibrated to the available range of (low) streamflows observed during the study. HEC-RAS models provided WP, depth and velocity, and stage-streamflow rating curves.

3.3.9 Photographic Monitoring

Photo-monitoring stations were established and monumented at prominent locations within each study site. Panoramic photographs taken on each field visit consisted of multiple frames spanning a length of the stream channel that were later stitched together to produce panoramic landscape images.

4 HYDROLOGY AND VEGETATION IN THE BIG SPRINGS COMPLEX

Unimpaired annual hydrographs for Reach No.3 provide a baseline comparison to the IFN findings in this Big Springs IFN Study (Figure 6). Previous efforts at computing historical, unimpaired streamflows in the Shasta River can be found in Smitherum (1926), Deas et al. (2004), Fua (1998), USBR (2005), Deas and Null (2007), and M&T (2009). A summary of mean monthly flows available from those sources that contain data specific to the Big Springs Complex is provided in Table 6. A recent peer-reviewed publication (Null et al. 2010) simulated unimpaired conditions for the Shasta River. Average historic baseflows ranged from 35 cfs to 141 cfs above Big Springs Creek. Shasta River winter baseflows were at, or exceeded, approximately 282 cfs below Big Springs Creek. According to Null et al. (2010), the unimpaired flow regime would increase floodplain inundation during high flows in winter and spring, opening floodplain and side-channel habitat for young salmon emerging from redds and rearing in the Shasta River. The stable, modeled inflow from Big Springs Creek maintained Shasta River baseflows above 150 cfs downstream of Big Springs throughout summer. Yearly low-flow conditions on the Shasta River occurred in early autumn (Null et al. 2010).

4.1 Unimpaired Annual Hydrographs for the TNC Study Site

Unimpaired annual hydrographs for the Shasta River at the TNC study site were reconstructed by combining several data sources that spanned seven WYs: WY1959 to WY1962 and WY1964 to WY1966 (Figure 6). The following data were used in the reconstruction: (1) daily average streamflow data for the USGS Shasta River near Edgewood (Sta. No 11516750) (which include Parks Creek winter diversions) for the entire WY, (2) daily diversion rates from the Edson-Foulke Ditch Company's diversion on the Shasta River located upstream of the USGS Edgewood gage, and (3) reasonable estimates of constant streamflow rates from known springs on the Shasta River and Parks Creek below Dwinnell Dam and I-5 (Table 2). Daily streamflow data for Parks Creek below the MWCD diversion between November and April, irrigation season diversions on the Shasta River upstream and downstream of the Edson-Foulke diversion, and flow accretions from groundwater were not accounted for in the unimpaired streamflow estimate. Without these data, unimpaired streamflows were estimated conservatively, i.e., actual unimpaired streamflows were likely greater. Streamflow data from the USGS gaging station at Shasta River near Yreka (USGS Sta. No 11517500) were used to provide a relative rank for these unimpaired WYs, from wetter to drier years (Figure 6).

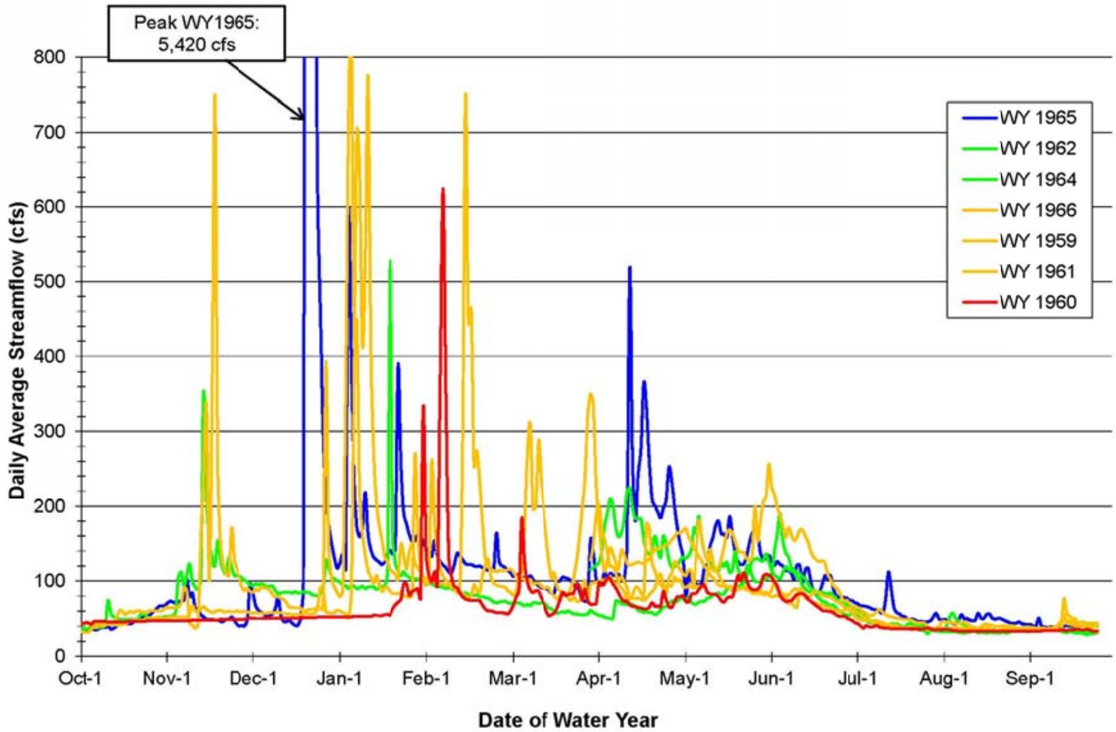


Figure 6. Estimated unimpaired annual hydrographs, for the Shasta River immediately downstream of the Parks Creek confluence in Reach No.3.

4.2 Hydrological Conditions in Spring/Summer 2010

The spring/summer 2010 runoff season produced an atypically wet spring, relative to observations over the last century, with later-than-usual snowmelt runoff. Snowmelt from the upper Shasta River and Parks Creek (diverted to Lake Shastina) peaked in early-June with snowmelt recession extending into late-June. Our first field observations in late-May 2010 occurred during low spring baseflows just prior to peak snowmelt runoff. Slightly higher streamflows were observed in late-June, when most snowmelt runoff was regulated by upstream irrigation diversions or captured in Lake Shastina. Low summer baseflows typical of the irrigation season were observed late-July and August. Study sites were visited on May 25 to 27, June 21 to 22, and August 10 to 12 (TNC site, Reach No.3, also was visited July 11) to assess baseflows. Baseflows measured on these study site field-days ranged from a maximum of 36 cfs at the TNC site to a minimum of 5.6 cfs at the UPC site (Table 6).

Table 6. Unimpaired mean monthly flow estimates from three sources documenting streamflows in the Upper Shasta River and Parks Creek. Blank cells indicate data is unavailable.

	Smitherum (1929) Table 1 (WY 1922)		**Deas and Null (2007) Table 1 (WY 2007)**			**Deas et al. (2004) Table 7 (WY 1936 to WY 1955 average)**		
	Run-off of Shasta River and Parks Creek at Upper Measuring Stations (AF)	*Mean Monthly Flow at Shasta River below Parks Creek (cfs)*	*Mean Monthly Flow at Shasta River above Parks Creek Confluence (cfs)*	*Mean Monthly Flow at Parks Creek at Shasta River Confluence (cfs)*	*Mean Monthly Flow at Shasta River below Parks Creek (cfs)*	*Mean Monthly Flow at Shasta River above Parks Creek Confluence (cfs)*	*Mean Monthly Flow at Parks Creek at Shasta River Confluence (cfs)*	*Mean Monthly Flow at Shasta River below Parks Creek (cfs)*
January	4,400	72	127	112	239			
February	8,100	141	177	81	258			
March	5,500	90	102	110	212			
April	6,000	105	105	52	157			
May	12,800	208	96	71	167	132	70.7	202.6
June	2,900	49	65	40	105	95.6	39.6	135.2
July			38	13	51	39.2	13.5	51.9
August			32	7	39	32.8	7.1	39.2
September			31	6	37	32.2	6.5	37.9
October	1,900	31	21	70	91			
November	3,500	59	43	95	138			
December	4,000	65	122	88	210			

Water level data loggers (Hobo® U20 Water Level Loggers) deployed at each study site recorded hourly stage heights and water temperatures from May 25 to August 10, 2010. The TNC site data logger was operated until November 12, 2010. A single stage-discharge rating curve at a given location or cross section could not be reliably constructed because of the confounding effects of aquatic vegetation, which was growing rapidly during the study period. At most sites, the channel bed had to be cleared of surrounding aquatic vegetation to enable a streamflow measurement. Nearly all measurements were rated "good" according to USGS discharge measurement protocol (Rantz 1982, Harrelson et al. 1994). At the TNC site, stage height sharply spiked on July 14 with a second spike, an apparent flood pulse, on October 25. Otherwise, stage heights fluctuated within 0.2 ft to 0.4 ft. Four distinct periods were observed in the TNC site's stage: (1) from late-May to approximately June 18, when stage height was relatively flat and fluctuated around 24 cfs (measured May 25); (2) through the end of June when flows fluctuated around 36 cfs (measured June 21); (3) a stable period from early-July through mid-September, when flows fluctuated in the range of 20 cfs to 24 cfs (measured August 10); and (4) a more variable period from late-September through the end of the monitoring period, when late-season irrigation withdrawals were ceasing. During late-June, snowmelt runoff from Parks Creek was reported to have bypassed the MWCD Diversion, resulting in a modest spring snowmelt pulse. During the July to August low flow period, stage increased gradually, despite steady or declining streamflows, caused by the prolific growth aquatic vegetation.

Table 7. Streamflows (cfs) measured and evaluated at the study sites during spring and summer 2010. Blank cells indicate data is unavailable

Study Site	May 25-27 (cfs)	June 21-22 (cfs)	July 11 (cfs)	August 10-12 (cfs)
Reach No.1				
Hole in the Ground (HIG) site	7.6	13.1		11.3
Reach No.2				
Upper Parks Creek (UPC) site	5.6	9.9		0.0
Lower Parks Creek (LPC) site	12.8	21.7		8.1
Reach No.3				
TNC site	23.7	36.0	34.1	19.7

4.3 Water Temperature Conditions during the IFN Study

As part of the IFN assessment water temperatures under existing conditions during our study period were evaluated. In addition, a 1 dimensional water temperature model was used to perform interim evaluation of the seasonal streamflow – water temperature relationship in the Big Springs Complex (Section 5). To present findings from the analysis of water temperature under existing conditions, exceedence profiles of measured water temperature were developed to estimate the existing thermal regime on a reach-scale map. This analysis relied on data collected by various private and public entities including: CDFW, Grant Davids Engineering, UC Davis Center for Watershed Sciences, Watercourse Engineering Inc. and McBain & Trush Inc. Water temperature monitoring locations are described in Table 8. A review of the available data indicated that there was sufficient and complete data for water year 2010 (WY2010) to examine sub-daily streamflow and water temperature data at multiple locations in each study reach. Therefore we chose WY 2010 as our example WY to represent existing water temperature conditions.

To illustrate the range of existing water temperature conditions, the instantaneous 50th, 90th, and 95th percentile water temperatures were identified at each study site for two periods: May (representing the spring IFN) and August (representing the summer IFN). Based on the exceedence analysis, longitudinal water temperature charts showing the 95th, 90th and 50th water temperature exceedence values were developed for each study reach: Parks Creek (Figure 7 – May, 2010 and Figure 8- August, 2010), Shasta River above Parks Creek (Figure 10 – May, 2010 and Figure 11- August, 2010), and Big Springs Creek (Figure 13 – May, 2010 and Figure 14 – August, 2010). These water temperatures reflect the diversions, mainstem and spring creek management strategies, and hydrologic and meteorological conditions during each analysis period. Streamflows at locations in each study reach above Parks Creek are shown in Figure 9 and Figure 12. Continuous streamflow data was not available below Parks Creek; adding the two upper reaches provides a reasonable estimate of streamflow between Parks Creek and Big Springs Creek.

Observed maximum (95 % exceedence) water temperatures in Parks Creek during May ranged from 18° C to 20° C (Figure 10) generally cooler than maximum thresholds for rearing salmonids (see Section 5.2). During the August period observed maximum (95 % exceedence) temperature in Parks Creek ranged from 24° C to 27° C (Figure 11), well within the detrimental range for salmonid rearing (Section 5.2). Observed maximum (95 % exceedence) water temperatures in the Shasta River

Table 8. Water temperature modeling locations, periods of record and managing entities.

Stream - Reach	Monitoring Site Name	Period of Record	Coordinates	Entity
Parks Creek	PRKSC1	3/5/10 – 10/8/10	41.497801N, 122.46112W	G. Davids Engineering
Parks Creek	PRKSC2	3/5/10 – 10/8/10	41.535618N, 122.443927W	G. Davids Engineering
Parks Creek	KTTLCL	6/3/10 – 10/8/10	41.552753N, 122.435254W	G. Davids Engineering
Parks Creek	PRKSC3	3/5/10 – 10/8/10	41.579364N, 122.431886W	G. Davids Engineering
Shasta River	SRGRAV	3/25/10 – 10/8/10	41.562307N, 122.410799W	G. Davids Engineering
Shasta River	CLEAR SPR	3/25/10 – 10/8/10	41.561942N, 122.416834W	G. Davids Engineering
Shasta River	SRNOPL	3/25/10 – 10/8/10	41.579048N, 122.428891W	G. Davids Engineering
Shasta River	SRabvPC	4/1/10 – 9/30/10	41.580962N, 122.42933W	Watercourse
Shasta River	SBS 6	3/27/08 –10/3/11	41.581998N, 122.430625W	CDFW
Shasta River	HIGPL	4/1/10 – 9/30/10	41.580498N, 122.423773W	Watercourse
Shasta River	HIGM	4/1/10 – 9/30/10	41.582593N, 122.430344W	Watercourse
Shasta River	SRabvBSC	4/1/10 – 9/30/10	41.592972N, 122.438904W	Watercourse
Shasta River	SRblwBSC	4/1/10 – 9/30/10	41.607092N, 122.452367W	UC Davis
Big Springs Creek	RM 2.2	4/1/10 – 9/30/10	41.599175N, 122.409622W	Watercourse
Big Springs Creek	RM 2.0	4/1/10 – 9/30/10	41.599056N, 122.412193W	Watercourse
Big Springs Creek	RM 1.9	4/1/10 – 9/30/10	41.600461N, 122.414961W	Watercourse
Big Springs Creek	RM 1.7	4/1/10 – 9/30/10	41.601320N, 122.418762W	Watercourse
Big Springs Creek	RM 1.6	4/1/10 – 9/30/10	41.601803N, 122.419972W	Watercourse
Big Springs Creek	RM 1.5	4/1/10 – 9/30/10	41.601891N, 122.422610W	Watercourse
Big Springs Creek	RM 0.9	4/1/10 – 9/30/10	41.599574N, 122.428693W	Watercourse
Big Springs Creek	RM 0.5	4/1/10 – 9/30/10	41.596227N, 122.433057W	Watercourse
Big Springs Creek	RM 0.3	4/1/10 – 9/30/10	41.596380N, 122.437247W	Watercourse
Big Springs Creek	RM 0.0	4/1/10 – 9/30/10	41.593672N, 122.438102W	Watercourse

above Parks Creek during May ranged from 15˚ C to 19˚ C downstream of Clear Springs (Figure 13). During the August period observed maximum (95 % exceedence) temperature in Parks Creek ranged from 17◦ C to 23◦ C downstream of Clear Springs (Figure 14), indicating that a thermal divide likely existed in this reach between suitable and detrimental salmonid rearing habitat. The instantaneous 95% exceedence temperature never exceeded 19˚ C in Big Springs Creek during either May or August.

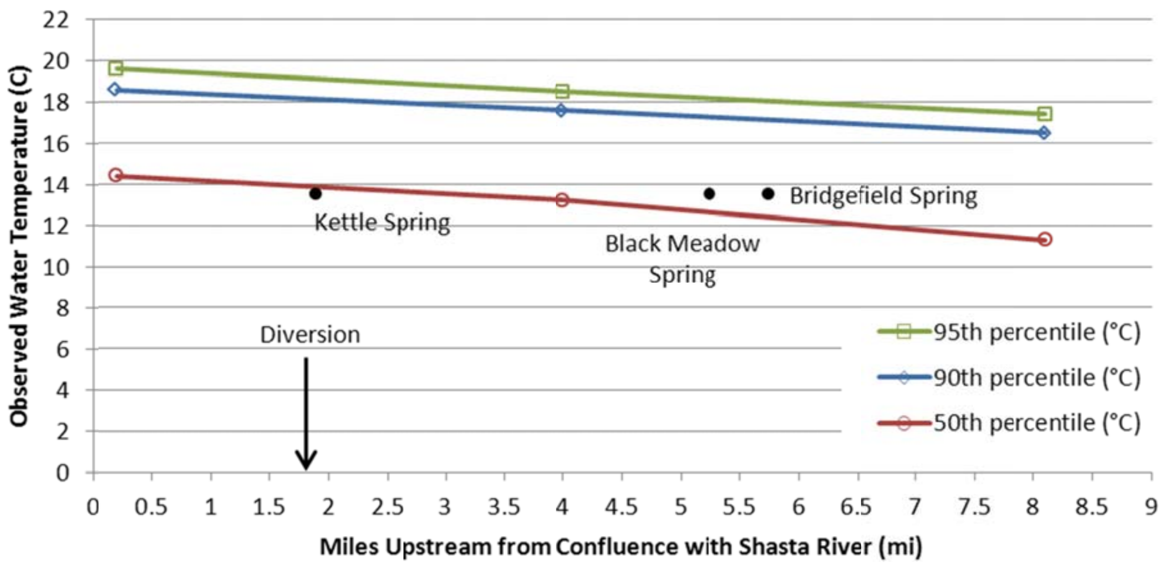


Figure 7. Observed water temperature exceedence values for May 2010, in Parks Creek.

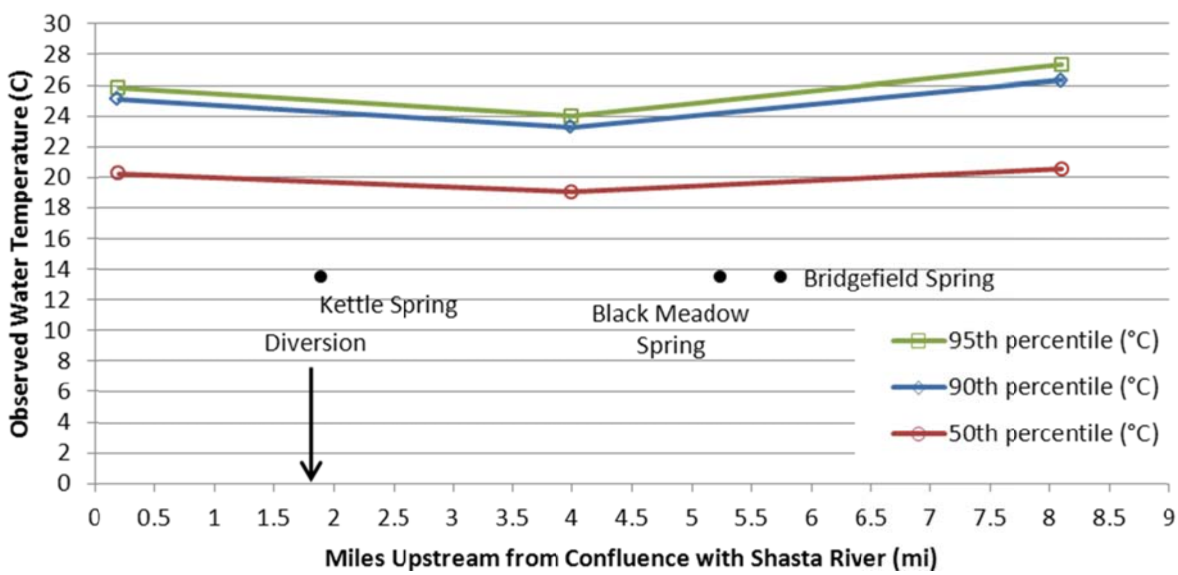


Figure 8. Observed water temperature exceedence values for August 2010, in Parks Creek.

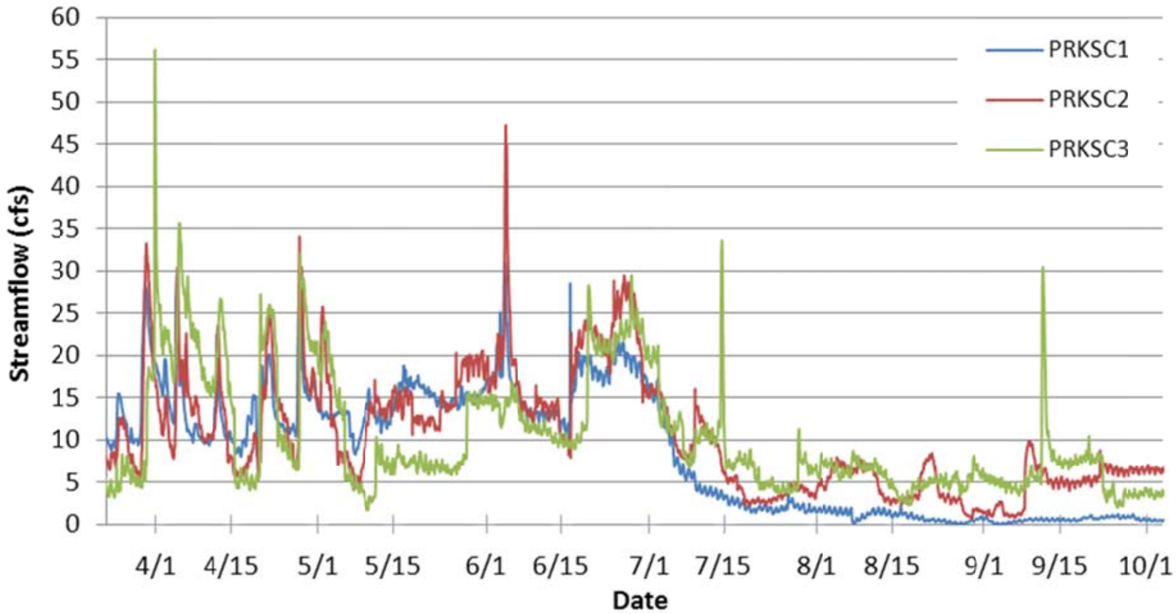


Figure 9. Observed streamflows for April 1 – October 1 2010, in Parks Creek.

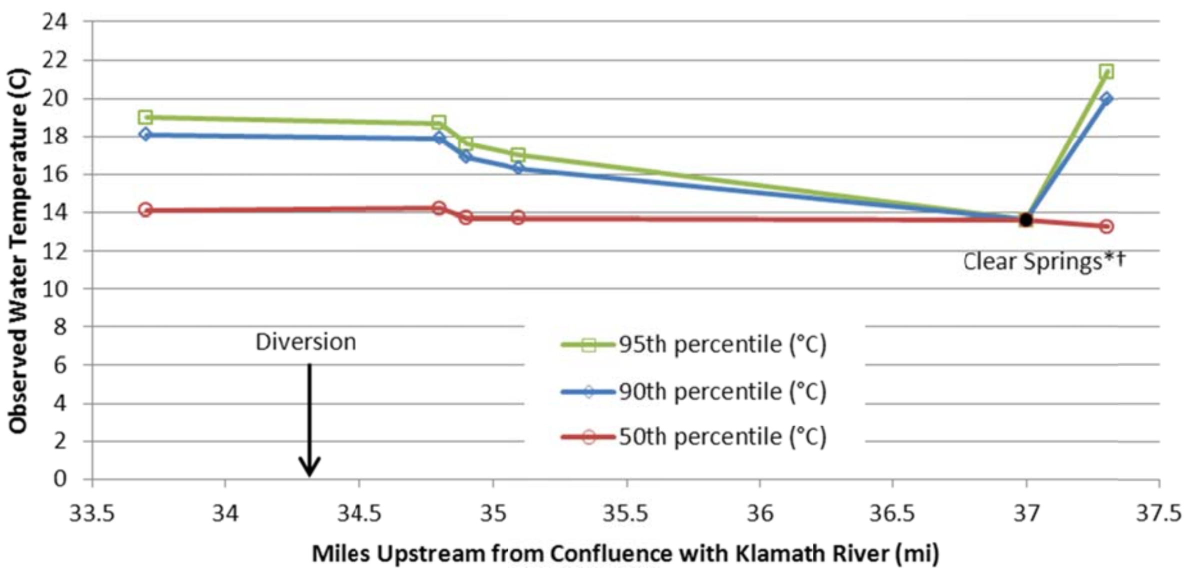


Figure 10. Observed water temperature exceedences for May 2010, in the Shasta River above Parks Creek.

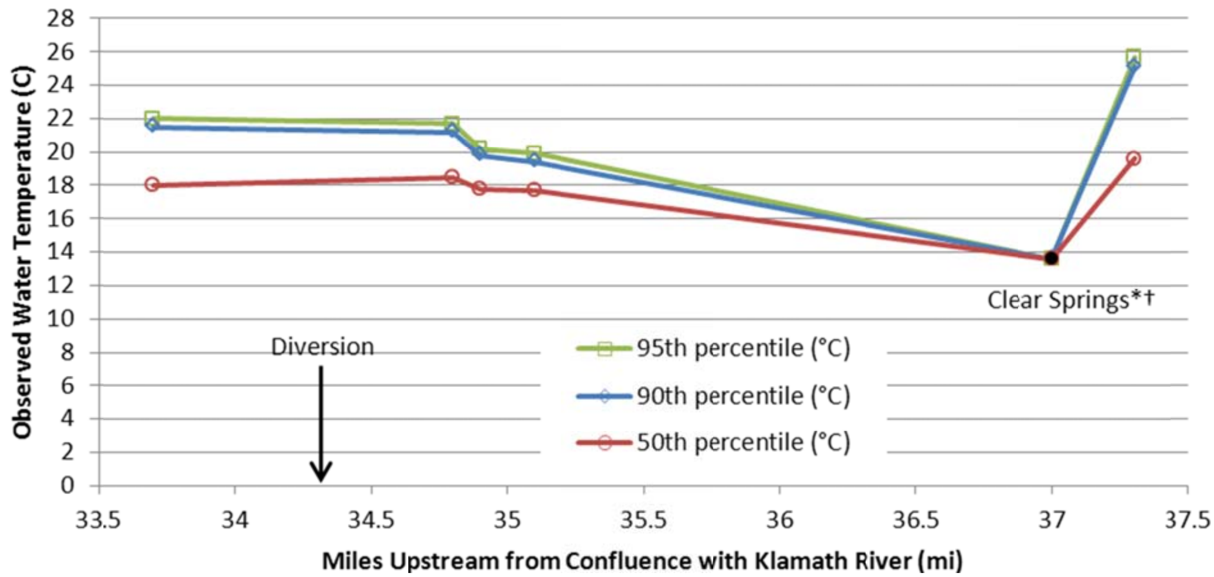


Figure 11. Observed water temperature exceedences for August 2010, in the Shasta River above Parks Creek.

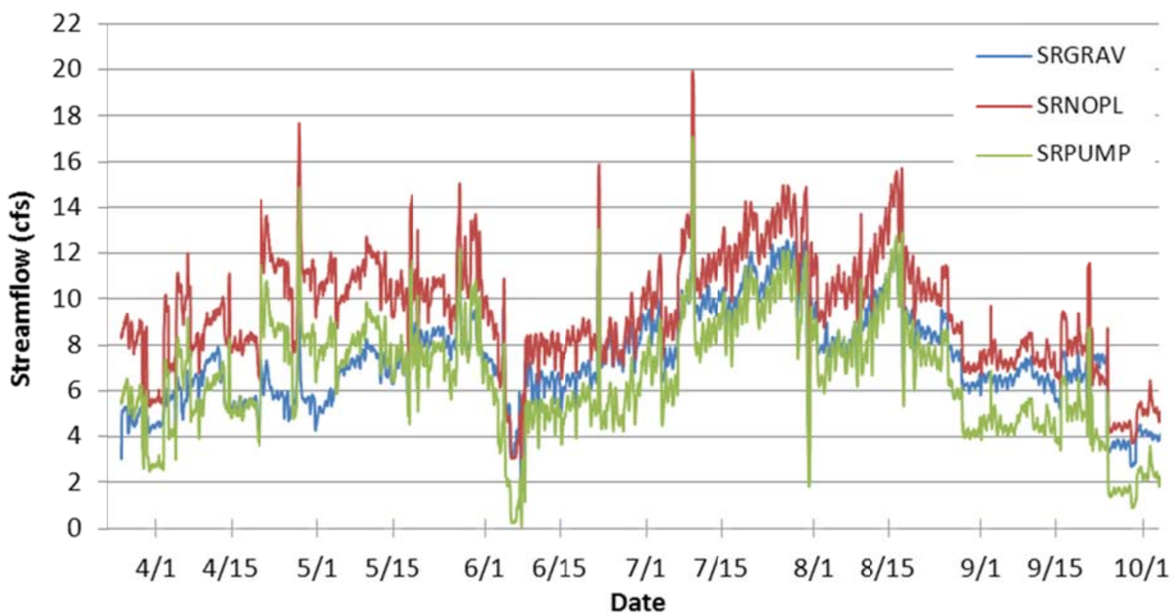


Figure 12. Observed streamflows for April 1 – October 1 2010, in the Shasta River above Parks Creek.

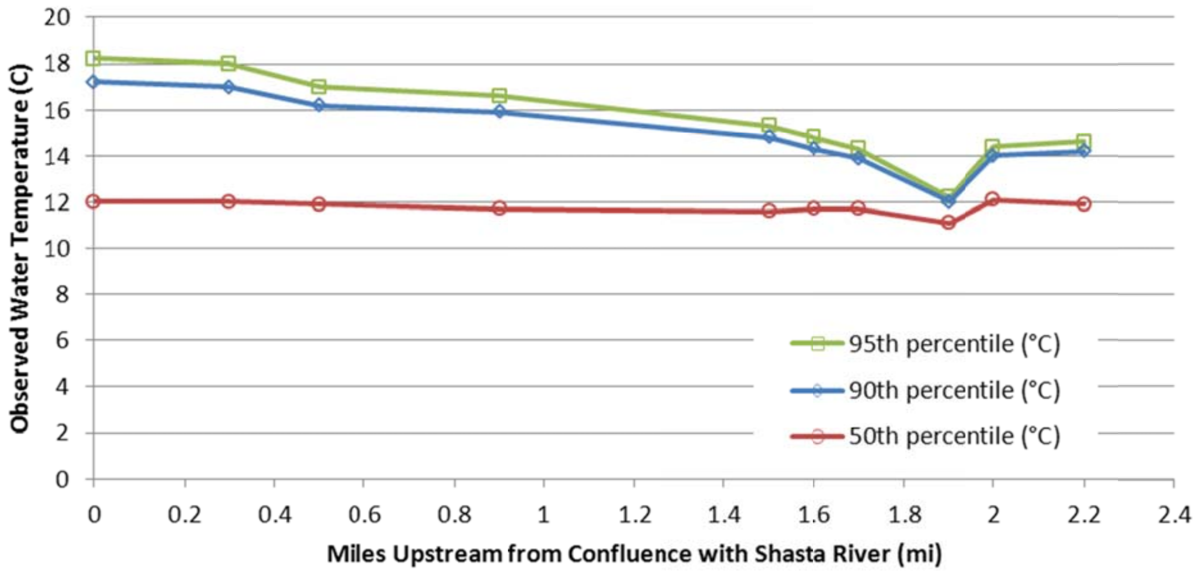


Figure 13. Observed water temperature exceedences for May 2010, in Big Springs Creek.

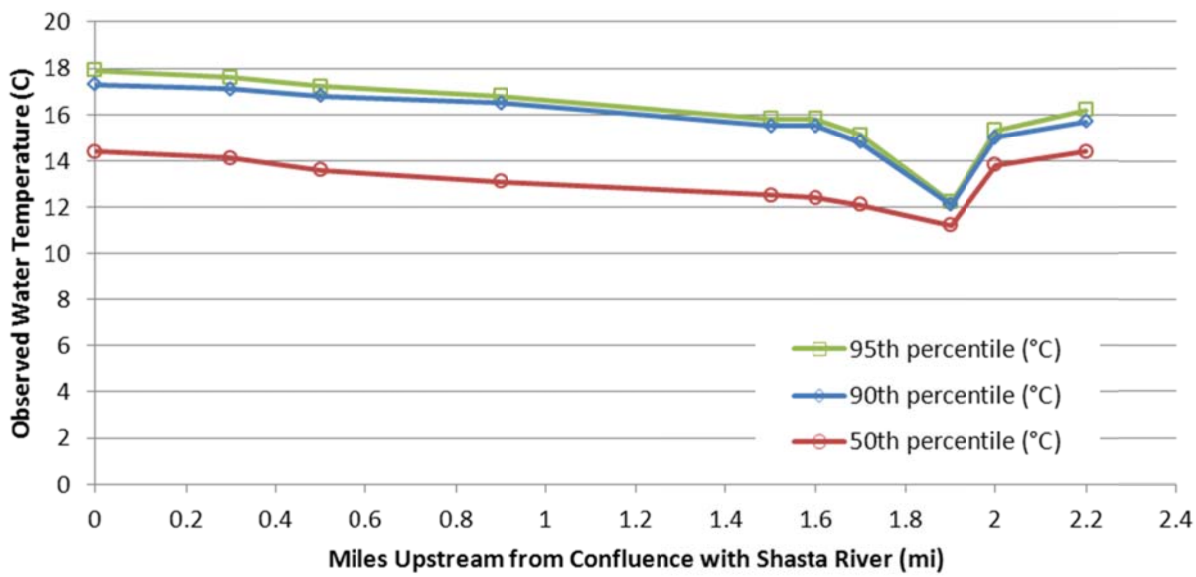


Figure 14. Observed water temperature exceedences for August 2010, in Big Springs Creek.

4.4 Aquatic Macrophytes

Prolific aquatic macrophytes growth is characteristic the Shasta River and its tributaries in the Big Springs Complex. The abundant aquatic macrophytes in the Big Springs complex are supported by the many constant-temperature spring sources with high nitrogen (N) and phosphorus (P) concentrations, (King 2011). A survey of the upper Shasta River from August of 2004 (St. John et al. 2005 cited in King 2011) found roughly 50% of the valley streambed covered with aquatic macrophytes. Aquatic macrophytes growth is low in winter and early spring due to cold water temperatures and low light conditions. Willis et al. 2012 found that aquatic biomass increases after March (the approximate seasonal minimum), reaching maximum biomass in September. Aquatic macrophytes observed during this study grew most dense in slow-velocity habitats, i.e., pools and channel margins, but also took root in some shallow riffles (Figure 15). The dominant aquatic macrophytes observed included, Northern water milfoil (*Myriophylum sibiricum*), water smartweed (*Persicaria amphibia*), common water weed (*Elodea canadensis*), fennel-leaf Pondweed (*Potamogeton pectinatus*), and white water-buttercup (*Ranunculus aquatilus*). Water parsnip (*Berula erecta*) was also abundant, encroaching along channel margins through the summer.

Figure 15. Aquatic vegetation observed within the Big Springs Creek channel at the end of the growing season, October 23, 2009.

Aquatic plants are directly related to almost all ecological metrics in the Upper Shasta River, including: hydraulic characteristics, sediment dynamics, stream stage, water temperature, invertebrate populations, and fish habitat (Willis et al. 2012). Many investigations have reported that widespread and dense coverage of aquatic macrophytes significantly increased river stage (Jeffres et al. 2009 and 2010, Davids 2011, King 2011, Willis et al. 2012). Growth of aquatic macrophytes is a known, common source of variability in flow resistance (Gurnell and Midgley 1994 and Sand-Jensen, 1998 as cited in King 2011). King (2011) noted that in the Upper Shasta River, at the peak of aquatic macrophyte coverage, Manning's *n* (a commonly used, empirically derived roughness coefficient) was approximately twice the value that occurred during low-coverage periods. During our field work, the dense vegetation exerted a dominant hydraulic control on the stream channel, dramatically affecting water surface elevations and consequently stream depths. For example, at the TNC site, stage heights measured at cross sections were at least 0.2 ft higher in August at 19.7 cfs than in May at 23.7 cfs. At the HIG site, effects of aquatic vegetation were even more pronounced: between June and August, flows decreased from 13.1 cfs to 11.3 cfs, but stage heights at cross sections increased by an average of 0.6 ft, with one cross section increasing more than 1.0 ft. A concurrent study at the HIG Ranch by Davids Engineering in 2010 recorded similar stream stage responses to aquatic vegetation: at a gaging site established downstream of the HIG Gravity Diversion, nearly identical stage heights of 0.72 ft and 0.71 ft were recorded May 6 and September 10, at streamflows of 7.9 cfs and 5.5 cfs respectively. Several of the aquatic vegetation species described above were observed in Parks Creek. However, there was significantly less growth in the UPC site, potentially because of the water limitation as the streambed was dry in August.

5 INTERIM ASSESSMENT OF WATER TEMPERATURE IN THE BIG SPRINGS COMPLEX

An interim evaluation of the seasonal streamflow – water temperature relationship in the Big Springs Complex was undertaken to compliment the physical streamflow habitat assessment (Section 3). The objective of evaluating the water temperature evaluation was defined in Stage No. 4 of the IFN methods (Section 3): *to determine whether recommended IFNs for the late-spring through early-autumn period are likely to satisfy identified water temperature criteria, especially those for summer rearing of juvenile salmonids*. A seasonally calibrated, sub-daily reach-scale flow and water temperature model that incorporates groundwater, water year type, springs and tailwater release management scenarios was the preferred tool to evaluate the complex relationship between instream flow management and water temperature in the Shasta River. However, such a model is beyond the scope of this interim IFN report. Rather, an interim level assessment of the streamflow-water temperature relationship in the Big Springs Complex was performed to meet the temperature evaluation objective. The interim assessment adequately addressed our objective of estimating the effect of discrete IFNs on water temperature in the study area, and provides a foundation for a more robust temperature model of the Big Springs Complex in the future. The primary task of the streamflow-water temperature assessment was to model the effects of discrete instream flow changes on water temperature and produce an estimated 90% and 50% streamflow-temperature exceedence curves at the streamflow-physical habitat study site locations used on this IFN study.

A brief overview of streamflow-water temperature patterns in the Shasta River below Dwinnell Dam are presented as background to a discussion of water temperature thresholds for various life history needs of salmonids. Then, the study reaches for water temperature modeling are identified. Finally, the methodologies used to complete each task and the respective results are presented.

5.1 Water Temperature in the Big Springs Complex

The Shasta River is a complex thermal environment. Although groundwater-dominated river systems, like the Shasta River below Dwinnell Dam, tend to have a more stable flow and thermal regime than surface water dominated systems, several factors complicate the streamflow-water temperature relationship in the Shasta River. During the late spring and summer irrigation season, low streamflows can lead to increased Shasta River water temperature because a shallow river has less thermal mass and a longer travel time, allowing atmospheric heating to have a stronger effect than during high flow conditions (Null et al. 2010). The large variation in ambient meteorological conditions between day and night time also creates a corresponding diurnal fluctuation in water temperature which may impact juvenile salmonid rearing strategies and success in certain reaches (Jeffres et al. 2009). When not diverted, numerous spring sources provide baseflow to the Shasta River throughout the summer and pockets of cool water can extend some distance downstream from spring sources, the length of which depends on the individual spring volumes, irrigation management, and instream and climatic factors. Diversion of springs for irrigation can reduce or remove these potential sources of localized thermal refugia. In addition, tailwater return flows from irrigated fields can create local and reach-scale warming on the mainstem Shasta River although many tailwater control projects have been implemented to address the effect tail water on thermal refugia (AquaTerra Consulting 2012). Besides the effect of spring sources, climatic conditions, diversions and irrigation return flows, other factors such as aquatic and riparian vegetation, beaver dams, and other factors may influence water temperature and quality at the reach or sub-reach scale.

5.2 Water Temperature Thresholds for Salmonid life History Needs

To determine whether recommended IFNs are likely to meet the thermal needs of rearing and migrating juvenile salmonids, it is necessary to establish water temperature criteria for salmonid life history needs. The Shasta River TMDL (NCRWQCB 2006) identified temperature thresholds that would produce chronic effects and lethality for a range of salmonid life stages in the Shasta River. Chronic water temperature thresholds defined in the TMDL (Table 9) for evaluating Shasta River watershed temperatures are not species specific. Rather temperature thresholds that produce chronic effects are based on *USEPA Region 10 Guidance For Pacific Northwest State and Tribal Temperature Water Quality Standards* (2003), for the "protection of migrating adult and juvenile salmonids and moderate to low density salmon and trout juvenile rearing." Chronic water temperature thresholds are established as maximum weekly maximum temperature (MWMT) or the maximum seasonal or yearly value of the daily maximum temperatures averaged over a running seven-day consecutive period. Lethal water temperature thresholds (Table 10) for steelhead, Chinook, and coho salmon were presented for three life stages in NCRWQCB (2006). The temperature thresholds are applicable during the time of year when the life stage of each species is present in the Shasta River Basin. While lethal water temperature thresholds (Table 10) are not presented as MWMT, these thresholds are based on periods of chronic exposure (greater than seven consecutive days). Although salmonids may survive brief periods at these temperatures, they are benchmarks for lethal conditions (NCRWQCB 2006).

Table 9. Water thresholds for chronic effects on salmonids.

Life Stage	MWMT (°C)
Adult Migration	20°
Adult Migration plus Non-Core Juvenile Rearing	18°
Core Juvenile Rearing	16°
Spawning, Egg Incubation, and Fry Emergence	13°

Source: USEPA 2003, as cited in NCRWQCB 2006.

Table 10. Lethal water thresholds (given chronic exposure) salmonid species.

Lethal Threshold (°C)			
Life Stage	**Steelhead**	**Chinook**	**Coho**
Adult Migration and Holding	24°	25°	25°
Juvenile Growth and Rearing	24°	25	25°
Spawning, Egg Incubation, and Fry Emergence	20°	20°	20°

Source: NCRWQCB 2006

In addition to the Shasta River TMDL, CDFW produced recommended optimal, sub-optimal and detrimental water temperatures thresholds for salmonids (primarily coho) in the Upper Shasta River based on a recent review of existing literature (Stenhouse et al. 2012). Optimal temperatures (10° C - 15.3° C) were defined as not limiting to "fish growth, swimming performance and disease resistance" and also not impairing metabolism, respiration or growth rates. Sub-optimal temperatures (15.3° C - 20.3° C) were defined as conditions under which salmonids can still experience positive growth rates but metabolism and respiration increase, pathogen virulence and disease susceptibility begin to increase and competition between salmonid and non-salmonid warm water species also potentially increases (Stenhouse et al. 2012). Detrimental growth (> 20.3° C) was defined as conditions where salmonids begin to experience "detrimental effects directly attributable to temperature," sub-lethal metabolic and respiratory stresses begin to accumulate and feeding behavior can be decreased on even eliminated (Stenhouse et al. 2012). The authors also noted that duration of detrimental temperatures, as well as limitations on food abundance influenced the cumulative effect of detrimental temperatures on salmonids.

Because the CDFW review was directly related to the Upper Shasta River, and because their findings correlated well with the Shasta River TMDL (NCRWQCB 2006), we chose to use the optimal, sub-optimal, and detrimental water temperatures thresholds established by Stenhouse et al. (2012) as the criteria for water temperature evaluation in this report. Chronic water temperature thresholds are an important metric of salmonid rearing success, but a single value threshold is a more sensitive metric to the risk of mortality caused by peak water temperatures (Stenhouse et al. 2012). Therefore, we chose the instantaneous daily maximum water temperature as the primary analytical tool to determine if the recommended IFNs are likely to satisfy identified water temperature criteria for rearing salmonids.

We chose to evaluate the instantaneous daily maximum modeled water temperature using the upper limit of sub-optimal criteria (> 20.3° C) established by Stenhouse et al. (2012). While the authors recommend using the upper limit of the optimal growth threshold as a single maximum summertime water temperature threshold in the Big Springs Complex (Stenhouse et al. 2012), this approach is beyond the scope of an interim minimum IFN assessment. The purpose of water temperature modeling in the context of this interim instream flow assessment was not to optimize the thermal conditions for rearing salmonids, but rather (as described above) to estimating whether recommended IFNs based on physical habitat assessment, where are likely to satisfy identified water temperature criteria. Therefore, our primary analytical measure of this condition was whether the upper limit of sub-optimal water temperature thresholds was exceeded during the hottest (e.g. 90% exceedence) day of the April-1- June 15th and the June 16th to September 6th IFN periods. While this approach provides an acceptable evaluation of interim minimum IFNs, future work should further refine understanding of fish response to the complex relationship between instream flows and water temperature in the upper Shasta River.

5.1 Study Reaches

The core reaches within the study area identified for the streamflow-water temperature evaluation are shown in Figure 16. The reaches encompass the physical habitat monitoring sites shown in Figure 2. Water temperature study reaches are:

1. *Shasta River above Parks Creek* – from RM 37.4 downstream to the confluence of Parks Creek (RM 35.0);
2. *Parks Creek*- from the confluence of the Shasta River (RM 0.0) upstream to Hwy I-5 (RM 8.2); and,
3. *Shasta River below Parks Creek* – from the confluence of Parks Creek (RM 35.0) downstream past Big Springs Creek to RM 32.2.

In addition to the three core reaches described above, two other reaches were used to provide streamflow and water temperature boundary conditions for the water temperature model.

4. *Big Springs Creek* – from the confluence with the Shasta River (RM 0.0) to Big Springs Dam (RM 2.2)
5. *Hole in the Ground Creek* – from the confluence with the Shasta River (RM 0.0) to the Hole in the Ground Ranch property line (RM 0.5)

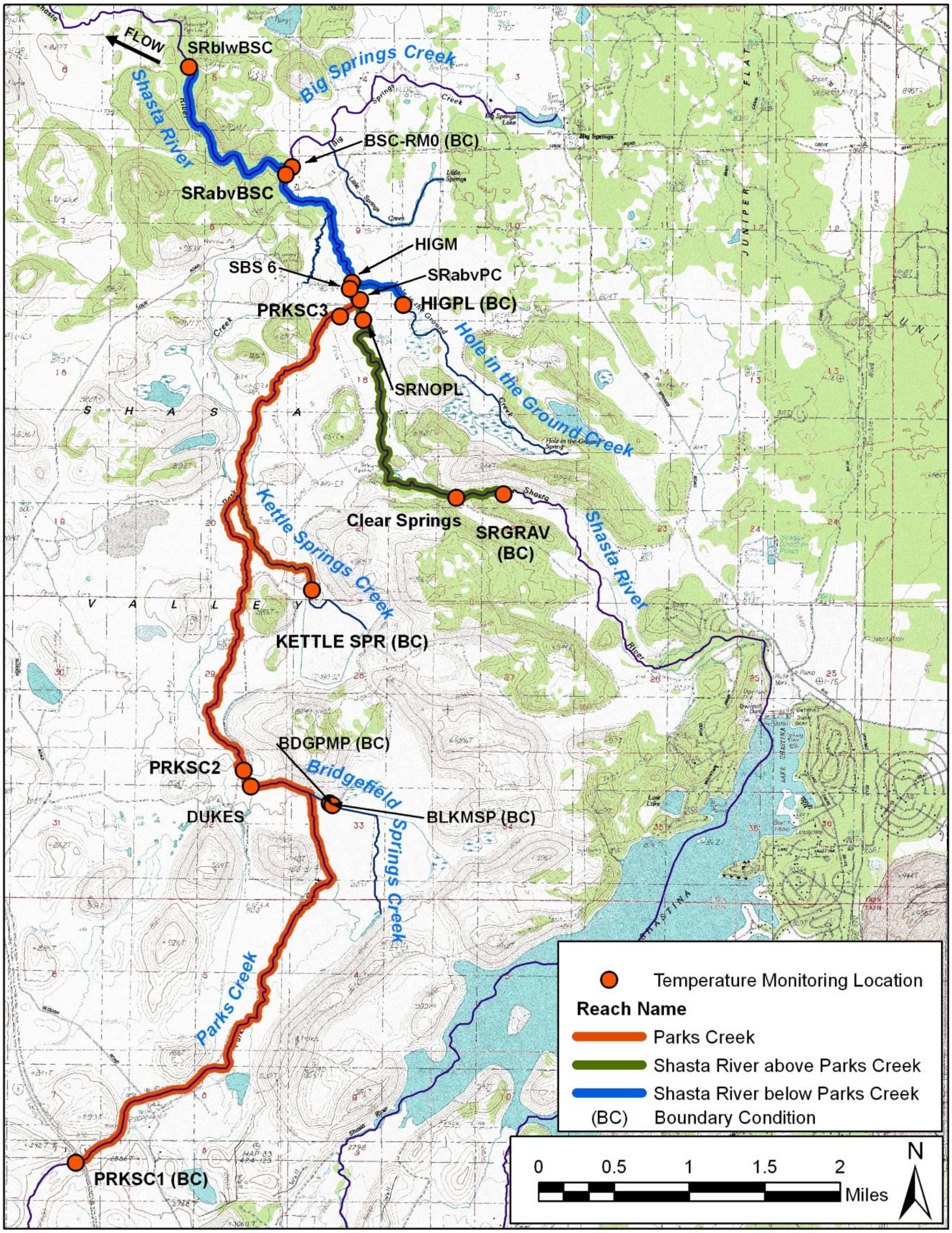


Figure 16. Reaches defined for streamflow-water temperature evaluation including water temperature monitoring locations and boundary conditions.

5.2 Methods

While the observed water temperatures (Section 4.3) during the relatively dry 2010 period give a sense of the thermal environment that juvenile salmonids experience under existing management conditions in the Big Springs Complex, this exercise does not indicate the extent that changes in hydrologic management could affect water temperature. Therefore, an equilibrium temperature modeling approach (Tanaka et al, 2009) was used to estimate the effect of potential instream flow scenarios on temperature exceedence values within the Big Springs Complex.

5.2.1 The Equilibrium Model

A one-dimensional equilibrium model was used to examine the effect of various water management scenarios on water temperatures in portions of Parks Creek and the Shasta River. This model was developed based on the net heat flux and advection-diffusion of a parcel of water with a specified volume. The basic equation guiding the model is shown in Equation 13:

$$\frac{dT_w}{dt} = S = \frac{q_{net} A_s}{C_p \rho V} \tag{13}$$

Where:

T_w	=	water temperature (°C)
t	=	time step (s)
S	=	sources and sinks (°C/s^1)
q_{net}	=	net heat flux (W/m^2)
A_s	=	area of water body surface (m^2)
C_p	=	specific heat of water at 15°C (4185.5 J/kg^1°C^1 where 1 J = 1 W·s)
ρ	=	calculated density of water (kg/m^3)
V	=	volume of water body (m^3)

Examining Equation 13 for a range of surface area to volume (A_s:V) ratios, quickly yields valuable insight. For bodies of water that have very large volumes compared to surface areas, that is a small A_s:V ratio (e.g., a reservoir), the rate of heat change is reduced. In contrast, for water bodies with a larger As: V ratio (e.g., wide, shallow streams), the rate of heat change increases.

For a fixed volume and surface area (i.e., steady flow in uniform channel geometry), total heat flux is solved for a time series of meteorological conditions (the time step could be a day, a week, etc.). This calculation is repeated for the same time series until the average change in temperature over time is negligible (e.g., $\Delta(dT/dt)_{daily} \rightarrow 0$), as shown in Figure 17. Note the diurnal variation in response to meteorological conditions (dashed line) suggests a dynamic condition, whereas, for example, the daily mean (heavy, solid line) indicates a steady rise and asymptotic approach to an equilibrium state.

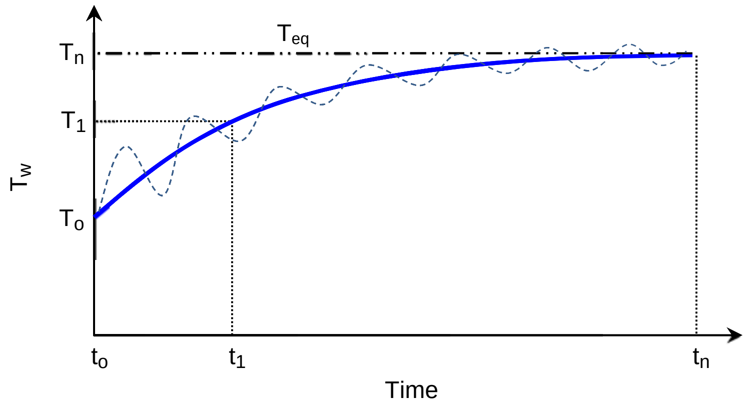


Figure 17. Theoretical rise to equilibrium water temperature from a parcel with an initial temperature less than equilibrium water temperature.

Boundary conditions for the equilibrium model included:

- Meteorological data from the Weed Airport weather station, and,
- Water temperature boundary conditions for:
    - Mainstem Shasta River,
    - Parks Creek,
    - Big Springs Creek, and,
    - Five major springs:
        - Bridgefield,
        - Black Meadow,
        - Kettle,
        - Clear, and
        - Hole in the Ground.

The equilibrium model predicts changes in water temperature longitudinally throughout each study reach as a function of meteorological conditions and flow management scenarios; however, the core output locations used are the lower Parks Creek Study Site and the Hole in the Ground Study Site. Equilibrium water temperatures will be modeled over two meteorological time periods corresponding to the spring pulse and smolt outmigration period (April 1st to June 15th) and the summer juvenile salmonid rearing period (June 16th to September 6th) as described in Section 2.1. While the effect of diversions and irrigation return flows are not directly assessed in this exercise, the model was calibrated to observed streamflow data and therefore a number of factors that affect water temperatures may be implicitly represented in the modeling results, including: irrigation return flows, baseflow accretions, loss due to seepage, bed conduction and other factors.

5.2.2 *Water Temperature Modeling Scenarios*

The IFNs recommended meeting physical habitat requirements in the Big Springs Complex (based on methods described in Section 3) can originate from many combinations of mainstem and spring-fed water sources. However, the downstream streamflow-water temperature relationship is partially a function of the temperature and streamflow of the upstream water sources (called boundary conditions). Therefore, it is necessary to define a specific set of boundary conditions (which constitutes a modeling scenario) to run the equilibrium modeling tool. Different modeling scenarios (i.e., different combinations of boundary conditions) have the potential to produce different downstream water temperatures, even if they produce the same streamflow at downstream locations.

It is important to note that modeling scenarios were *not* developed as recommended or prescriptive flow scenarios, but rather to simply estimate extent of water temperature variation (given the meteorological conditions in the spring and summer of 2010) that could be achieved with hydrologic management of various spring and mainstem sources. With this goal in mind, two categories of boundary condition scenarios were established: *spring flow scenarios* and *mixed flow scenarios.* As described above, the modeling scenarios are simplified to reflect only variations in mainstem and spring flow boundary conditions, existing channel geometry and ambient meteorological conditions.

- **Spring flow scenarios** – the IFNs recommended at each physical habitat site were achieved by using the maximum estimated baseflow from spring sources within each study reach. When the total estimated available spring flow from all sources was not sufficient to achieve the recommended IFN, the deficit was made up by streamflow from mainstem sources (either Mainstem Shasta River below Dwinnell, Parks Creek at I-5, or a combination of these two sources).
- **Mixed flow scenarios** – the IFNs recommended at each physical habitat site where achieved by using half the maximum estimated baseflow from spring sources within each study reach with the additional flow derived from mainstem boundary sources.

A third scenario, *mainstem flow scenarios*, was considered in which the IFNs recommended at each physical habitat site where achieved by using only streamflow from mainstem boundary sources within each study reach. However, this scenario was not prioritized as high as *spring flow* and *mixed flow scenarios* because of the importance of spring flow and spring sources for rearing juvenile salmonids (Chesney et al. 2009). Unfortunately, due to limited time and budget no *mainstem flow scenarios* were run.

Considerable research exists which suggests that protecting cool spring-fed water sources provides the most benefit to salmonid life histories in the Big Springs Complex (Chesney et al. 2009, Jeffres et al. 2009, Null et al. 2010). However, the capacity for spring sources to effect mainstem rearing conditions has largely been unaddressed. Therefore, the purpose of developing *spring flow scenarios* (Scenarios 3-6) for both the April 1st to June 15th IFN and June 16th to September 6th IFN, was to estimate the capacity for cool water spring sources to affect the downstream thermal rearing environment for juvenile salmonids. Likewise, *mixed flow scenarios* where developed to establish the effect reduced spring flow contribution (to the total recommended IFN) on water temperature at downstream locations. Together *spring flow*, and *mixed flow* scenarios also help to estimate the longitudinal extent of temperature thresholds given variability in upstream boundary conditions. Specific scenarios, modeling results and implications for IFNs from the water analysis are presented along with the physical habitat IFNs for HIG (Sections 6.1.4 and 6.1.5) Parks Creek (Sections 6.2.4 and 0), TNC (Section 6.3.4 and 6.3.5) and Reach No. 5 (Section 6.5).

5.2.3 Simulation period

To estimate whether recommended IFNs for the late-spring through early-autumn period were likely to satisfy identified water-temperature criteria, two exceedence days in both the spring (April 1st to June 15th) and the summer (June 16th to September 6th) periods were evaluated. Conditions representing the 50th and 90th percentile warming conditions (i.e., net heat flux due to meteorological conditions) were identified for each period. By identifying key heating periods based on net heat flux, the simulated IFN scenarios illustrate each stream's potential response to adverse heating conditions.

Net heat flux was determined using an equilibrium temperature model developed to examine heat flux at the air-water interface of a body of water of specified dimensions. The net heat flux (q_n) was calculated using the heat budget equation (14):

$$q_{net} = q_{sn} + q_{at} + q_{ws} - q_e - q_h \qquad (14)$$

Where:

q_{net} = net heat flux (Wm^{-2})

q_{sn} = net short wave radiation flux (Wm^{-2})

q_{at} = long wave (atmospheric) radiation flux (Wm^{-2})

q_{ws} = water surface long wave radiation flux (Wm^{-2})

q_e = evaporative (latent) heat flux (Wm^{-2})

q_h = conductive (sensible) flux (Wm^{-2})

Once q_{net} was determined for the study period, 50th and 90th percentile heating days for each IFN period were identified by analyzing daily maximum q_{net} using the Weibull approach (Maidment 1993). 50th and 90th percentile heating days for each IFN period are identified in Table 11:

Table 11. 50th and 90th percentile heating days in 2010 for each IFN period.

IFN Period	50th percentile	90th percentile
Smolt Outmigration - 4/1-6/15	4/18/2010	4/22/2010
Summer Rearing - 6/16-9/6	7/11/2010	8/16/2010

5.2.4 Modeling Assumptions and Limitations

To complete the analysis of the effects of IFN streamflows on water temperatures in the study reaches, several assumptions were made. All water temperature models include assumptions and estimates that may limit the models ability to predict water temperature, and responsible application of the modeling results should include thorough consideration for the limitations of both available data and modeling refinement. In this project, assumptions were made regarding channel geometry as well as boundary condition streamflows and water temperatures – key components in water temperature modeling. These assumptions should be considered when interpreting the results of the IFN streamflow-water temperature modeling. Limitations of the water temperature modeling presented here include:

- Boundary conditions for spring flow contributions are based on a percentage of estimated maximum available spring flow (Table 2) inherent in each scenario:
    - Spring Flow Scenario (100%)
    - Mixed Flow Scenario (50%)
    - Mainstem Scenario (0%) (no mainstem scenarios were run).

  Actual spring flow may vary throughout the season.

- Reach-averaged channel geometries were used in the equilibrium model based on cross sections surveyed in each reach at the physical habitat study sites. Actual cross section geometry varies within each reach.
- Water velocity and travel time between computation nodes were based on estimated channel slope and roughness.

- The observed water temperature at boundary condition locations on a modeled exceedence day were used as the mainstem water temperature boundary conditions, regardless of simulated streamflow volume.
- Boundary condition water temperatures for the Parks Creek springs (e.g., Bridgefield, Black Meadow, and Kettle Springs) were estimated. As Bridgefield Springs and Black Meadow currently are not connected to Parks Creek, an assumption was made that water from these sources would be piped to the mainstem Parks Creek under a potential future instream flow management action. Water temperatures at the mouth of Kettle Springs were modeled based on observed water temperatures approximately 0.5 mi downstream from the spring source.
- Subsurface and overland accretion from irrigation practices were assumed negligible.
- The effect of aquatic and riparian vegetation was not evaluated.
- Water temperature results are one-dimensional and do not account for isolated, local thermal refugia, which may play an important role in salmonid LHTs in the Big Springs Complex.

6 MINIMUM INSTREAM FLOW NEEDS (IFN) IN THE BIG SPRINGS COMPLEX

In this section, the interim minimum IFNs for each salmonid life stage within the Big Springs Complex (described in Section 2) are identified based on the physical and thermal habitat assessment methods as described in Section 3 and Section 5, respectively. This section is divided into five primary sub-headings associated with each of the study sites and reaches:

- Section 6.1 – Interim IFNs for Reach No. 1 (based on the HIG Study Site);
- Section 6.2 – Interim IFNs for Reach No. 2 (based on the UPC and LPC Study Sites);
- Section 6.3 – Interim IFNs for the Reach No. 3 (based on the TNC Study Site);
- Section 0 – Interim IFNs for Reach No. 4; and,
- Section 6.5 – Interim IFNs for Reach No. 5.

Within each sub-heading (6.1- 6.5) the evaluation of physical and thermal habitat needs for five salmonid life stages (described in Section 2) are presented. Not all the methods described in Section 3 and Section 5, are applicable to every salmonid life stage described in Section 2. For example, the Wetted Perimeter approach (Section 3.2.2) is a tool to identify minimum IFNs for juvenile rearing habitat and is not applicable for adult salmon migration and spawning. Table 12 shows which assessment methods used to determine IFNs for each salmonid life stage. Although multiple assessment methods are used to evaluate each salmonid life stage (except Early Adult Chinook Salmon Migration which was based solely on RCT), typically one method became the primary analytical tool for recommending an interim IFN. At the end of each Section (6.1- 6.5) a concise summary of IFNs for each salmonid life stage and the primary analytical measure(s) used to determine them is included.

Table 12. Assessment methods used to analyze identify IFNs for each salmonid life stage.

Method	**September 7 to September 30:** Early Adult Chinook Salmon Migration	**October 1 to December 31:** Adult Salmon Migration and Spawning Habitat	**January 1 to March 31:** Winter Juvenile Salmonid Rearing Habitat	**April 1 and June 15:** Spring Pulse and Smolt Outmigration	**June 16 to September 6:** Summer Juvenile Salmonid Rearing Habitat
Regional Regression			✓		✓
Wetted Perimeter			✓		✓
R2 Cross			✓		✓
DHM		✓		✓	
RCT	✓	✓			
HHTs			✓	✓	✓
Bench Inundation				✓	
Water Temperature Model				✓	✓

There cannot be one optimal streamflow that serves all IFNs simultaneously. However, spatially they can be accommodated, but not optimized, over a specified range of streamflows. IFNs are quantified for each life stage within the study sites independently, i.e., without addressing specific LHTs, as if each reach independently supports all life stages from egg through smolt outmigration. In Section 6, these IFN findings introduced below are integrated into recommended daily average minimum instream streamflows for the Big Springs Complex. These interim recommendations, which only address Moyle's Tier No.1 objectives, are an important, step toward basin wide population recovery.

6.1 IFNs for Hole-in-the-Ground (HIG) Study Site

The mainstem Shasta River upstream of the Parks Creek confluence was evaluated for minimum IFNs at the HIG site for Reach No.1.

6.1.1 Early Adult Chinook Salmon Upstream Migration: September 7-30 (3 weeks)

RCT Threshold

RCTs were surveyed over a narrow range of streamflows in Reach No.1c, 13.1 cfs and 7.6 cfs, because streamflow variability was low during our short study period (Figure 18). More RCT surveys will be needed to completely develop streamflow-mRCT rating curves at different densities of aquatic vegetation growth. The interim objective was to identify a streamflow for September that would produce an mRCT of 1.0 ft deep. The RCT survey at 13.1 cfs on June 21, 2010, had an mRCT of 0.95 ft. Shallower surveyed RCTs were 0.8 ft deep (Figure 18). Continued growth and biomass accumulation of submerged aquatic vegetation by early-September, raised the mRCT and shallower riffle RCTs at 13.1 cfs by an additional 0.2 ft to 0.3 ft. The other RCT survey on May 26, 2010, with an mRCT of 0.75 ft at 7.6 cfs (Figure 18), was considerably less influenced by the dense vegetation that grew the entire summer and persisted into fall than the survey on June 21, 2010. Shallower surveyed RCTs in the HIG site at 7.6 cfs in May varied between 0.7 ft and 0.6 ft deep (Figure 18).

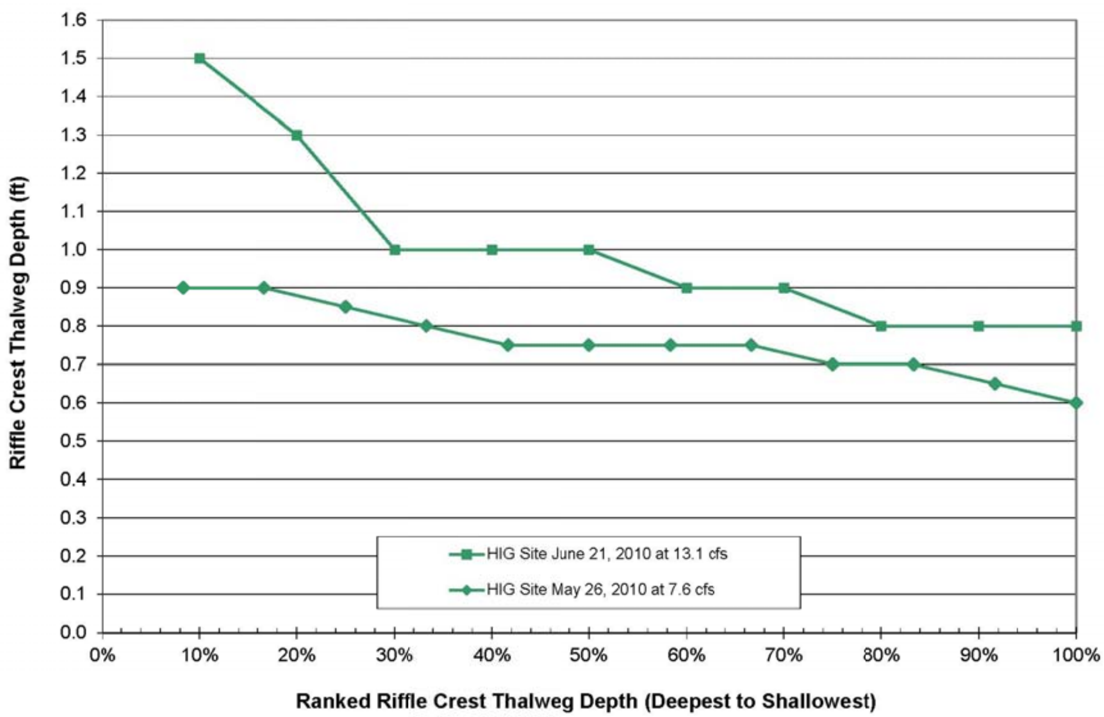


Figure 18. Ranked riffle crest thalweg depths (RCTs) at the HIG Study Site.

HIG Study Site Adult Salmon Migration Minimum IFN Finding

At the HIG site, a 13.1 cfs streamflow approximately met minimum Tier No.1 adult Chinook upstream migration depth thresholds based on results using a threshold adult Chinook passage depth of 1.0 ft for the mRCT and an RCT90 of 0.8 ft at 13.1 cfs (Figure 18). While not as desirable as 1.0 ft, adult migration would not likely be compromised at the RCT90. However, both RCT surveys were taken before aquatic vegetation completely dominated riffle hydraulics. Although aquatic vegetation die-back typically begins in September, riffle hydraulics are still highly impacted, much more so than in May and June when the RCTs were surveyed. A conservatively small adjustment factor of 0.15 ft stage height was considered to account for this hydraulic impact (i.e., at 13.1 cfs in September, the mRCT likely will be closer to 1.15 ft than 1.0 ft). Actual depth increases would exceed 0.15 ft. Therefore, a minimum mRCT that would not discourage individual adult Chinook salmon (defined by mRCT > 1.0 ft) from migrating into or through the HIG site in September would require less streamflow than the 13 cfs required in spring months. Adding 0.15 ft to both mRCT survey results and interpolating between data points suggested that a minimum IFN of 10 cfs from September 7 through September 30 would meet the minimum Tier No.1 adult Chinook upstream migration threshold mRCT of 1.0 ft.

6.1.2 Adult Salmon Spawning and Migration: October 1 - December 31 (12 weeks)

Regional Regression Methods

IFNs were computed for spawning salmonids (Chinook, steelhead, all species pooled) using regional regression methods predicting the optimal streamflow described by Swift (1979) and Hatfield and Bruce (2000) (Table 13). An optimal spawning streamflow, which roughly provides the most spawning habitat, should provide greater benefits than a “minimum” flow. Based on our evaluations, streamflow estimates for spawning habitat derived from both methods (111 cfs and 78 cfs, respectively, for Chinook spawning habitat abundance) were too high in the contemporary post-dam channel morphology at the HIG site, even as optimum streamflows. Unfortunately, neither model accounts for dam impacts to channel morphology. As a result of Dwinnell Dam, the channel at the HIG site has become highly constricted by encroaching vegetation and silt deposition, exacerbated by the lack of scouring high streamflows. Under these conditions, the optimal streamflows (and greater) would exceed depths and velocities observed as suitable for salmonid spawning within the HIG site. Therefore the predicted optimum streamflows from regional regression methods described by Swift (1979) and Hatfield and Bruce (2000) where not used as an analytical component in recommending IFNs for Adult Salmon Spawning and Migration.

Table 13. Predicted optimum IFNs for spawning habitat from regional regression models developed by Swift (1979) and Hatfield and Bruce (2000).

	HATFIELD and BRUCE (2000)			**SWIFT (1979)**	
	Chinook spawning (cfs)	**Steelhead spawning (cfs)**	**All Species spawning (cfs)**	**Chinook spawning Q_{cc} (cfs)**	**Coho spawning Q_{sc} (cfs)**
Reach No. 1C: Hole in the Ground (HIG) site	118	137	82	175	99

Direct Habitat Mapping (DHM) Methods

Salmonid spawning habitat was mapped in 2010 on May 25 (7.6 cfs), June 21 (13.1 cfs), and August 8 (11.3 cfs) using DHM methods (Figure 19). The range in available streamflows surveyed was unfortunately narrow, and even though streamflow magnitude was slightly greater later in the summer, less spawning habitat was being measured under the monitoring protocol used. For example, spawning habitat polygons measured on May 25, 2010, collectively had a total habitat area more than twice the total recorded on two subsequent dates (Figure 19). Furthermore, the prolific growth of aquatic macrophytes that encroached into the spawning riffles at the HIG site, either blanketed spawnable channel bed and/or constricted free-flowing portions of the stream channel to create excessive spawning velocities. Thus, traditional streamflow-habitat rating curves for each spawning habitat location could not be constructed from the field data, nor could hydraulic habitat modeling cope with the intensive and constantly changing macrophyte growth, which was more pronounced at the HIG site than at all the other study sites. Future IFN studies will need to empirically measure spawning habitat and generate streamflow-spawning habitat rating curves. This will only need to be done during the spawning season and will possibly require several sampling intervals to account for progressive seasonal aquatic macrophyte die-off occurring through late-fall.

With macrophyte growth between June and September, spawning habitat polygons, mapped on May 25, 2010, (at 7.6 cfs) were more representative of October and November spawning habitat conditions than the spawning habitat polygons mapped in June and August. The May spawning habitat polygons occupied approximately 90% of the channel bed likely to support spawning, i.e., favorable bed composition and hydraulic setting (Figure 19). Therefore an increase in streamflow greater than 7.6 cfs, under the hydraulic conditions present on May 25, 2010, could not generate an appreciably greater spawning polygon area because almost all the spawnable channel bed (i.e., favorable bed composition) was already included within the polygons mapped at 7.6 cfs.

A photograph from the TNC study site provides a visual of a spawning riffle almost completely within the mapped spawning habitat polygon on October 13, 2009 (Figure 20). The riffle in Figure 20 is similar to the mapped spawning habitat polygon at cross section No.1 and No.2 within the HIG study site (Figure 19). If adult Chinook salmon had been spawning on May 25, 2010, at the HIG site, which is just a hypothetical situation because Chinook salmon spawn in the fall, their dorsal fins and backs would have been exposed. In a more real situation, this scene would be closely replicated in the photograph at the TNC site taken in Reach No.3 during the spawning season on a wide transverse bar (Figure 9) that had identical riffle depths and velocities to those measured in the HIG riffle on May 25, 2010. At streamflows only 1 cfs or 2 cfs less than 7.6 cfs, spawning depths would rapidly become the limiting hydraulic factor for defining this HIG site riffle as usable spawning habitat. A streamflow of 8 cfs would provide minimum Tier No.1 spawning habitat.

RCT Threshold

However, adult upstream migration, which occurs from September through December, is arguably just as important for population survival as spawning. The 10 cfs IFN finding for Chinook migration in September, which was adjusted 0.15 ft deeper to account for the dense aquatic vegetation, will produce a shallower mRCT as the vegetation dies back. The 13.1 cfs streamflow measured in May, with minimal growth present, met the 1.0 ft minimum depth allowing a measurement error of 0.1 ft.

HIG Study Site Adult Salmon Spawning and Migration Minimum IFN Finding

At the HIG site, a minimum IFN range of 10 cfs to 13 cfs would provide for both Tier No.1 Chinook and coho spawning habitat availability and adult migration. This streamflow range provides an mRCT of 1.0 ft spanning a long period of variable aquatic vegetative die-back during the months of September through December. If only spawning habitat was considered, and not adult migration or the use of a shallower minimum mRCT (e.g., mRCT of 0.8 ft), the IFN finding would be 8 cfs based strictly on the DHM polygon survey on May 25, 2010. However, this IFN addresses both adult spawning and migration and therefore the higher flow necessary for adult migration is the determining factor.

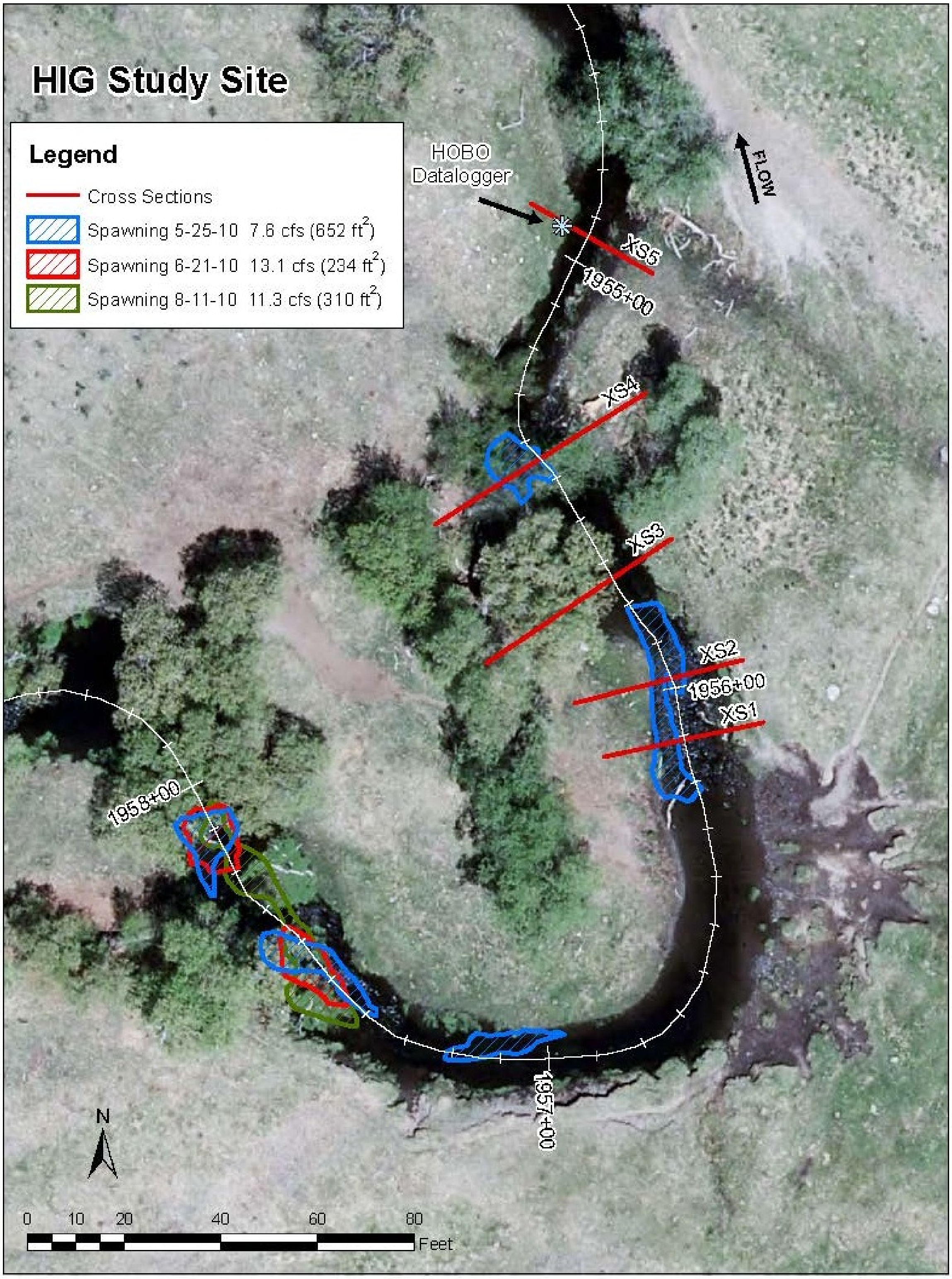


Figure 19. DHM spawning habitat polygons within the HIG site mapped at 7.6 cfs, 13.1 cfs, and 11.3 cfs in WY2010.

Figure 20. Several adult Chinook salmon spawning in a riffle on TNC Reach No.3. Depth of flow was 0.85 ft deep, observed on October 13, 2009, at 24 cfs.

6.1.3 Juvenile Salmonid Winter Rearing: January 1 - March 31 (12 weeks)

Regional Regression Methods

The two regional regression methods, Swift (1979) and Hatfield and Bruce (2000), predicted IFNs of 25 cfs and 32 cfs, respectively, at the optimal streamflow for 'all species' juvenile salmonid rearing (Table 14). The IFN for fry habitat of 5 cfs for Chinook salmon was considerably lower than the all species estimates using Hatfield and Bruce (2000), while the IFN for steelhead fry habitat was nearly the same as the all species estimates (Table 14).

Standard Setting Methods

The WP method, using the maximum breakpoint, predicted a minimum juvenile rearing habitat IFN of 4 cfs, which was an average derived from three cross sections. The R2 Cross method, which used a 0.4 ft depth and 1.0 ft/sec velocity, predicted an average streamflow of 7 cfs and 9 cfs using the incipient asymptote method as the minimum juvenile rearing habitat IFN (Table 15).

Table 14. 'Optimal' streamflows for fry and juvenile salmonid rearing habitat at the HIG Study Site predicted from regional regression methods by Swift (1979) and Hatfield and Bruce (2000).

	HATFIELD-BRUCE (2000)						***SWIFT (1979)***
	Chinook (cfs)		**Steelhead (cfs)**		**All Species (cfs)**		**All Species (cfs)**
	Fry	**Juv**	**Fry**	**Juv**	**Fry**	**Juv**	**Rearing**
Reach No. 1C: Hole in the Ground (HIG) site	11	40	25	54	23	48	42

Hydraulic Habitat Thresholds (HHTs) on cross sections and Longitudinal Velocity Profiles

Hydraulic variability was documented within a patch of encroaching aquatic vegetation just upstream of HIG cross section No.1 on August 11, 2010, at 11.3 cfs (Figure 21). Habitat quality was considered high when high hydraulic diversity was measured. Dense aquatic vegetation provided abundant, high quality juvenile rearing cover for all salmonid species examined. Water depth and velocity profiles measured across the cross section captured numerous locations where aquatic vegetation grew from channel bed up to water surface, forcing streamflow to pass between narrow gaps in the dense vegetation. This condition created multiple shear zones with ample escape cover close to salmon feeding stations. Water depths and velocities at the surface, mid-column, and near-bottom (0.2, 0.6, and 0.8 of total depth) were measured at 1 ft stations within a 20 ft x 20 ft grid spanning the channel. Aquatic vegetation covered more than 60% of the channel bed, with dense watercress encroaching along both channel margins. Water depths ranged up to 1.4 ft and mean column velocities ranged from near zero up to 1.4 ft/sec; maximum velocities at each station were approximately 0.5 ft/sec higher (Figure 22). Point velocities varied considerably from surface to bottom and across each cross section, indicating considerable hydraulic diversity and thus high habitat quality was present (though not formally quantified) at the 11.3 cfs streamflow level at this site.

Table 15. Instream Flow Needs (in cfs) for fry and juvenile rearing calculated from the Wetted Perimeter (WP) "Breakpoint" and "Incipient Asymptote" and R2 Cross methods for the HIG Study Site. Blank cells indicate data is unavailable.

Site	Unit	WP "Breakpoint" (cfs)	WP "Incipient Asymptote" (cfs)	R2 Cross 0.3ft, 1.0 ft/s (cfs)	R2 Cross 0.4ft, 1.0 ft/s (cfs)
HIG site Cross Section No.					
1	Riffle	3	6	7	
2	Riffle	2	13	5	
4	Pool-Tail	6	8	9	
	Average	**4**	**9**	**7**	

Figure 21. Pool-tail at HIG study site just upstream of cross section No.1, which demonstrates the high hydraulic diversity that provides the high quality salmonid rearing habitats associated with submerged aquatic vegetation. Photo taken August 11, 2010, at 11.3 cfs.

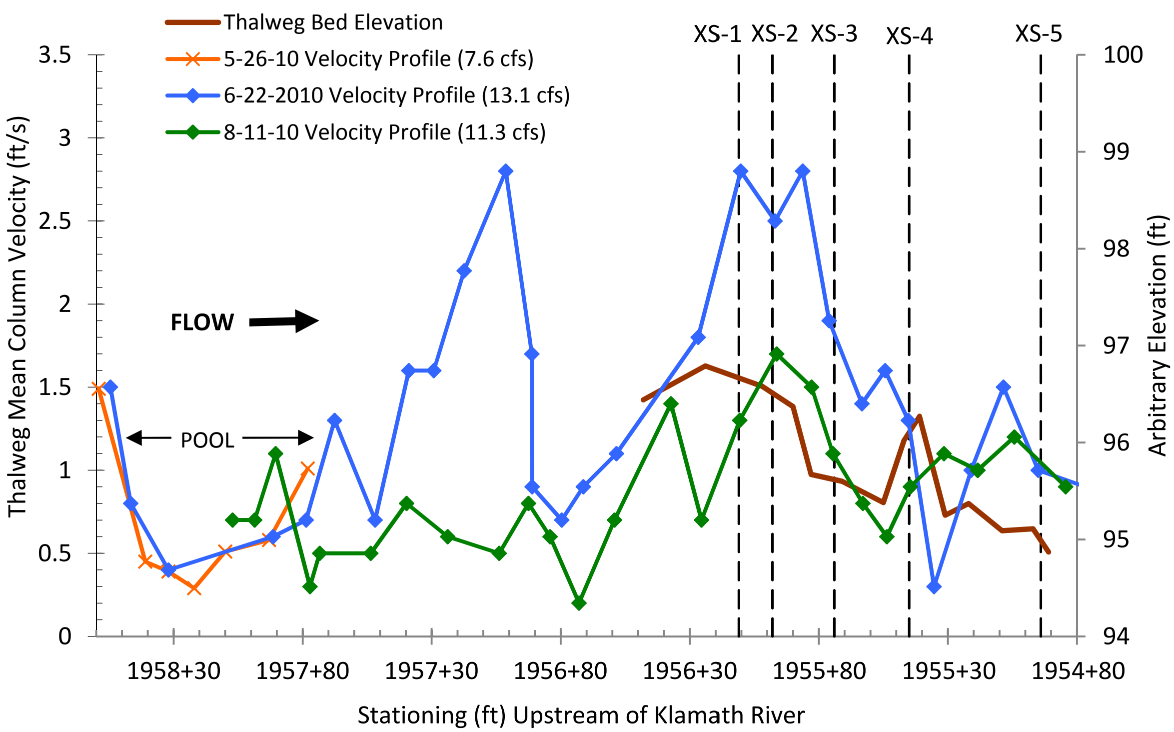


Figure 22. Mean column velocities (ft/sec) measured along the thalweg of the HIG study site.

Hydraulic measurements collected during the observed streamflows at the HIG study site on May 26, 2010, are summarized in (Table 16). Neither pool nor riffle cross sections exceeded the minimum juvenile rearing habitat HHTs of 0.5 ft/sec for pool cross sections and 1.0 ft/sec for riffle cross sections (Table 16). The other two measured streamflows of 13.1 cfs in June and 11.3 cfs in August also did not exceed the HHTs. The 13.1 cfs streamflow observed in June exhibited lower cross-sectional average velocities than the 7.6 cfs streamflow that was observed in May. Prolific growth of aquatic vegetation over the summer significantly influenced these average velocities, except for the pool on cross section No.3 at the HIG study site, where average velocity remained constant (Table 16).

Table 16. Summary of average and maximum water depths and average column velocities in the cross sections at the HIG study site during the late spring and summer of 2010.

Survey Date and Flow	Cross Section	Unit	Average cross section Depth (ft)	Maximum cross section Depth (ft)	Average cross section Velocity (ft/s)	Maximum cross section Velocity (ft/s)
	1	Riffle	0.34	0.50	0.89	2.16
5/26/10	2	Riffle	0.37	0.60	0.85	2.32
Q= 7.6 cfs	3	Pool	0.67	1.30	0.44	1.35
	4	Pool-tail	0.48	1.00	0.48	1.39
	5	Pool	0.79	1.70	0.32	0.95
	1	Riffle	0.43	0.9	0.87	2.56
6/22/10	2	Riffle	0.52	0.8	0.85	2.63
Q= 13.1 cfs	3	Pool	0.83	1.2	0.42	2.29
	4	Pool-tail	0.82	1.3	0.36	1.45
	5	Pool	1.20	1.9	0.40	1.18
	1	Riffle	0.72	1.5	0.36	1.45
8/11/10	2	Riffle	0.66	1.5	0.41	1.66
Q= 11.3 cfs	3	Pool	1.20	2.8	0.42	1.38
	4	Pool-tail	0.99	1.6	0.26	1.20
	5	Pool	0.96	2.3	0.43	1.10

The juvenile HHT was also assessed by surveying a longitudinal velocity profile of the HIG study site's pool at cross section No. 3, which included measurements of depths and velocities along the channel thalweg. The objective of this was to identify a streamflow that would produce a velocity greater than 0.5 ft/sec in the slowest portion of the pool. The slowest segment of the pool at cross section No. 3 had average column velocities of approximately 0.33 ft/sec at 7.6 cfs and 0.42 ft/sec at 13.1 cfs (Figure 22).

HIG Study Site Juvenile Salmonid Winter Rearing Minimum IFN Finding

A minimum IFN of 7 cfs to 10 cfs at the HIG site will provide Tier No.1 winter juvenile salmonid rearing habitat. This IFN finding is based both on the two R2 Cross and WP Incipient Asymptote riffle assessments, which averaged 7 cfs and 9 cfs, respectively (Table 15), and also on the HHT longitudinal profile for the study site's pool at cross section No. 3, which approached the 0.5 ft/sec threshold velocity within a minimum measurement error of 0.1 ft/sec at a late-spring streamflow of 8 cfs (Figure 22). HHTs measured at riffle cross sections were less reliable for estimating minimum streamflows as summer progressed and aquatic vegetation increasingly dominated riffle hydraulics.

6.1.4 Spring Snowmelt Pulse: River Productivity and Smolt Outmigration: April 1 - June 15 (10 weeks)

Bench Inundation Threshold

Streamflows adequate to just inundate benches within the HIG study site were not observed during the scheduled field visits. A bench in the study site on the left bank (just left of center in the photograph) would have required an additional 0.2 ft increase in stage to initiate inundation (Figure 23). This stage increase corresponded to a total streamflow of 22 cfs to 26 cfs. Another encroached bar feature (as far downstream in the photograph as possible) on the right bank also would have had its lower bench surface inundated by 20 cfs to 25 cfs, though not the upper bar surface with the white log. In April 2011, a small pulse streamflow was released from Dwinnell Dam. Bill Chesney of CDFW photographed the HIG study site (Figure 24). Although the peak streamflow was not measured, the planned release of 24 cfs plus spring accretion would have produced a total pulse streamflow of 30 cfs to 35 cfs. Looking downstream, the left bank bench is completely exposed at 7.6 cfs (Figure 23) and completely inundated during the April 21, 2011, planned release (Figure 24).

Figure 23. HIG study site looking downstream. Photo taken May 25, 2010, at 7.6 cfs.

Hydraulic Habitat Threshold (HHT) for Large Juvenile Salmonid Rearing and Outmigration

The highest streamflow encountered during our field visits was 13.1 cfs. Mean column velocities along the thalweg of the study site's pool at cross section No. 3 did not exceed the threshold of 1.5 ft/sec for outmigrating smolt habitat at 13.1 cfs (Figure 22). In April 2011, a core of higher velocity streamflow, estimated at 30 to 35 cfs, passed along the pool's left bank (Figure 25). The narrow bubble line indicated a fast velocity core generating a distinct shear zone along this core's right flank, providing a velocity break (shear zone) that could be used by smolts for foraging. This 30 cfs to 35 cfs streamflow likely exceeded a minimum snowmelt pulse IFN, using the 1.5 ft/sec threshold.

Figure 24. HIG study site looking downstream at approximately 30 cfs to 35 cfs. Photo taken April 21, 2011, by Bill Chesney CDFW.

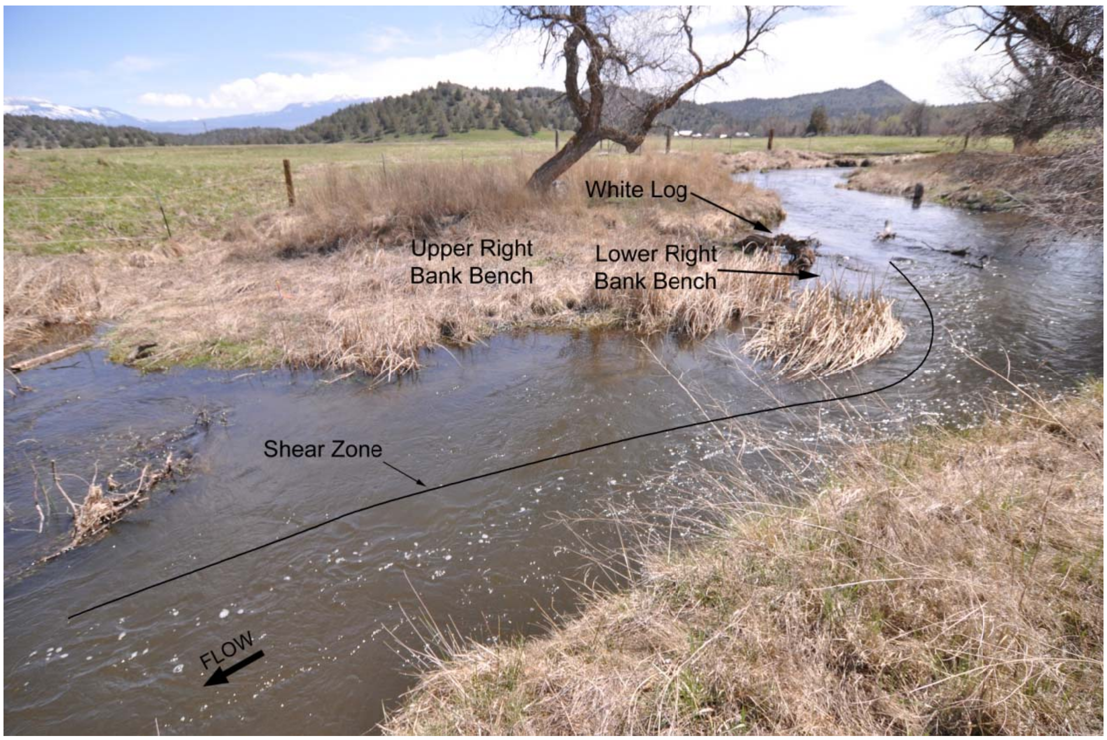


Figure 25. HIG study site looking upstream during April 21, 2011, pulse flow release from Dwinnell Dam. With spring accretion and the planned 24 cfs release, the streamflow in the photograph would have been 30 cfs to 35 cfs. This streamflow range is on the brink of entirely inundating the upper portion of the right bank bench (photograph taken by Bill Chesney, CDFW).

HIG Study Site Snowmelt Pulse Minimum IFN Finding Based on Physical Habitat

A minimum IFN range of 20 cfs to 25 cfs would provide Tier No.1 juvenile and smolt rearing habitat capacity and would likely improve overall stream productivity, e.g., for BMI and other organisms. This finding was based on the comparison of photos taken on both May 25, 2010, at 7.6 cfs (Figure 23) and on April 21, 2011, at an estimated 30cfs to 35 cfs (Figure 24, Figure 25), which clearly show an exposed bench and inundated bench, respectively. Flows between 20 cfs to 25 cfs would inundate the right bank bench in Figure 24.

HIG Study Site Water Temperature Modeling Scenarios, Results and Implications for IFNs for the Spring Pulse and Smolt Outmigration Period (April1 – June 15)

Table 17 shows the four water temperature modeling scenarios developed for the Shasta River above Parks Creek during the Spring Pulse and Smolt Outmigration period. The scenarios include both *spring flow* and *mixed flow* boundary conditions and the 90th and 50th percentile warming days for each IFN period are modeled (See Sections 5.2.2 and 5.2.3 for a discussion of modeling scenarios and exceedence days).

*Table 17. Water temperature modeling scenarios for the Shasta River above Parks Creek, during April 1 –June 15 IFN period. K represents the % exceedence day and * represent a model boundary condition location.*

Time	Scenario	K	Date	$Q_{SRGRAV*}$	$Q_{Clear\ Springs*}$	Q_{SRNOPL}	$Q_{SRabvPC}$
4/1-6/15	*Spring*	*90%*	*4-22*	18.8	3.2	22	22
4/1-6/15	*Spring*	*50%*	*4-18*	18.8	3.2	22	22
4/1-6/15	*Mixed*	*90%*	*4-22*	20.4	1.6	22	22
4/1-6/15	*Mixed*	*50%*	*4-18*	20.4	1.6	22	22

Results from the water temperature model indicate that the recommended Spring Pulse and Smolt Outmigration IFNs for the Shasta River above Parks Creek (22 cfs) are likely to satisfy identified water temperature criteria under the *spring flow scenario* (Figure 26 and Figure 27) and are on the threshold of satisfying water temperature criteria under the *mixed flow scenario* (Figure 28 and Figure 29). Although daily maximum water temperatures on the warmest days (90 % exceedence) reach the upper end of sub-optimal water temperature criteria of 20.3^{o}C (Stenhouse et al. 2011), the boundary conditions in the spring period are generally cool enough and the IFNs are high enough to buffer the effects of warm air temperature. Downstream of Clear Springs modeled daily maximum water temperatures never exceed 20.3^{o}C during the median (50% exceedence) warming day under the *spring flow scenario* (Figure 27) and only reached 21^{o}C during the *mixed flow scenario* during this period (Figure 29). The modeling results suggest that the April 1st to June 15th IFNs could provide thermally suitable rearing habitat throughout the reach, though the extent and distribution of this habitat may vary depending on year-type and regional water use strategies

In addition, data collected by Davids Engineering indicate that the HIG reach from the Pump Diversion downstream to the property boundary (Reach No.1c in our study) is gaining flow from groundwater seepage or small surface springs, either of which appears to contribute cold water and reduce the water temperature in this reach (Davids 2011). This effect is not incorporated into the water temperature model, which indicates that our results may be conservatively warm estimates of actual water temperature under either of the modeled scenarios (*spring flow and mixed flow*).

Interpretation of modeling results on the Shasta River above Parks Creek is somewhat limited because release temperatures from Lake Shastina that correspond to the recommended IFNs are unknown. Also any potential hypolymnic effects from Shastina are not considered in this model. The existing boundary conditions upstream of Clear Springs are likely to be conservatively warm estimates of water temperature during the April1 – June 15th period. Modeling results for the recommended April 1st to June 15th IFNs suggest that a wide distribution of thermally suitable habitat for rearing salmonids, including coho, would be available during the spring rearing and smolt outmigration period. Therefore the temperature modeling results support the April 1st to June 15th IFNs recommended based on the physical habitat assessment in Section 6.1.4.

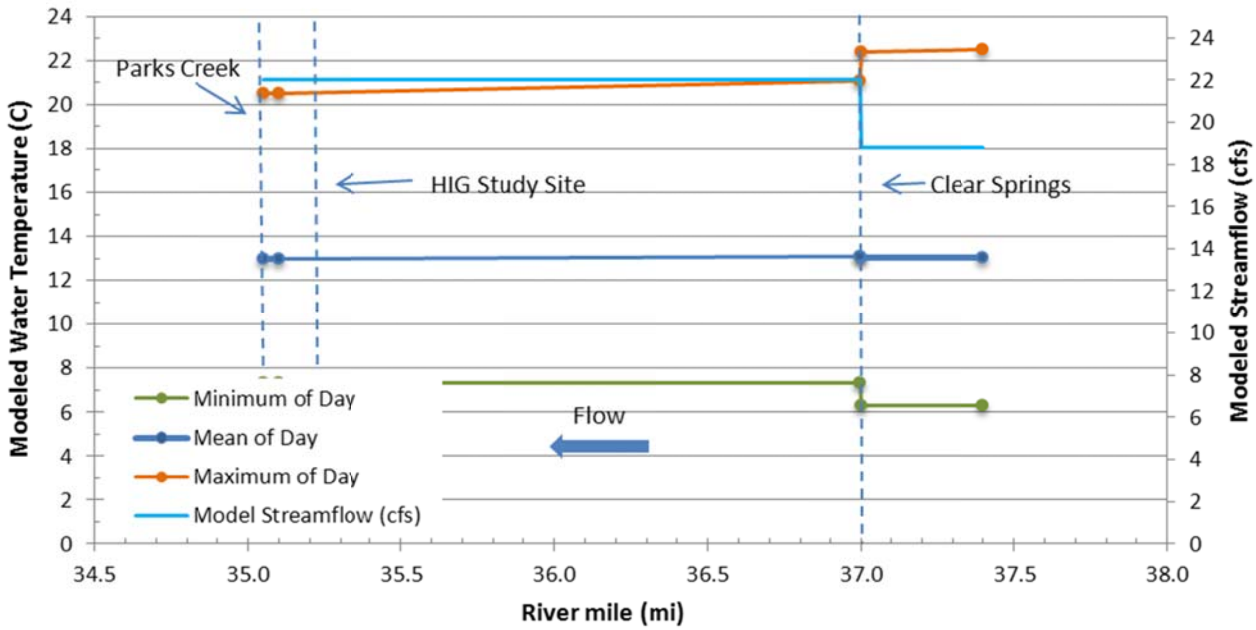


Figure 26. Modeled water temperatures for the 90% exceedence day of the April 1 to June 15 IFN; Shasta River above Parks; spring flow scenario.

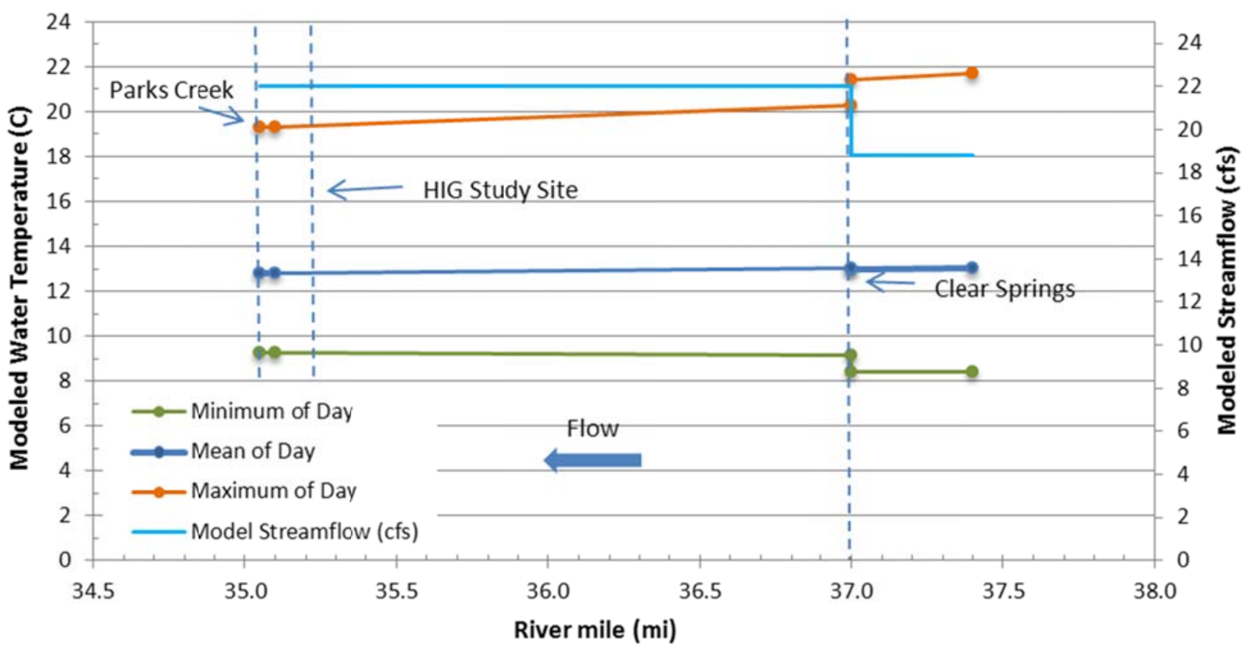


Figure 27. Modeled water temperatures for the 50% exceedence day of the April 1 to June 15 IFN; Shasta River above Parks; spring flow scenario.

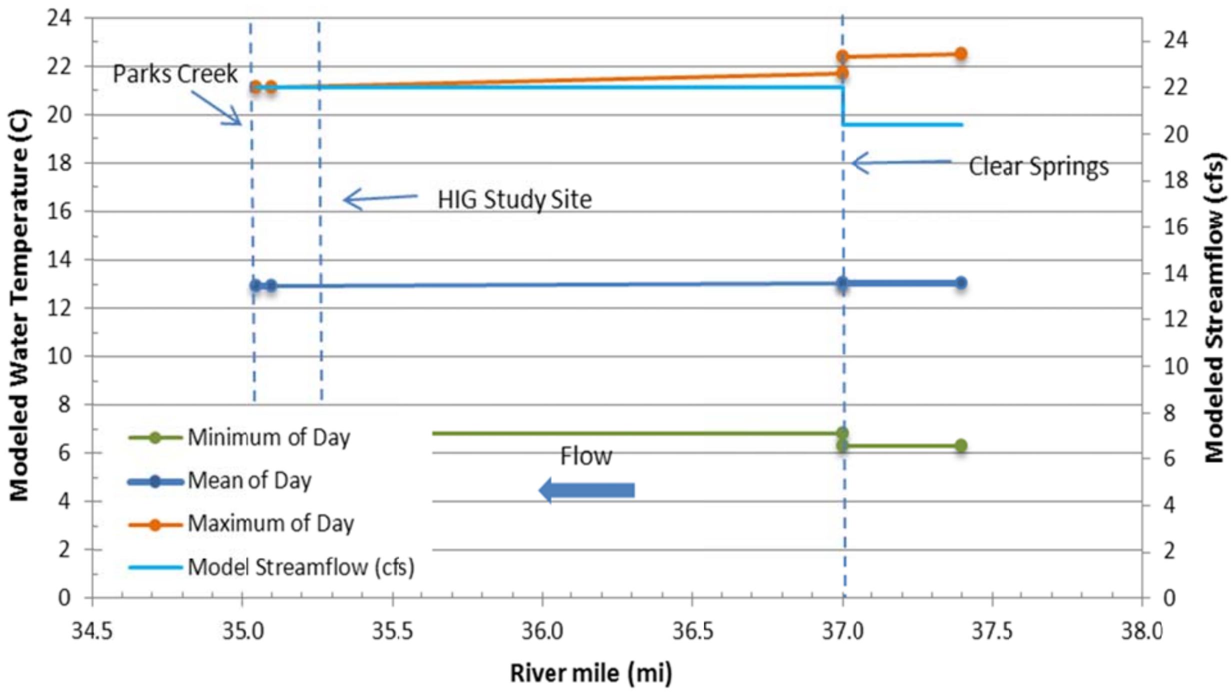


Figure 28. Modeled water temperatures for the 90% exceedence day of the April 1 to June 15 IFN; Shasta River above Parks; mixed flow scenario.

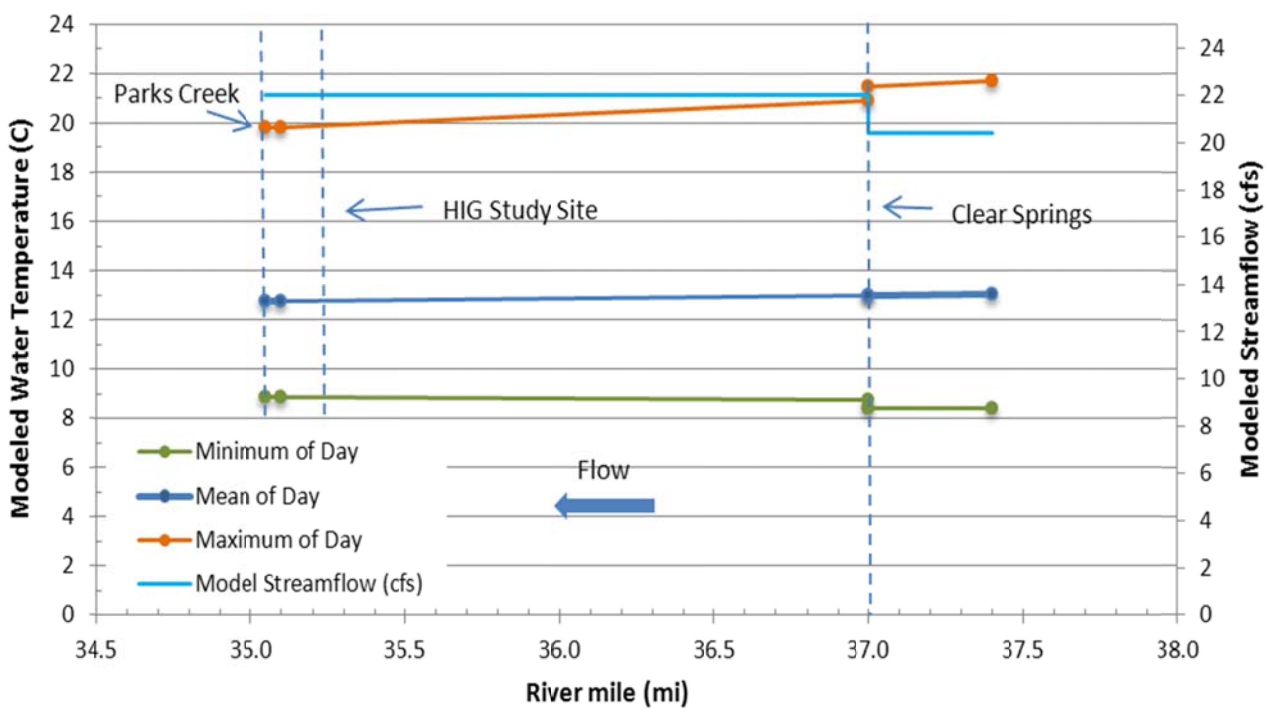


Figure 29. Modeled water temperatures for the 50% exceedence day of the April 1 to June 15 IFN; Shasta River above Parks; mixed flow scenario.

6.1.5 Juvenile Salmonid Summer Rearing: June 16 - September 6 (15 weeks)

The minimum IFN for juvenile salmonid rearing habitat for summer, based on physical habitat, would be the same as the 6 cfs to 10 cfs winter rearing minimum IFN finding. The warmest hourly water temperatures observed during the study period generally remained below 22^{o}C (Figure 30). A close-up, downstream view of the HIG study site at 11.2 cfs on August 10, 2010, (Figure 31) compared to a photo taken on May 25, 2010 (Figure 23), shows how the aquatic vegetation has grown into the channel. Due to complex habitat provided by the aquatic vegetation, (and if water temperature is not limiting), a lower IFN of 6 cfs would provide Tier No.1 minimum IFNs for juvenile salmonid rearing. This is also supported by the minimum R2 Cross and Wetted Perimeter asymptote from Table 15 which are 5 cfs and 6 cfs, respectively.

The following conclusions were drawn from observations collected during the 2010 field season:

- The HIG site exhibited a summer water temperature regime that likely enabled coho over-summer rearing habitat to persist, but a brief period of several days occurred in late-July and early-August when daily maximum temperatures exceeded 20^{o}C. Recent data collected by Davids Engineering indicate that the HIG reach from the Pump Diversion downstream to the property boundary (Reach No.1c in our study) may be gaining flow from groundwater seepage or small surface springs, either of which likely contributes cold water to this reach. Continued improvements in land management and diversion practices will likely create suitable water temperature conditions in this reach (Reach No.3c).
- The HIG Ranch downstream of Clear Springs provided suitable water temperatures for all but a six week period from mid-July through August. During this time, maximum daily water temperatures exceeded 20^{o}C and reached a maximum temperature of 23.3^{o}C. We assume these temperatures would have displaced over-summering juvenile coho as was observed by Chesney et al. (2009) at similar sites on the Shasta River. However, small pockets of thermal refugia may have persisted in close association with Clear Springs or wherever groundwater accretion occurs.
- Clear Springs produces an estimated 2.5 cfs with a constant water temperature of 13.6^{o}C, which would provide suitable rearing habitat at the spring source (although there is no spring channel associated with Clear Springs) and for a distance downstream, depending on the streamflow and water temperature from upstream of Clear Springs and the prevailing climatic conditions that increase water temperatures during summer.
- The south property boundary of the Emmerson HIG Ranch receives streamflow with warm water temperatures, resulting either from irrigation return flows in the region or from Dwinnell Dam releases, or both.

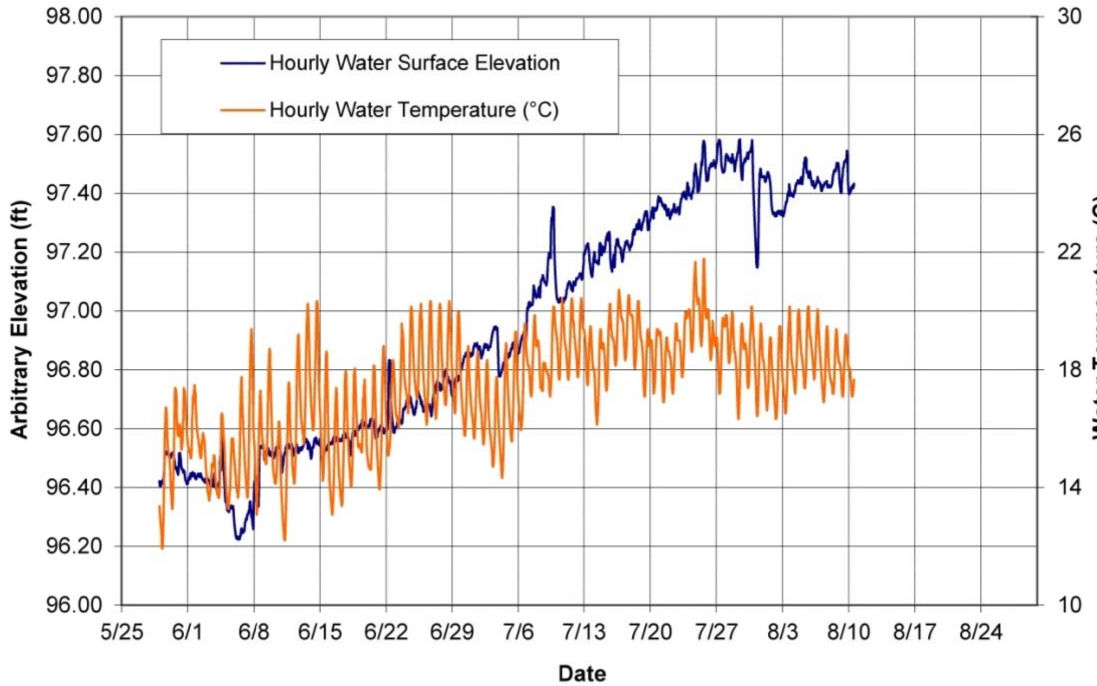


Figure 30. Water temperatures and surface elevations recorded hourly at the HIG study site in 2010.

Figure 31. HIG study site looking downstream. Photograph taken August 10, 2010, at 11.3 cfs.

HIG Study Site Water Temperature Modeling Scenarios, Results and Implications for IFNs for the Summer Juvenile Rearing Period (June 16 – September 6)

Table 18 shows the four water temperature modeling scenarios developed for the Shasta River above Parks Creek during the Summer Juvenile Salmonid Rearing Habitat period. The scenarios include both *spring flow* and *mixed flow* boundary conditions and the 90th and 50th percentile warming days for each IFN period are modeled (See Sections 5.2.2 and 5.2.3 for a discussion of modeling scenarios and exceedence days).

*Table 18. Water temperature modeling scenarios for the Shasta River above Parks Creek. K represent the exceedence day and * represent a model boundary location.*

Time	Scenario	K	Date	$Q_{SRGRAV*}$	$Q_{Clear\ Springs*}$	Q_{SRNOPL}	$Q_{SRabvPC}$
6/16-9/6	*Spring*	*90%*	*8-16*	6.1	1.9	8	8
6/16-9/6	*Spring*	*50%*	*7-11*	6.1	1.9	8	8
6/16-9/6	*Mixed*	*90%*	*8-16*	7.05	0.95	8	8
6/16-9/6	*Mixed*	*50%*	*7-11*	7.05	0.95	8	8

Modeled water temperatures for the recommended summer rearing IFN on the Shasta River above Parks Creek (6 to 10 cfs) indicate that the majority of the mainstem habitat downstream of Clear Springs would be either just above, or on the threshold of suitable thermal conditions for juvenile coho, during the warmest days in summer, under either the spring flow (Figure 32 and Figure 33) or the mixed flow (Figure 34 and Figure 35) scenarios. Under the both scenarios, the thermal advantage provided by Clear Springs is somewhat reduced to the higher volume 5-7 cfs of warm water from upstream required by the recommended IFN. Modeled maximum daily water temperatures on the warmest days (e.g. 90% exceedence days) range between 23^{o}C and 21^{o}C. As described above the modeling results are likely conservative estimates, however, it is safe to assume that mainstem summer low flows above Clear Springs will be significantly warmer than the 13.5^{o}C produced at Clear Springs. Therefore, to reduce the upstream thermal mass and improve the thermal effect of Clear Springs both locally and on downstream rearing, it is recommended that the lower boundary IFN for physical habitat (6 cfs) be preferred in the summer months. This is supported because the diverse physical habitat that exists, even during low flows, in the Shasta River above Parks Creek is still likely to provide suitable physical conditions for rearing salmonids (as described in Section 6.1.5.)

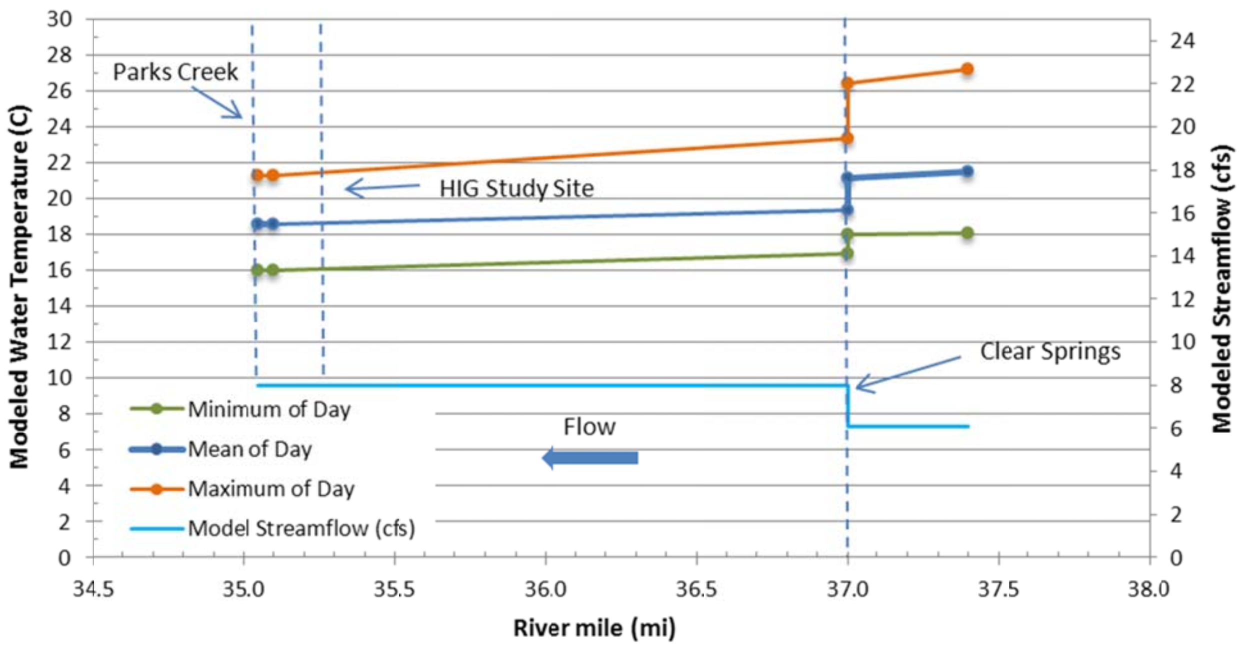


Figure 32. Modeled water temperatures for the 90% exceedence day of the June 16 to September 6 IFN; Shasta River above Parks; spring flow scenario.

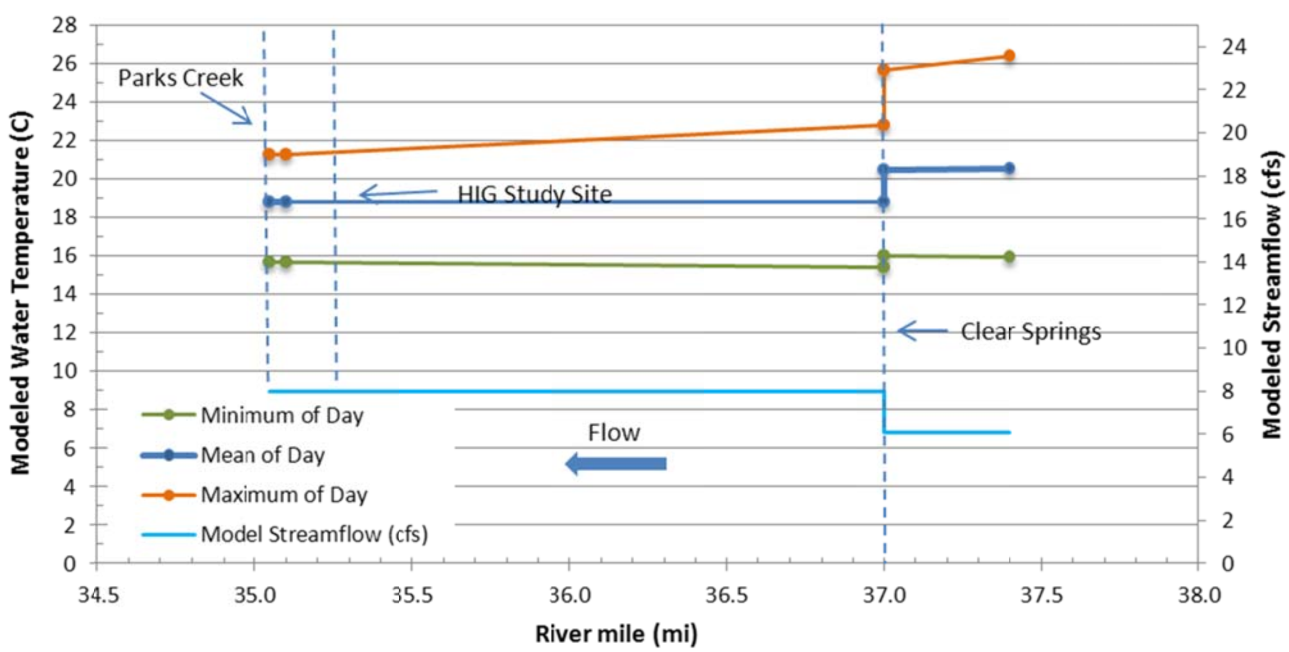


Figure 33. Modeled water temperatures for the 50% exceedence day of the June 16 to September 6 IFN; Shasta River above Parks; spring flow scenario.

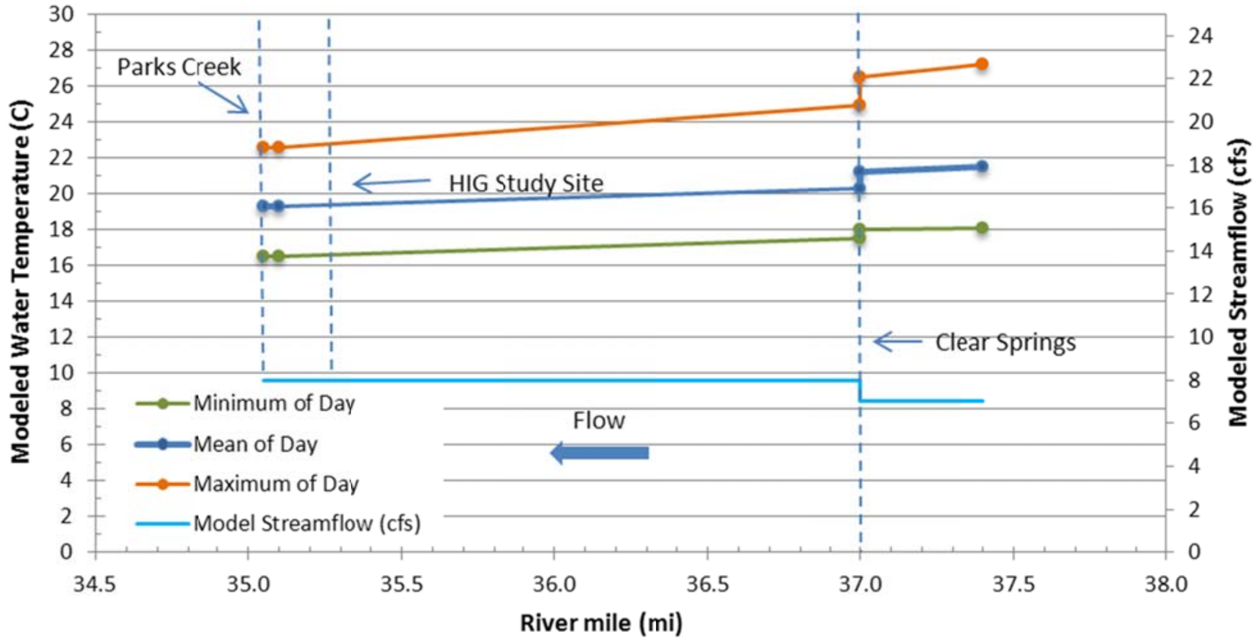


Figure 34. Modeled water temperatures for the 90% exceedence day of the June 16 to September 6 IFN; Shasta River above Parks; mixed flow scenario.

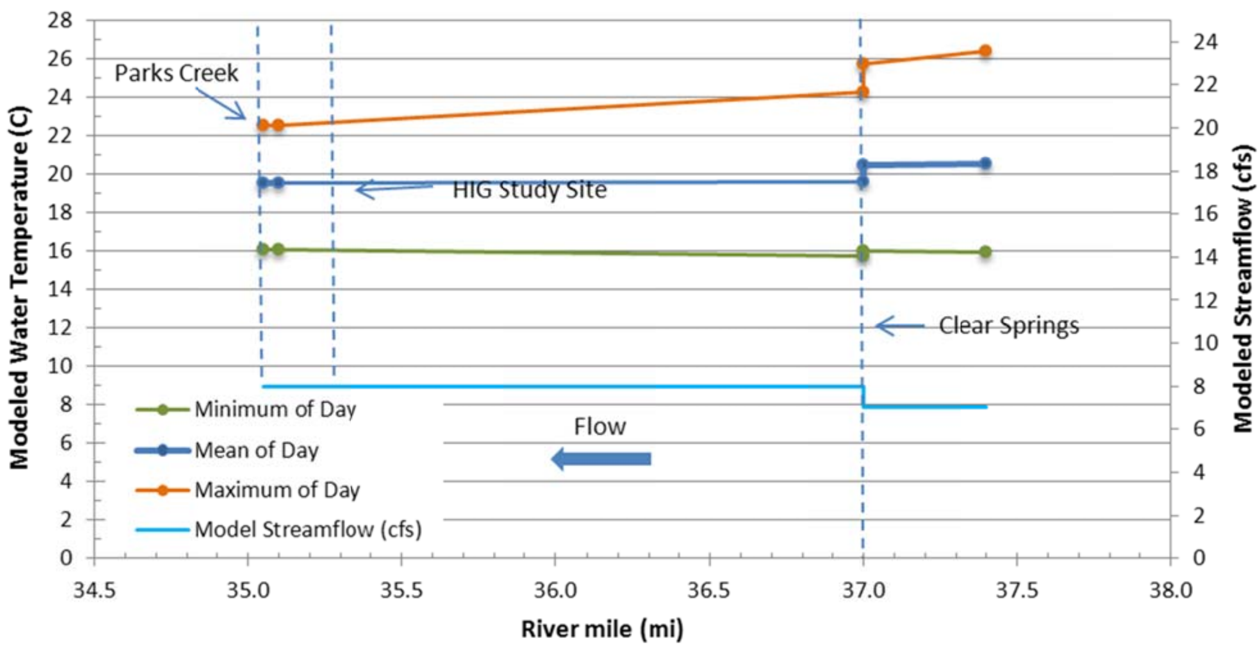


Figure 35. Modeled water temperatures for the 50% exceedence day of the June 16 to September 6 IFN; Shasta River above Parks; mixed flow scenario.

6.1.6 *Summary of IFN Findings for the HIG Study Site.*

Minimum IFN findings (Q_{MIN}) for the mainstem Shasta River above Parks Creek confluence (Reach No. 1) assessed at the HIG study site are presented in Table 19.

Table 19. Minimum IFN findings (Q_{MIN}) for the mainstem Shasta River above Parks Creek.

Salmonid Life Sage	Q_{MIN} (cfs)	Primary Analytical Measure
September 7 to September 30: Early Adult Chinook Salmon Migration	Q_{MIN} = 10 cfs	mRCT of 1.0 ft (Figure 18) adjusted for a 0.15 ft stage increase due to increase in stage from late-summer, dense aquatic plant growth.
October 1 to December 31: Adult Salmon Migration and Spawning Habitat	Q_{MIN} = 10 cfs to 13 cfs	mRCT of 1.0 ft influenced by seasonal aquatic vegetative growth requiring 13 cfs later in the season; Q_{MIN} for spawning habitat, independent of adult migration needs, was 8 cfs (Figure 19).
January 1 to March 31: Winter Juvenile Salmonid Rearing Habitat	Q_{MIN} = 7 cfs to 10 cfs	Two R2 Cross and WP Incipient Asymptote riffle assessments averaged 7 cfs and 9 cfs, respectively (Table 15) and the HHT long profile for the study site's largest pool achieving an extrapolated 0.5 ft/sec threshold velocity at 10 cfs.
April 1 and June 15: Spring Pulse and Smolt Outmigration	Q_{MIN} = 20 cfs to 25 cfs	Incipient bench inundation estimates based on photo observations with flows ranging from 7.6 cfs to approximately 30 cfs (Figure 23, Figure 24, Figure 25). Interim IFNs supported by water temperature assessment.
June 16 to September 6: Summer Juvenile Salmonid Rearing Habitat	Q_{MIN} = 6 cfs	The physical habitat recommendation ranges between 6 and 10 cfs; however, the water temperature assessment indicates improved thermal conditions for rearing salmonids from the lower IFN recommendation - 6 cfs (Section 6.1.5).

The water temperature modeling results indicate that lower summer flows (June 16th to September 6th) may improve the thermal conditions for rearing salmonids; however, the response of real-time water temperatures to instream flows may differ from modeled predictions for several reasons. Future upstream boundary conditions could be cooler than those used in the temperature modeling and factors such as irrigation return flows, baseflow accretions, loss due to seepage and bed conduction can all affect water temperature (Section 5.2). Direct monitoring of the streamflow-water temperature relationship during implementation of the interim IFNs is recommended to validate or refine IFNs during the Summer Juvenile Salmonid Rearing Habitat period.

6.2 IFNs for UPC and LPC Study Sites

6.2.1 *Early Adult Chinook Salmon Upstream Migration: September 7 through September 30*

An mRCT of 1.0 ft, as a threshold for Chinook salmon adult upstream migration, was not observed during our three field site visits at either of these study sites. The closest depth observed was the 12.8 cfs streamflow at the LPC study site, with an mRCT of 0.92 ft (Figure 36), which was measured on May 27, 2010. With the prolific growth of aquatic macrophytes yet to dominate channel hydraulics in May, the mRCT by early-September would be measurably deeper. At the UPC study site, with an mRCT of 0.8 ft, the migration threshold depth for coho salmon and steelhead was surveyed at 9.9 cfs. mRCT depths at similar streamflows (9.9 cfs at UPC study site and 8.1 cfs at LPC study site) were comparable (Figure 36) even though the LPC study site is narrower as a result of evident headcutting and dominated more by submerged and emergent aquatic vegetation.

UPC and LPC Study Sites Minimum Adult Salmon Migration IFN Finding

At the LPC study site, a minimum IFN of 11 cfs to 15 cfs during September 7 through September 30 was assessed for Tier No.1 adult Chinook migration. The minimum IFN for migration was assessed using a threshold depth of mRCT = 1.0 ft and adjusting for a late-summer minimum increase in stage of 0.15 ft (as done at the HIG study site). Streamflows between 11 cfs and 15 cfs may not have occurred in many unimpaired, drier years during September (no unimpaired annual hydrographs have been estimated for Parks Creek) before the autumn rains arrived. For coho salmon and steelhead trout, using a threshold mRCT of 0.8 ft, the minimum IFN for adult upstream migration would be 8 cfs to 10 cfs (again adjusting for aquatic macrophyte effects observed at the LPC study site). A minimum IFN range of 11 cfs to 15 cfs provides Tier No.1 adult Chinook migration at both Parks Creek study sites.

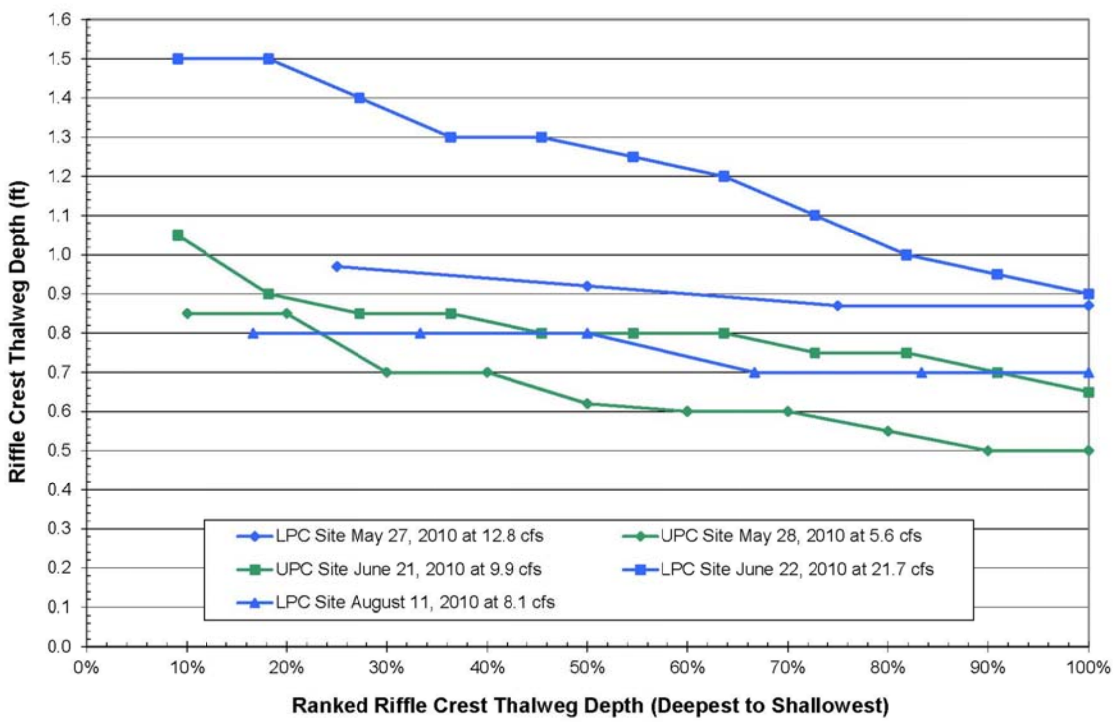


Figure 36. Ranked riffle crest thalweg depths (RCT) at UPC and LPC study sites.

6.2.2 Adult Salmon Spawning and Migration UPC: October 1 - December 3 (8 weeks)

<u>Regional Regression Methods</u>

IFNs were computed for spawning salmonids (Chinook, Steelhead, All Species Pooled) using the regional regression methods of Swift (1976, 1979) and Hatfield and Bruce (2000) (Table 8). Based on our site-specific evaluations at the UPC study site and LPC study site, the regional regression predictions were too high as minimum IFNs (i.e., 66 cfs for Chinook (Hatfield and Bruce 2000), 92 cfs for Chinook (Swift 1979), and 51 cfs for coho (Swift 1979)), and likely too high as contemporary optimum spawning flows because the available spawning habitat at these sites achieved depth and velocity criteria at lower flows.

DHM Spawning Habitat and RCTs

Spawning habitat polygons were mapped at three streamflows (8.1 cfs, 12.8 cfs, and 21.7 cfs) in the LPC study site and at two streamflows (5.6 cfs and 9.9 cfs) in the UPC study site. The sum of the polygons in LPC, representing the total spawning habitat available, was too limited to establish a quantitative relationship between streamflow and spawning habitat area (e.g., only 120 ft^2 of total spawning habitat was mapped at 21.7 cfs). In the UPC study site, only two relatively low streamflows were available for habitat mapping. However, total spawning polygon area almost doubled between 5.6 cfs and 9.9 cfs (327 ft^2 up to 621 ft^2, respectively). The mRCT at 9.9 cfs was 0.8 ft in the UPC study site, which would be marginally sufficient to maintain spawning depths upstream in the pool/run tails. Spawning polygons at 9.9 cfs were beginning to occupy most of the spawnable substrate area present in the UPC study site's pool and run tails (Figure 37). Higher streamflows would provide more spawning habitat, but the rate of increase would decline as flows increase.

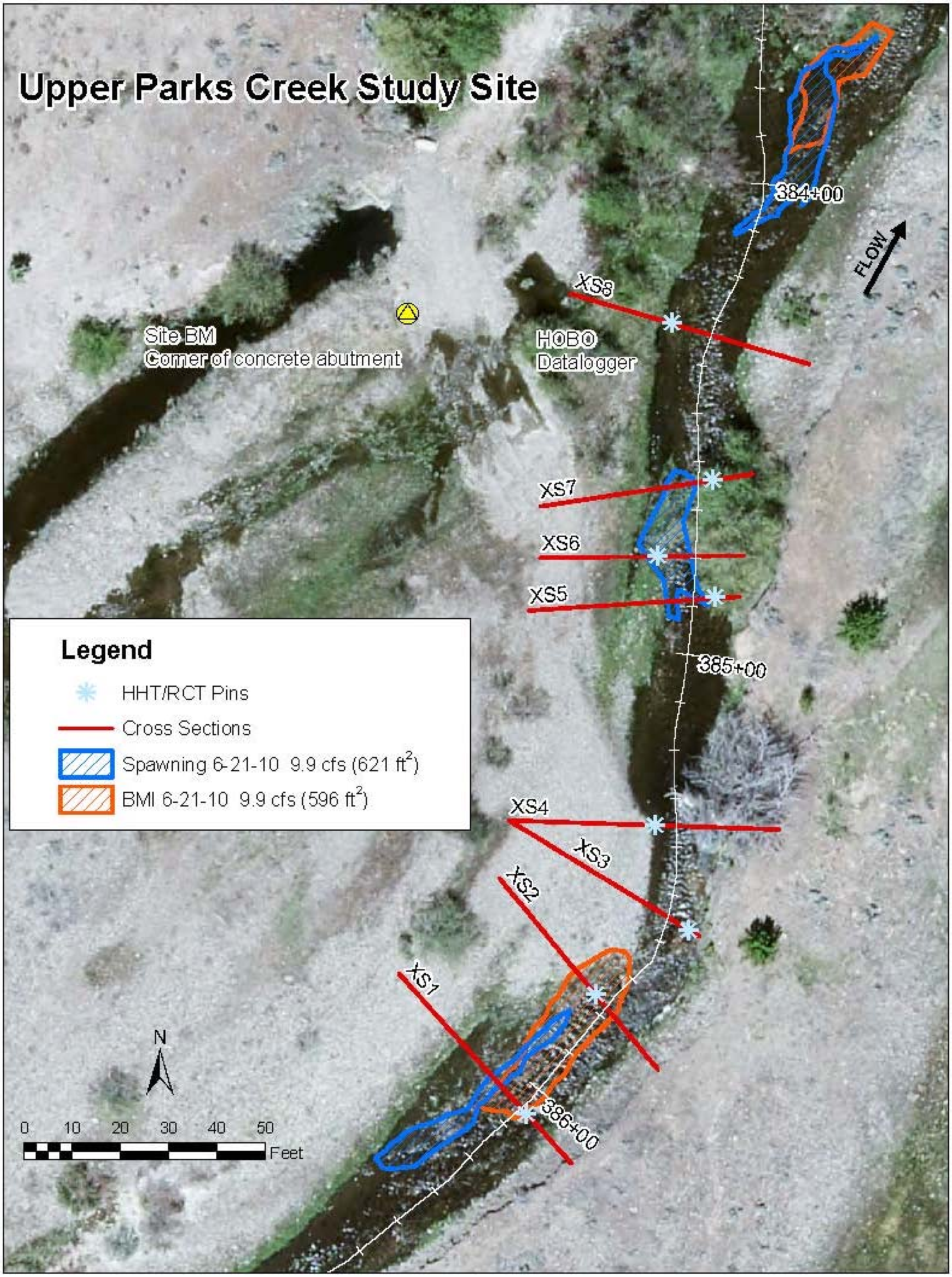


Figure 37. DHM polygons for salmonid spawning habitat and BMI riffle habitat in the UPC study site mapped on June 21, 2010, at 9.9 cfs.

UPC/LPC Study Site Salmon Spawning and Migration Minimum IFN Finding

For the Parks Creek mainstem channel, a minimum IFN of 10 cfs provides Tier No.1 salmonid spawning habitat based on the DHM polygons occupying most of the available spawnable streambed at 9.9 cfs. Adult migration IFNs would be the same as those presented in Section 6.2.1, i.e., 11 cfs to 15 cfs.

6.2.3 Juvenile Salmonid Winter Rearing: January 1 - March 31 (12 weeks)

Regional Regression Methods

The UPC and LPC study sites could become important fry and juvenile rearing habitats in the Big Springs Complex. IFNs were computed for rearing juvenile salmonids using the established regional regression methods. For 'all species', the Hatfield and Bruce (2000) method predicted fry and juvenile rearing IFNs of 12 cfs and 27 cfs. Swift (1979) predicted 21 cfs for juvenile salmonid rearing (Table 20).

Table 20. 'Optimal' streamflows for fry and juvenile salmonid rearing habitat at the UPC and LPC Study Sites predicted from regional regression methods by Swift (1979) and Hatfield and Bruce (2000).

	HATFIELD-BRUCE (2000)						SWIFT (1979)
	Chinook (cfs)		Steelhead (cfs)		All Species (cfs)		All Species (cfs)
	Fry	Juv	Fry	Juv	Fry	Juv	Rearing
Reach No. 2A: Upper Parks Creek (UPC) site	4	18	12	33	12	27	21
Reach No. 2C: Lower Parks Creek (LPC) site	6	24	16	39	15	33	27

Standard Setting Methods

IFNs were computed for each riffle cross section using the standard setting methods and were then averaged for each site (Table 21). This step followed the approach described by Swift (1979), in which the preferred rearing discharge is selected at the center point with the highest curvature in the WP-discharge relationship. Several cross sections had WP rating curves with breakpoints that were vague and thus the qualitative visual determination was inexact. Using the WP method, predicted IFNs for fry/juvenile rearing was less than 5 cfs at both the LPC and UPC study sites (Figure 38). Using the R2 Cross method with the application of 0.3 ft depth and 1.0 ft/sec velocity criteria, IFNs for fry/juvenile rearing habitat were 8 cfs and 7 cfs at the at the LPC site and UPC site, respectively. Applying the incipient asymptote instead of the breakpoint, the WP method predicted an IFN for juvenile rearing habitat between 9 cfs and 18 cfs (Figure 38 and Table 21).

Table 21. Instream Flow Needs (in cfs) for fry and juvenile rearing calculated from the Wetted Perimeter (WP) "Breakpoint" and "Incipient Asymptote" and R2 Cross methods for the UPC and LPC Study Sites. Blank cells indicate data is unavailable.

Site	Unit	WP "Breakpoint" (cfs)	WP "Incipient Asymptote" (cfs)	R2 Cross 0.3ft, 1.0 ft/s (cfs)
LPC site Cross Section No.				
2	Riffle	5	13	10
3	Riffle	6	17	6
5	Riffle	4	21	9
7	Riffle	4	22	7
	Average	**5**	**18**	**8**
UPC Site Cross Section No.				
1	Pool-Tail	5	13	6
2	Riffle	4	10	
3	Riffle	4	13	8
5	Riffle	1	9	9
6	Riffle	1	14	5
	Average	**3**	**12**	**7**

HHTs on cross sections and Longitudinal Velocity Profiles

HHTs were evaluated for the UPC study site at eight pool and riffle cross sections (Figure 37). HHTs were not met for riffles or pools at 5.6 cfs, but were achieved in the riffles and almost achieved in the pools at 9.9 cfs. In the LPC study site, eight pool and riffle cross sections also were evaluated (Figure 39). HHTs were not met for the riffle or pool cross sections at 8.1 cfs, but were achieved at 12.8 cfs.

Differences were evident in channel hydraulics and juvenile rearing habitat quality and abundance between the LCP and UPC site (Figure 40, Figure 41). A significantly more pronounced higher velocity core passed through the pool, with riffle velocities significantly faster and more turbulent at 9.9 cfs than at 5.6 cfs. The pool at 9.9 cfs would have predictably greater diversity and abundance of fry, juvenile, and smolt rearing habitat, as well as more productive BMI riffle habitat. Similarly, significant differences in habitat availability and quality were evident at the LPC site (Figure 42-Figure 44). The channel was considerably more complex hydraulically at 12.8 cfs in May (Figure 42) than at 8.1 cfs in August (Figure 44). At 21.7 cfs, the deeper, faster streamflow inundating the coarse channel bed would provide high quality habitat for older juveniles and smolts (Figure 43).

A longitudinal velocity profile was surveyed through the pools in both the UPC (Figure 45) and LPC (Figure 46) study sites. The UPC pool velocity profile did not exceed the HHT of 0.5 ft/sec at 5.6 cfs, but it did exceed this threshold at 9.9 cfs (Table 22). The LPC pool velocity profile was approximately at the HHT threshold of 0.5 ft/sec with streamflows of 8.1 cfs and 12.8 cfs (Figure 43).

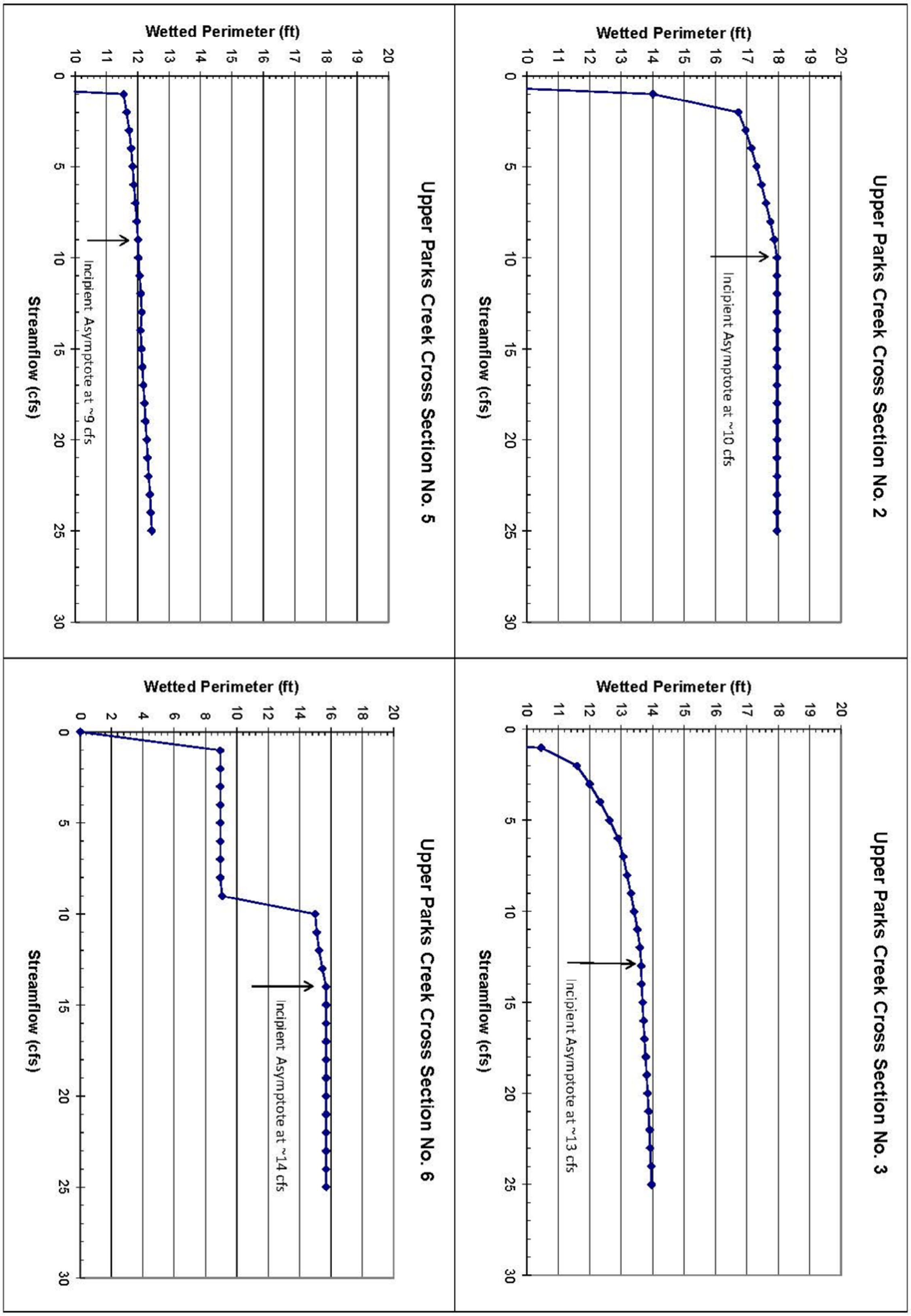


Figure 38. WP curves with incipient asymptote at four cross sections within the UPC study site.

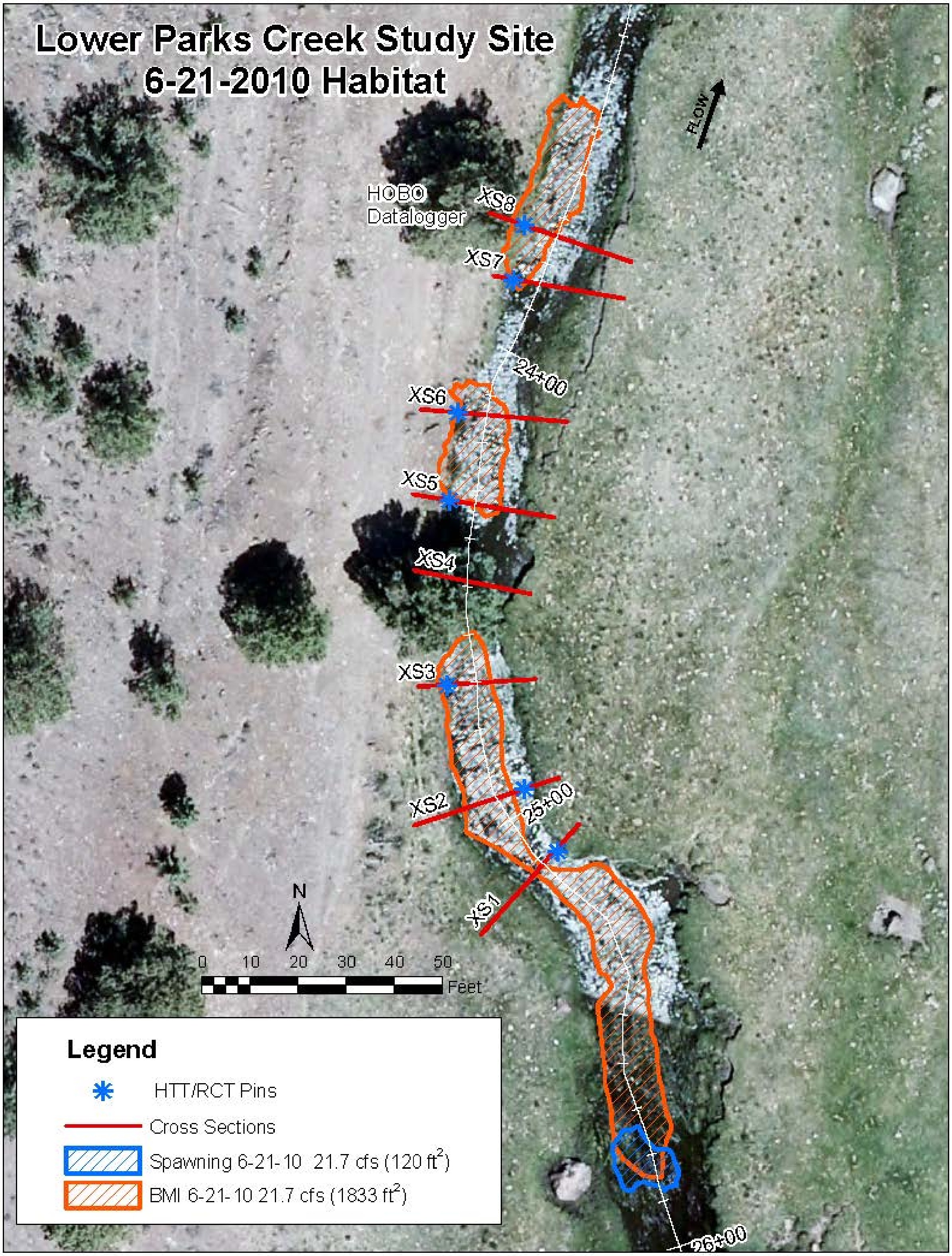


Figure 39. LPC study site with BMI and spawning habitat polygons mapped at 21.7 cfs on June 21, 2010.

Table 22. Summary of average and maximum water depths and velocities determined for cross sections in the UPC and LPC study sites.

	Cross Section	Unit	Average Depth (ft)	Maximum Depth (ft)	Average cross section Velocity (ft/s)	Maximum cross section Velocity (ft/s)
UPC study site	1	Pool-Tail	0.40	0.85	0.52	1.38
5/27/2010	2	Riffle	0.19	0.40	1.22	2.86
Q = 5.6 cfs	3	Riffle	0.40	0.60	0.68	1.71
	4	Pool	1.36	2.60	0.14	0.94
	5	Riffle	0.43	0.75	0.61	1.01
	6	Riffle	0.27	0.60	0.85	2.23
	7	Riffle-tail	0.28	1.20	0.56	3.34
	8	Pool	0.57	1.00	0.34	0.81
UPC study site	1	Pool-Tail	0.52	0.80	0.95	1.63
6/22/2010	2	Riffle	0.29	0.50	2.12	3.37
Q = 9.9 cfs	3	Riffle	0.53	0.70	1.65	2.76
	4	Pool	1.53	2.90	0.37	1.17
	5	Riffle	0.63	0.95	1.20	1.81
	6	Riffle	0.34	0.60	1.62	2.85
	7	Riffle-tail	0.40	1.40	0.79	3.77
	8	Pool	0.79	1.10	0.60	1.42
LPC study site	1	Run	1.05	1.70	0.79	2.27
5/27/2010	2	Riffle	0.73	1.20	0.99	1.84
Q = 12.8 cfs	3	Riffle	0.76	1.20	1.28	2.58
	4	Pool	1.21	1.80	0.51	1.34
	5	Riffle	0.70	1.20	1.18	2.12
	6	Pool	0.79	1.40	0.84	1.73
	7	Riffle	0.79	1.30	1.13	2.96
	8	Run	0.68	1.10	1.07	2.63
LPC study site	1	Run	0.98	1.80	1.35	2.67
6/22/2010	2	Riffle	0.78	1.40	1.41	2.29
Q = 21.7 cfs	3	Riffle	0.79	1.30	1.93	3.24
	4	Pool	1.36	1.90	0.79	1.31
	5	Riffle	0.81	1.00	1.70	2.57
	6	Pool	0.91	1.40	1.24	1.94
	7	Riffle	0.87	1.20	1.69	3.48
	8	Run	0.72	1.00	1.45	3.53
LPC study site	1	Run	0.87	1.50	0.63	1.90
8/11/2010	2	Riffle	0.61	1.00	0.67	1.64
Q = 8.1 cfs	3	Riffle	0.55	1.00	1.35	2.50
	4	Pool	0.97	1.55	0.40	1.05
	5	Riffle	0.52	0.90	1.02	1.76
	6	Pool	0.53	1.10	0.86	2.08
	7	Riffle	0.57	0.95	0.83	2.23
	8	Run	0.44	0.80	0.84	2.16

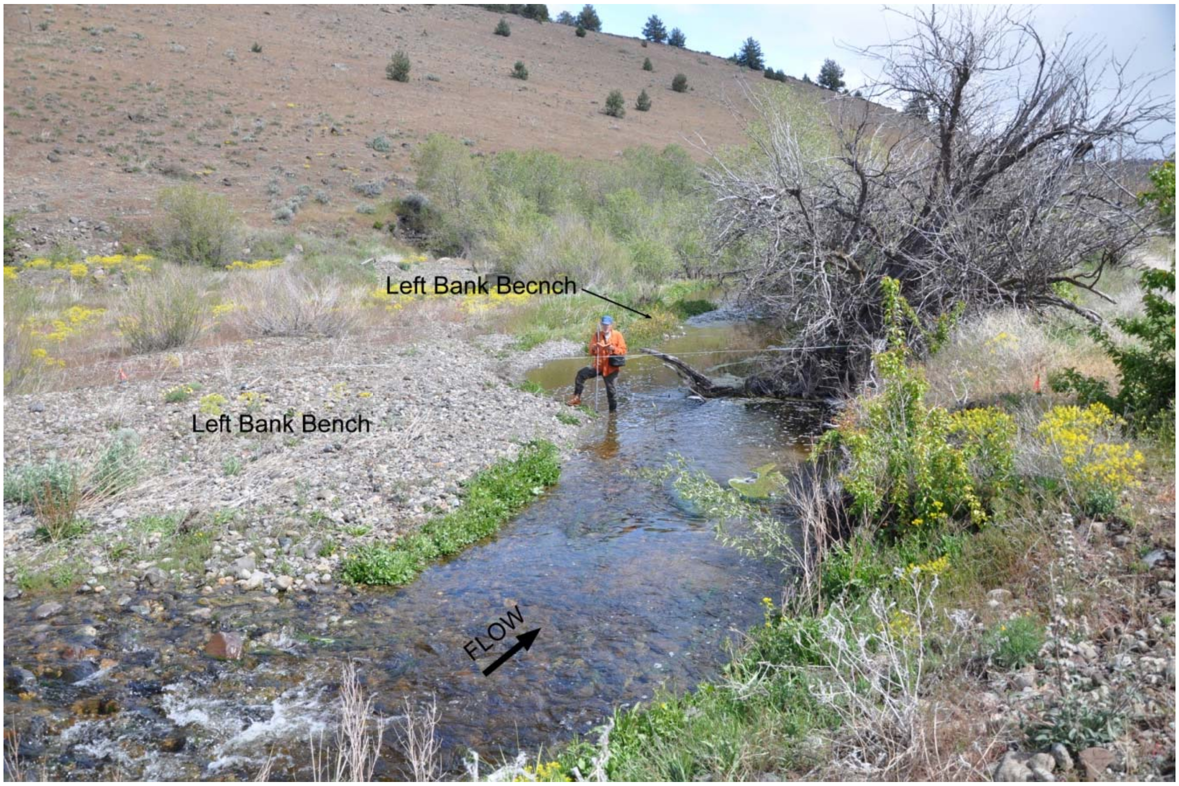


Figure 40. UPC study site looking downstream. Photograph taken May 25, 2010, at 5.6 cfs.

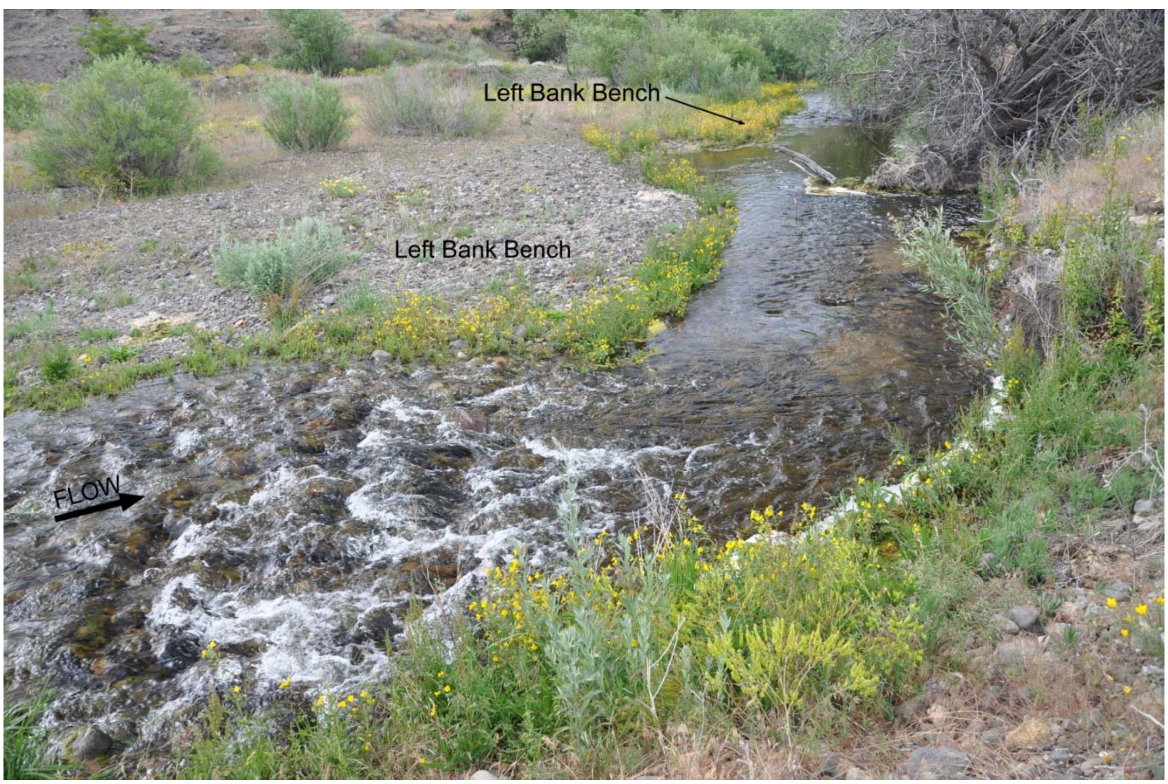


Figure 41. UPC study site looking downstream. Photograph taken June 22, 2010, at 9.9 cfs.

Figure 42. LPC study site looking upstream. Photograph taken May 25, 2010, at 12.8 cfs.

Figure 43. LPC study site looking upstream. Photograph taken June 21, 2010, at 21.7 cfs.

Figure 44. LPC study site looking upstream. Photograph taken August 10, 2010, at 8.1 cfs.

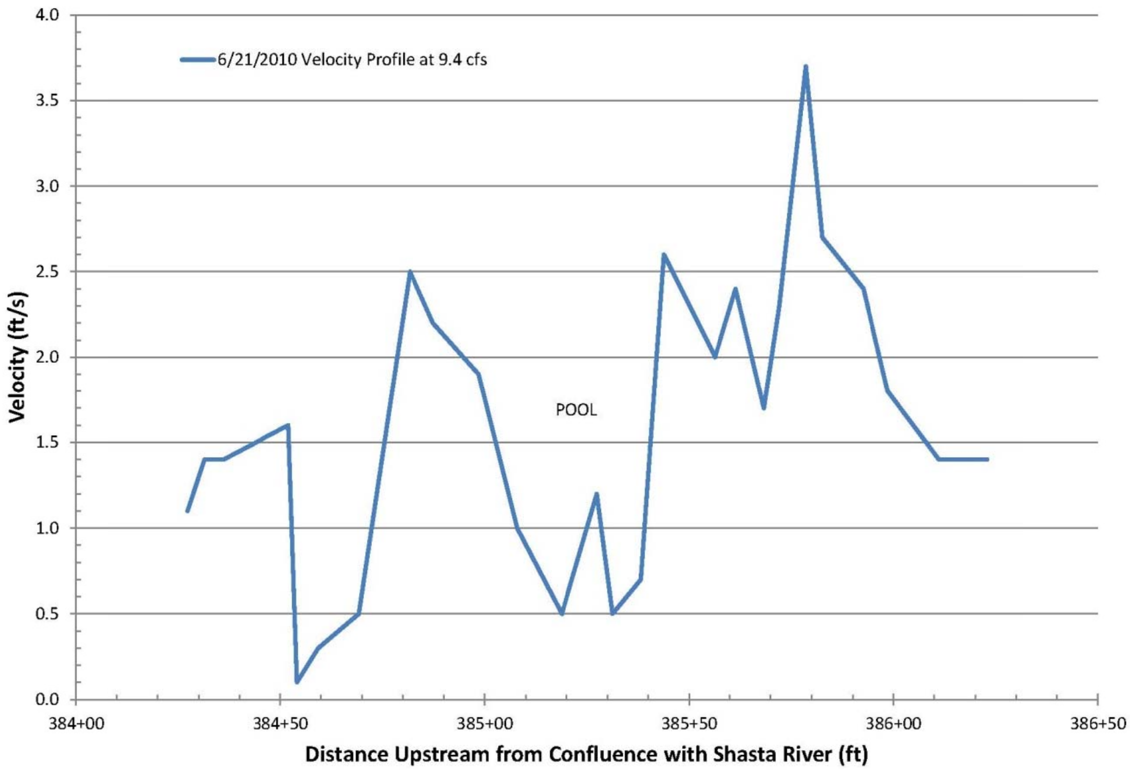


Figure 45. Mean column velocities (ft/sec) along the thalweg of the UPC study site.

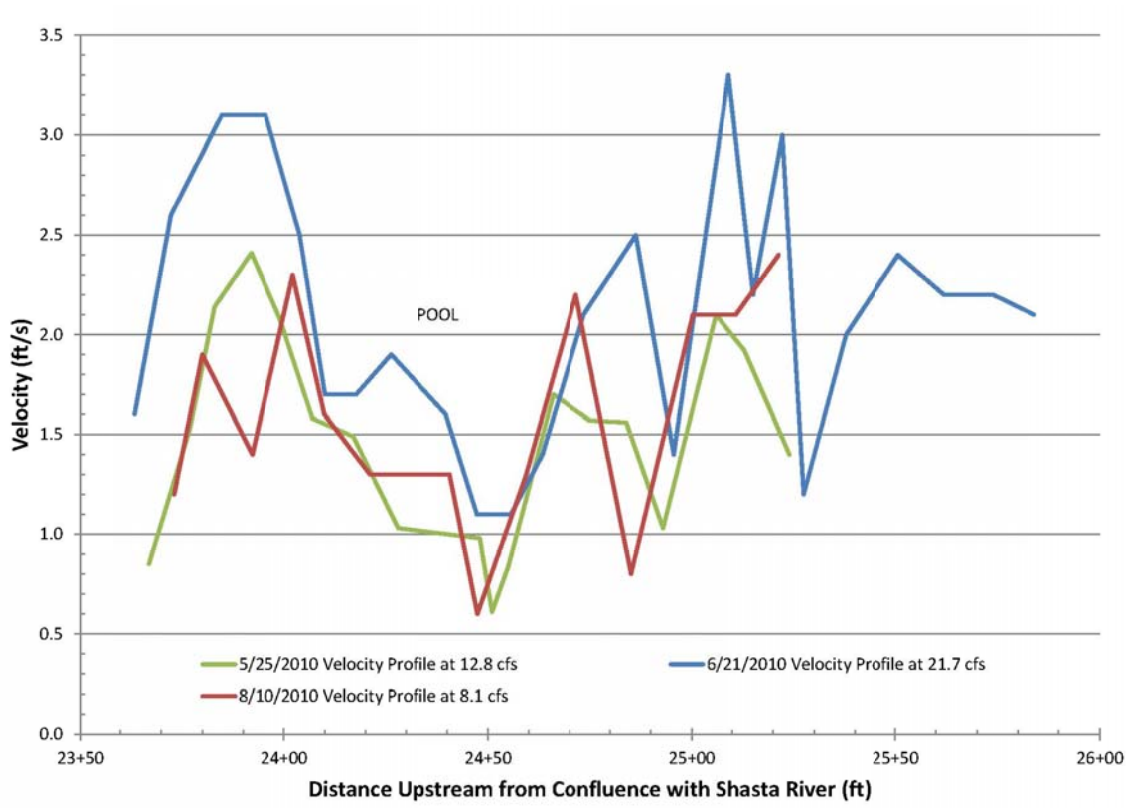


Figure 46. Mean column velocities (ft/sec) along the thalweg of the LPC study site.

UPC and LPC Study Sites Juvenile Salmonid Winter Rearing Minimum IFN Finding

A minimum IFN of 10 cfs and 12 cfs would provide Tier No.1 winter juvenile salmonid rearing habitat at the UPC and LPC study sites, respectively. Both estimates were based on the HHTs for pool and riffle cross sections presented in Table 22. As a comparison, WP incipient asymptote riffle assessments at LPC and UPC ranged from 9 cfs to 14 cfs and 13 cfs to 22 cfs, respectively (Table 21).

6.2.4 Spring Snowmelt Pulse: Stream Productivity and Smolt Outmigration between April 1 and June 15

Bench/Bar Inundation Thresholds

The UPC site has a left bank bench, which can be seen on the right-hand side, foreground of the photograph taken at the site (Figure 47). This bench would require an additional 0.15 ft minimum stage increase above the stage height for the 9.9 cfs streamflow observed (Figure 41), to begin inundation. Evaluation of photographs taken May 25, 2010, at 5.6 cfs (Figure 40 and Figure 47), June 22, 2010, at 9.9 cfs (Figure 41), and April 22, 2011, at an estimated streamflow in excess of 25 cfs (Figure 48), produced an estimated inundation threshold equivalent to a 20 cfs to 25 cfs streamflow.

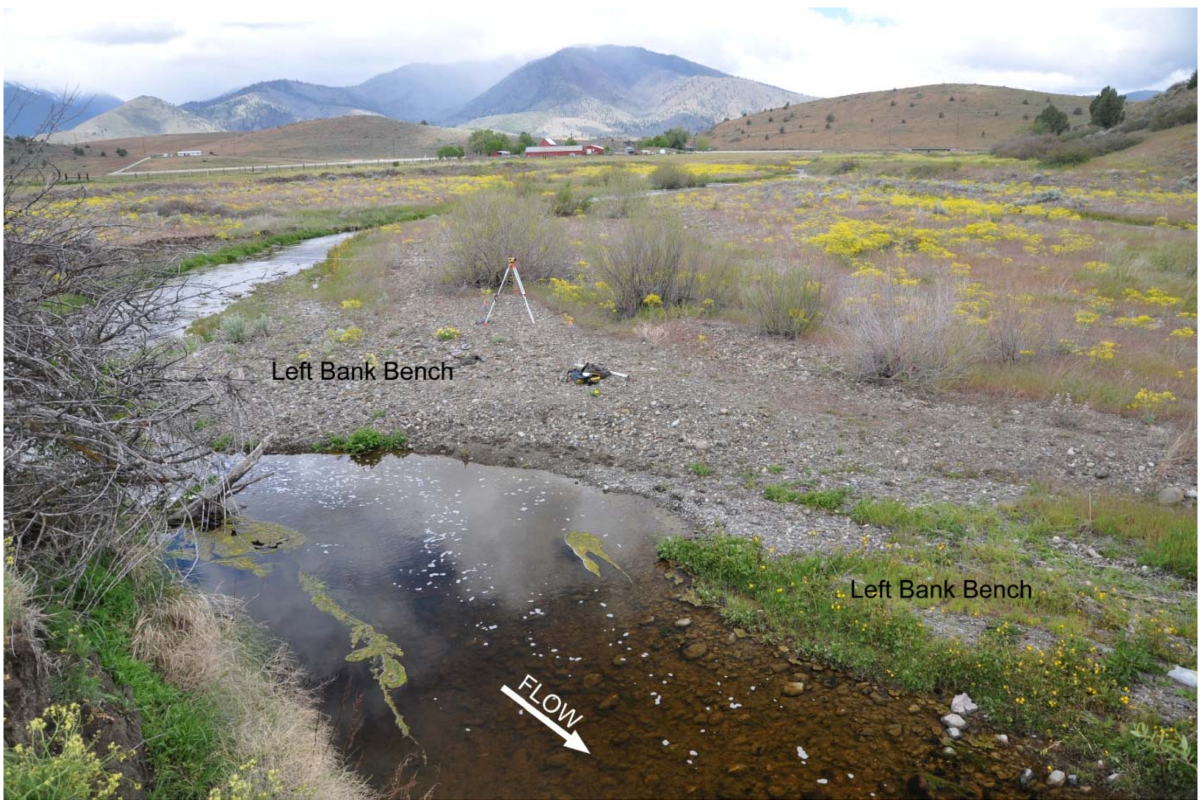


Figure 47. UPC study site looking upstream, with a prominent bench adjacent to the pool (left bank foreground). Photograph taken May 25, 2010, at 5.6 cfs.

Figure 48. UPC study site looking from left to right bank. Photograph taken from left bank bar shown in foreground of Figure 47 on April 22, 2011, by Bill Chesney CDFW (streamflow ungaged).

HHT for Large Juvenile Salmonid Rearing and Smolt Outmigration

A longitudinal velocity profile through the pool's thalweg in the LPC study site was below the 1.5 ft/sec threshold for Tier No.1 smolt habitat (Figure 39) at 21.7 cfs, and exceeded 1.0 ft/sec in the pool's deepest section. The longitudinal velocity profile in UPC study site at the highest streamflow measured (9.9 cfs) also was below the HHT of 1.5 ft/sec for smolt habitat.

Productive BMI Riffle Habitat

Productive BMI Habitat in the LPC study site ranged from 809 ft^2 at 12.8 cfs up to 1,834 ft^2 at 21.7 cfs (Figure 39). BMI polygons occupied more than 90% of the available riffle substrate at 21.7 cfs.

UPC and LPC Study Sites Spring Snowmelt Pulse Minimum IFN Finding from Physical Habitat

For both sites, a minimum IFN of 20 cfs to 25 cfs would improve smolt rearing habitat and increase stream productivity during the snowmelt runoff period. A compelling finding leading to this recommendation was the BMI riffle habitat polygons occupying more than 90% of the available LPC riffle-bed at 21.7 cfs. 'Snowmelt' IFNs for Parks Creek could be similar to those appropriate for the HIG site above the Parks Creek confluence, if the present post-dam channel morphology remains the same. The 20 cfs to 25 threshold streamflow targets bench inundation (Tier No. 1), not inundation depths required to create abundant and high quality bench and side-channel habitat.

UPC and LPC Study Site Water Temperature Modeling Scenarios, Results and Implications for IFNs for the Spring Pulse and Smolt Outmigration Period (April1 – June 15)

Table 23 shows the four water temperature modeling scenarios developed for Parks Creek during the Summer Juvenile Salmonid Rearing Habitat period. The scenarios include both *spring flow* and *mixed flow* boundary conditions and the 90th and 50th percentile warming days for each IFN period are modeled (See Sections 5.2.2 and 5.2.3 for a discussion of modeling scenarios and exceedence days).

*Table 23. Water temperature modeling scenarios for Parks Creek. K represents the exceedence day and * represents a model boundary location.*

Time	Scenario	K	Date	$Q_{PRKSC1*}$	$Q_{bridgefield*}$	$Q_{Black Meadow*}$	Q_{PRKSC2}	$Q_{kettle*}$	Q_{PRKSC3}
4/1-6/15	*Spring*	*90%*	*4-22*	11	3.2	0.8	15	7	22
4/1-6/15	*Spring*	*50%*	*4-18*	11	3.2	0.8	15	7	22
4/1-6/15	*Mixed*	*90%*	*4-22*	16.5	1.6	0.4	18.5	3.5	22
4/1-6/15	*Mixed*	*50%*	*4-18*	16.5	1.6	0.4	18.5	3.5	22

Modeled water temperatures indicate that the recommended Spring Pulse and Smolt Outmigration IFN for Parks Creek (22 cfs) is likely to satisfy identified water temperature criteria, under either *spring flow* (Figure 49 and Figure 50) or *mixed flow* (Figure 51 and Figure 52) scenarios. On the warmest (90%) days is spring modeled daily maximum water temperatures never exceed 19° C during either scenario. The modeling results suggest that the April 1st to June 15th IFNs could provide thermally suitable rearing habitat, though the extent and distribution of this habitat may vary depending on year-type and regional water use strategies. The temperature model suggest that the thermal effect of spring flow (Bridgefield, Black meadow and Kettle) on mainstem water temperatures is relatively much smaller during April 1st to June 15th period than it is during the summer months (compare Figure 49 - Figure 52 with Figure 55 - Figure 58) due to the cooler mainstem boundary conditions in spring. This does not diminish the value of springs to rearing coho. As in the Shasta River above Parks, modeling results support the recommend IFNs for the Spring Pulse and Smolt Outmigration in Parks Creek.

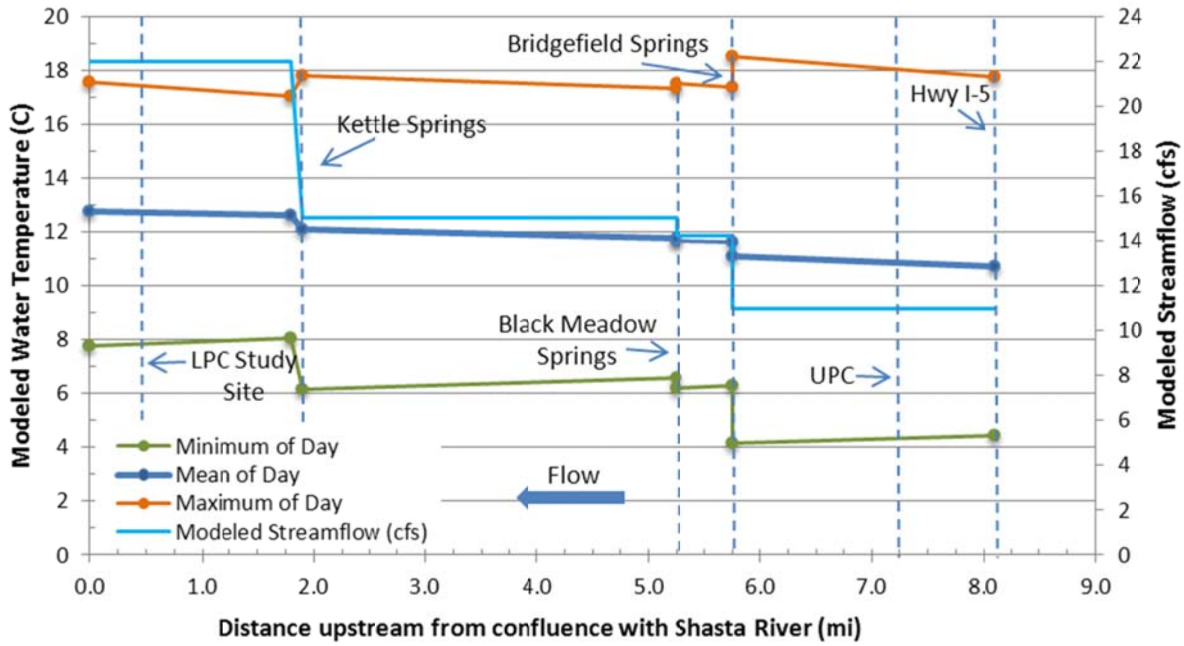


Figure 49. Modeled water temperatures for the 90% exceedence day of the April 1 to June 15 IFN; Parks Creek; spring flow scenario.

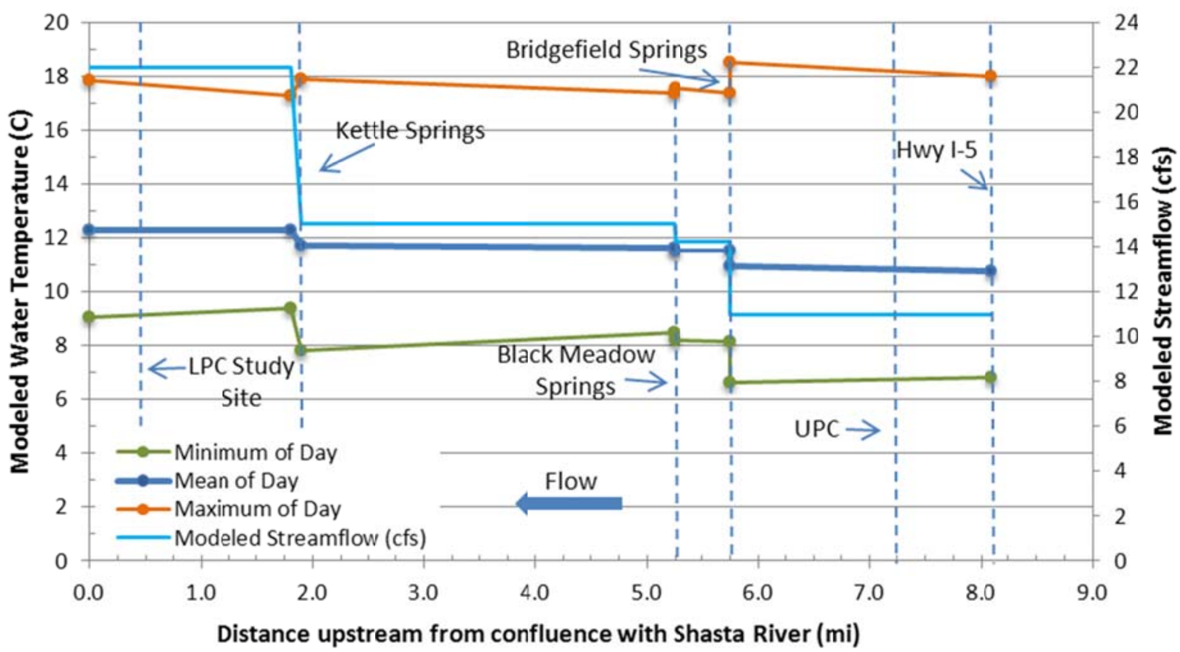


Figure 50. Modeled water temperatures for the 50% exceedence day of the April 1 to June 15 IFN; Parks Creek; spring flow scenario.

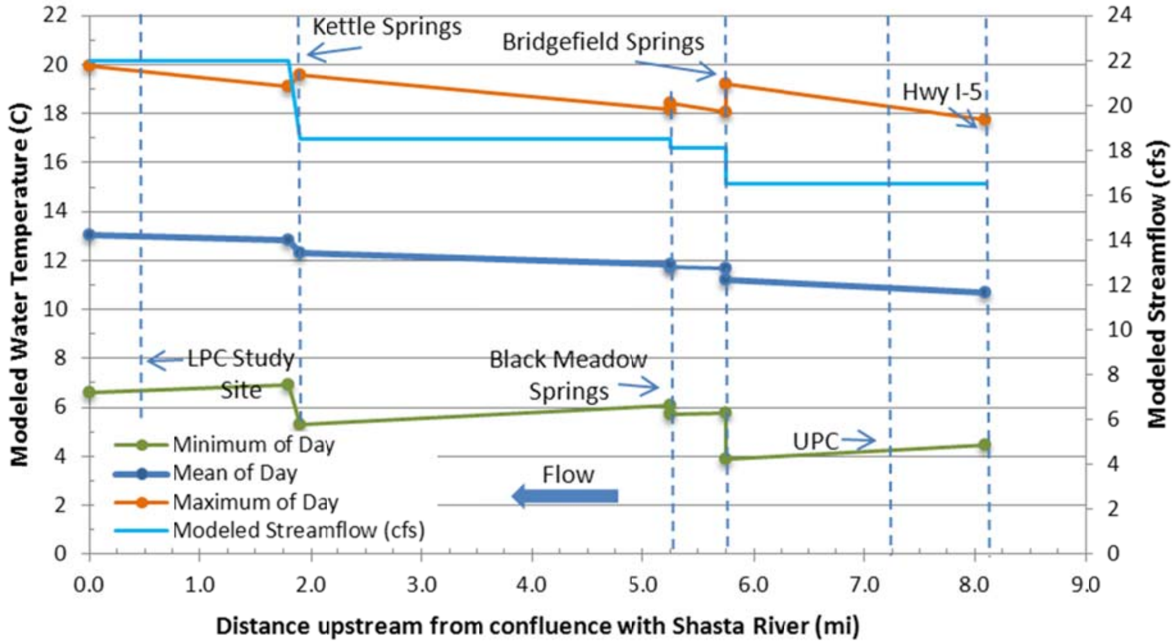


Figure 51. Modeled water temperatures for the 90% exceedence day of the April 1 to June 15 IFN; Parks Creek; mixed flow scenario.

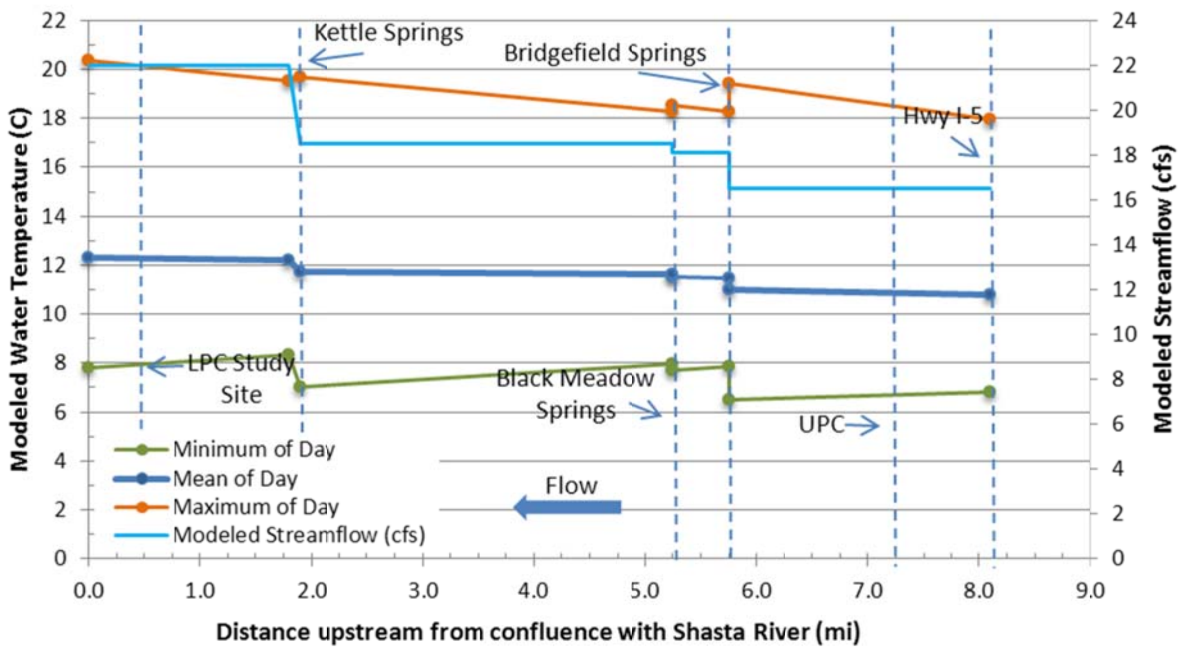


Figure 52. Modeled water temperatures for the 50% exceedence day of the April 1 to June 15 IFN; Parks Creek; mixed flow scenario.

6.2.5 Juvenile Salmonid Summer Rearing: June 16 - September 6 (11 weeks)

For physical habitat needs, the minimum IFN for juvenile salmonid rearing habitat for summer would be the same as the suggested 10 cfs to 12 cfs winter rearing minimum IFN. By late-June 2010, observed water temperatures in UPC were already exceeding 22^0C (Figure 53), while in LPC water temperatures were exceeding 22^0C by mid-June (Figure 54).

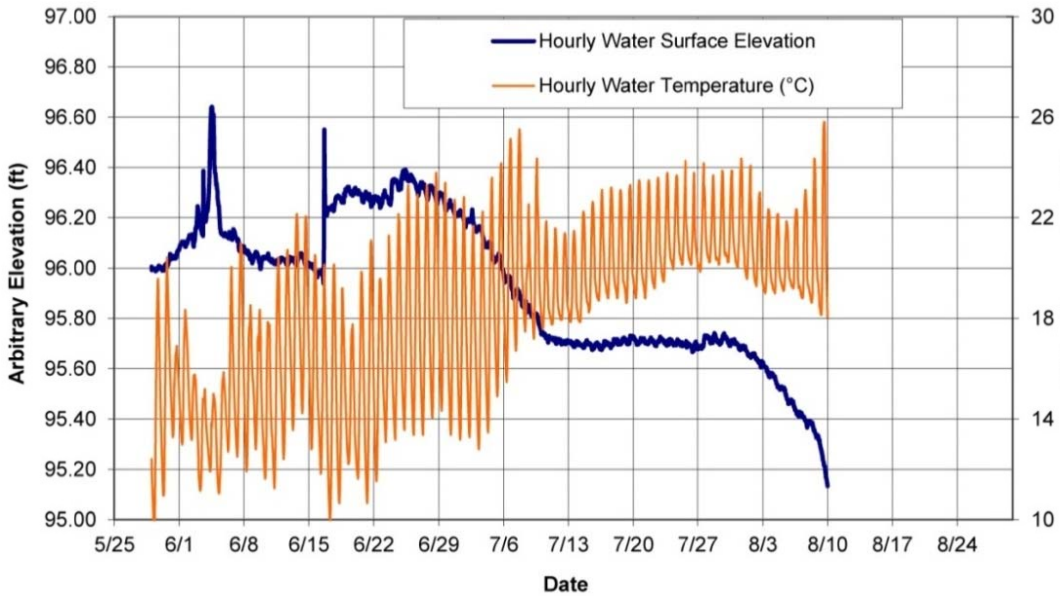


Figure 53. Water temperatures and hourly water surface elevations in 2010 at the UPC study site.

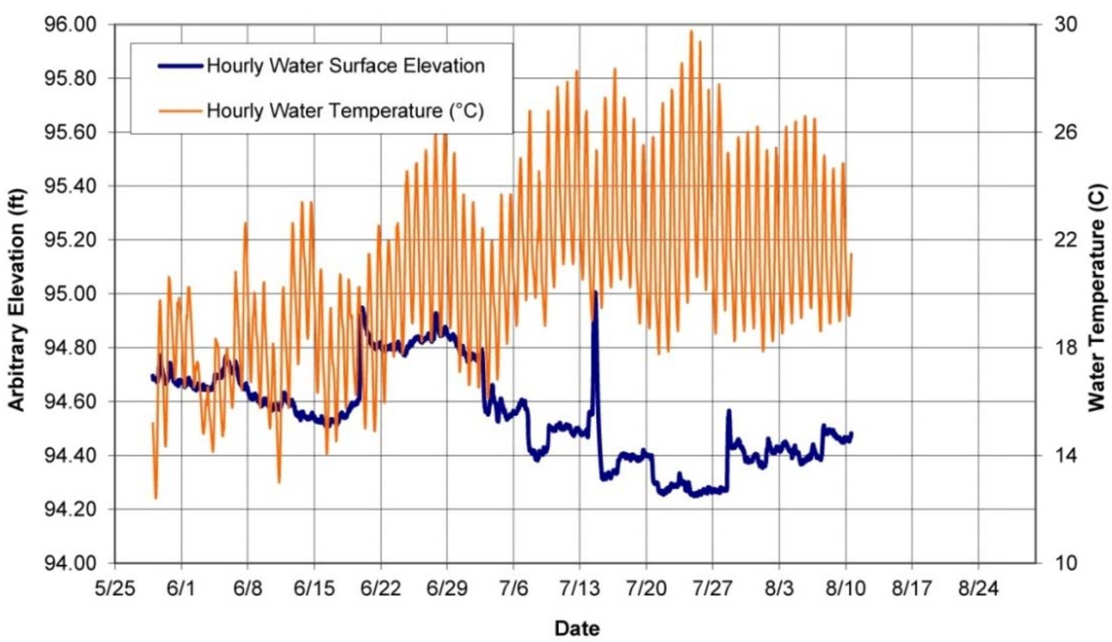


Figure 54. Water temperatures and hourly water surface elevations in 2010 at the LPC study site.

UPC and LPC Study Site Water Temperature Modeling Scenarios, Results and Implications for IFNs for the Summer Juvenile Rearing Period (June 16 – September 6)

Table 24 shows the water temperature modeling scenarios developed for developed for Parks Creek during the Summer Juvenile Salmonid Rearing Habitat period. The scenarios include both *spring flow* and *mixed flow* boundary conditions and the 90th and 50th percentile warming days for each IFN period are modeled (see Sections 5.2.2 and 5.2.3 for a discussion of modeling scenarios and exceedence days).

*Table 24. Water temperature modeling scenarios for Parks Creek. K represent the exceedence day and * represent a model boundary location.*

Time	Scenario	K	Date	$Q_{PRKSC1*}$	$Q_{bridgefield*}$	$Q_{Black\ Meadow*}$	Q_{PRKSC2}	$Q_{kettle*}$	Q_{PRKSC3}
6/16-9/6	*Spring*	*90%*	*8-16*	1	3.2	0.8	5	7	12
6/16-9/6	*Spring*	*50%*	*7-11*	1	3.2	0.8	5	7	12
6/16-9/6	*Mixed*	*90%*	*8-16*	6.5	1.6	0.4	8.5	3.5	12
6/16-9/6	*Mixed*	*50%*	*7-11*	6.5	1.6	0.4	8.5	3.5	12

Modeled water temperatures indicate that for the summer rearing IFN on Parks Creek (10 to 12 cfs) the majority of the mainstem habitat is not suitable for coho rearing, under the *spring flow scenario* on the warmest (90%) or even median (50%) exceedence days (Figure 55 and Figure 56 respectively). The spring creek tributaries, and specifically habitat near spring sources have been identified as valuable over-summering habitat for juvenile coho (Chesney 2009), and the modeling results suggest that spring flows may provide limited instream benefit to mainstem water temperatures. However, due to rapid warming in the mainstem, these tributaries are not likely to cool mainstem water in lower Parks Creek enough to provide suitable mainstem rearing habitat (the potential off-channel benefit of the springs was beyond the scope of this project).Therefore, a streamflow that meets the requirements of physical habitat in lower Parks Creek is not likely to benefit a mainstem coho rearing strategy because water temperatures already limit mainstem rearing habitat.

Juvenile fish are known to migrate between mainstem and spring sources during the summer months, likely in response to temperature (Chesney 2009). If valuable off channel spring creek habitat is maintained, reducing the summer LPC IFN to a streamflow which supports juvenile access to spring creeks, and minimal mainstem habitat (e.g. 7-8 cfs as supported by the R2 Cross results), would increase the thermal benefit of spring sources by decreasing thermal mass of mainstem flow, and decreases the impact of a large block of warm water on downstream rearing habitat (e.g. below Parks Creek and Big Springs Creek). In addition, summer mainstem flow from Parks Creek upstream of Bridgefield Springs is very warm (e.g. Figure 55). Therefore, to reduce the thermal impact of warm water on downstream spring-mainstem confluence locations, while maintaining aquatic habitat for non-salmonid species, the recommend summer rearing IFN for UPC is reduced to 2 cfs based on the breakpoint of the WP curves for this reach (Figure 36)

Comparing the summer time *spring flow* (Figure 55 and Figure 56) and *mixed flow* (Figure 57 and Figure 58) scenarios, indicates the value of spring creeks may have on thermal conditions. Although modeling results suggest that spring creeks are not able support good thermal conditions in downstream mainstem habitat, they may significantly reduce daily maximum water temperatures near spring creek-mainstem confluence locations. Therefore, protecting spring flow sources and spring-mainstem confluence habitat is supported as an important restoration objective by the water temperature modeling results. Further modeling is needed to fully address the effect of spring creeks on mainstem temperatures and to thermal conditions within spring creeks themselves. Note that for this analysis, thermal conditions in spring creeks were not modeled, but rather spring sources were used as a boundary condition to the mainstem water temperature model (see discussion in Section 5.2.4).

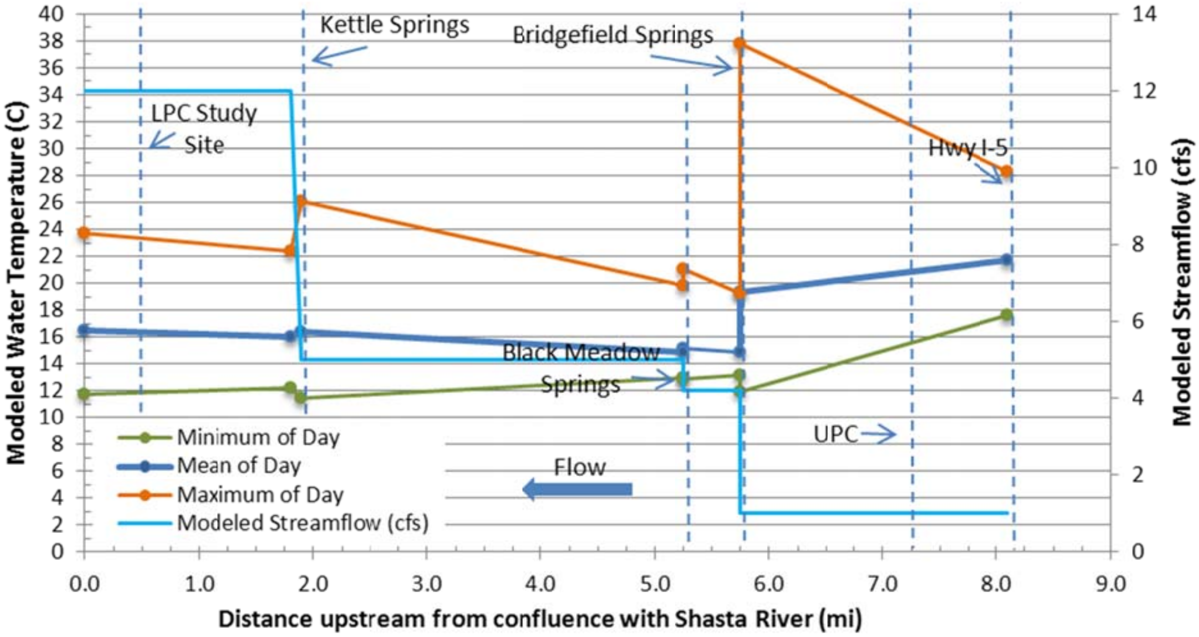


Figure 55. Modeled water temperatures for the 90% exceedence day of the June 16 to September 6 IFN; Parks Creek; spring flow scenario.

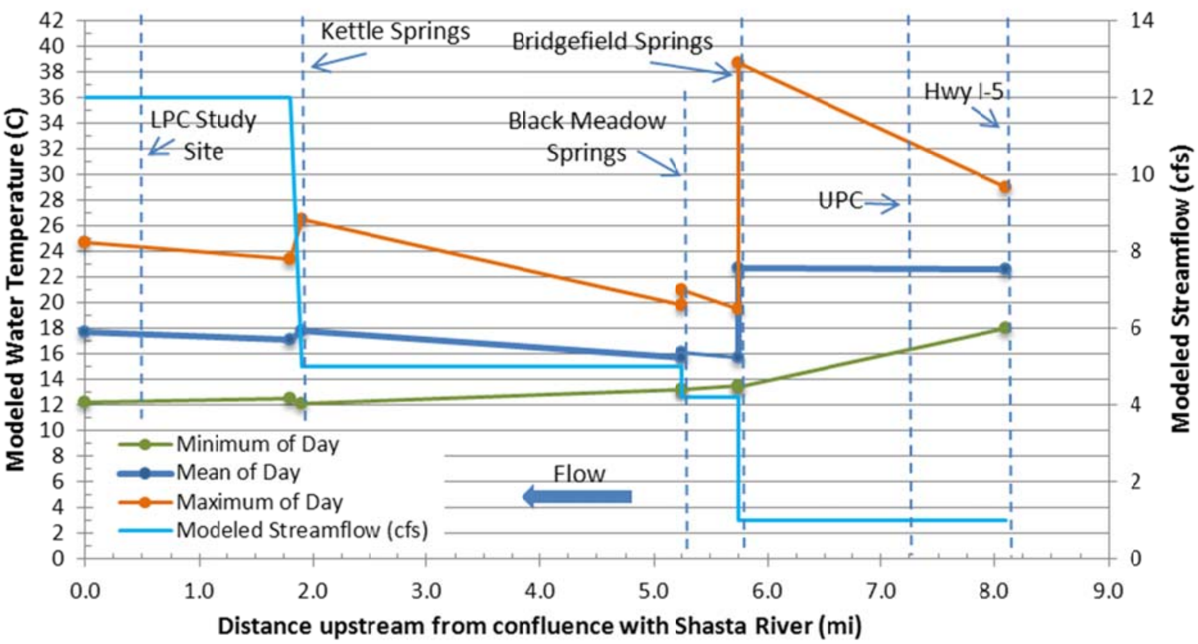


Figure 56. Modeled water temperatures for the 50% exceedence day of the June 16 to September 6 IFN; Parks Creek; spring flow scenario.

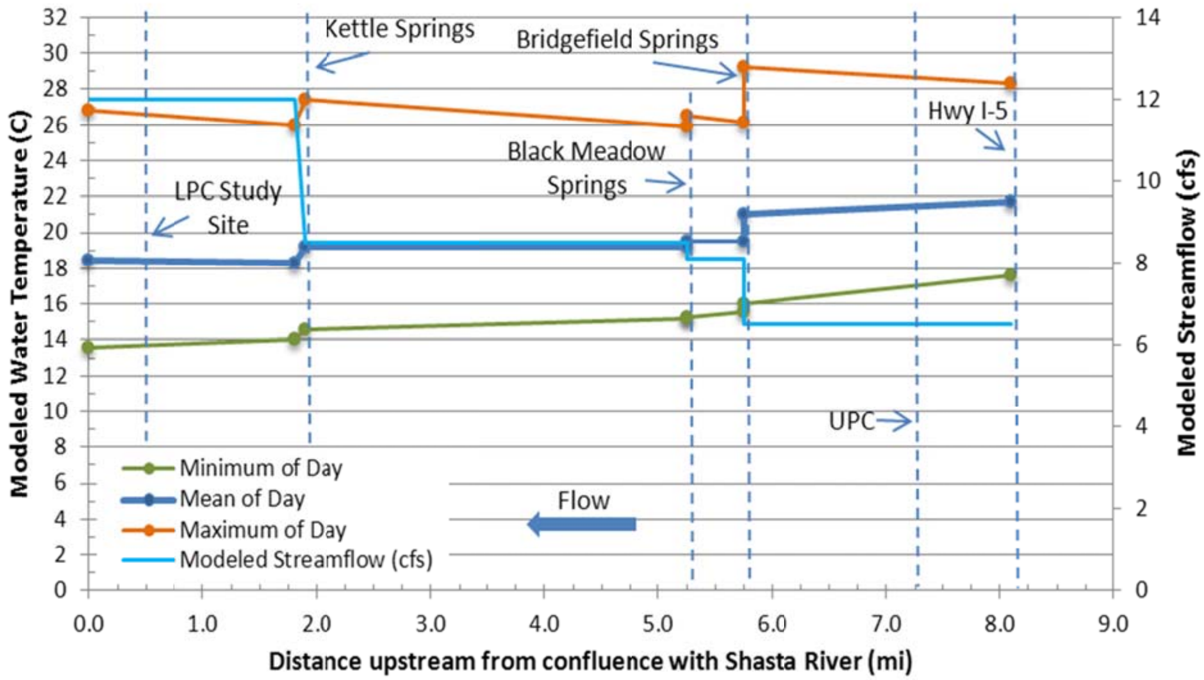


Figure 57. Modeled water temperatures for the 90% exceedence day of the June 16 to September 6 IFN; Parks Creek; mixed flow scenario.

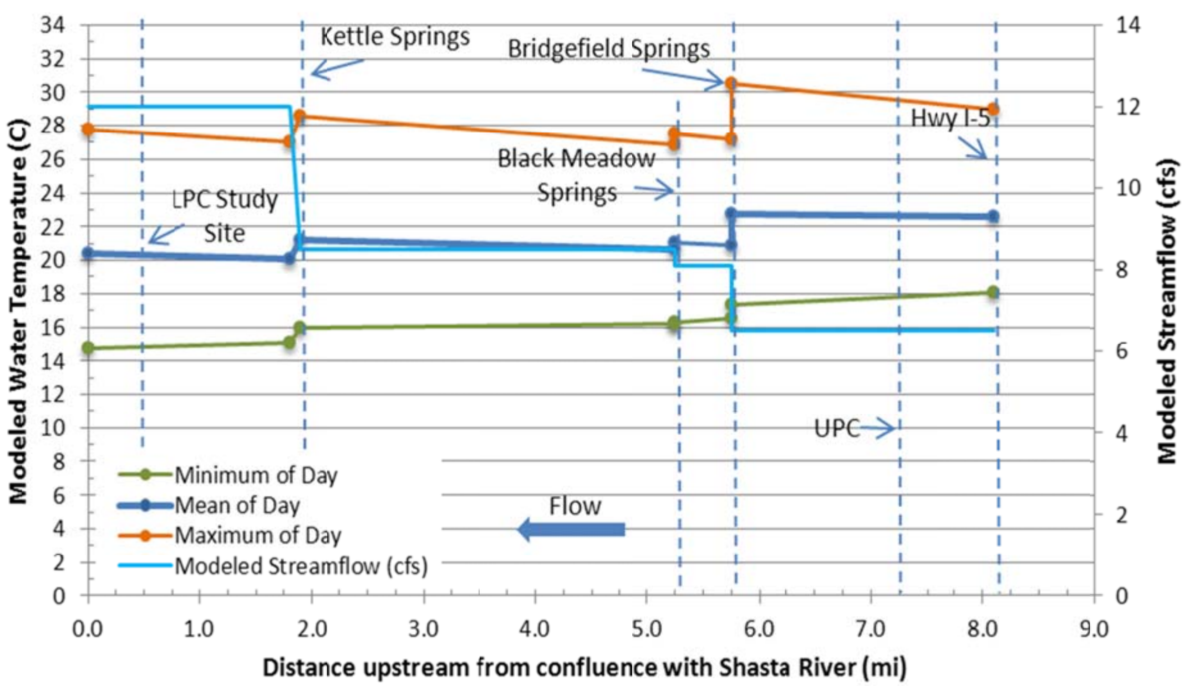


Figure 58. Modeled water temperatures for the 50% exceedence day of the June 16 to September 6 IFN; Parks Creek; mixed flow scenario.

6.2.6 Summary of Minimum IFN Findings for UPC and LPC Study Sites.

Minimum instream flows for Parks Creek (Reach No. 2) assessed at the UPC and LPC study sites are presented in Table 25.

Table 25. Minimum IFN findings for the Upper and Lower Parks Creek Study Sites.

Salmonid Life Sage	Q_{MIN} (cfs)	Primary Analytical Measure
September 7 to September 30: Early Adult Chinook Salmon Migration	LPC & UPC Q_{MIN} = 11 cfs to 15 cfs	mRCT of 1.0 ft (Figure 36) adjusted for a 0.15 ft stage increase due to hydraulic impacts from aquatic plant growth at the LPC study site.
October 1 to December 31: Adult Salmon Migration and Spawning Habitat	LPC & UPC Q_{MIN} = 11 cfs to 15 cfs	mRCT of 1.0 ft deep influenced by seasonal aquatic vegetative growth for adult migration. A minimum IFN for spawning habitat, independent of adult migration needs, was 10 cfs based on the DHM polygons in the UPC study site occupying most of the available spawnable streambed at 9.9 cfs (Figure 37).
January 1 to March 31: Winter Juvenile Salmonid Rearing Habitat	UPC Q_{MIN} = 10 cfs LPC Q_{MIN} = 12 cfs	The HHT averaged results for pool and riffle cross sections (Table 22). As a comparison, WP incipient asymptote assessments at LPC and UPC averaged 12 cfs and 18 cfs, respectively (Table 21).
April 1 to June 15: Spring Pulse and Smolt Outmigration	LPC & UPC Q_{MIN} = 20 cfs to 25 cfs	Initiation of bench inundation between 20 cfs and 25 cfs at the UPC study site and abundant BMI riffle habitat at 21.7 cfs within the LPC study site (Figure 43). Figure 48 provides a glimpse of what this range would look like in the UPC site (approximately 20 cfs to 25 cfs). This Interim IFN is supported by water temperature assessment.
June 16 to September 6: Summer Juvenile Salmonid Rearing Habitat	UPC Q_{MIN} = 2 cfs LPC Q_{MIN} = 7 cfs	The physical habitat recommendations are 10 cfs at UPC and 12 cfs at LPC. However temperature modeling suggests these IFNs will exceed the temperature thresholds in mainstem Parks Creek. An IFN which supports juvenile access to spring creeks, and minimal mainstem habitat (e.g. 7 cfs in LPC -supported by the R2 Cross results), would increase the thermal benefit of spring sources and spring-mainstem confluence habitat.

As with the HIG study site, the water temperature modeling results for Parks Creek indicate that lower summer flows may improve the thermal conditions for rearing salmonids; however, the response of real-time water temperatures to instream flows may differ from modeled predictions for several reasons. Future upstream boundary conditions could be cooler than those used in the temperature modeling and factors such as irrigation return flows, baseflow accretions, loss due to seepage and bed conduction can all affect water temperature (Section 5.2). Direct monitoring of the streamflow-water temperature relationship during implementation of the interim IFNs is recommended to validate or refine IFNs during the Summer Juvenile Salmonid Rearing Habitat period.

6.3 IFNs for the TNC Study Site

6.3.1 Early Adult Chinook Salmon Upstream Migration: September 07 - September 30 (3 weeks)

mRCT Threshold

RCTs were surveyed at 23.7 cfs on May 25, 36.0 cfs on June 21, and 19.7 cfs on August 10, 2011. Within the TNC study site, there were four RCTs; surveys on May 25 and June 21 included additional mainstem channel RCTs downstream of the study site boundary but upstream of Big Springs Creek confluence. The August 10 survey (n=4) at 19.7 cfs had an mRCT of 0.95 ft (Figure 59). Early in the season, with considerably less rooted aquatic vegetative growth, the May 25 survey at 23.7 cfs had an mRCT of 0.95 ft (n=7). The third RCT survey on June 21, with moderate vegetative influence and higher streamflow, had an mRCT of 1.2 ft (n=11) at 36.0 cfs (Figure 59). Rooted aquatic vegetation in WY2010 along the TNC reach typically raised water surfaces on cross sections another 0.4 ft to 0.5 ft by the summer's end. With aquatic vegetation shaping a trapezoidal channel by mid-August, an open lane of streamflow that was relatively deeper than would have occurred without the flow resistance induced by the plants would allow unimpeded Chinook salmon access from Big Springs Creek upstream to Parks Creek confluence for the streamflows observed. During spawning gravel inventories, Chinook salmon were observed swimming unimpeded through RCTs within the TNC study site at 24 cfs.

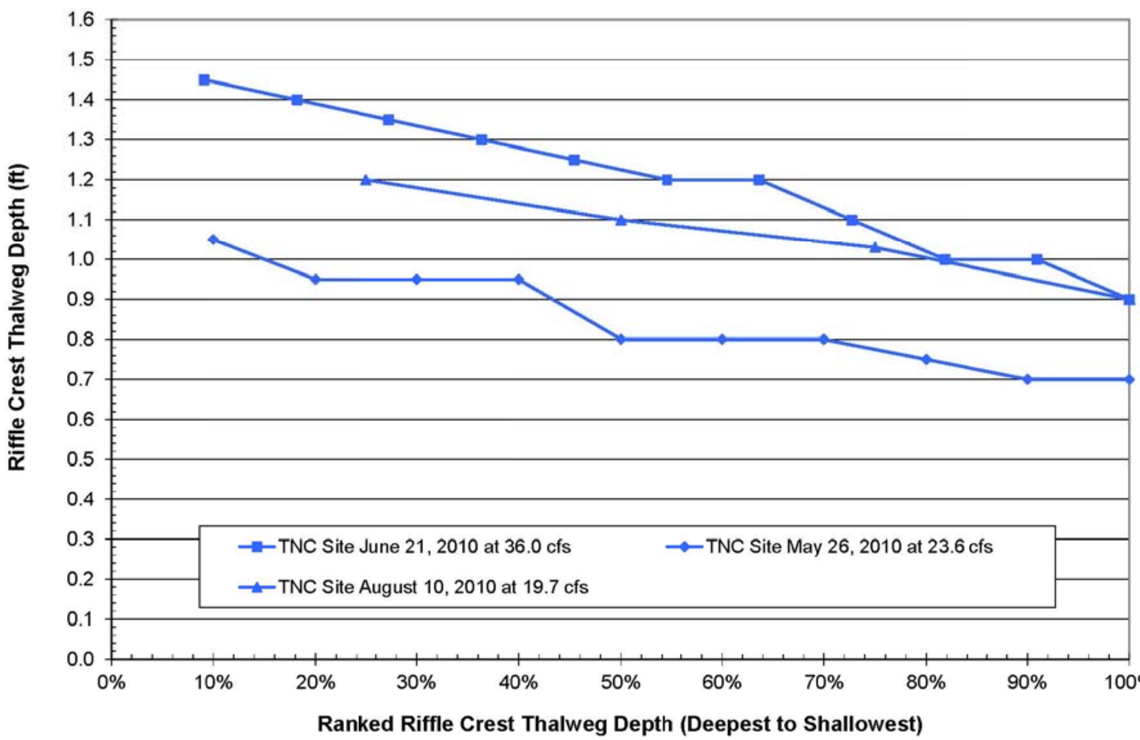


Figure 59. Ranked RCTs at the TNC study site.

TNC Study Site Salmon Migration Minimum IFN Finding

For the TNC study site (Reach No. 3), Tier No.1 early Chinook salmon migration requires a minimum IFN of 20 cfs during September 7 through September 30. Using a threshold mRCT of 1.0 ft for Chinook salmon will mean that some riffles will be shallower than 1.0 ft (Figure 59) at 20 cfs. This finding also was affected by the impaired channel morphology, such that with the loss of peak floods, many bar surfaces are encroached by dense grasses and sedges. Vegetative encroachment induces deposition of fine bed material onto the bar surfaces and has created a narrower, trapezoidal low-flow channel promoting greater depths at baseflows. Unimpaired channel morphology, with wider and more gently sloping bar faces, would likely have required greater streamflows, approximately 40 cfs to 50 cfs, to achieve an mRCT of 1.0 ft.

6.3.2 Adult Salmon Spawning and Migration: October 1 - December 31 (12 weeks)

The TNC mainstem (Reach No.3) offers 6,500 ft of abundant, high quality spawning gravel (M&T 2010) with spawning habitat conditions well-suited for both Chinook and coho salmon. Given its strategic location in the Upper Shasta River relative to Dwinnell Dam, many LHTs dependent on the Big Springs Complex are considered high priorities for salmonid recovery (M&T 2009). However, no LHT can be considered recoverable without the provision of good spawning streamflows.

Regional Regression Methods

Swift (1979) and Hatfield and Bruce (2000) models were used to predict streamflows providing good spawning habitat conditions (Table 8). Swift (1979) predictions were 151 cfs for Chinook and 97 cfs for coho. Hatfield and Bruce (2000) predictions were 116 cfs for Chinook, 134 cfs for Steelhead, and 80 cfs for all species combined. Both regional regression methods may be over-estimating streamflows necessary for providing spawning habitat availability because they do not explicitly factor in a spring-fed hydrograph, dam impacts to channel morphology, and dense seasonal aquatic vegetation growth, which all affect riffle and pool tail depths and velocities in the Big Springs Complex.

DHM and HHT Methods

Four riffle/pool tails within the TNC study site were DHM mapped at streamflows of 23.7 cfs, 36.0 cfs, and 19.7 cfs in May, June, and August 2010, respectively. The DHM spawning habitat polygons generated from this mapping were overlaid onto high resolution, ortho-rectified aerial photographs taken in May 2009 (Figure 60). Spawning-gravel substrate mapped during the spawning gravel inventory (M&T 2010) also was plotted onto this photograph to delineate total spawnable substrate boundaries (Figure 60). Furthermore, Chinook salmon redds mapped in October 2009 were also plotted onto this aerial photograph (Figure 60). The portion of Reach No. 3 that had spawnable substrate, the portion of this substrate that met the HSC criteria at three streamflows (i.e., the DHM spawning habitat polygons), and the location of Chinook salmon redds is shown (Figure 60).

Three DHM sample periods were insufficient to establish complete streamflow-habitat rating curves for each riffle/pool tail, i.e., a curve could not be fit to an X-Y plot of only three points. In anticipation of this constraint imposed by the budget and narrow timeframe for fieldwork, HHTs were used in combination with the DHM mapped polygons to estimate the streamflow-habitat rating curves. Two points must be measured or modeled, including a downstream HHT point for minimum depth and an upstream HHT point maximum velocity. With only three field trips, upstream and downstream HHT points had to be modeled at cross sections passing through or close to the points. Vertical dashed lines for each riffle/pool tail spawning habitat are used to indicate the downstream and upstream HHT streamflows (Figure 61). Both vertical lines box-in the streamflow-habitat rating curve with the DHM polygon areas providing shape to the curve. The horizontal dashed line at the top, indicating the total area with spawnable substrate, also boxes-in the rating curve; if every ft^2 of spawnable channel bed substrate met the HSC criteria at a given streamflow, then polygon area would equal total substrate area at that streamflow. However, complete overlap is highly unlikely because some portion of the spawnable channel bed surface would be too shallow and/or fast for spawning. Instead, the streamflow–habitat rating curve would not achieve maximum substrate area.

With the pronounced trapezoidal configuration of the post-dam channel bed, a very large percentage of the spawnable bed can provide spawning habitat over a narrow flow range. The large spawning habitat polygon intersected by cross section No.6, No.7, and No.8 included approximately 75% of the total spawnable channel bed at 37 cfs, and a range of 20 cfs to 50 cfs likely generated abundant spawning habitat for the same spawning location (Figure 61). The other spawning polygons within the TNC reach designated by Spawning Area No.2 (Figure 62), No.3 (Figure 63), and No.4 (Figure 64) had streamflow ranges for relatively abundant spawning habitat of 15 cfs to 55 cfs for cross section No.4 (Figure 62), 24 cfs to 37 cfs for cross section No.2 (Figure 63), and 18 cfs to 34 cfs for cross section No.1 (Figure 64). Figure 65 and Figure 66 show how Spawning Area No.1 looked at 24 cfs with and without Chinook salmon actively constructing redds.

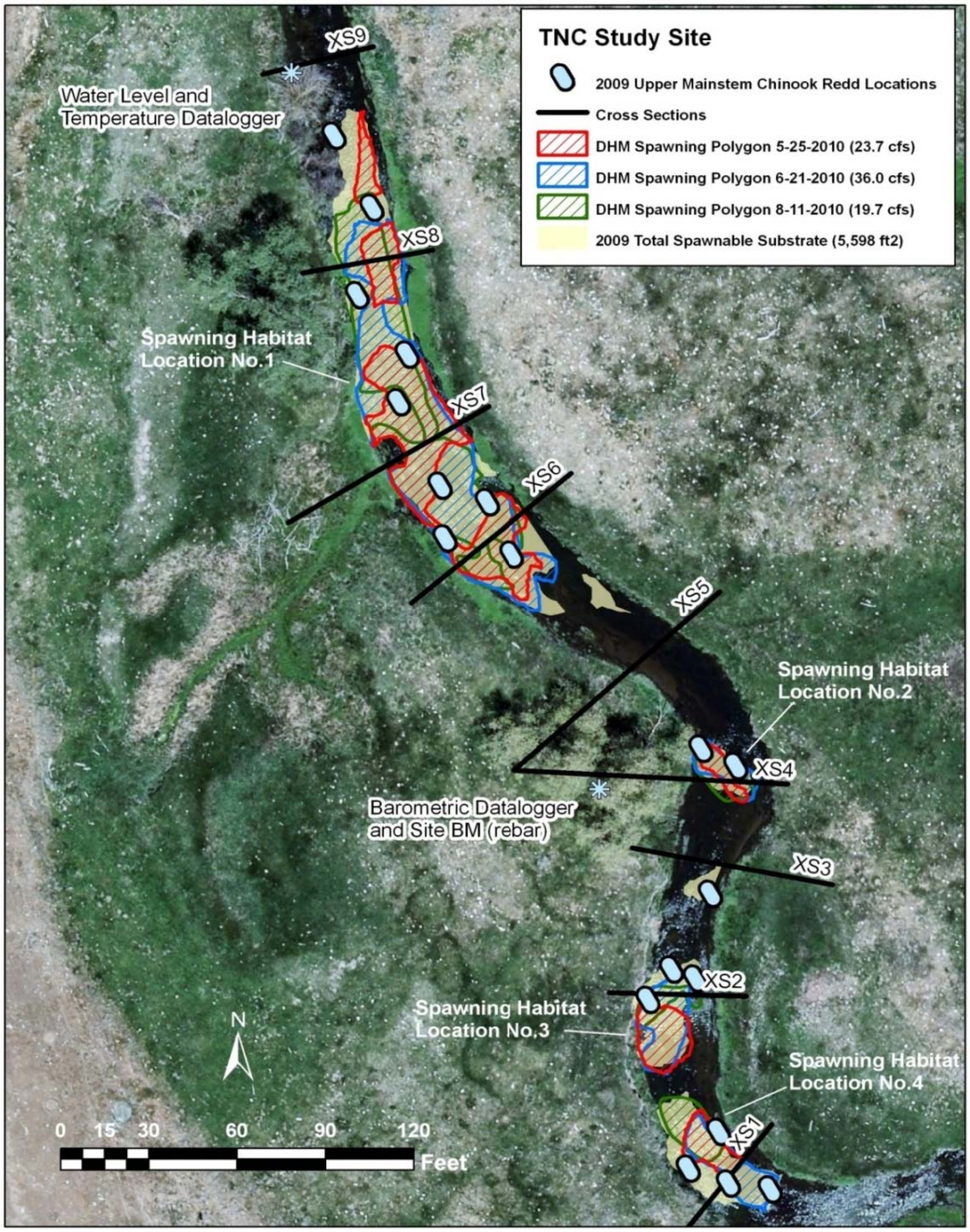


Figure 60. Spawning gravel polygons mapped in 2009 and DHM spawning habitat polygons mapped at the TNC study site during three site visits in 2010.

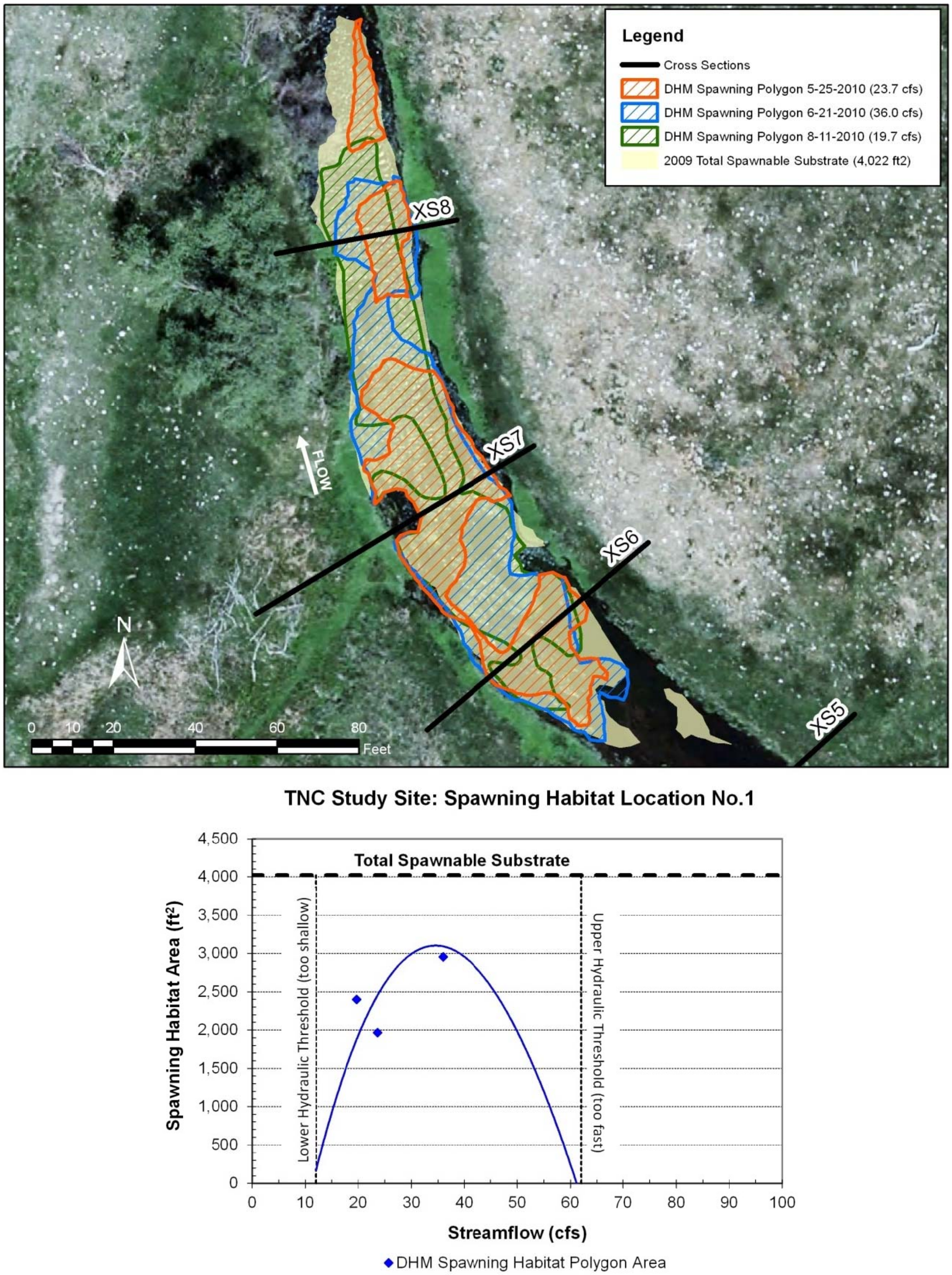


Figure 61. Spawning habitat polygons, total spawnable area, and streamflow–habitat rating curve for Spawning Habitat Location No. 1 in the TNC study site.

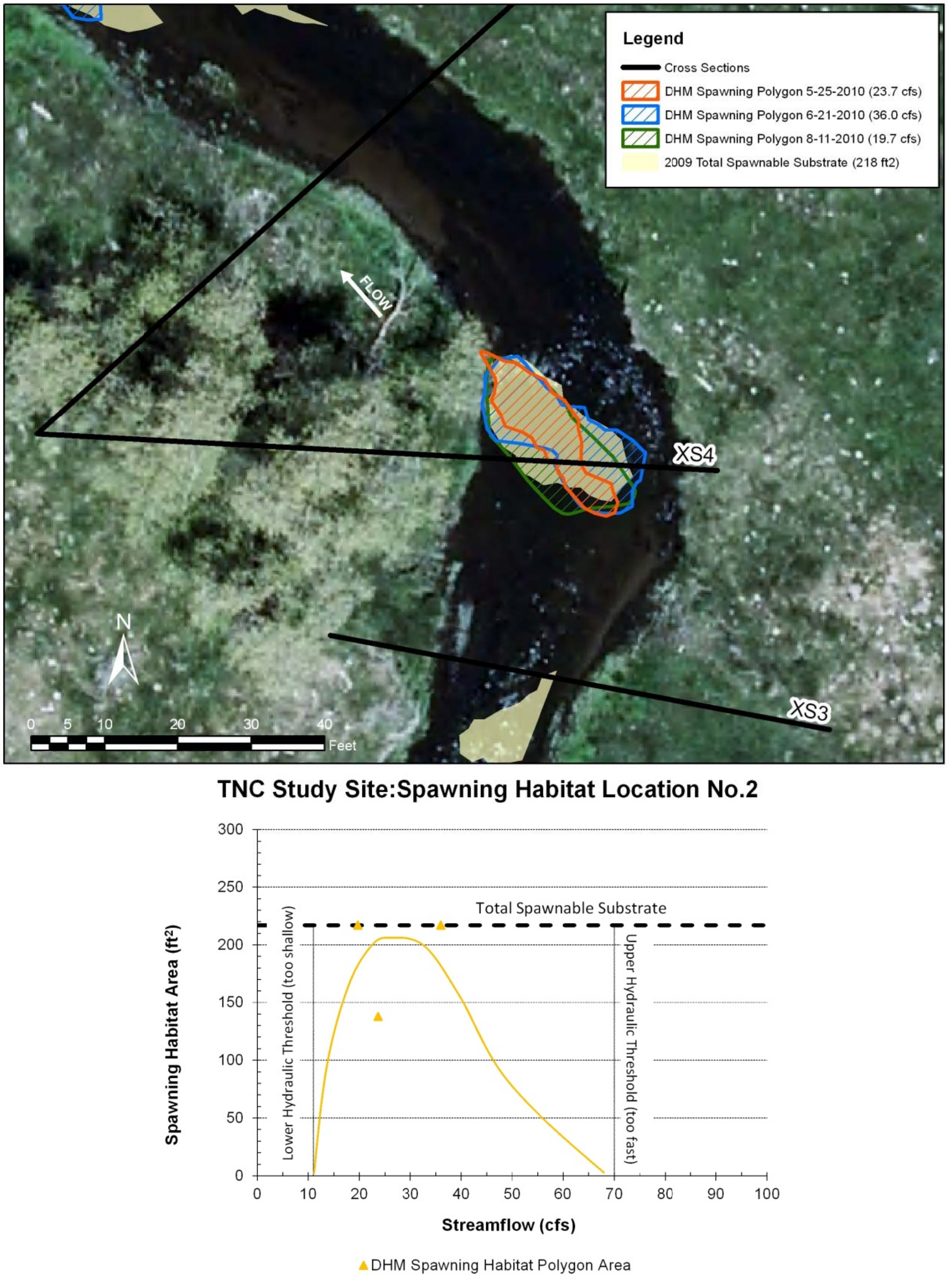
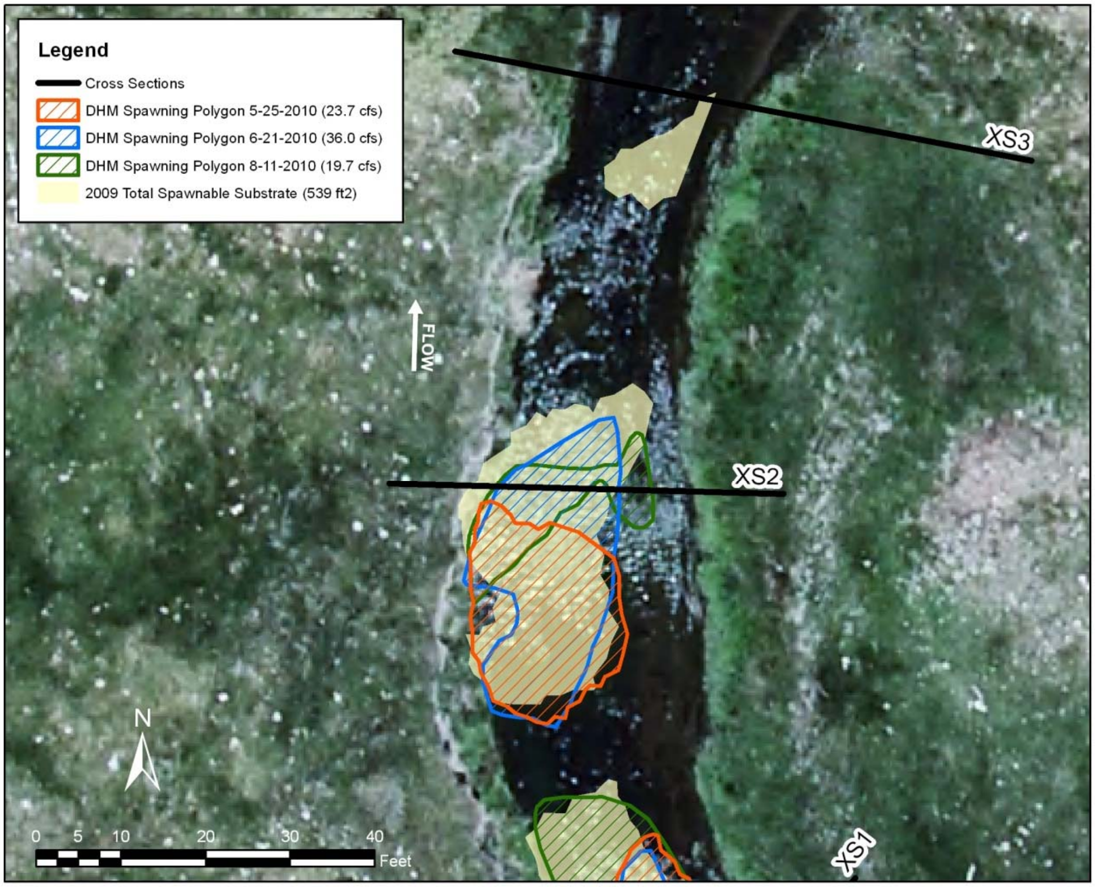


Figure 62. Spawning habitat polygons, total spawnable area, and streamflow–habitat rating curve for Spawning Habitat Location No. 2 in the TNC study site.



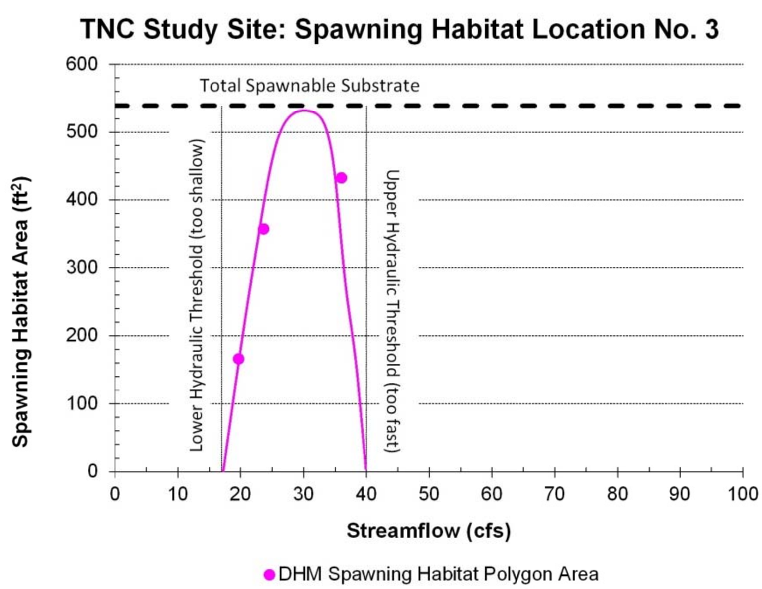


Figure 63. Spawning habitat polygons, total spawnable area, and streamflow–habitat rating curve for Spawning Habitat Location No. 3 in the TNC study site.

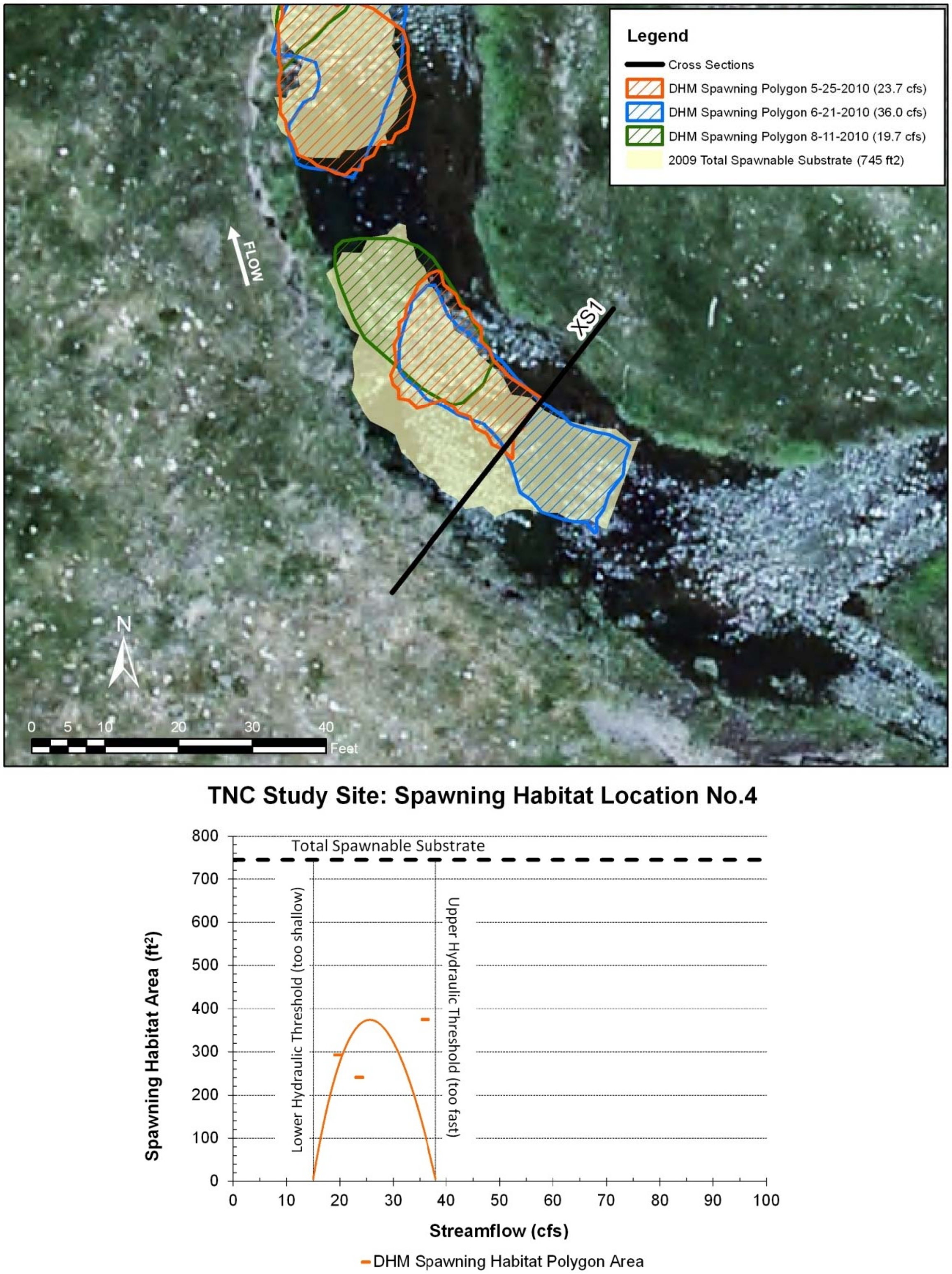


Figure 64. Spawning habitat polygons, total spawnable area, and streamflow–habitat rating curve for Spawning Habitat Location No.4 in the TNC study site.

The spawning gravel polygon downstream of TNC Riffle cross section No.6 provided the most spawning habitat in the TNC study site (Figure 61). More than 20 adult Chinook constructed at least nine redds in this riffle in 2009 at 22 cfs to 24 cfs. The pool-tail at TNC Riffle cross section No.6 had an average depth exceeding 0.5 ft at flows above 24 cfs; velocities measured at 23.7 cfs in May 2010 ranged between 0.9 ft/sec and 2.1 ft/sec across most of the cross section. TNC Riffle cross section No.7 and No.8 also had average depths exceeding 0.5 ft and velocities generally exceeding 1.0 ft/sec, but reached 3.0 ft/sec at some cross section stations.

The four estimated streamflow-spawning habitat rating curves, and the range of streamflows generating abundant habitat for each, provided interim quantification of natural spawning habitat variability. The lowest streamflow just barely providing the first minimally-sized patch of spawning habitat (e.g., a minimum spawning area of 20 ft^2) was not recommended as the Tier No.1 estimated minimum IFN. A Chinook spawning run needs greater habitat selection for each individual adult to reduce redd super-positioning and to encourage redd construction for the entire adult run over a sufficient range of hydraulic settings. The lowest streamflows over the range providing abundant habitat at the four spawning riffle/pool tails assessed were 20 cfs, 15 cfs, 24 cfs, and 18 cfs.

<u>TNC Study Site Adult Spawning and Migration Minimum IFN Finding</u>

A minimum IFN range of 20 cfs to 22 cfs will provide Tier No.1 spawning habitat in Reach No.3 from October 1 through December 31. This IFN range accounts for possible differences in rating curve shapes constructed by the lower/upper HHTs (Figure 61 to Figure 64), which are likely if more streamflows could have been habitat mapped. A 24 cfs streamflow was photographed on October 13, 2009, within Reach No.3, which is an atypically wide, transverse bar where more streamflow would be needed to maintain sufficient water depths for spawning (Figure 65). Chinook salmon were observed spawning on this feature at 24 cfs (Figure 66), and were also observed to be present in a nearby broad riffle at 24 cfs.

Although considerably higher than 22 cfs, the regional regression methods suggest that118 cfs for might have been appropriate for Tier No.2 Chinook salmon spawning habitat in a pre-Dwinnell Dam channel morphology when a range of streamflows, rather than a minimum streamflow, would be targeted. However, the range of estimated unimpaired baseflows (Figure 67), suggests that 118 cfs would have been higher than a typical autumn/early-winter baseflow (estimated between 40 and 80 cfs). Regardless, the pre-Dwinnel mainstem pool tails and riffles would likely have been less trapezoidal and consequently would have required more streamflow to meet the HSC criteria. In Figure 65, the right bank 'bench' (streamflow in the photo is from right to left) is an encroached point bar with a sharp radius of curvature (in the photo's background the downstream mainstem channel can be seen meandering behind the point bar). The original cobble bed surface of this bar is approximately 0.5 ft to 0.7 ft below the present surface of grasses and sedges with deposited silt and sand. This un-encroached bar would have provided abundant spawning habitat over the full range of unimpaired baseflows (Figure 67).

All of Reach No.3 was walked to investigate potential migration barriers (i.e., critical riffles) and identify spawning patches requiring greater streamflows to create spawning habitat than required for those patches assessed within the study site. No migration barriers were conspicuous, but other habitat units outside of the study site had several large patches of spawnable substrate that would require a wider upper range of streamflows for abundant spawning availability than the 20 cfs to 50 cfs range for the spawning habitat at cross sections No.6 to No.8 in the TNC study site (Figure 61).

Figure 65. Oblique bar utilized for spawning in the TNC reach. Photograph taken on October 13, 2009, at 24 cfs.

Figure 66. Chinook salmon spawning on an oblique bar in TNC Reach No.3 on October 13, 2009, at 24 cfs.

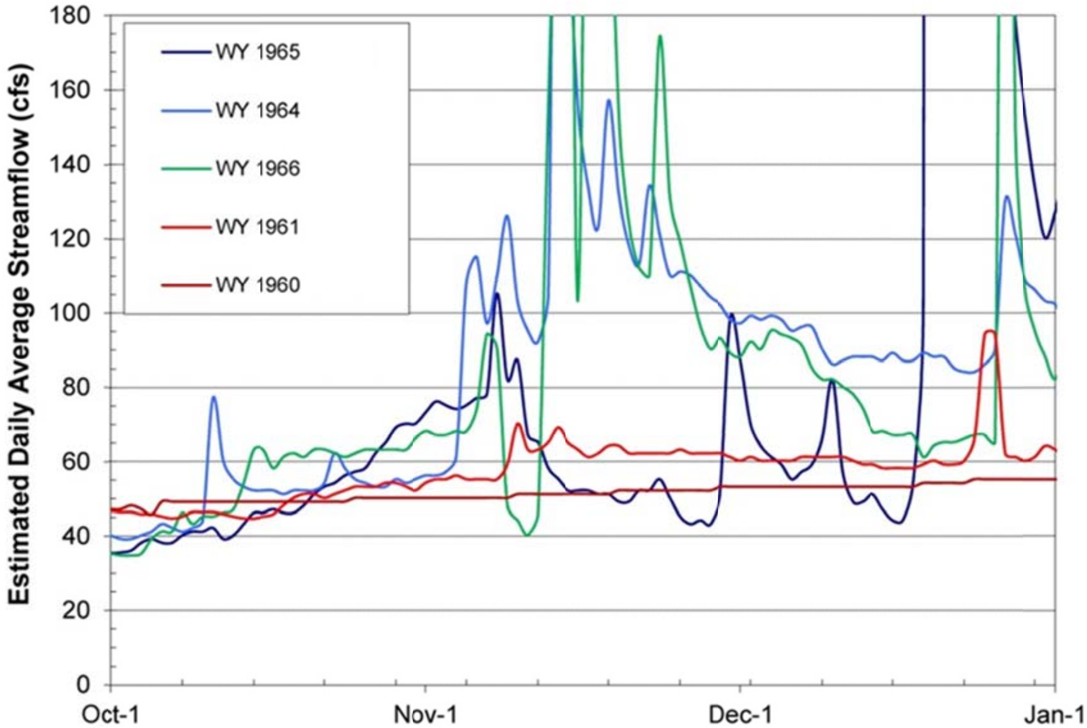


Figure 67. Fall season daily average hydrographs at the TNC study site estimated using Shasta River at Edgewood (USGS Sta. No 11516750) daily average streamflow data plus 20.2 cfs constant unimpaired flow from springs on the Shasta River below Dwinnell Dam and from springs on Parks Creek below I-5.

An important objective for identifying IFNs for Tier No.2 Chinook and coho salmon spawning would be to consider variable streamflows during the spawning season, as occurred in unimpaired hydrographs (Figure 6). Fall rainfall events increased unimpaired streamflows in most years through the early fall spawning season (October), with flows ranging from 28 cfs to 40 cfs on October 1 then increasing to 40 cfs to 70 cfs by early-November. Storm hydrographs in November and December greatly increased flow variability during the latter half of the spawning season (Figure 6). Salmon and steelhead could migrate farther into foothill and headwater spawning reaches at the higher baseflows that occurred. Variable streamflows would have reduced super-positioning of redds by allowing salmon more spawning site selection throughout the spawning season (i.e., redd super-positioning was not considered in our Tier No.1 assessment). As implied in a reviewers comment to Swift (1979), redds near the channel thalweg are at greater risk of scour during fall and winter high flow events, and high flow during spawning season may increase survival although the total spawning habitat available may be less than during lower flows. Varying flows during the spawning season may increase overall spawning distribution and utilization of spawning gravels, reduce super-positioning and consequent egg mortality, and reduce risk of scour-induced egg mortality from winter floods, relative to a minimum IFN range of 20 cfs to 22 cfs.

6.3.3 Juvenile Salmonid Winter Rearing: January 1 - March 31 (12 weeks)

Regional Regression Methods

Minimum IFNs for fry and juvenile salmonid rearing habitat were computed using Hatfield and Bruce (2000) and Swift (1979) regional regression methods (Table 26). The IFN selected from these regional analyses addressing general winter rearing habitat condition was the Hatfield and Bruce (2000). All Species juvenile rearing estimate of 47 cfs and Swift's (1979) all juvenile species estimate of 41 cfs. These estimates do not account for dam impacts to channel morphology, baseflows largely dominated by springs, or dense aquatic vegetative growth, and are thus considered provisional recommendations.

Table 26. 'Optimal' streamflows for fry and juvenile salmonid rearing habitat at the TNC Study Site predicted from regional regression methods by Swift (1979) and Hatfield and Bruce (2000).

	HATFIELD-BRUCE (2000)						***SWIFT (1979)***
	Chinook (cfs)		**Steelhead (cfs)**		**All Species (cfs)**		**All Species (cfs)**
	Fry	**Juv**	**Fry**	**Juv**	**Fry**	**Juv**	**Rearing**
Reach No. 3: TNC site	11	39	25	54	23	47	41

Standard Setting Methods

The two standard setting methods, WP and R2 Cross, appeared to be measuring different components of overall juvenile salmonid rearing habitat within the TNC study site. The WP method produced an average estimate of 6 cfs at the breakpoint, which varied from 4 cfs to 10 cfs among 6 riffle cross sections (Table 27). These minimum IFNs were similar to the Hatfield and Bruce (2000) fry rearing estimate (Table 26) because standard-setting methods will explicitly target flows that are sufficient to provide a minimum level of hydraulic habitat for fish (Annear et al. 2004). Streamflows in this 5 cfs to 10 cfs range likely provide abundant, high-quality fry rearing habitat that requires slow velocities and shallow water. However, these velocity at these flows will not likely provide Tier No.1 rearing habitat for larger juveniles. By using 0.4 ft and 1.0 ft/sec criteria in the model, the R2 Cross method targeted larger juveniles. Minimum IFN needs for juveniles were substantially greater than those of fry, producing an R2 Cross estimate of 19 cfs (Table 27). Applying the incipient asymptote instead of the breakpoint, the WP method predicted an IFN for juvenile rearing habitat between 20 cfs and 30 cfs (Figure 68, Table 27).

Table 27. Instream Flow Needs (in cfs) for fry and juvenile rearing calculated from the Wetted Perimeter (WP) "Breakpoint" and "Incipient Asymptote" and R2 Cross methods for the TNC Study Site. Blank cells indicate data is unavailable.

Site	**Unit**	**WP "Breakpoint" (cfs)**	**WP "Incipient Asymptote" (cfs)**	**R2 Cross 0.3ft, 1.0 ft/s (cfs)**	**R2 Cross 0.4ft, 1.0 ft/s (cfs)**
TNC site Cross Section No.					
1	Riffle	6	20		21
2	Riffle	10	34		20
4	Riffle	8	28		
6	Riffle	6	30		18
7	Riffle	4	21		22
8	Riffle	4	18		15
	Average	**6**	**27**		**19**

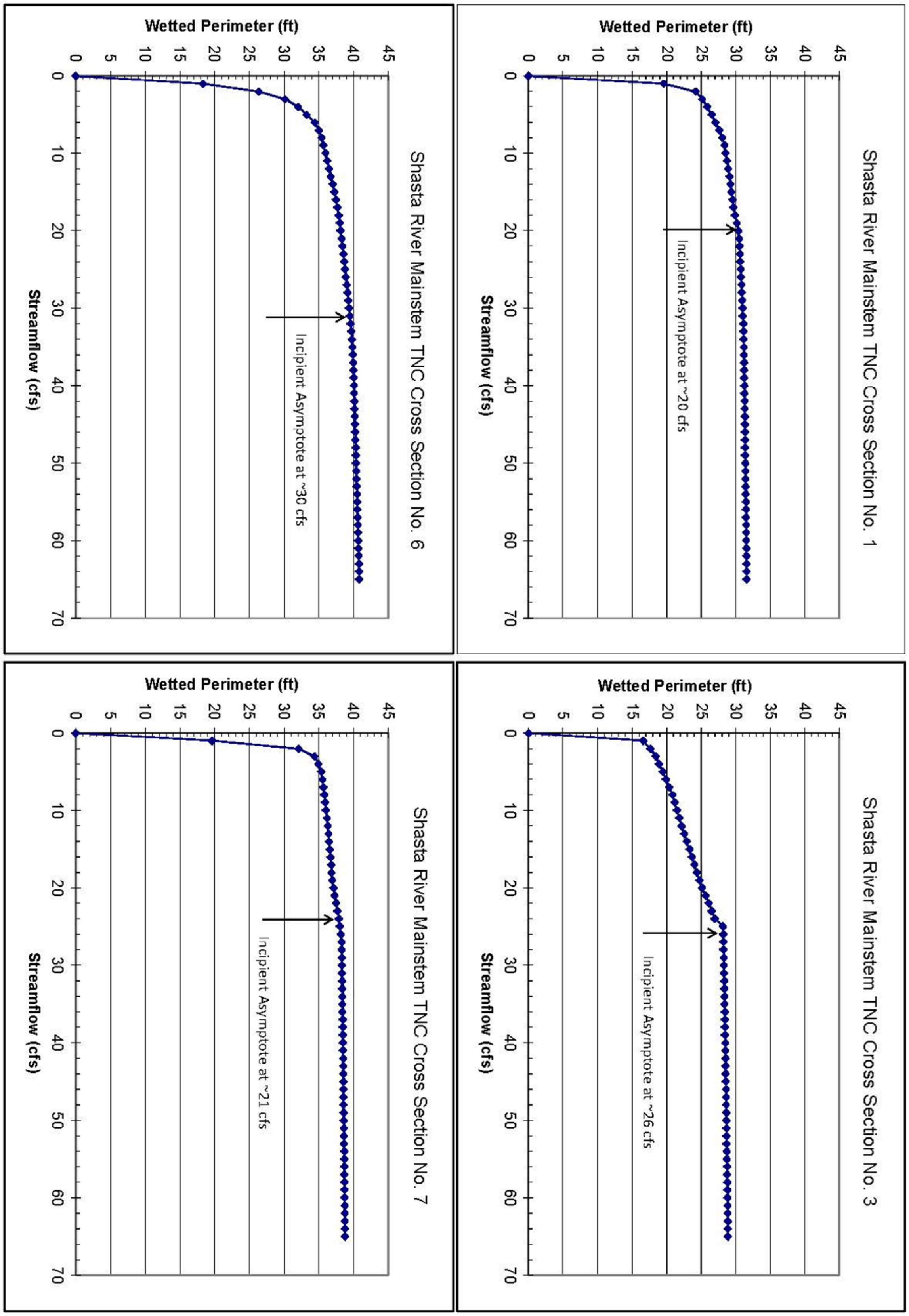


Figure 68. WP curves with incipient asymptote at four cross sections within the TNC study site.

HHTs on cross sections and Longitudinal Velocity Profiles

HHTs were evaluated for TNC study site Pool cross section No.5 and Riffle cross section No.6 (Figure 69, Figure 70). The cross-sectional average velocity for the pool cross section exceeded 0.5 ft/sec at the three streamflows measured (36 cfs, 23.7 cfs, and 19.7 cfs) and for the riffle was exceeded by the 36 cfs and 23.7 cfs streamflows, but not by the 19.7 cfs streamflow. As the season progressed and aquatic vegetation grew denser, the percentage of either cross section's width with velocities greater than 1.0 ft/sec dropped, but not appreciably (Figure 70). The hydraulic habitat threshold of 1.5 ft/sec for a pool's core velocity was surpassed on August 10 at 19.7 cfs in TNC Study Site Pool cross section No.5 (Figure 70).

TNC Study Site Juvenile Salmonid Winter Rearing Minimum IFN Finding

A minimum IFN of 20 cfs will provide Tier No.1 winter juvenile salmonid rearing habitat in Reach No.3 based on the R2 Cross riffle results (Table 27) and the HHT pool result (Figure 70). An additional IFN study on winter rearing habitat will need to be done when aquatic plants have completely died-back, at least as much as the plants will naturally during the dormant season. Absent the hydraulic influence of dense plant growth, the HHTs will change, relative to our analysis under summer conditions. This could result in slightly lower IFN winter rearing baseflows (e.g., 16 cfs to 18 cfs) that can only be reliably resolved by empirical measurement during winter and not by insensitive hydraulic modeling.

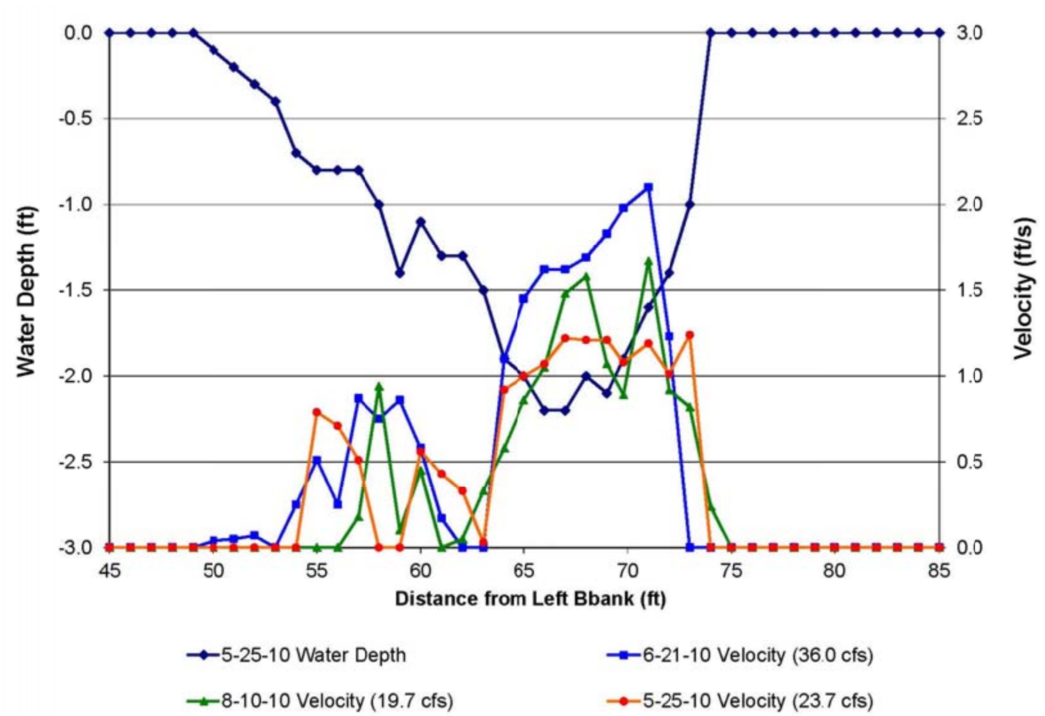


Figure 69. Water depths and average column velocities at TNC Site Pool cross section No.5 at three streamflows.

6.3.4 Spring Snowmelt Pulse: River Productivity and Smolt Outmigration: April 1 - June 15 (10 weeks)

April through mid-June is critical for salmonid growth (McCormick and Saunders 1987). Improved growth generally translates into better health and greater survival in subsequent freshwater life stages and ocean survival (Hume and Parkinson 1988; Ward and Slaney 1988; Ward et al. 1989; Hayes et al. 2008). In the unimpaired annual hydrographs for the TNC study site (Figure 6), the predictable spring snowmelt pulse likely increased habitat capacity and helped realize the mainstem's productive potential. Physical habitat capacity was increased/improved by creating more hydraulic complexity within the mainstem channel (than occurring at lesser baseflows) and by providing greater, long-duration streamflows to connect off-channel features, such as scour channels and benches, with the mainstem channel. Productive potential was realized by keeping water temperatures within the range of rapid growth for both BMIs and fish into late-spring and/or early-summer, as well as by expanding the size and depth of riffles, which generally leads to more productive BMI habitat and keeps macrophytes from silting-over (i.e., prevents smothering micro-crustaceans in the aquatic vegetation).

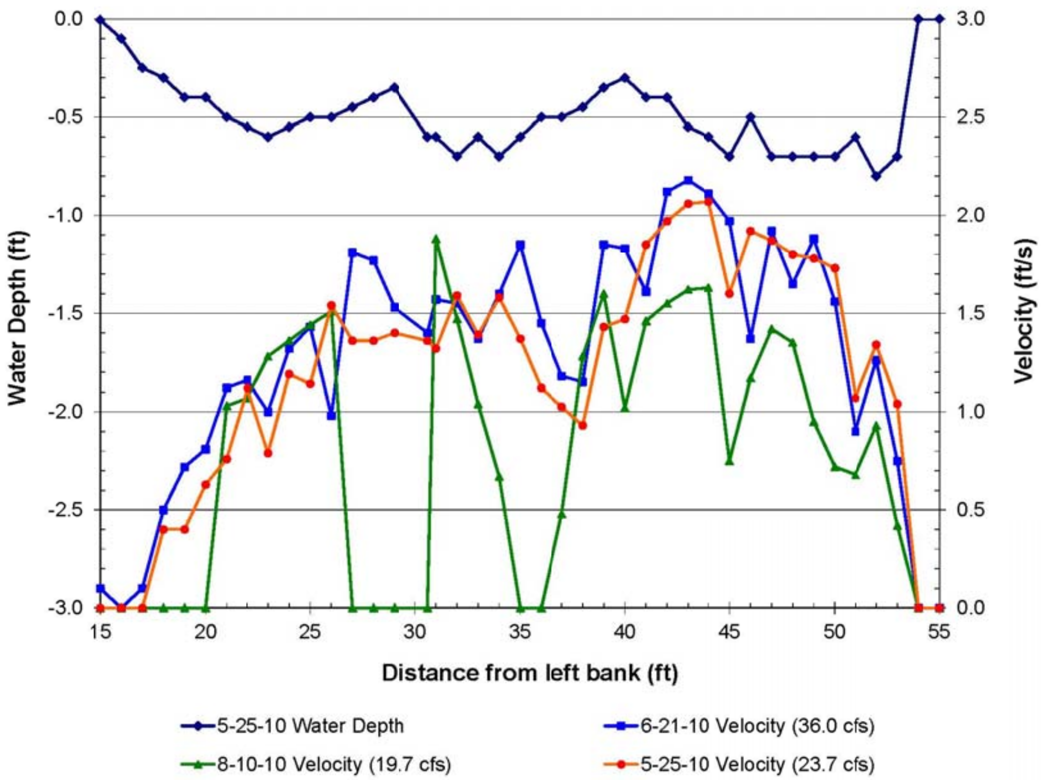


Figure 70. Water depth and average column velocities at TNC Study Site Riffle cross section No.6 at three streamflows.

<u>*Habitat Rating Curve for Productive BMI Riffle Habitat*</u>

Productive riffle habitat for BMIs was mapped using DHM and habitat suitability criteria of streamflow depth > D_{50} particle size and average column velocity > 1.5 ft/sec. Riffle BMI habitats in the TNC study site were mapped at three streamflows (Figure 71). Similar to the spawning habitat rating curves, a productive riffle habitat rating curve was developed (Figure 72). The upper limit of this curve was constrained by total riffle gravel area, which was equal to 5,525 ft^2 within the TNC site. Between 35 cfs and 45 cfs 70% of the available riffle habitat met the depth and velocity criteria for BMI (Figure 72). The depth and velocity criteria are for minimum thresholds only. Therefore, the rating curve cannot decline at higher streamflows (i.e., streamflows cannot be too deep or too fast for BMI habitat). An additional polygon mapping at 50 cfs to 55 cfs would greatly help in estimating whether the curve's maximum inflection point is between 25 cfs and 30 cfs (i.e., strictly interpreting the three data points) or occurs between 40 cfs and 50 cfs. Nonetheless, these estimates obtained provide a strong basis for assessing IFNs to produce productive riffle habitat.

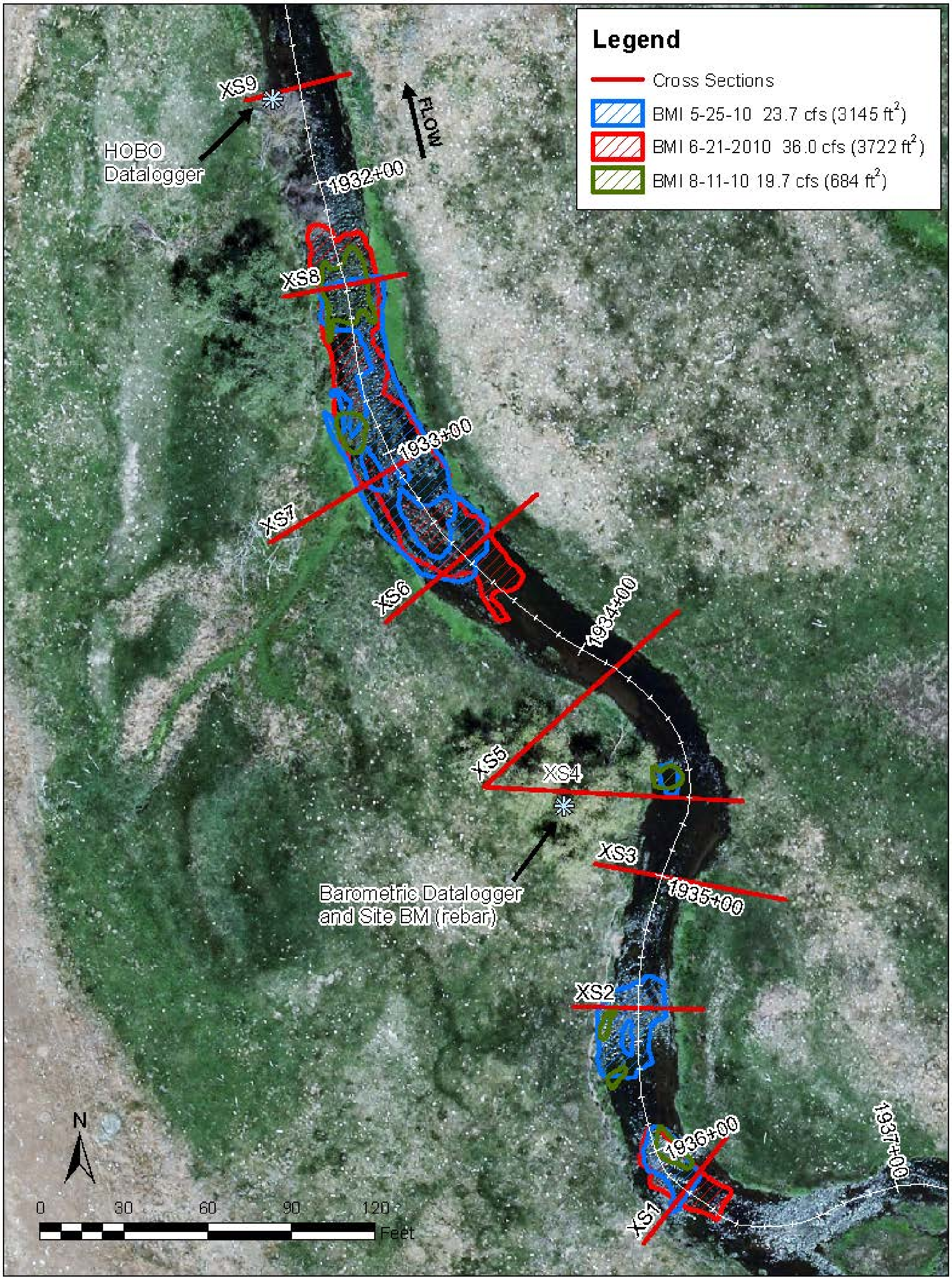


Figure 71. Productive BMI riffle habitat polygons within the TNC study site mapped at 19.7 cfs, 23.7 cfs, and 36.0 cfs.

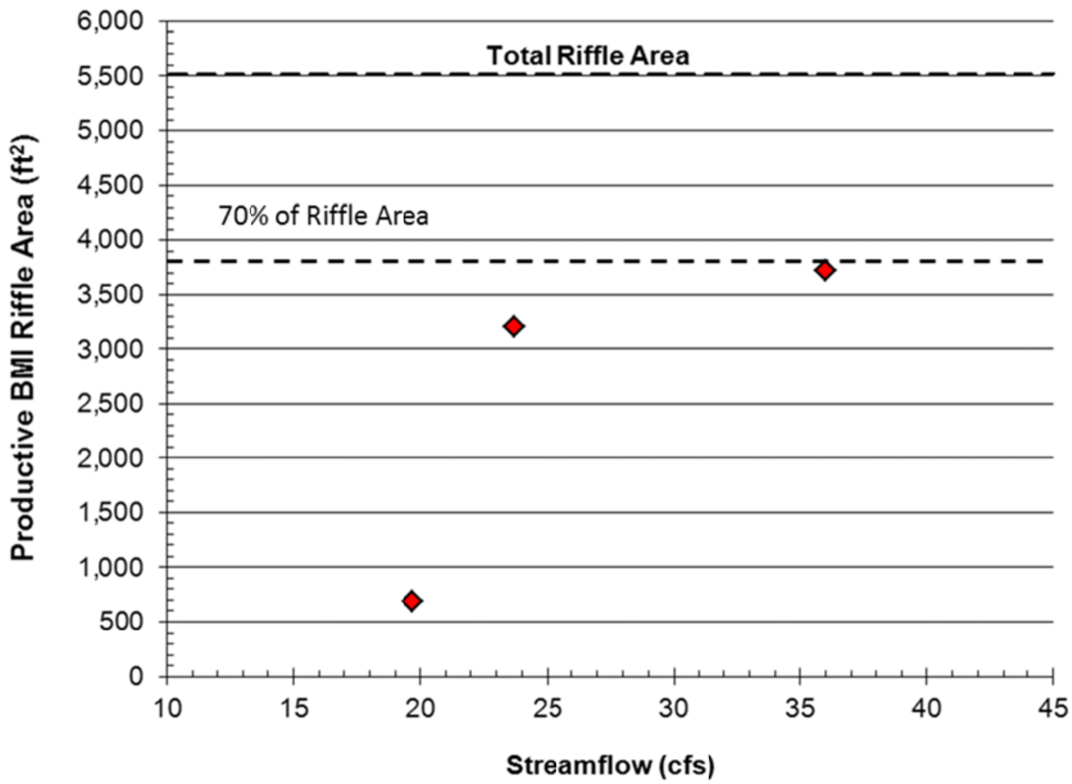


Figure 72. BMI habitat mapped in the TNC study site and a curve fit by eye to the three mapping data points constrained by a total riffle area of 5,525 ft^2.

<u>*HHT for Large Juvenile Salmonid Rearing and Outmigration*</u>

A core of relatively fast streamflow (exceeding 1.5 ft/sec to 2.0 ft/sec) passing through a pool creates shear zones at the sharp interchange between fast to slow velocities along the core's margins (Vogel 1981) that promote high-quality large juvenile and smolt habitat. TNC Pool cross section No.5, located midway in the TNC study site's largest pool, had velocities ranging from 1.5 ft/sec to 2.0 ft/sec at 36 cfs (Figure 69). More pools need to be monitored over a wider range of streamflows than were available during our sampling season. Field observations outside the TNC study site at 36 cfs, but within Reach No.3, showed other pools behaving similarly, with the largest, deepest pools not yet exhibiting a fast central velocity core extending at least halfway through the pool.

<u>*Bench and Scour-Channel Inundation Thresholds*</u>

Contemporary benches, occupied/formed by dense emergent vegetation, were observed being inundated at 40 cfs (Figure 73). Scour channel entrances in Reach No.3 have aggraded through a process of encroachment, 0.6 ft to 1.0 ft deep. Historically these scour-channels may have initiated when mainstem streamflows exceeded 65 cfs to 85 cfs, as estimated from rating curves at riffle crests. From the unimpaired hydrographs, a 65 cfs to 85 cfs window for initiating flow down scour-channels was the norm in most WYs (Figure 6). Today these same scour-channels require mainstem streamflows exceeding 150 cfs to 200 cfs. Although the unimpaired hydrographs show flows of 150 cfs to 200 cfs occurring in most WYs, the timing was sporadic and duration short-lived (Figure 6).

Figure 73. Shallow inundated rearing habitat on TNC Shasta Big Springs Ranch downstream of Louie Bridge on June 24, 2010, at 40 cfs.

TNC Study Site Spring Snowmelt Pulse Minimum IFN Finding Based on Physical Habitat

A minimum IFN of 40 cfs for a spring snowmelt pulse will begin inundating contemporary benches and significantly expand productive BMI riffle habitat, but cannot accomplish what the natural snowmelt pulse once did. This IFN recommendation was based on: (1) observed incipient inundation of contemporary benches (Figure 73) at 40 cfs, (2) a probable inflection in the riffle BMI habitat rating curve between 35 cfs and 40 cfs (Figure 72), and (3) the TNC study site's largest pool having velocities ranging from 1.5 ft/sec to 2.0 ft/sec at 36 cfs (Figure 69). Annual unimpaired snowmelt hydrographs at the TNC study site sustained springtime and early-summer streamflows typically ranging annually between 80 cfs and 125 cfs. Many scour-channels, side-channels, and benches that historically provided high-quality rearing habitat during smolt outmigration have aggraded. Reduced magnitude, duration, and frequency of peak streamflows below Dwinnell Dam and below the MWCD Parks Creek diversion have allowed riparian vegetation to encroach onto point bars and into side-channels. Encroachment by grasses and sedges created ideal hydraulic roughness for depositing fine suspended load and bed material load when flooding did occur. Subtle increases in aggraded bed elevation of scour channel and side-channel entrances relative to the thalweg of the adjacent mainstem riffle crest greatly affect the magnitude/duration/frequency of side-channel streamflows.

In keeping to minimum IFNs under the Tier 1 objective, a 40 cfs minimum IFN in springtime for Reach 3 would: (1) provide abundant BMI riffle habitat with sufficient duration for downstream migrating juveniles and smolts to feed, and (2) create sufficient hydraulic diversity in pools that in turn should improve juvenile and smolt physical habitat. The first accomplishment addresses habitat productivity and the second addresses habitat capacity, under the geomorphic constraints imposed by the present channel morphology. Streamflows greater than 40 cfs will be needed to improve juvenile habitat on benches (i.e., incipient inundation is not sufficient).

During snowmelt runoff, recruitment of native riparian vegetation often depends on seed release occurring during streamflows are of sufficient magnitude and timing to raft seeds onto moist floodplain surfaces (Patten 1998). Alteration of the magnitude and/or timing of streamflows will affect riparian recruitment, though these effects were not quantified in this IFN study. The spring snowmelt pulse generally coincides with pre-smolts and smolts leaving the Shasta River. A healthy, productive river corridor promotes continued growth during downstream migration, as well as the opportunity to emigrate rapidly if local climatic conditions and water temperatures rapidly become adverse. Juvenile emigration from the TNC study site (RM 34.9) to the Klamath River (RM 0) requires traversing approximately 27.6 miles of low gradient valley river channel and another 7.3 miles through the steeper Shasta Canyon. Survival rates in 2008 ranged from 0.64 to 0.89 in this reach during a time period when streamflows declined from approximately 120 cfs on April 1 to 60 cfs in early-May (see Chesney et al. 2009, Figure 15, pg. 42). Higher spring pulse flows could substantially increase survival during outmigration by accelerating growth and reducing vulnerability to predation.

Productivity will exert a critical role in determining the viability of salmonid LHTs in the Shasta Basin, particularly when population levels are severely constrained, because it influences a population's ability to replace itself and rebound from threatening low levels. Moussalli and Hilborn (1986) state: "*The life history of a population consists of a sequence of density-dependent stages linked by density-independent survival rates.*" Productivity improves survival rates during and between successive salmonid life stages, which translates into bigger and healthier fish as well as higher ecological condition in general. Restoration actions in the Shasta Basin, such as prescribing instream flows, should promote productivity as much, or even more, than adding habitat capacity.

TNC Study Site Water Temperature Modeling Scenarios, Results and Implications for IFNs for the Spring Pulse and Smolt Outmigration Period (April1 – June 15)

Table 29 shows the two water temperature modeling scenarios developed for developed for the Shasta River below Parks Creek during the Spring Pulse and Smolt Outmigration Period. Due to time and budget constraints, only *spring flow* scenarios were included in the boundary conditions. The 90th and 50th percentile warming days for each IFN period where modeled (See Sections 5.2.2 and 5.2.3 for a discussion of modeling scenarios and exceedence days).

*Table 28. Water temperature modeling scenarios for the Shasta River below Parks Creek. K represent the exceedence day and * represent a model boundary location.*

Time	Scenario	K	Date	Q_{SBS6}	$Q_{HIG\ Spring*}$	$Q_{SRabvBSC}$	Q_{BSC*}	$Q_{SRblwBSC}$
4/1-6/15	*Spring*	*90%*	*4-22*	44	3	47	78.8	115
4/1-6/15	*Spring*	*50%*	*4-18*	44	3	47	68	125.8

The modeled water temperature scenarios in Shasta River below Parks Creek examined the original IFNs recommended based on the physical habitat needs (e.g. 40 cfs for the Spring Pulse and Smolt Outmigration and 20 cfs for the Summer Juvenile Rearing Periods), not the revised IFNs based on the subsequent upstream water temperature assessment presented in Sections 6.1 and 0. Modeling results for the effects of the combined Parks Creek and Upper Shasta River *spring flow* scenario on downstream reaches during the Spring Pulse and Smolt Outmigration Period are presented in Figure 74 and Figure 75. Between Parks Creek and Big Spring Creek modeled daily maximum temperature during the Smolt Outmigration (April 1 –June 15) never exceed 19° C. In addition, the upstream IFNs for the April 1 –June 15 period were not revised as a result of water temperature modeling presented in Sections (6.1.4) and (6.2.4). Therefore, the modeling results in Shasta River below Parks Creek, as well as upstream locations, support the minimum IFNs recommended from the physical habitat assessment during the April 1 – June 15 period in the TNC reach.

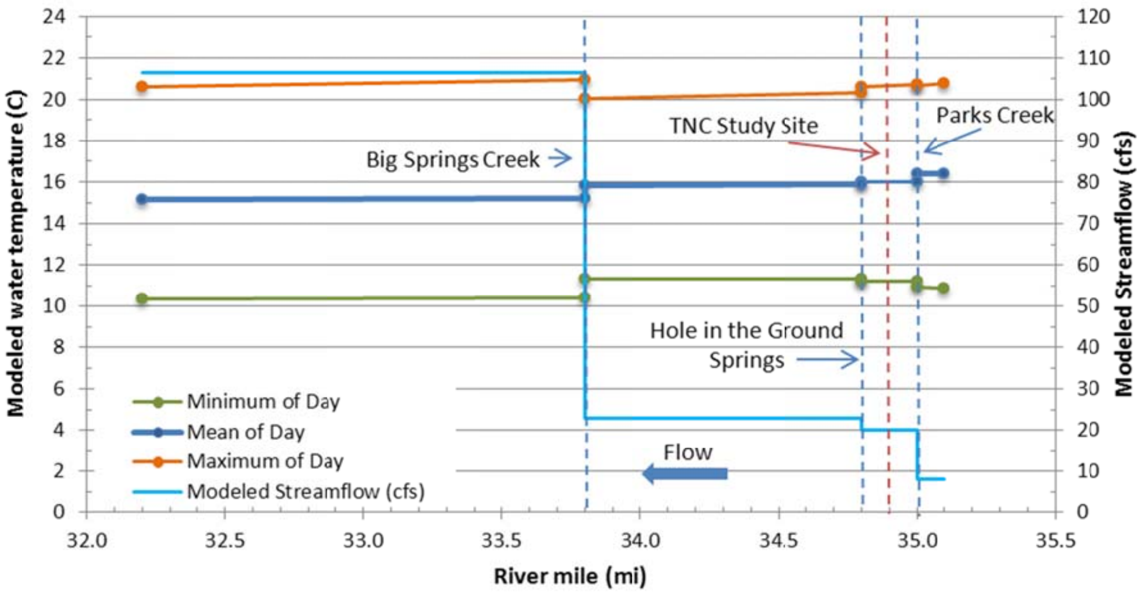


Figure 74. Modeled water temperatures for the 90% exceedence day of the April 1 to June 15 IFN; Shasta River below Parks; spring flow scenario.

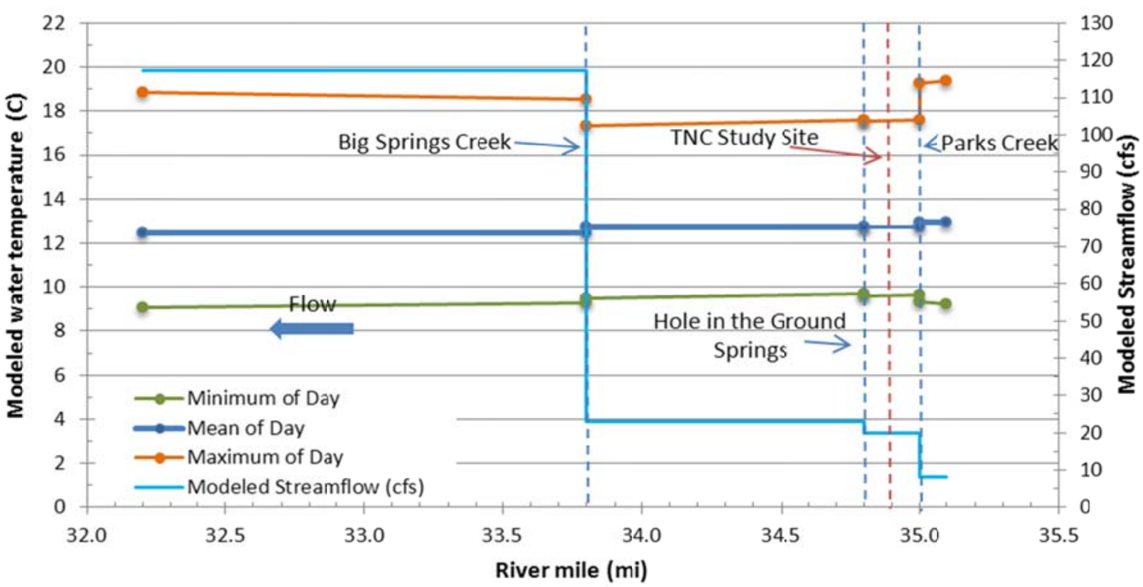


Figure 75. Modeled water temperatures for the 50% exceedence day of the April 1 to June 15 IFN; Shasta River below Parks; spring flow scenario.

6.3.5 Juvenile Salmonid Summer Rearing: June 16 - September 6 (11 weeks)

The minimum IFN for juvenile salmonid rearing based on physical habitat needs is the same 20 cfs as the winter rearing minimum IFN finding. Daily maximum water temperatures exceeded 20^{o}C by early-July in TNC Reach No.3. This temperature increase corresponded with the small decrease in stage and discharge at the tail-end of the snowmelt runoff in 2010, occurring considerably later than in previous drier WYs. Maximum temperatures exceeding 20^{o}C persisted through late-August. Based on similar conditions documented in Chesney (2009), these conditions would have prohibited over-summer rearing by juvenile coho salmon.

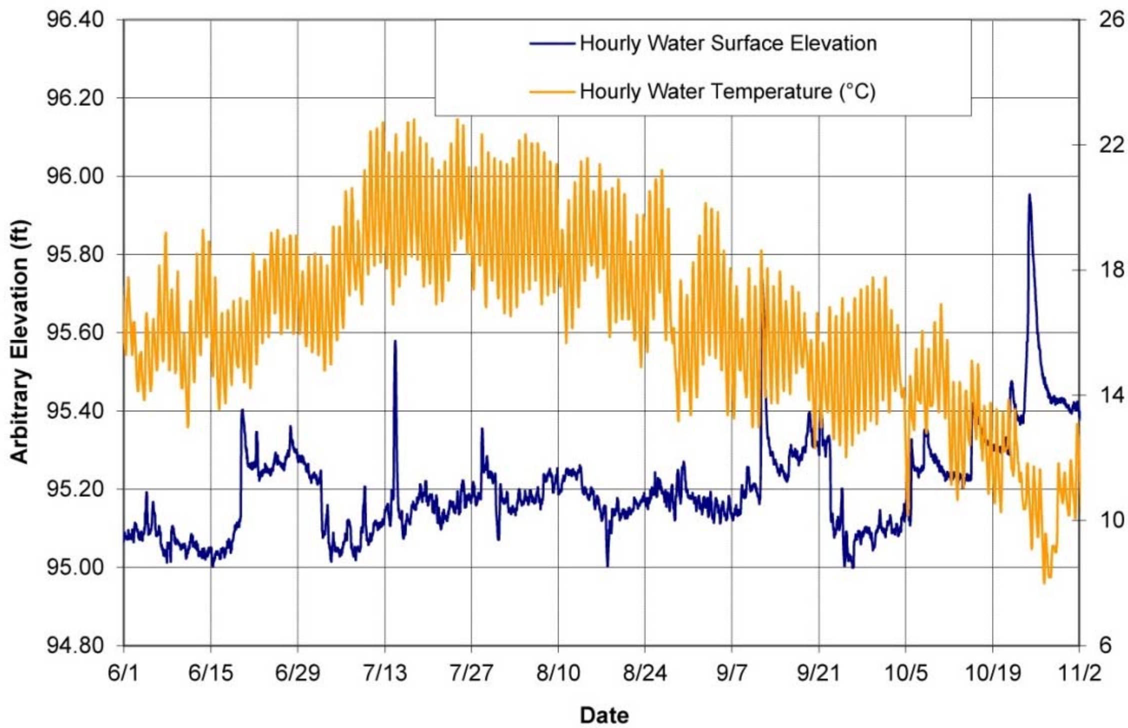


Figure 76. Water temperatures and surface elevations recorded hourly at the TNC study site in 2010.

TNC Study Site Water Temperature Modeling Scenarios, Results and Implications for IFNs for the Summer Juvenile Rearing Period (June 16 – September 6)

Table 29 shows the two water temperature modeling scenarios developed for the Shasta River below Parks Creek during the Summer Juvenile Salmonid Rearing Habitat period. As described above, only *spring flow* scenarios were included in the boundary conditions. The 90th and 50th percentile warming days for each IFN period where modeled (See Sections 5.2.2 and 5.2.3 for a discussion of modeling scenarios and exceedence days).

*Table 29. Water temperature modeling scenarios for the Shasta River below Parks Creek. K represent the exceedence day and * represent a model boundary location.*

Time	Scenario	K	Date	Q_{SBS6}	Q_{HIG} Spring*	$Q_{SRabvBSC}$	Q_{BSC*}	$Q_{SRblwBSC}$
6/16-9/6	*Spring*	*90%*	*8-16*	20	3	23	61.4	76.4
6/16-9/6	*Spring*	*50%*	*7-11*	20	3	23	53.4	84.4

Modeling results for the effects of the combined Parks Creek and Upper Shasta River *spring flow* scenario on downstream reaches during the Summer Rearing period are presented in Figure 77 and **Error! Reference source not found.**. Between Parks Creek and Big Spring Creek modeled daily maximum temperature between June 15-September 6th exceeds 20° C on both the 90% and the 50% exceedence days. While the upstream IFNs for the April 1 –June 15 period where not revised as a result of water temperature modeling, the summer IFNs were modified based on the result of the water temperature analysis (See 6.1.6 and 6.2.6). The benefit of the new IFNs on downstream thermal habitat has not been quantified; however, the reduced thermal mass (from Parks Creek and the Shasta River) in the summer time is expected to reduce the thermal impact to rearing habitat downstream of Big Spring Creek. Therefore, modeling results for June 15-September 6th support reducing the summer minimum IFN to 13 cfs (the sum of IFNs from Parks Creek and Shasta River above Parks Creek).

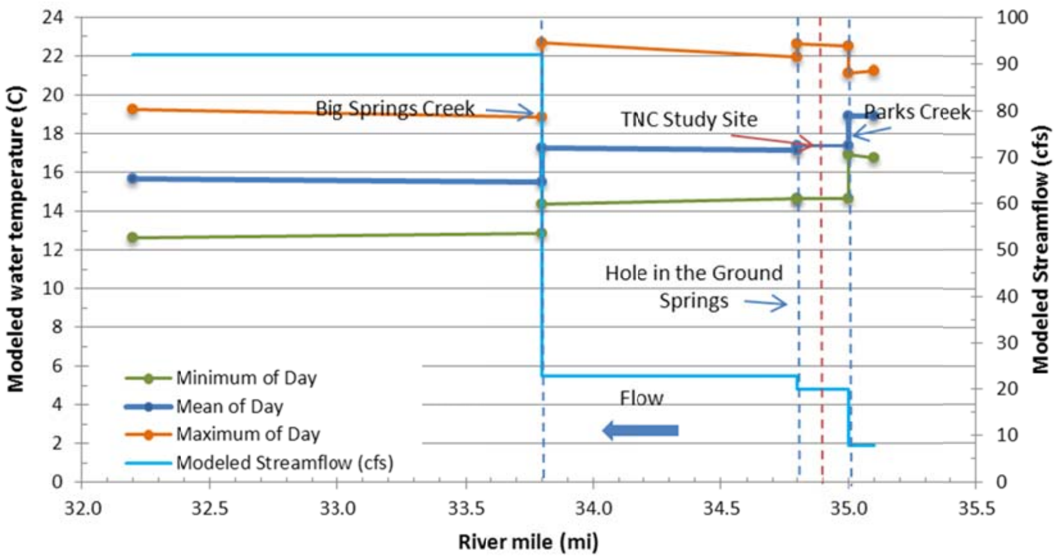


Figure 77. Modeled water temperatures for the 90% exceedence day of the June 16 to September 6 IFN; Shasta River below Parks; spring flow scenario.

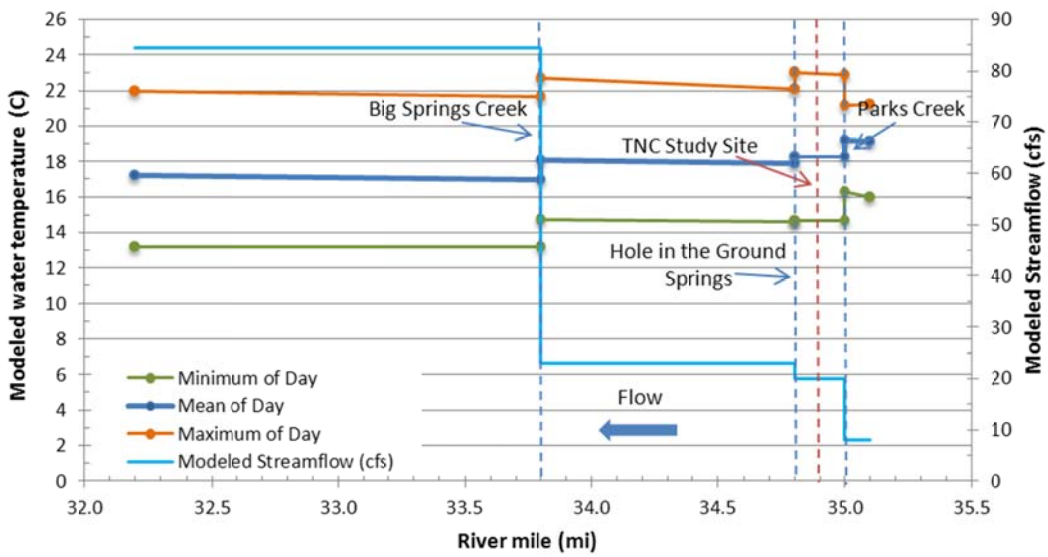


Figure 78. Modeled water temperatures for the 50% exceedence day of the June 16 to September 6 IFN; Shasta River below Parks; spring flow scenario.

6.3.6 Summary of Minimum IFN Findings for the TNC Study Site

Minimum instream flows for the mainstem Shasta River between Parks Creek confluence downstream to Big Springs confluence (Reach No.3), assessed at the TNC study site are presented in Table 30.

Table 30. Minimum IFN findings for the Shasta River between Parks Creek and Big Springs Creek.

Salmonid Life Sage	Q_{MIN} (cfs)	Primary Analytical Measure
September 7 to September 30: Early Adult Chinook Salmon Migration	Q_{MIN} = 20 cfs	Seasonal streamflow providing minimum mRCT of 1.0 ft (Figure 59)
October 1 to December 31: Adult Salmon Migration and Spawning Habitat	Q_{MIN} = 20 cfs to 22 cfs	Median streamflows on the steep rising limb of the four DHM-generated spawning habitat rating curves (Figure 61 to Figure 64).
January 1 to March 31: Winter Juvenile Salmonid Rearing Habitat	Q_{MIN} = 20 cfs	Based on the R2 Cross riffle results (Table 27) and HHT results for pools (Figure 69). As a comparison, WP incipient asymptote riffle assessments averaged 27 cfs (Table 27).
April 1 to June 15: Spring Pulse and Smolt Outmigration	Q_{MIN} = 40 cfs	Initiation of bench inundation at 40 cfs (Figure 73). In addition 70% of the mapped suitable substrates are providing BMI habitat (depth and velocity) at 36 cfs (Figure 72). This interim IFN is supported by water temperature assessment.
June 16 to September 6: Summer Juvenile Salmonid Rearing Habitat	Q_{MIN} = 13 cfs	The physical habitat recommendation is 20 cfs based R2 Cross and HHT results. However, warm summer temperatures at the TNC site and lower recommended IFNs at upstream sites (Section 6.1.5 and Section 6.2.5) due to water temperature constraints support a lower, spring

		flow driven IFN of 13 cfs.

The water temperature modeling results for the TNC site indicate that lower summer flows may improve the thermal conditions for rearing salmonids; however, the response of real-time water temperatures to instream flows may differ from modeled predictions for several reasons. Future upstream boundary conditions could be cooler than those used in the temperature modeling and factors such as irrigation return flows, baseflow accretions, loss due to seepage and bed conduction can all affect water temperature (Section 5.2). Direct monitoring of the streamflow-water temperature relationship during implementation of the interim IFNs is recommended to validate or refine IFNs during the Summer Juvenile Salmonid Rearing Habitat period.

6.4 IFNs for Reach No.4

No additional field studies were conducted for Reach No. 4 as part of this project because of the funding and time constraints, and the availability of data from other studies. For example, an extensive, baseline ecological study by Jeffres et al. (2009) included quantitative assessment of aquatic BMIs, fish habitat, and water temperatures. However, no streamflow-habitat rating curves were developed for spawning or juvenile salmonid rearing in their study. Given the rapid response of Big Springs Creek channel to recently restricted cattle grazing (refer to Figure 57 in Jeffres et al. 2009), streamflow-habitat relationships are rapidly changing along this reach (Jeffres et al. 2010).

Streamflow measured in Big Springs Creek at the Waterwheel by TNC and UC Davis, plus 7.0 cfs from Little Springs Creek, equals the total streamflow at the confluence of Big Springs Creek with the mainstem Shasta River, without adjusting for potential groundwater accretions and/or losses. Unimpaired streamflow from Big Springs at Waterwheel is approximately 89 cfs (Jeffres et al. 2010). In March 2009, TNC acquired the Shasta Big Springs Ranch and an easement on the adjacent Busk Ranch. The Shasta Big Springs Ranch, contiguous with TNC's Nelson Ranch, encompasses 1.4 miles of Big Springs Creek and nearly 7 miles of the mainstem Shasta River extending from the confluence of the Shasta River and Parks Creek downstream below the Grenada Irrigation District Diversion. With the new ownership, there will still be diversions. At this time, an instream flow study to assess future diversion effects does not appear warranted because: (1) the anticipated diversion rate is relatively small, (2) annual streamflows vary over a very narrow range, and (3) streamflow-habitat relationships are rapidly changing under the restricted cattle grazing. A reliable Big Springs contribution of 70 cfs into the mainstem Shasta River channel will have considerable importance in meeting IFNs for Reach No.5 and farther downstream, including the Shasta Canyon mainstem.

6.5 IFNs for Reach No.5

Field studies were conducted on Reach No.5, but to a limited extent. Given a conservative 70 cfs spring baseflow from Big Springs with an additional 7 cfs from Little Springs, the minimum IFNs for Reach No.3 in this report, and 4 cfs from HIG Spring entering below the TNC study site (but upstream of the Big Springs Creek confluence with the mainstem channel), minimum baseflows in Reach No.5 would vary between 101 cfs and 103 cfs annually. Although no physical habitat quantification was attempted and may not be warranted in the future, observed juvenile rearing habitat was abundant throughout the summers of WY2009, WY2010, and WY2011. Dense aquatic macrophyte biomass occupying most of the trapezoidal mainstem channel created a maze of juvenile feeding lanes widely interspersed with high quality cover. The quality and complexity of this habitat maze will depend considerably more on the extent and timing of aquatic growth than on the range of baseflows likely to be released.

Another high priority habitat for Reach No.5 was the spring snowmelt pulse to promote productivity and juvenile rearing habitat capacity when aquatic macrophyte growth is minimal, as well as improve the growth of juvenile salmonids and out-migrating smolts. Our primary source of information for a snowmelt pulse IFN was the 2008 Nelson Ranch study by TNC and UC Davis (Jeffres et al. 2008), which documented juvenile rearing habitat displacement resulting from abrupt streamflow reductions at the onset of irrigation beginning April 1. The entire bench between stations at 16 and 23 in the cross section was inundated entirely by a late-winter streamflow of 137 cfs (Figure 68). The early-autumn streamflow of 127 cfs on October 4, 2007, has a higher stage height, due to the dense aquatic vegetation, than the stage recorded at 137 cfs on March 20, 2007. Initial inundation of the lower bench surface occurred at 90 cfs.

Though the IFN scenarios address study sites in Parks Creek and the Upper Shasta River, flows from those reaches may affect existing downstream reach-scale cool-water habitat in the Shasta River below Parks Creek and also downstream of Big Springs Creek. An analysis of the effect of INF scenarios in Parks Creek and the Upper Shasta River on the Shasta River below Parks Creek illustrated that instream flows from the upstream reaches may warm or cool downstream reaches depending on ambient meteorological conditions and downstream streamflows and water temperatures. Results for the effects of the combined Parks Creek and Upper Shasta River *spring flow* scenario on downstream reaches are presented in Figure 74 - Figure 75 and Figure 77-**Error! Reference source not found.**. During the spring IFN (April 1 through June 15), streamflows contributed from Parks Creek and the Upper Shasta River are generally cooler than those contributed by Big Springs Creek in both the 90th (Figure 74) and 50th (Figure 75) percentile heating day scenario. However, the trend is reversed during the summer IFN (June 16 through September 6), when streamflows from Parks Creek and the Upper Shasta River are generally warmer than flows below Big Springs Creek. These results suggest that the effect of any potential upstream water management action should take the downstream effects into consideration, particularly during the summer when reach-scale cool water habitat is limited to Big Springs Creek and the Shasta River downstream of the confluence with Big Springs Creek.

It is important to note that *spring flow scenarios* were not used to develop the boundary conditions to the lower Shasta River from Big Springs Creek or Hole in the Ground Springs. Instead existing streamflow and water temperature data were used to develop the boundary conditions for these tributaries for several reasons. Unlike the other reaches no study cross sections were developed for Big Springs Creek or the lower Shasta River reach in questions. Similarly, no minimum instream flow prescriptions were developed for Reach No. 4 (See 0). Finally, previous work by TNC (2012) examined the implications of various instream dedications based on their water rights at Shasta Big Springs Ranch and the Nelson Ranch and found little temperature impact associated with leaving flows instream under current conditions. The outcome of the TNC analysis and other studies in the project reach identified that managing temperature with instream flow faced several challenges in these reaches, including but not limited to:

- Thermally degraded waters for managed sources (e.g., Big Springs Lake, Little Springs, Hole in the Ground Creek)
- Complex water operations (e.g., Little Springs Creek sub-watershed diversions into Big Springs Creek sub-watershed, as well as into the Hole in the Ground sub-watershed)
- Variability in spring flows due to external factors (e.g., seasonally varying spring flow production possibly influenced by (a) geohydrology, (b) groundwater recharge rates from distant sources, (c) regional groundwater pumping, (d) other factors.

Due to these various factors, and local complexity, the basic thermal assessment methodology applied to other reaches in this study was not readily applicable to the lower Shasta River. Therefore, existing streamflow and water temperature data were used to develop the boundary conditions (from Big Springs Creek and Hole in the Ground Springs) to the lower Shasta River.

Reach No.5 Minimum IFN Finding

A minimum pulse IFN of 135 cfs in Reach No.5 will provide Tier No. 1 habitat capacity and productivity by beginning to inundate entire bench surfaces based on their identified locations as determined by Jeffres et al. (2008) (Figure 68). However, this minimum will not be sufficient to hydraulically connect scour-channels and side-channels with the mainstem. In addition, further water temperature modeling is necessary to address the effect of upstream management including Big Springs Creek on water temperature in Reach 5.

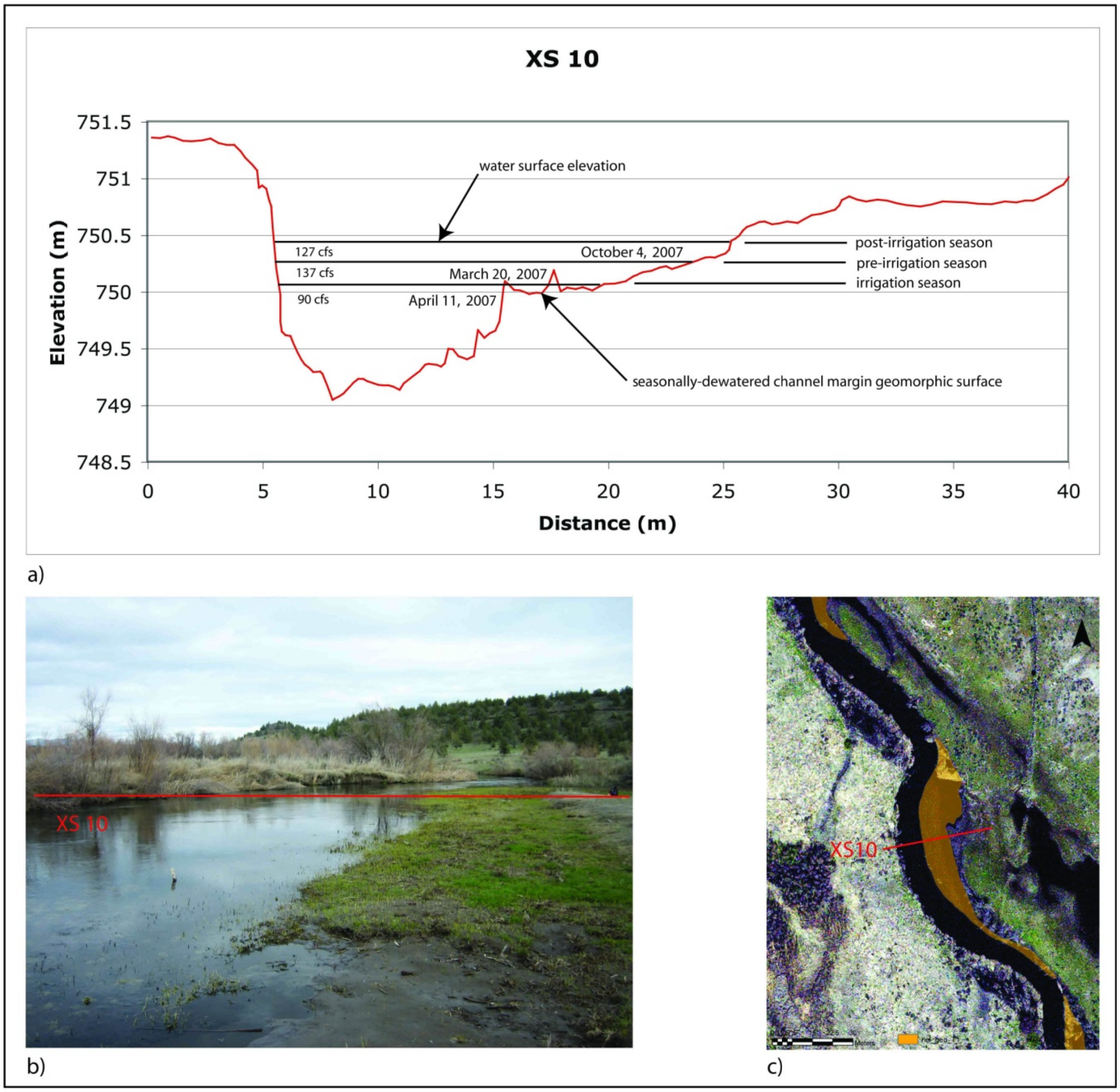


Figure 79. Habitat loss associated with irrigation-driven dewatering of channel margin surfaces: (a) irrigation season water withdrawals and seasonally variable aquatic vegetation growth substantially alter water surface elevations; (b) channel margin surface partially inundated prior to initiation of irrigation season (March 20, 2007);(c) orange polygons in planform map represent surfaces inundated during non-irrigation season and dewatered during the irrigation season. Reprinted from Jeffres et al. (2008).

7 MINIMUM INSTREAM FLOW RECOMMENDATIONS FOR THE BIG SPRINGS COMPLEX

All IFN findings from the previous chapter are summarized in Table 31, and the IFNs at each study site in this table were estimated independently of the other study sites. For example, in the Big Springs Complex, Reach No.3 is the recipient of streamflows from Parks Creek (Reach No.2) as well as the Shasta River mainstem above Parks Creek (Reach No.1). Likewise, Reach No.5 is the streamflow recipient of Reach No.3 and Reach No.4. If a minimum IFN identified independently for Reach No.3 required more streamflow from Reach No.1 and No.2 than the sum of their independently estimated minimum IFNs then the shortfall for Reach No.3 must come from another source.

Fortunately, discrepancies in spatial continuity of streamflows were minor between the Big Springs Complex reaches examined. Choosing the upper streamflow of a recommended IFN range (i.e., choosing 15 cfs for Reach 2 because the recommended IFN range at the UPC study site was 11 cfs to 15 cfs) did create an overage in Reach No.3. The sum of 13 cfs for Reach No.1 and 15 cfs for Reach No.2 exceeded the minimum spawning and migration IFN for Reach No.3 at the TNC study site (20 cfs to 22 cfs). Other, smaller discrepancies did not warrant changing Table 31 to satisfy continuity rigidly.

Table 31. Recommended interim minimum IFNs for priority reaches in the Big Springs Complex.

Salmonid Life Sage	REACH 3 TNC Study Site IFN Q_{MIN} (cfs)	REACH 2A UPC Study Site IFN Q_{MIN} (cfs)	REACH 2C LPC Study Site IFN Q_{MIN} (cfs)	REACH 1C HIG Study Site IFN Q_{MIN} (cfs)
September 7 to September 30: Early Adult Chinook Salmon Migration	20	11 to 15	11 to 15	10
October 1 to December 31: Chinook and coho Salmon Spawning Habitat and Adult Chinook Migration	20 to 22	11 to 15	11 to 15	10 to 13
January 1 to March 31: Winter Juvenile Salmonid Rearing Habitat	20	10	12	7 to 10
April 1 to June 15: Spring Pulse and Smolt Outmigration	40	20 to 25	20 to 25	20 to 25
June 16 to September 6*: Summer Juvenile Salmonid Rearing Habitat	13	2	7	6

Complex IFNs cannot be summarized satisfactorily as a single table because it is difficult to incorporate inter-annual variability and thus these recommended interim minimum IFNs should not be considered a set-in-stone operations table for releasing and/or bypassing instream flows (Table 13). This study had no charge to recommend releases from Dwinnell Dam, allocate spring bypass flows, or change MWCD's diversion operations on Parks Creek for meeting minimum IFNs recommended. These minimum IFN recommendations do satisfy prioritized life stage needs by reach and time period and provide a starting point from which an operations plan can move forward.

Future IFNs for one reach could supersede the IFNs of another reach and time period depending on priorities. Channel reach and salmonid life stage priorities were as follows: Reach No.3 was given priority for winter and summer juvenile rearing, Reach No.1 and No.2 were given priority for adult upstream migration and spawning, and Reach No.5 was given priority for spring snowmelt pulses and smolt outmigration, although water temperature modeling for late-spring through early-fall juvenile rearing habitat could supersede upstream minimum rearing streamflows (i.e., upstream streamflows may have to be higher than their minimums to achieve favorable water temperatures in Reach No.5). Priority for the juvenile summer rearing period also could have IFNs in Reach No.1 and No.2 trump Reach No.3 pending water temperature modeling on Reach No.1c below Clear Springs and Reach No.2c below Kettle Springs) as well as on summer juvenile rearing within Kettle Springs and Bridgefield Springs channels.

7.1 Summary

Recommended interim IFNs for the Big Springs Complex are minimums based on an interim assessment of physical and thermal habitat requirements of salmonids (Table 31). The highly variable inter-annual hydrographs for the Shasta River mainstem immediately downstream of the Parks Creek confluence stress the minimal nature of these interim IFNs compared to magnitude of flows constituting the unimpaired annual hydrograph, particularly during wetter WYs with the natural flow regime intact (Figure 6). Considerable inter-annual streamflow variability is evident over much of the year, but also there is relative uniformity and thus predictability of streamflows from mid-June through late-October (Figure 6). This predictability of seasonal streamflows is characteristic of streams in this climatic region (Gasith and Resh 1999). Future instream flow recommendations, addressing Moyle's Tier No.2 and Tier No.3 objectives, will need to value and adapt to the variability and the uniformity. Future releases of annual spring pulse flows, to partially replace snowmelt runoff stored behind Dwinnell Dam, will need to be contingent on the WY type. Provision of suitable streamflow and thermal regimes is essential for supporting the Shasta basin ecosystem overall and maintaining the valuable resources it provides.

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9 APPENDIX

The technical authors of this report have included a list of comments that, while beyond the scope of this interim IFN recommendation study, document insights made by the authors to help inform the long term evaluation instream flows in the Big Springs complex. In addition, these comments are also intended to provide a cross-walk between the methods in this study and future work that could be done in the basin.

9.1 Comment No. 1: Minimum IFNs at Upstream Big Springs Complex Boundary

IFNs were evaluated near the bottom of Reach No.1, and not at the top near Dwinnell Dam. Differences in channel shape and other characteristics between the top and bottom segments of this reach would have been minor prior to Dwinnell Dam. With no major contributing tributaries in Reach No.1, minimum IFNs would be expected to apply throughout Reach No.1. However, warm-water baseflow dam releases (e.g., juvenile rearing IFNs) would substantially negate fishery benefits upstream, until countered by colder spring flows contributing to mainstem baseflows farther downstream. Streamflows below the minimum IFNs would be preferable to water that is too warm, however, reduced flows tend to be more responsive to atmospheric heating as a result of their reduced thermal mass (Palmer et al. 2009). Water temperatures in sub-reaches of Reach No.1 (Figure 2) will need to be modeled based on release temperature from Lake Shastina under different stage and climatic conditions before identifying desired bypass spring flows and/or devising strategies for irrigating with warm dam releases in exchange for bypassing cold spring flows into the mainstem channel. The mixing of these two sources should be prevented whenever feasible.

Although Dwinnell Dam does not affect Reach No.2, bypass flows below the MWCD diversion would eventually become too warm as the summer progresses, and streamflows above the MWCD diversion will become less than the 10 cfs minimum IFN for salmonid juvenile rearing at the UPC study site (Table 31). Desirable baseflows throughout Reach No.2 would depend on the extent (e.g., springs and mainstem channel immediately downstream functioning as thermal refugia) and location of desired thermal conditions, and could be achieved by combining flows from different sources. For example, 2 cfs from Bridgefield Springs, 4 cfs from Kettle Springs, and MWCD diversion bypass streamflows would achieve one set of thermal conditions, whereas 3 cfs from both springs would achieve another. Strategies for irrigating with warm bypass streamflows in exchange for cold spring flows would expand the size and quality of thermal refugia for juvenile salmonid rearing.

9.2 Comment No. 2: Late-Spring through Early-Fall Water Temperature Assessment

The preliminary investigation of water temperature presented in this report has provided valuable insight to potential water management strategies on the Upper Shasta River and Parks Creek. An analysis of the results suggests that some management strategies may benefit on-going efforts to balance water use with coho salmon population recovery, and further refinements may provide additional direction. However these results are interim and more detailed water modeling is necessary to better describe the effect of management scenarios on thermal habitat. *Ultimately, management decisions should be based on the response of fish to local refugia and estimates of survival based on physical/thermal habitat as well as biological factors.* To identify the response of fish to local refugia, and the response of local refugia to management actions, further water temperature investigation is recommended.

The recommendations to improve understanding of the effects of potential water management strategies include:

- Refined water temperature and streamflow monitoring of spring sources, the conveyance of spring sources to the mainstem reaches, and their confluence with mainstem waterways and impacts downstream.
- Refined monitoring of sub-reach scale local refugia, and the response of fish to changes in refugia.
- Extend the analysis to include multiple year-types to consider the effects of a range of upstream, mainstem streamflows and water temperatures.
- Extend the analysis to include a more refined and comprehensive water flow and temperature model that simulates sub-daily (hourly) water temperature for each of the IFN periods. In this manner, a more refined set of flows could be developed to address the changes in water temperature from, for example, April 1 to June 15 – a period of remarkable change in atmospheric thermal loading.
- Extend the period of analysis to consider the effects of water management strategies over a period during which exposure to elevated water temperatures over consecutive days may have a greater effect on juvenile rearing than the single "bad" day (e.g., weekly time step).
- Evaluate alternative configurations of off-channel spring sources to examine their potential role as off-channel refugia vs. mainstem refugia.

Future modeled diversion scenarios in assessing water temperatures should consider the following:

- Tailwater reduction and control at (a) Shasta Big Springs Ranch (TNC), (b) HIC Ranch, (c) Hidden Valley Ranch, (d) Rogenbuck, and (d) Shasta Springs Ranch;
- Dwinnell Dam baseflow and spring pulse release minimum IFNs;
- Parks Creek baseflow and spring pulse bypass streamflow minimum IFNs;
- Re-operation of the HIG pump diversion to a new location upstream of Clear Springs;
- Unimpaired and regulated Hidden Valley Springs flow contributing to the Shasta River;
- Unimpaired and regulated Clear Springs flow contributing to the Shasta River;
- Unimpaired and regulated Bridgefield Springs flow contributing to Parks Creek;
- Unimpaired and regulated Kettle Springs flow contributing to Parks Creek;
- Elimination of the backwater from the Parks Creek Cardoza Diversion;
- Unimpaired and regulated HIG Springs flow contributing to the Shasta River mainstem; and
- Unimpaired and regulated Little Springs flow contributing to Big Springs Creek.

9.3 Comment No. 3: Better Quantification of Spring Flows and Groundwater Accretion/Loss

The most distinguishing feature of the Shasta Basin, relative to supporting anadromous salmonid populations, has been the cumulative contribution of many springs sustaining high, year-round baseflows. An accounting of all spring locations and quantification of unimpaired or diverted flows remains incomplete, although knowledge in this area has been substantially improved recently as a result of efforts by the Shasta River Tailwater Reduction Program by SVRCD and AquaTerra Consulting. Better information will be essential to modeling streamwater temperatures in the Big Springs Complex. Natural groundwater accretion will be more difficult to quantify, in part, because of the difficulty in continuously and accurately gaging mainstem and tributary streamflows that is due to the prolific growth of aquatic macrophytes. A gaging station designed and operated to overcome these problems upstream of the MWCD diversion on Parks Creek would make an important contribution to future instream flow assessments incorporating springs and groundwater accretion and losses for the Big Springs Complex.

9.4 Comment No. 4: Inter-Annual Streamflow Variability is Essential to Implementing IFNs

The interim minimum IFNs (Table 13) do not account for natural inter-annual streamflow variability. Unimpaired annual hydrographs at the TNC study site provide ample evidence that inter-annual streamflow variability was essential (Figure 80). The magnitude, frequency, duration, timing, and rate of change of channel-scouring streamflows, using a threshold streamflow of 85 cfs, differed broadly by WY type (Figure 80). Desired future IFNs might be expected to achieve a similar magnitude, frequency, duration, timing, and rate of change as the natural regime. This would require variable inter-annual flow releases below Dwinnell Dam and/or variable bypass streamflows at MWCD's Parks Creek diversion. In Wet WYs, more scour-channel habitat would become available for a longer duration than in a Dry WY. Moyle's Tier No.2 and No.3 population and ecosystem objectives will require incorporating inter-annual variability into IFNs expected to recover salmonid populations.

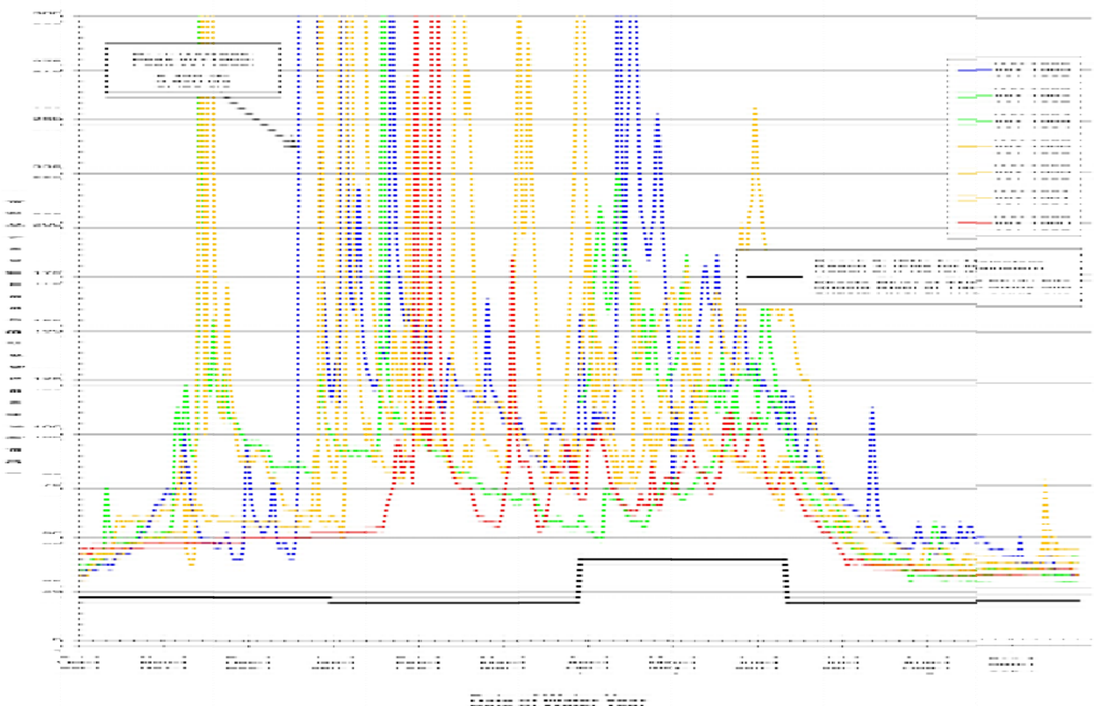

Figure 80. Estimated unimpaired annual hydrographs for the Shasta River below Parks Creek constructed from Shasta River near Edgewood CA daily average flow data (USGS Sta. No 11516750) + Edson-Foulke spring/summer diversions + 23.2 cfs cumulative springs discharge. WYs are plotted with colored lines depicting wetter or drier annual yields; the ratio of annual yield to the historical average annual yield is indicated as a percentage. Notable features of these unimpaired hydrographs include: ascending baseflows in October and November during the salmon spawning season, frequent winter floods exceeding 200 cfs, and occasionally attaining 500 cfs, a modest but distinct annual snowmelt flood in all water years, and low summer and fall baseflows in the 30 cfs to 50 cfs range.

9.5 Comment No. 5: Annual Snowmelt Pulse Flexibility and Cooperative Release Strategies

Minimum snowmelt pulse streamflows are recommended between April 1 and June 15 (Table 13). The spring pulse minimum of 40 cfs should have a strong inter-annual component not addressed in the Tier No.1 IFNs. In dry years, there might be no pulse released/bypassed, whereas in wet years a snowmelt pulse's magnitude would exceed the 40 cfs minimum. Duration of the pulse also should have a strong inter-annual component. A minimum duration between April 1 and June 15 should be four weeks, but again could vary by WY type (e.g., a six week minimum in above-normal WYs). In drier WYs, a snowmelt pulse will be more likely to happen early (e.g., mid-April). In wetter WYs, the pulse will have a greater magnitude and longer duration, but might not begin until mid-May. Prescribing annual flexibility for minimum IFNs was beyond the scope and authority of this study.

Streamflow magnitudes and durations recommended for spring pulses could be operationally partitioned among several flow sources, including dam releases and bypass flows. For example, the spring snowmelt hydrograph in Reach No.5 could be extended once irrigation season begins on April 1 by using unimpaired flows from Big Springs Creek (89 cfs) for two weeks into April. Then annual pulse flow releases could include a four to six week release from Dwinnell Dam extending from April 16 to May 31 down Reach No.1, followed by a variable bypass flow period on Parks Creek extending from May 16 to June 15 down Reach No.2, which would bypass natural, greater snowmelt peaks. Such pulse flows, collectively, would provide ecologically-significant snowmelt flood pulses down Reach No.3 and on into Reach No.5. These ideas are meant just to be suggestive not prescriptive.

9.6 Comment No. 6: Early Chinook Salmon Migration Access Primarily Depends on Streamflows Originating from Springs

Early Chinook migration IFNs from September 7 to 30 in the unimpaired hydrograph required streamflows that relied almost entirely on sources originating from springs. Not until the first or second week of October did a gradual ramping of baseflows generally occur from seasonal rainfall. Unless spring flows are specifically allocated to achieve adult September migration streamflows in all WYs, future bypass streamflows at the MWCD diversion on Parks Creek and Dwinnell Dam releases must be operationally synchronized with unimpaired runoff events.

9.7 Comment No. 7: A Direct Relationship between Streamflow and Water Quality Not a Given

Spring water is the highest quality water available during baseflow periods, and as a result, it warrants the highest possible consideration for managing IFNs for native salmonids. In contrast, Dwinnell Dam releases and irrigation return-flows can be of the lowest quality from late-spring through early-fall, and could thus be viewed as a lower quality source than natural springs for meeting IFNs. For example, a high baseflow release of excessively warm water in August may provide ample physical habitat capacity, but cannot support a rearing juvenile coho salmon. Future baseflows, for meeting minimum IFNs and future IFNs, will require highly orchestrated mixing of multiple water sources. However, two important factors must be determined for this vision to become a reality: (1) how much streamflow, and from what source, will be necessary to provide suitable water temperatures; and (2) at what temperatures, and where, should these management programs be implemented? Although our interim IFNs are a useful kick-start to this process, CDFW will need to answer/solve both these factors before an operational plan can be offered to basin water users. For the foreseeable future, some reaches within the Big Springs Complex that might otherwise provide high quality summer rearing habitat may have temporarily insurmountable challenges with regard to maintaining suitable thermal conditions (specifically, late-summer flow releases from Dwinnell Dam and bypass flows on Parks Creek). Creative solutions preventing cold water from mixing with warm should receive high priority.

The proposed changes will necessarily be incremental because it takes time for new ideas to settle into both human institutions and societies. However, traditional water temperature assessment relies strictly on fixed thresholds and this all-or-none approach (e.g., less than 18°C is good for juvenile coho rearing but water temperatures greater than 18°C are unacceptable) is not well-suited to fostering the types incremental changes needed. Instead, a growth modeling approach toward valuing incremental adjustments that lead to water temperature improvement is needed (Atkinson et al. 2011).

9.8 Comment No. 8: Construct Water Balance Spreadsheet to Assess Water Diversion Strategies

To aid future management of streamflows at the basin scale, a simple water-balance spreadsheet will be a necessary early step to establish hydrologic connectivity throughout the Big Springs Complex, as well as for balancing and allocating streamflows within specific reaches. This spreadsheet would be used to evaluate (1) potential sources of water available to achieve IFNs within reaches and (2) the implications for instream flows assigned in one reach to other reaches downstream. The following streamflow inputs are suggested as a basis for the water-balance spreadsheet:

<u>Reach No.1</u>

- Bypass flow from Dwinnell Reservoir
- Spring flows from Hidden Valley Springs (~1.2 cfs) and Clear Springs (~2.5cfs)
- Groundwater accretion (estimated up to 2.8 cfs downstream of Clear Springs

<u>Reach No.2</u>

- Bypass flow on Parks Creek at I-5
- Spring flows from Bridgefield Springs (ranging from 1.9 cfs during the non-irrigation season to 4.4 cfs during the irrigation season), Black Meadow Springs (ranging from 0.6 cfs during the non-irrigation season to 1.0 cfs during the irrigation season), and Kettle Springs (ranging from 3.0 cfs during the non-irrigation season to 7.0 cfs during the irrigation season)

<u>Reach No.3</u>

- The sum of Shasta River (Reach No.1) and Parks Creek (Reach No.2) will equal total streamflow at the top of Reach 3 (no groundwater accretions or losses are assumed for this reach);
- Spring flows from HIG Springs contributes 4.0 cfs of flow into Reach No.3 just downstream of the TNC study site.

<u>Reach No.4</u>

- A bypass flow immediately downstream of Big Springs Creek. Streamflow measured on Big Springs Creek at the Waterwheel by TNC and UC Davis plus 7.0 cfs from Little Springs Creek equals the total streamflow at the confluence of Big Springs Creek and the Shasta River (assuming no groundwater accretions or losses); unimpaired streamflow from Big Springs is approximately 89 cfs (Jeffres et al. 2010).

<u>Reach No.5</u>:

- The sum of Shasta River (Reach No.3) and Big Springs Creek (Reach No.4) equals the total streamflow at the top of Reach No.5, with no groundwater accretions or losses downstream to approximately Highway A-12.

9.9 Comment No. 9: Future Water Temperature Modeling Scenarios Specifically Target Improved Irrigation Practices

Improved irrigation practices could provide immediate and highly valuable benefits to salmonid populations in the Shasta Basin. The number of days temperature exceeded 23^{o}C was plotted for WY2008 in Reach No.1 and Reach No.3 (Figure 81). Water temperatures at the upstream 'Fence' property line of the HIG Ranch were equally poor in WY2010, but improved at the downstream end of Reach No.1 (at the HIG study site) and at the TNC study site. These water temperature improvements resulted from changes in irrigation practices on the HIG Ranch. Two temperature-related field studies within the Shasta Big Springs Complex focused primarily on Reach No.1 and No.2, including Davids (2011) and Aquaterra (2012). These reports will have water temperature data collected prior to WY2010 that offer a useful comparison to the summer WY2010 temperatures measured. Given the encouraging results, future improvements to irrigation practices only will continue if their benefits are quantified. Water temperature modeling will be one of the best and most economical tools to accomplish this.

Table 32. Summary of water temperatures in Reach No.1 to Reach No.3 in summer 2010 (April through September) from data collected by M&T and AquaTerra Consulting.

Temperature Monitoring Site	**Data Source**	**Daily Maximum (^{o}C)**	**MWAT* (^{o}C)**	**MWMT** (^{o}C)**
Shasta River HIG South Property Line	Aqua Terra (105SRHIGF)	27.9	21.5	27.0
Shasta River HIC Below Pump Diversion	Aqua Terra (105SRHIG4)	23.3	19.7	22.4
Shasta River HIG Clear Springs	Aqua Terra (105SRHGCS)	13.7	13.6	13.6
Shasta River HIG M&T Site	M&T (9727236)	21.8	19.2	20.4
Upper Parks Creek M&T Site	M&T (9727234)	25.8	21.4	25.8
Lower Parks Creek M&T Site	M&T (9727235)	29.8	23.3	28.2
Parks Creek Mouth	Aqua Terra (105SRPARK)	26.0	21.4	24.8
TNC Study Site	M&T (9727238)	22.8	19.9	22.4

*Maximum of the floating weekly average water temperature
** Maximum of the floating weekly maximum water temperature

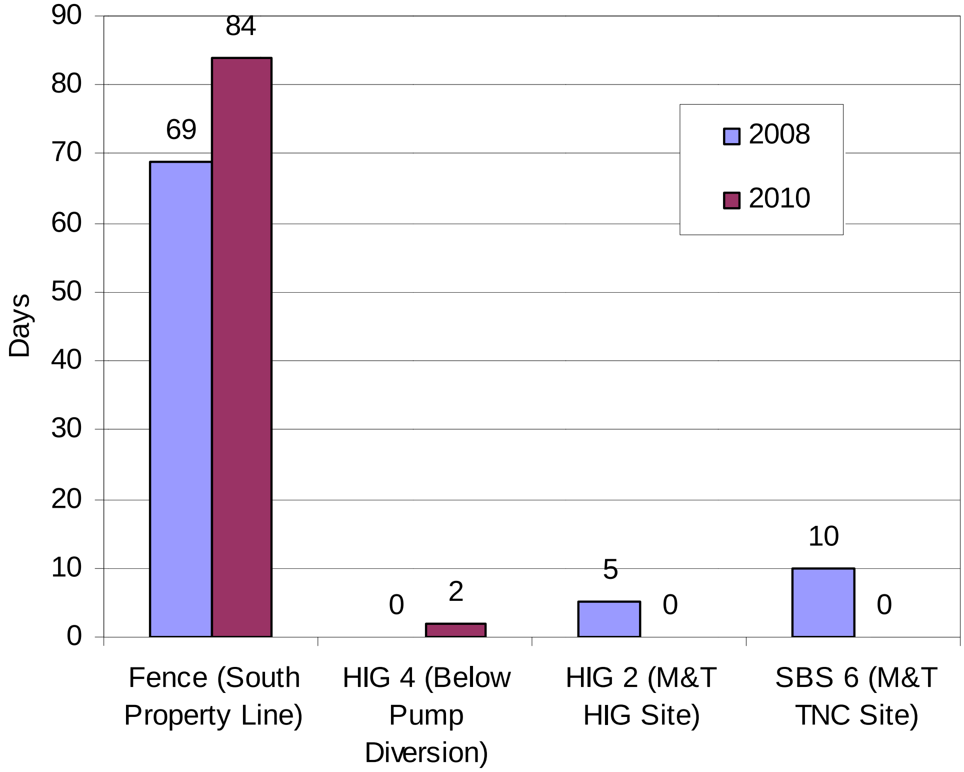

Figure 81. Number of days by site in 2008 and 2010 that maximum daily water temperatures equaled or exceeded 23 °C (replicating Figure 11 in Chesney et al. 2009 where data were available).