Assessment of Restoration Actions on Big Springs Creek, Shasta River, California 2009-2010

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1.0 Executive Summary

1.1 Introduction

In 2008, the University of California, Davis Center for Watershed Sciences, and Watercourse Engineering, Inc. (Watercourse Engineering) implemented a baseline assessment of Big Springs Creek to quantify the physical, chemical, and biological characteristics of the creek prior to restoration (Jeffres et al. 2009, Nichols et al. 2010). That assessment identified elevated water temperatures as the key impairment limiting anadromous salmonid habitat in Big Springs Creek and the Shasta River downstream of the confluence between the two waterways. Following the baseline assessment, a portion of the property that contains Big Springs Creek was purchased by The Nature Conservancy (TNC) and named Shasta Big Springs Ranch (SBSR). Additionally, TNC purchased a conservation easement on the adjacent Busk Ranch, through which the remaining portion of Big Springs Creek flows. Beginning in March 2009, TNC implemented restoration actions throughout Big Springs Creek on both the Shasta Big Springs and Busk Ranches. Primarily, these actions consisted of fencing the riparian corridor to limit access to the creek and prevent in-stream grazing by cattle. Other restoration activities included tailwater and return flow management.

Concurrent with these restoration activities was on-going monitoring of several abiotic and biotic elements from the baseline assessment. These elements included aquatic vegetation, geomorphology, hydrology, hydraulics, water temperature, water quality, and fish assemblage and habitat usage. This report presents data collected between 1 April 2009 and 31 March 2010 for each of these elements. In addition to describing creek conditions during the project period, this report also presents an evaluation of the response of each of the aforementioned monitored elements to restoration activities by comparing conditions identified during the project period (2009-2010) to pre-restoration conditions documented by Jeffres et al. (2009). This evaluation shows that post-restoration changes to the size and spatial extent of aquatic vegetation communities throughout Big Springs Creek were the primary agents behind changes observed in the baseline monitoring elements, and had the greatest impact on water temperatures – the primary limiting condition for salmonids.

1.2 Aquatic Vegetation

Aquatic vegetation was the key agent driving physical, chemical, and biological changes in Big Springs Creek following the implementation of restoration activities (i.e. fencing and cattle exclusion) during the project period. Following fencing activities, seasonal growth of both emergent and submerged aquatic plants was allowed to continue unabated, with the largest changes in plant biomass observed in channel reaches most heavily impacted by cattle grazing during the year prior to restoration. The seasonal growth and senescence of the aquatic vegetation community acted as a key agent in moderating spatial and temporal trends in channel morphology, hydraulics, water quality, water temperature and salmonid habitat availability throughout Big Springs Creek.

1.3 Geomorphology

Channel cross-sectional surveys conducted throughout Big Springs Creek in 2008 and 2009 revealed remarkably wide and shallow channel morphologies, as evidenced by elevated bankfull channel width-to-depth ratios prior to and following passive restoration actions. However, qualitative observations made during cross-section surveys, combined with hydraulic investigations, indicated the spatial distribution of aquatic macrophytes was the dominant control on channel bed sedimentation, erosion dynamics and local expressions of channel morphology. Thus, while minimal changes were observed in bankfull width-to-depth ratios (mean = +1.1%) and bankfull cross sectional areas (mean = +0.3%) during this short post-restoration period, localized sediment deposition and erosion dynamics fostered by the growth of aquatic macrophytes resulted in substantially more lateral variability in cross-section bed topography between 2008 and 2009. Over the short term (several years), with continued cattle exclusion, seasonal patterns of aquatic macrophyte growth will likely be the dominant control on hydrogeomorphic processes and channel cross-section morphology in Big Springs Creek.

1.4 Hydrology

Big Springs Creek is hydrologically characterized by fairly stable baseflow derived from discrete and diffuse groundwater sources. During the project period, mean irrigation season discharge in Big Springs Creek at the waterwheel was 61 ft^3/s ($\sigma = 9$), while minimum discharge during the irrigation season was approximately 44 ft^3/s. Discharge magnitudes in Big Springs Creek rebounded rapidly to unimpaired baseflow conditions in early October 2009 following the cessation of upstream irrigation diversions, with mean non-irrigation season discharge magnitudes of 80 ft^3/s ($\sigma = 4$).

With the continued use of groundwater-derived spring-flows for irrigation purposes on the Shasta Big Springs and Busk Ranches, as well as the continuance of regional groundwater pumping, the magnitude, timing, and variability of streamflow in Big Springs Creek showed minimal response to cattle exclusion. Observed small reductions in mean, non-irrigation season streamflows following cattle exclusion were likely the surface water response to accumulated depletion of regional groundwater recharge during four consecutive years of drought in the Shasta River valley.

1.5 Hydraulics

While groundwater-derived streamflow characteristics (magnitude, timing and variability) in Big Springs Creek remained relatively unchanged in response to restoration actions, the hydraulic response (i.e. stream depth, wetted cross-sectional area and flow velocities) to cattle exclusion and resultant growth of aquatic vegetation was pronounced, albeit somewhat spatially and temporally variable. During the project period, the growth and senescence cycles of aquatic macrophytes and resultant sediment deposition and erosion dynamics played a large role in determining local hydraulic conditions, largely illustrated by variable changes in stream depth, wetted cross-sectional area, and stream velocity. While post-restoration changes to stream depths and cross-sectional area were spatially variable, consistent changes in lateral velocity profiles were observed, principally expressed by high flow velocity corridors between patches of aquatic vegetation. The majority of streamflow was routed through these unvegetated, high-velocity corridors.

1.6 Water Temperature

Additional water temperature monitoring of discrete springs led to a refinement in the preliminary profile developed in Jeffres et al. 2009. These observations illustrated that spring sources emerge at stable temperatures of 10-12^oC and contribute a steady source (~40 ft^3/s) of cool water to Big Springs Creek. Water temperatures of other significant inflow sources, such as releases from Big Springs Dam, were also monitored. However, the water temperatures of those non-spring sources were more variable and seasonally deviated from spring sources. Though temperatures of inflow sources were comparable in 2009 to 2008, the presence of aquatic vegetation and underlying effects of aquatic vegetation growth on stream geomorphology, hydraulics and shading resulted in decreased rates of heating from pre-restoration to post restoration conditions.

A comparison of 2009 to 2008 water temperature conditions at several locations along the longitudinal profile of Big Springs Creek illustrated that while parts of Big Springs Creek responded with decreased rates of heating to restoration actions, other reaches in which those actions were delayed did not respond as strongly – in fact, heating rates increased in these areas. Maximum water temperatures increased above the waterwheel (RKM 2.8) by as much as 1.9^oC from 2008 to 2009, where cattle exclusion was delayed until July 2009, curtailing the period of recovery for aquatic vegetation in that reach. Below the waterwheel, where cattle exclusion commenced in March 2009, maximum water temperatures decreased by as much as 1.7^oC. Overall, water temperatures at the mouth of Big Springs Creek were cooler in 2009 compared to 2008 and resulted in increased habitat available to salmonids. Furthermore, the benefit likely extended into the Shasta River downstream of its confluence with Big Springs Creek, resulting in many more kilometers of improved habitat conditions beyond Big Springs Creek and illustrating the value of targeted restoration actions.

1.7 Water Quality

A wide range of physical and chemical water quality parameters were collected in Big Springs Creek to extend the baseline existing conditions data set and to assess potential changes through time. Post-restoration monitoring confirmed that the springs provide geologic forms of inorganic nitrogen and phosphorus that are vital to the primary productivity and anadromous fish production potential of Big Springs Creek and the downstream Shasta River. Sources of nutrients may vary among different spring sources, with adjacent land use activities contributing as well. The system was nitrogen limited downstream in the Shasta River, but growth limitation was not generally attained in Big Springs Creek. Thus, aquatic vegetation in this shallow, clear stream was not limited by light or nutrients, leading to the extensive growth that impacts many of the critical factors (geomorphology, flow, temperature, etc.) in the creek. The extensive growth appeared to have reduced nitrogen concentrations in the immediate aftermath of grazing removal; however, additional data are required to determine if this is a persistent reduction, a relic of natural inter-annual variability, or a combination of the two.

1.8 Fish Assemblage and Habitat Usage

Habitat conditions changed considerably for salmonids after restoration actions were put in place. The largest change for salmonids in the system was the removal of cattle and growth of aquatic macrophytes. It was not possible to compare the habitat usage in Big Springs Creek by juvenile coho from the 2008-2009 and 2009-2010 sampling periods due to such small numbers. This was in large part due to the small number of adult returns (28) to the Shasta River during 2008-2009 sampling effort compared to 249 the previous year (CDFG unpublished data). However, the presence of adult and juvenile Chinook salmon and steelhead provided some indication of habitat conditions in Big Springs Creek. Adult Chinook redd counts were relatively similar in 2008 and 2009, yet the apparent productivity between the two years is significantly different. In the 2008-2009 sampling period 0.0004 juvenile Chinook were observed per linear meter surveyed, while during the 2009-2010 sampling period 0.086 juvenile Chinook were observed per linear meter surveyed, illustrating a 215-time increase in juvenile Chinook despite comparable adult returns in 2008 and 2009. Abundant habitat was available throughout Big Springs Creek due to the growth of aquatic macrophytes, which provided cover, depth, and a velocity refuge. Juvenile Chinook that reared in Big Springs Creek appeared to grow at a rapid rate due to abundant food resources and the high quality habitat found in Big Springs Creek. In the 2009-2010 sampling season 0+ steelhead were greater than two times more abundant than during 2008-2009. Similar to Chinook, the exclusion of the cattle was likely the primary cause for the increase in the 0+ steelhead numbers. The removal of the cattle allowed for successful spawning and provided rearing habitat for small juvenile steelhead.

1.9 Conclusions

The implementation of passive restoration actions (i.e. fencing and cattle exclusion) resulted in significant changes throughout Big Springs Creek, culminating with the reduction of maximum water temperatures and improved habitat conditions for anadromous and resident salmonids. The key factor driving physical, chemical, and biological changes in Big Springs Creek was the growth of aquatic macrophytes. Both submerged and emergent macrophyte growth improved salmonid habitat by promoting geomorphic changes such as scouring of fine sediments from gravels; hydraulic changes such as creating diverse lateral velocity profiles and increasing mean flow velocities; and water temperature changes principally illustrated by reduced maximum water temperatures through the reduction of potential solar loading by providing shade and reducing travel times. The resulting improved salmonid habitat was evident by the increased abundance of salmonid populations.

Observations made for each abiotic and biotic element monitored during this study have yielded recommended monitoring and assessment actions that will provide a foundation of information from which to understand complex spatial and temporal interactions between physical stream conditions and biotic community structure and behavior. Understanding such interactions is necessary to effectively and adaptively manage on-going restoration actions in an effort to meet to the principal objectives of increasing the spatial extent of habitat suitable to salmonids throughout Big Springs Creek and the Shasta River below.

2.0 Introduction

The Shasta River is the fourth largest tributary to the Lower Klamath River. Once one of the most productive salmon streams in California, the Shasta River historically produced roughly half of the Chinook salmon in the Lower Klamath River watershed while contributing less than one percent of the mean annual flow measured at the mouth of the Klamath River at Orleans (Wales 1951, NRC 2004). This prodigious historical production of salmon was largely related to the unique hydrologic and geologic setting of the Shasta River, where streamflow is principally dominated by groundwater discharge from several large groundwater springs.

The Shasta River flows northwestward from its headwaters on Mount Eddy to its confluence with the Klamath River. Located along this flowpath are several groundwater springs, often collectively referred to as the "Big Springs Complex.". Several of the largest springs collectively form or provide tributary streamflow to the Shasta River tributary Big Springs Creek (Figures 1 and 2). Voluminous and cold (10^{o}C to 12^{o}C at the source) baseflows within Big Springs Creek are optimal for winter and summer salmonid rearing, while geologically derived nutrients fuel productivity in the downstream aquatic food web. Reliable flows, optimal temperatures, and nearly unlimited food explain the historically high salmon production of the Shasta River. However, more than a century of intense cattle grazing and poor management practices have significantly degraded the spawning and rearing potential of Big Springs Creek. Additionally, the creek had become a source of significant thermal loading to the Shasta River, impacting salmonid habitat conditions for tens of kilometers downstream (Nichols et al. 2010)

Central to recovery of the salmonid population in the Shasta River is the management and restoration of Big Springs Creek. Restoring physical habitat, flow, and water temperature regimes in Big Springs Creek was shown to have the highest potential for maintaining and eventually restoring coho salmon in the Shasta River watershed (Jeffres et al. 2009). In March 2009, The Nature Conservancy, California (TNC) initiated a multi-year river restoration effort on Big Springs Creek through the acquisition of Shasta Big Springs Ranch and an easement on the adjacent Busk Ranch (Figures 1 and 2). Together, Shasta Big Springs Ranch and the Busk Ranch easement provided access and restoration opportunities along the entire length of Big Springs Creek. Unlike many restoration efforts, the UC Davis Center for Watershed Sciences in association with Watercourse Engineering Inc. (Watercourse Engineering) was able to obtain baseline data prior to the beginning of restoration activities (Jeffres et al. 2009), thus allowing for the quantification of physical, chemical, and biological responses to restoration actions along Big Springs Creek.

3.0 Project Description

Only 10% of riverine restoration projects conducted in the United States include some form of monitoring or assessment of restoration progress or outcomes (Bernhardt et al. 2005). Consequently, many opportunities to adaptively manage restoration efforts and to learn from project successes or failures are lost. The goal of the UC Davis Center for Watershed Sciences/Watercourse Engineering assessment of restoration activities throughout the Shasta Big Springs and Busk Ranches is to support on-going conservation and restoration planning on these ranches, as well as throughout the Shasta River basin. These efforts are principally directed towards the management of coho and Chinook salmon, as well as steelhead.

From March 2008 through January 2009, the UC Davis Center for Watershed Sciences and Watercourse Engineering conducted a comprehensive baseline assessment of physical, chemical, and biological conditions throughout Big Springs Creek prior to initiation of restoration actions by TNC (see Jeffres et al. 2009). Following the purchase of Shasta Big Springs Ranch and the Busk Ranch easement, and the initiation of restoration actions by TNC in March 2009, monitoring and assessment of aquatic habitat conditions were continued by UC Davis and Watercourse Engineering as part of this study. The objectives of this study were three-fold:

1) document change in the physical, chemical, and biological condition of aquatic habitats following the initiation of restoration actions along Big Springs Creek from April 2009 through March 2010;
2) identify and quantify factors that continue to limit salmonid production in Big Springs Creek; and
3) identify the restoration and water resource management actions that improved habitat during the project period and will continue to directly improve salmonid spawning and rearing conditions throughout Big Springs Creek.

Summarized below are the project scope of work, a general description of the project area, and a summary of restoration actions initiated by TNC during the project period.

3.1 Scope of Work

The scope of work outlined herein includes the physical habitat, water quality, and fish habitat utilization data collected between April 2009 and March 2010. These data document physical, chemical, and biological conditions during the first year following the initiation of restoration activities on the Shasta Big Springs and Busk Ranches.

Physical habitat data included continuous streamflow and water temperature monitoring, geomorphic surveys, and aquatic macrophyte biomass monitoring throughout Big Springs Creek. Furthermore, complex geomorphic and hydraulic conditions driven by interactions between streamflow, sediment deposition, and aquatic macrophyte growth were assessed at selected locations along Big Springs Creek. To continue monitoring hydrologic conditions throughout the Shasta Big Springs and Busk Ranches, streamflow monitoring stations were maintained at previously established locations in the Shasta River, Parks Creek, Big Springs Creek, and selected spring-fed tributaries including Hole in the Ground Creek and Little Springs Creek to define the hydrology and quantify spring flow accretions (see Jeffres et al. 2009). Water temperature data were collected throughout Big Springs Creek and its tributaries to quantify and assess changes to longitudinal thermal gradients.

Water quality characterization included systematically sampling water quality at source spring waters to Big Springs Creek, and at multiple downstream sites along Big Springs Creek and the Shasta River below to capture seasonal variations in water chemistry (particularly the nutrients nitrogen and phosphorus) and other water quality characteristics.

Fish abundance and habitat utilization were quantified through extensive snorkel surveys of Big Springs Creek. Surveys were tied to physical and chemical habitat characterizations described previously to determine seasonal distribution of salmonids of different age, life history, and environmental tolerance.

In accordance with the project work scope, monitoring of physical, chemical, and biological conditions was conducted on waterways throughout the Shasta Big Springs and Busk Ranches. However, as restoration actions have largely focused on Big Springs Creek, only data collected from Big Springs Creek during the project period will herein be presented and compared to pre-restoration data.

3.2 Project Area

Together, the Shasta Big Springs and Busk Ranches encompass approximately 4,500 acres and part or all of five rivers or creeks: Big Springs Creek, the Shasta River, Parks Creek, Little Springs Creek, and Hole in the Ground Creek (Figure 2). Big Springs Creek, the primary focus of this study, flows westward for approximately 3.7 km. The upper 1.5 kilometers of Big Springs Creek flows through the Busk Ranch, while the lower 2.2 kilometers flow through the Shasta Big Springs Ranch before entering the Shasta River at river kilometer 54.2 (Figures 1 and 2). Big Springs Creek emanates from Big Springs Lake and several discrete springs located downstream of Big Springs Dam. During summer baseflow, Big Springs Creek accounts for approximately 80% of the streamflow downstream in the Shasta River. Big Springs Lake was impounded around 1875 to support irrigation activities on adjacent lands, and inundated the easternmost portion of the groundwater springs complex (i.e., the source water for the lake). Through time an extensive network of irrigation canals and associated features evolved to the current land use conditions.

The Shasta River flows approximately 97 km northwestward from its headwaters to its confluence with the Klamath River and is the fourth largest tributary in the Lower Klamath River system (Figure 1). Bounded by the Scott Mountains to the west, Siskiyou Mountains to the north, and the Cascade Volcanic Range to the south and east, the Shasta River Basin exhibits considerable spatial variability in geologic and hydrologic characteristics. Tributaries from the Scott and Siskiyou Mountains flow northeast to the Shasta River, roughly perpendicular to the northerly strike of a the Eastern Klamath Belt, a geologic province comprised of a complex assemblage of Paleozoic sedimentary and metamorphic rocks and Mesozoic intrusives (Hotz 1977). Northerly and westerly flowing tributaries to the Shasta River drain both the northern slopes of Mount Shasta and the western slopes of the Cascade Range, regions largely underlain by porous volcanic rocks of the Western and High Cascades geologic provinces. The Shasta River flows for most of its length along the floor of Shasta Valley, an area underlain principally by a complex assemblage of High Cascade Plio-Pleistocene andesitic and basalitic lava flows and volcaniclastic materials derived from a Late Pleistocene debris avalanche from ancestral Mount Shasta (Wagner 1987, Crandell 1989). Low-gradient basalt flows (e.g., Plutos Cave Basalts) dominate the eastern portions of Shasta Valley, while western regions exhibit a mosaic of andesitic and dacitic hillocks and depressions formed by the aforementioned debris avalanche. Holocene basalt flows are the primary water-bearing geologic formation within the Shasta River basin, and are the principal source of spring-flow to Big Springs Creek. The local climate is semi-arid with mean annual precipitation varying between 25.4 cm and 45.7 cm (Vignola and Deas 2005), much of which falls as snow in higher elevations during the winter months.

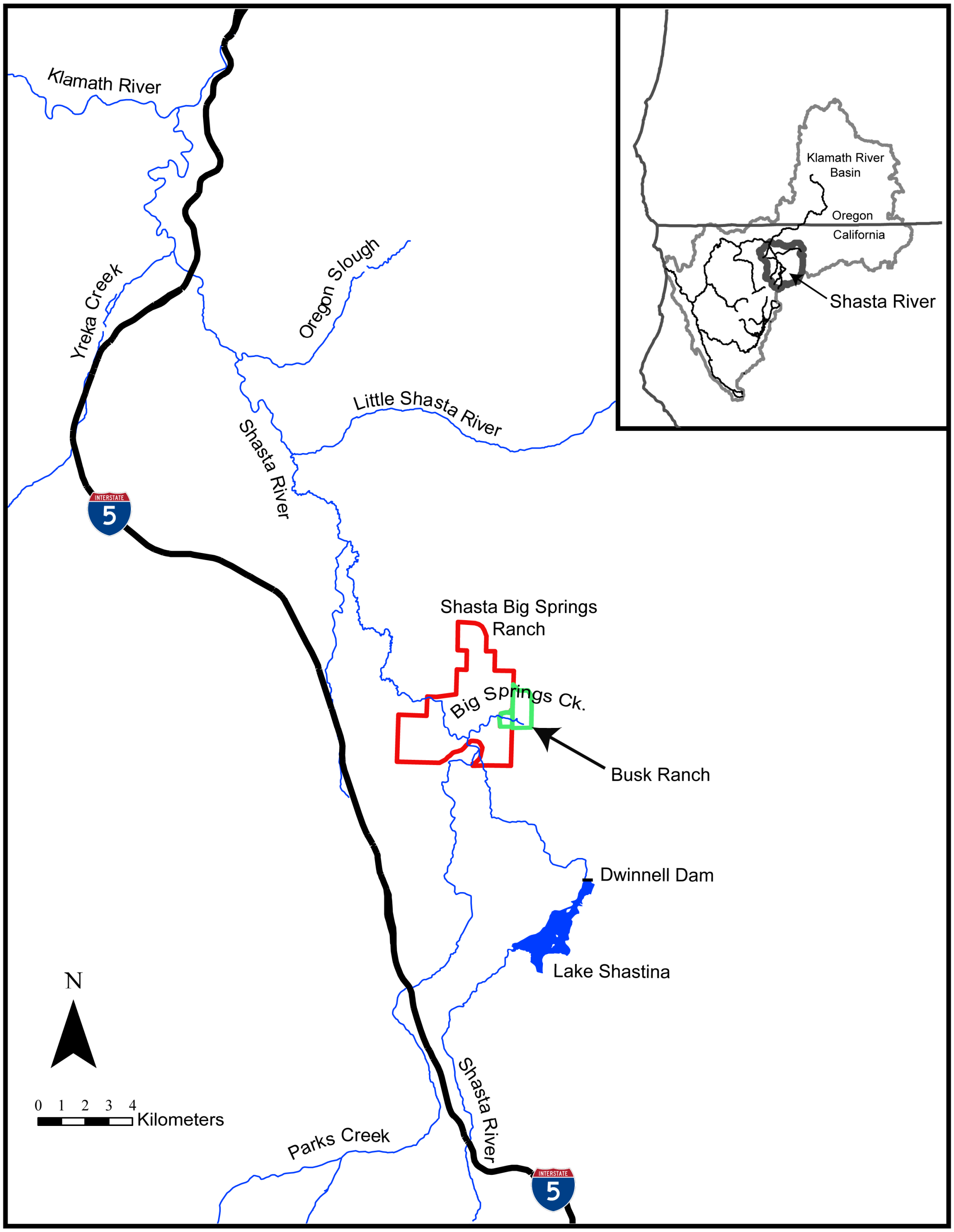

Figure 1. Location of the Shasta River within the Klamath basin and Big Springs Ranch within the Shasta River basin.

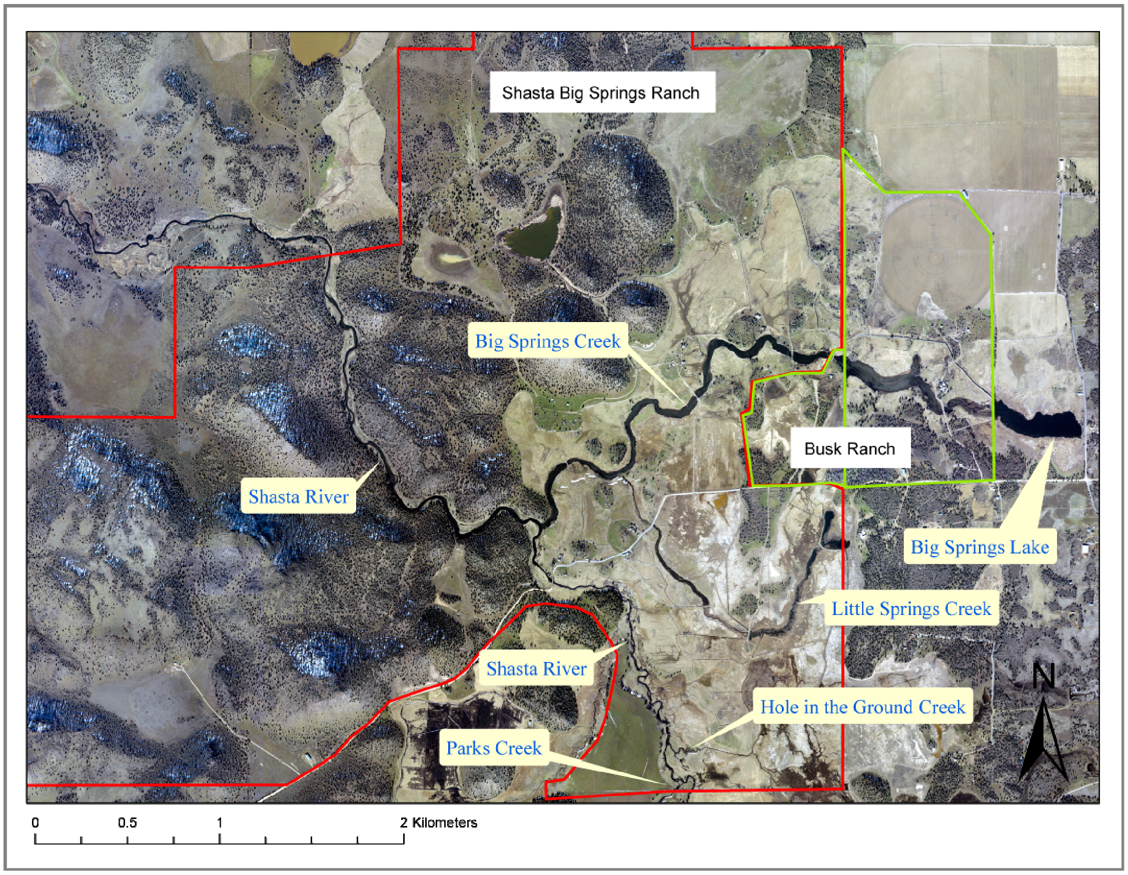

Figure 2. Major waterways on the Shasta Big Springs and Busk Ranches.

3.3 Summary of Restoration Actions

In March 2009, The Nature Conservancy, California (TNC) purchased Shasta Big Springs Ranch and a conservation easement on the easterly adjacent Busk Ranch (Figure 2). Immediately following acquisition of Shasta Big Spring Ranch, TNC excluded cattle from the Shasta River, Big Springs Creek, Little Springs Creek, Hole in the Ground Creek, and adjacent riparian areas using a combination of existing fence lines and temporary electric fencing. Additionally, TNC undertook numerous ranch management efforts to improve irrigation efficiencies and reduce tailwater return while actively maintaining the cattle ranch. Permanent barbed-wire fencing is currently being installed along the aforementioned waterways throughout Shasta Big Springs Ranch.

Restoration actions on the Busk Ranch have primarily consisted of cattle exclusion using permanent barbed wire fencing along Big Springs Creek. However, permanent fencing was not established along Big Springs Springs Creek through the Busk Ranch until July 2009, thus preventing cattle exclusion from the river during the peak growth period for aquatic vegetation. Also, cattle on the Busk Ranch are permitted limited access to the creek at designated watering lanes.

During the project period, restoration actions consisted primarily of passive efforts at cattle exclusion using riparian fencing on both the Shasta Big Springs and Busk Ranches. As such, post-restoration changes in physical, chemical, and biological conditions throughout Big Springs Creek principally reflect a riverine ecosystem response to riparian fencing and resultant cattle exclusion. Active restoration activities throughout Shasta Big Springs Ranch are currently being undertaken. Such actions include riparian and emergent vegetation plantings, as well as irrigation water management.

3.4 Monitoring Data Organization

Physical habitat data collected from Big Springs Creek during the project period included surveys of geomorphic conditions, hydrologic/hydraulic conditions, water temperature and water quality. Concurrent biological monitoring included aquatic macrophyte biomass and fish abundance surveys. When possible, these data were compared to similar baseline data sets collected prior to the initiation of cattle exclusion in March 2009 (see Jeffres et al. 2009), thus allowing quantitative assessment of the initial physical habitat and ecological community response to restoration actions.

Typically, riverine monitoring data is structured to logically present physical habitat observations (i.e. hydrology, hydraulics, geomorphology, water quality, and water temperature) prior to dependent (typically) biological community data. However, physical and biological monitoring efforts throughout Big Springs Creek during the project period revealed the growth of aquatic macrophytes as the primary driver of physical habitat change, both seasonally and in response to restoration actions. Observations indicated that with relatively stable hydrologic conditions driven by groundwater-derived baseflows, short-term temporal changes to physical habitat conditions (hydraulics, geomorphology, water temperature and water quality) were principally driven by spatial and temporal variations in aquatic macrophyte growth throughout Big Springs Creek. As such, aquatic macrophyte survey data collected during the project period is presented in this report prior to physical habitat survey/monitoring data – data that is largely driven by and dependent upon observed spatial and temporal changes in the aquatic macrophyte community. Fish abundance data follows our presentation of physical habitat data.

4.0 Aquatic Vegetation

The growth of aquatic macrophytes as a result of cattle exclusion was the single largest driver of habitat change, both physical and ecological, in Big Springs Creek. The prolific growth of aquatic macrophytes creates a unique ecological environment where aquatic macrophytes act as a substrate for benthic macroinvertebrates, while simultaneously providing complex habitat for fish - conditions largely lacking in Big Springs Creek when aquatic macrophytes are absent. Along with providing direct benefits to invertebrates and fish, the seasonal growth and senescence of aquatic macrophytes largely drive physical processes within the creek by controlling spatial trends in geomorphic conditions, hydraulic conditions and water quality/temperature. By removing the disturbance associated with cattle grazing from Big Springs Creek and allowing the natural growth cycle of aquatic macrophytes to proceed unabated, habitat conditions changed throughout the creek. Because of the importance of the growth of aquatic macrophytes in the restoration of Big Springs Creek, we will first outline changes in aquatic macrophytes as a result restoration activities, and then discuss the corresponding changes to physical and ecological habitat conditions.

4.1 Methods

Three (3) 100-meter study reaches were selected for monthly aquatic macrophyte sampling along Big Springs Creek (Figure 3). On each sampling date, six sample sites were randomly selected within each study reach. A square PVC-frame quadrat was used to delineate an area of 0.37 m^2 and all above-ground biomass within the quadrat was removed. Harvested plant material was vigorously agitated in the stream to reduce the presence of clinging macroinvertebrates (epibiota) and other detrital material prior to being placed in individually labeled bags and returned to the laboratory for analysis. In the laboratory, samples were placed in a drying oven, dried to a constant mass at 65ºC for at least 72 hours (h), and subsequently weighed. Samples were then ashed in a muffle furnace for four hours at 475ºC, cooled to a constant mass and reweighed to derive an ash free dry mass (AFDM) for each sample. Mean standing stock for macrophytes and filamentous algae is reported as grams ash-free mass dry per square meter ($g\ AFDM \cdot m^{-2}$). Samples were not collected at the ”Isotope” and “Downstream Crossing” sample locations in October 2009 due to the presence of Chinook salmon spawning. It was determined that sampling could be stressful to the spawning salmon. In December 2009, samples were not collected at the two upstream locations due to high winds not allowing for accurate collection of the samples.

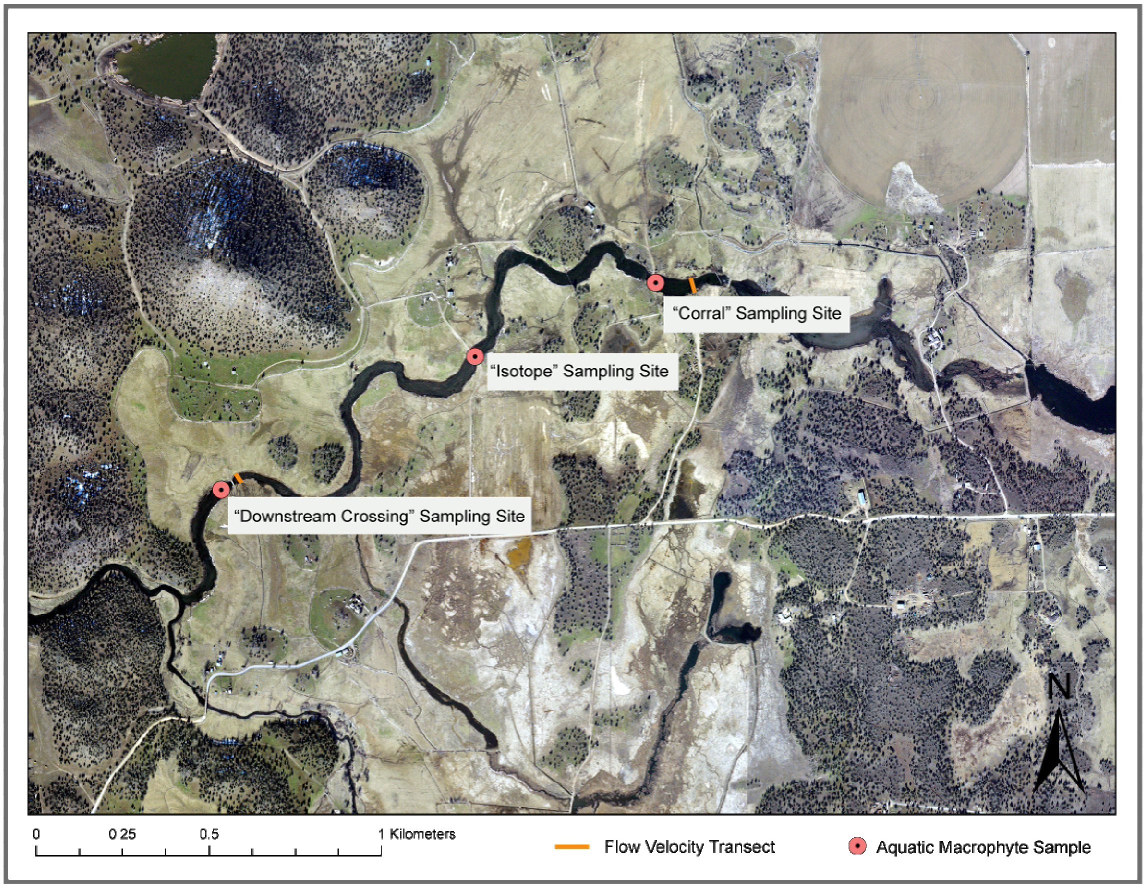

Figure 3: Aquatic macrophyte sampling sites along Big Springs Creek. Flow velocity transect locations at the "Corral" and "Downstream Crossing" study sites are also identified.

4.2 Data Analysis

From March 2008 through March 2009, the lack of exclusion fencing allowed cattle intermittent access to Big Springs Creek for grazing on aquatic macrophytes. The duration and timing of grazing access depended entirely upon the periodic rotation of grazed pastures. This intermittent grazing access, while forcing periodic removal of aquatic vegetation biomass from the creek, did allow a natural trend in vegetation growth to occur throughout the 2008 growing season. Seasonal growth trends were characterized by increased macrophyte growth through the spring and summer of 2008, followed by a gradual senescence during the late fall, winter, and early spring of 2009. This seasonal trend in aquatic macrophyte growth and senescence is observed in many shallow, lowland rivers, and, particularly those with elevated nutrients and minimal riparian shading (Clarke, 2002). Prior to cattle exclusion in March 2009, aquatic macrophyte sampling occurred only at the "Isotope" sampling site (Figure 3). Results of this sampling effort indicated that despite cattle grazing within the stream, vegetation biomass increased throughout the summer of the 2008 (Jeffres et al. 2009), with mean standing crop at the "Isotope" sampling site exhibiting a spring-time low of 35.7 g/m^2 AFDM and a fall maximum of 182.1 g/m^2. It should be noted that this standing crop was grazed by cattle during this time.

Immediately following cattle exclusion in April 2009, biomass sampling and qualitative observations revealed that initial aquatic macrophyte community size and composition varied greatly, depending on the location within Big Springs Creek (Figure 3). The primary cause of this difference was management of cattle during the winter prior to cattle exclusion (January though March 2009). Cattle were primarily grazed on pastureland adjacent to the “Downstream Crossing” sampling site, with intermittent access to pastures adjacent to the ”Isotope” sampling site, and little to no access to pastures adjacent to the “Corral” sampling site. The amount of cattle grazing on adjacent pastureland, and consequently the stream, during the previous winter was inversely proportional to the biomass of aquatic macrophytes measured at each sampling site at the beginning of the post-exclusion study period in April 2009 (Figure 4).

As summer progressed and length of day increased following cattle exclusion, plant biomass increased at the “Isotope” and “Downstream Crossing” study sites (Figure 4). At the “Downstream Crossing” site, mean standing crop of macrophytes increased from a low of 2.65g/m^2 AFDM in April 2009 to a high of 145 g/m^2 AFDM in September 2009. At the “Isotope” sampling site, mean standing crop increased from a low of 62.25 g/m^2 AFDM in April 2009 to a high of 211.58 g/m^2 AFDM in August 2009. The April 2009 macrophyte samples collected at the “Downstream Crossing” and “Isotope” sampling sites were representative of both natural seasonal fluctuations in biomass as well as previous disturbance by cattle.

Biomass remained relatively constant throughout the post-cattle exclusion sampling effort at the “Corral” sampling site (Figure 4). It is hypothesized that minimal cattle grazing at this site during the previous winter allowed the maximum potential biomass to be reached in early spring 2009, allowing the mean standing crop to remain fairly stable throughout the summer. Despite the large biomass measured during the first sample collection, variance was high and samples were statistically similar from April 2009 through January 2010. Furthermore, the macrophyte assemblage was different at the ”Corral” sampling site, compared to the “Isotope” and “Downstream Crossing” sampling sites. The “Corral” sampling site exhibited a macrophyte assemblage dominated by water smartweed (*Polygonum amphibium*), which is a more robust, woody-stemed plant than those found at the lower two sampling locations which were primarily northern watermilfoil (*Myriophyllum sibericum*) and watercress (*Nasturtium* sp.). Qualitative observations suggest the morphology of the smartweed may have facilitated its continued growth during the winter 2009 at the “Corral” sampling site.

4.3 Response to Restoration Actions

Comparison of the mean standing crop of aquatic macrophyte samples collected at the “Isotope” sampling site in March 2008 (pre-restoration), April 2009 (immediately following cattle exclusion) and March 2010 (one year following cattle exclusion) allows direct analysis of the macrophyte community response to passive restoration actions. While the expected seasonal growth and senescence of the standing crop was observed during both 2008-2009 (see Jeffres et al. 2009) and 2009-2010 (Figure 4), the impacts of cattle grazing were principally illustrated by statistically significant differences between mean standing crop measured from macrophyte samples collected in March 2008 and April 2009 (35.7 g/m^2 and 62.25 g/m^2 AFDM, respectively) compared to the mean standing crop of samples collected in March 2010, (307.52 g/m^2 AFDM) – resulting in an approximately 394% increase in the standing crop at the "Isotope" sampling site one year following cattle exclusion.

Similar post-cattle exclusion differences in macrophyte biomass were also observed at the "Downstream Crossing" study site. Comparison of the mean standing crop of aquatic macrophyte samples collected in April 2009 (2.65 g/m^2 AFDM) and March 2010 (158.38 g/m^2 AFDM) reveal an increase of approximately 60 times the spring-time standing crop one year following cattle exclusion.

Interestingly, mean standing crop of aquatic macrophytes at the "Corral" sampling site has seen a gradual decrease in biomass following cattle exclusion. Reasons for this reduction are unclear, and may be related to successional dynamics or self-shading as plant biomass reaches a yet undescribed threshold. Future data collection will be necessary to ultimately determine the cause decrease in the corral biomass.

It should also be noted that post-restoration changes in mean biomass of standing macrophyte crops throughout Big Springs Creek may be influenced by changing species composition in response to cattle exclusion. In absence of cattle grazing, unfettered inter-species competition for nutrient and light resources likely impact standing crop biomass at any one location. However, this impact currently remains unquantified.

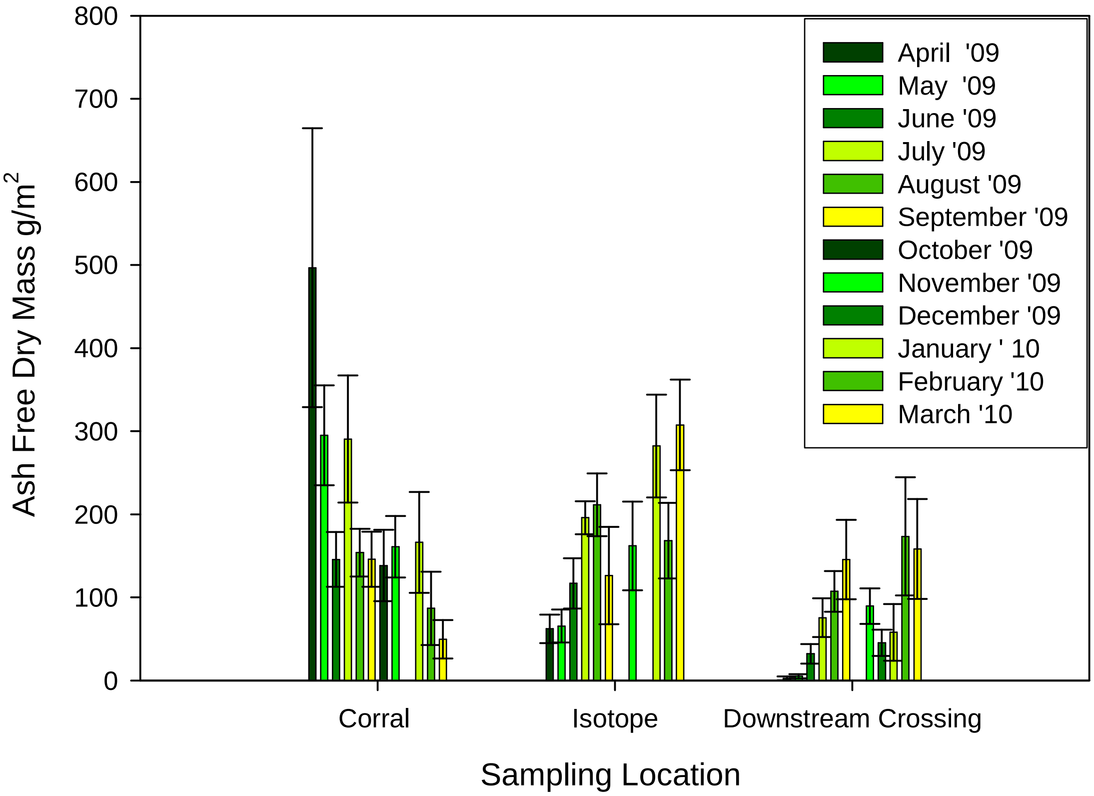

Figure 4. Ash Free Dry Mass (AFDM) of aquatic macrophytes collected in Big Springs Creek from April 2009 through March 2010. Bars represent the mean value of the six subsamples and error bars are standard error.

4.4 Summary

Aquatic macrophytes are the primary driver of physical and ecological change in the restoration of Big Springs Creek. Historical ranch management resulted in a range of pre-restoration conditions throughout the creek in 2008-2009, with some channel reaches exhibiting abundant aquatic vegetation, and other reaches exhibiting almost no aquatic vegetation. Because of the variety of conditions at the start of restoration, different patterns of biomass accumulation and species composition were observed at the different sampling locations throughout Big Springs Creek (Figure 3). The location with the least amount of cattle disturbance prior to cattle exclusion had the largest biomass compared to the other two locations, while the site with the highest amount of cattle disturbance had the lowest amount of biomass. As time from cattle exclusion (April 2009) increased, standing macrophytes crops became more similar, and by September 2009, all three sampling locations had statistically similar aquatic macrophyte biomass. As daylight length and temperature decreased in the winter of 2010, sites with less robust macrophyte species saw a decline in biomass, but still remained much higher than the initial, pre-restoration condition. After one year of cattle exclusion (March 2010) the ”Isotope” and “Downstream Crossing” study sites had equaled or exceeded their maximum biomass accumulation during the previous summer (2009). This suggests that the increased minimum biomass during the winter following cattle exclusion will lead to increased spring vegetation biomass and increased benefits of depth, cover and velocity refuge for salmonids earlier in the year during the critical juvenile rearing period.

5.0 Geomorphology

Geomorphic studies provide a critical foundation for understanding the abiotic habitat conditions upon which ecological communities develop and function. Furthermore, documenting spatial and temporal varitation in gemorphic conditions prior to and following riverine restoration actions can facilitate the formulation of adaptive management strategies and help understand the phyiscal/abiotic drivers of observed ecological responses to restoration actions. Throughout Big Springs Creek, spatial patterns of seasonal aquatic macrophyte growth appeared to be principal drivers of observed geomorphic conditions. As such, restoration actions consisting of cattle exclusion had a direct impact on local changes in channel morphology. Post-restoration channel moprhology conditions throughout Big Springs Creek, and the repsonse to cattle exlcusion, are presented and discussed herein.

5.1 Methods

Post-restoration changes in channel morphology throughout Big Springs Creek were assessed through the comparison of repeat topographic surveys of channel cross-sections performed during summer/fall of 2008 and 2009. Sixty-four (64) channel cross-sections were surveyed along Big Springs Creek through the Shasta Big Springs and Busk Ranches in 2008 (see Jeffres et al. 2009). Forty-three (43) cross-sections locations surveyed in 2008 were re-occupied in 2009 (Figure 1). Topographic surveys were conducted across the channel bottom using a TOPCON HiperLite Plus Real-Time Kinematic (RTK) survey unit. Elevations of channel bankfull conditions were estimated for each cross section based on observed topographic breaks in the channel bank. Channel width-to-depth ratios for each surveyed cross-section were calculated by dividing the bankfull channel width by mean bankfull depth. During survey activities in 2008 and 2009, the lateral distribution of aquatic macrophyte patches across each cross section was noted. Only cross-sectional morphology data collected in both 2008 and 2009 is presented and compared herein.

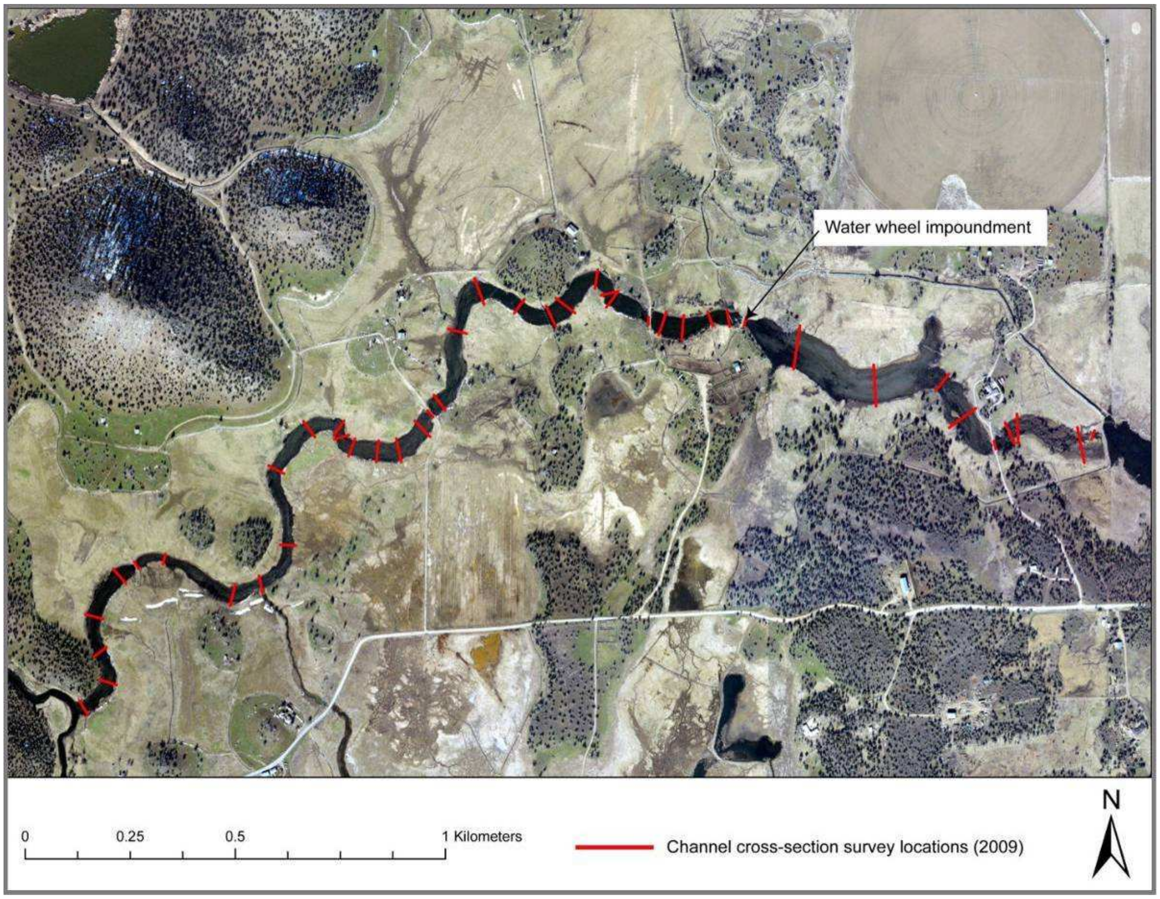

Figure 5: Channel cross-section locations surveyed along Big Springs Creek in 2008 and 2009.

5.2 Data Analysis

Channel cross sectional surveys conducted throughout Big Springs Creek in 2008 (see Jeffres et al. 2009) and 2009 revealed remarkably wide and shallow channel morphologies, as evidenced by elevated bankfull channel width-to-depth ratios. Such geomorphic conditions are common in spring-fed streams, and may be attributable to the reduced range of streamflow magnitudes and the near absence of large floods cable of moving large sediment (where present), aquatic/riparian vegetation, or other debris (Whiting and Moog 2001). Under such conditions, Whiting and Moog (2001) hypothesize that streamflow is routed around in-channel obstacles, necessitating larger cross-sectional areas to convey the available streamflow. Furthermore, without bed shear stresses necessary to incise into the channel, channel widening becomes the mechanism through which to increase cross sectional area.

Under such conditions, the spatial distribution and effects of flow resistance elements (e.g. downed timber, vegetation, small islands) likely provide the primary control on hydraulic (principally streamflow routing) and dependent geomorphic conditions in spring-fed creeks. In Big Springs Creek, the lack of woody riparian vegetation allows flow resistance elements to be dominated by submerged and emergent aquatic macrophytes, whose seasonal growth patterns (see Section 4) appear to be the principal drivers of temporal changes in cross-section channel morphology. Herein, cross-sectional survey data is presented from pre-restoration (2008) and post-restoration (2009) periods throughout Big Springs Creek, and then compared in order to quantify observed changes in channel morphologies in response to cattle exclusion.

5.2.1 *Channel Conditions - 2008*

As summarized by Jeffres et al. (2009), cross-sectional channel morphologies in Big Springs Creek were characterized by elevated bankfull width-to-depth ratios (mean = 62; σ = 30), with minimum ratios (9) at laterally-confined road crossings, and maximum values (134) throughout an approximately 400 meter channel reach immediately above a flow through impoundment known as the waterwheel, which widens channel conditions upstream (Figures 5 and 6). Analysis of cross-section data from transects surveyed along this reach in 2008, but not re-occupied during survey efforts in 2009, revealed even higher width-to-depth ratios (maximum = 237) – conditions which have remained relatively similar in 2009. This wide and shallow channel reach along Big Springs Creek was identified immediately downstream from the two groundwater spring complexes (Big Springs Lake and Alcove Spring complexes) that provide the majority of streamflow to Big Springs Creek (Figure 8). Prior to restoration actions, average and maximum bankfull width-to-depth ratios in Big Springs Creek were significantly greater than the average (34; σ = 24) and maximum (98) values identified by Whiting and Moog (2001) in selected spring-fed streams throughout Oregon and Idaho. Reasons for elevated bankfull width-to-depth ratios in Big Springs Creek compared to spring-fed creeks in Oregon and Idaho are uncertain, but may be related to the presence of numerous spring seeps along the channel bed, particularly in the channel reaches upstream the waterwheel impoundment. Spring seeps within the bed may inhibit channel bank formation, thus increasing the width of the channel where such seeps are present.

5.2.2 *Channel Conditions - 2009*

Channel cross-sections re-surveyed in 2009 continued to exhibit elevated bankfull width-to-depth ratios, ranging from nine (9) at a bridge crossing to 171 at a shallow riffle upstream from the waterwheel impoundment. The mean bankfull width-to-depth ratio for all surveyed cross-sections in 2009 was 63, with a standard deviation (σ) of 34. Minimum width-to-depth ratios continued to be found at channel locations laterally confined by bedrock or bridge abutments. Maximum width-to-depth ratios continued to be identified in channel locations immediately upstream from the flow through waterwheel impoundment.

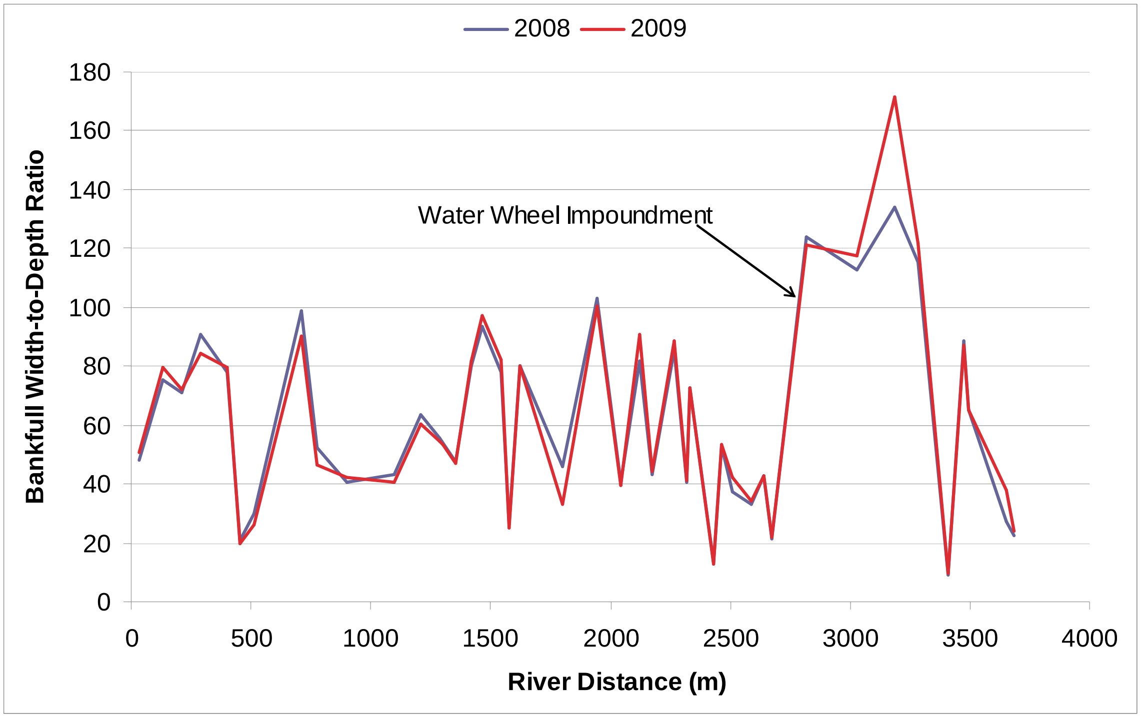

Figure 6: Longitudinal trends in bankfull width-to-depth ratios throughout Big Springs Creek in 2008 and 2009. Width-to-depth ratios were remarkably high and stable during both 2008 and 2009.

Qualitative observations made during cross-section surveys, combined with detailed velocity transects performed at two locations in 2009 (Figure 10), indicated the spatial distribution of aquatic macrophytes was the dominant control on channel bed sedimentation and erosion dynamics. The patchy and irregular spatial distribution of in-stream vegetation diverted most streamflow through multiple channels flowing around clumps of emergent and submerged aquatic vegetation, producing a channel planform often referred to as “pseudo-bradied”. In some locations, streamflow was routed through a single channel surrounded by patches of aquatic macrophytes. Reduced streamflow velocities within the patches of submerged and emergent aquatic macrophytes promoted fine sediment deposition within and behind the vegetation patches. By forcing the majority of streamflow around vegetation patches, streamflow velocities in unvegetated “corridors” were increased. Observed consequences of this hydraulic phenomenon were large and abrupt velocity gradients along the edges of vegetation patches, as well as local scouring of fine sediments along the higher velocity corridors. These sedimentation and erosion dynamics were most pronounced during the peak macrophyte growth periods through the summer and fall of 2009. Without flood flows in Big Springs Creek, depositional patches remained relatively stable following the winter macrophyte senescence, thus maintaining the aforementioned “pseudo-braided” channel form throughout the year.

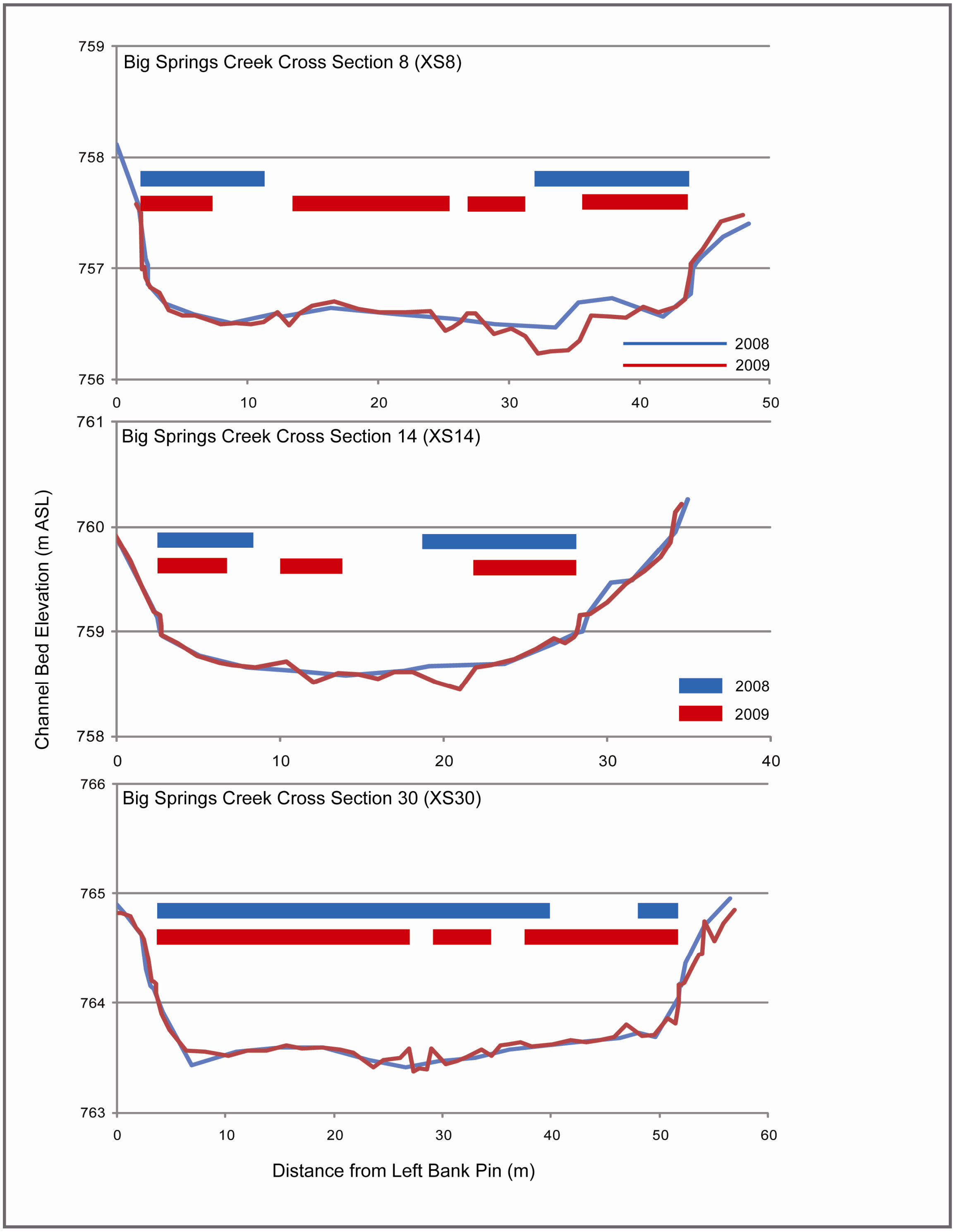

Figure 7: Representative cross section topographic surveys occupied in both 2008 and 2009. Lateral distribution of aquatic macrophyte patches are illustrated for 2008 (blue bars) and 2009 (red bars) Channel widths and depths did not appreciably change during the project period. However, local changes in erosion and deposition largely coincided with deviations in the lateral distribution of aquatic macrophytes.

5.3 Response to Restoration Actions

Individual (or "at-a-station") channel cross-section forms are typically thought to adjust to changes in river discharge, sediment transport/deposition and the composition of boundary/bank materials - with discharge presenting the dominant (and only independent) control on channel dimensions (i.e. width, depth, cross-sectional area). Consequently, in a baseflow dominated river such as Big Springs Creek, it might be expected that cross-sectional channel forms would be largely stable given: 1) relatively consistent/stable groundwater-derived streamflows and absence of large flood events which can erode and or deposit large amounts of sediment; and 2) unchanging composition of boundary/bank materials at each cross-section location. However, this model of channel form adjustment to changes (or lack thereof) in hydrologic and geomorphic conditions largely neglects the influences of aquatic vegetation on channel morphology.

Prior to March 2009, in-stream cattle grazing and subsequent removal of submerged and emergent aquatic vegetation had pronounced effects on channel morphology, principally through bank destabilization, fine-sediment introduction, and widening/shallowing of the river channel. Furthermore, lateral variability in channel bed topography was minimized as cattle removed patches of aquatic macrophytes, and through both grazing and trampling, mobilized previously stable fine sediment. This fine sediment was subsequently deposited diffusely downstream, resulting in relative lateral homogeneity of channel bed topography (see Jeffres et al. 2009). Following cattle exclusion in March 2009, recovery of aquatic macrophyte communities was allowed to progress largely unabated (see section 4). While minimal changes were observed in bankfull width-to-depth ratios (mean = +1.1%)(Figure 6) and bankfull cross sectional areas (mean = +0.3%) during this short post-restoration period, localized sediment deposition and erosion dynamics fostered by the growth of aquatic macrophytes resulted in substantially more lateral variability in cross-section bed topography between 2008 and 2009 (see Figure 7). Of particular note were areas of sediment scour and deposition observed along numerous cross-section transects, geomorphic processes which appear to be principally controlled by the presence (deposition) and absence (erosion) of aquatic macrophytes. In some locations, fine sediment deposition in macrophyte patches between 2008 and 2009 exceeded 20 cm, while fine sediment scouring (usually less than 5 cm) along high-velocity corridors between macrophyte patches revealed underlying gravel-sized bed materials. These gravel materials were unable to be transported by available bed shear stresses under spring-fed baseflow conditions.

5.4 Summary

Cross-sectional data and qualitative field observations from 2008 and 2009 indicate that over the short term (several years), with continued cattle exclusion, seasonal patterns of aquatic macrophyte growth will likely be the dominant control on hydrogeomorphic processes and channel cross-section morphology in Big Springs Creek. While further investigation is needed to understand long-term trends in the spatial distribution and persistence of aquatic macrophyte communities in Big Springs Creek, it is anticipated that shallow, low-velocity channel margins will experience continued aquatic macrophyte colonization and associated sediment deposition. Such a condition may eventually lead to the establishment of more permanent emergent plants such as tules and cattails, creating narrower and deeper channel morphologies with higher streamflow velocities in one or several unvegetated corridors.

6.0 Hydrology

Nearly all of the water in the Shasta River flows through Shasta Big Springs Ranch. Along the southern ranch boundary, streamflows from the Park's Creek tributary combine with the predominantly spring-fed streamflows from the Upper Shasta River below Dwinnell Dam and Hole in the Ground Creek (Figure 8). Approximately 2 kilometers downstream from the southern ranch boundary, the groundwater-fed Big Springs Creek joins the Shasta River, nearly quadrupling its mean annual discharge. Quantifying the magnitude, variability and timing of streamflows throughout Shasta Big Springs Ranch, and particularly Big Springs Creek is a critical piece of ongoing restoration efforts at Shasta Big Springs Ranch.

6.1 Methods

River stage was monitored continuously at seven stream gauge locations (Figure 8) throughout Shasta Big Springs Ranch during the project period. River stage data were collected at 10-minute sampling intervals using Global Water WL-16 submersible pressure transducers, and streamflows were periodically measured at each gauge location using standard methodologies (Rantz 1982). Point velocities were measured within vertical bins across river cross-sections at 0.6 of the stream depth using a Marsh McBirney Flo-Mate electromagnetic velocity meter attached to a top-set wading rod. Vertical bin widths typically did not exceed 5% of the channel cross-section wetted width. Discharge measurements were calculated using USGS mid-section velocity-area methods (Rantz 1982). Streamflow rating curves were subsequently developed to estimate continuous streamflow magnitudes at each location.

Prior to March 2009, nine river stage gauges were maintained and rated for streamflow throughout Shasta Big Springs Ranch to understand spatial differences in the timing, magnitude and variability of streamflow and irrigation water management (see Jeffres, et al, 2009). However, as cattle were excluded from waterways throughout Shasta Big Springs Ranch in March 2009 as part of river restoration efforts, the resulting seasonal growth and senescence dynamics of aquatic macrophytes and the associated affects on river stage, hindered the ability to accurately rate stream gauges without downstream control structures (e.g. a permanent weir). Prior to March 2009, in-stream cattle grazing largely minimized aquatic macrophyte growth, facilitating the successful development of rating curves that were accurate across multiple seasons (see Jeffres et al, 2009). Consequently, while river stage data were collected and streamflows were periodically measured at each stream gauge location (Figure 8) during the project period to help identify and understand gross variations in streamflow magnitude and timing, only a single gauge along Big Springs Creek (herein referred to as the Big Springs Creek waterwheel gauge) was able to be rated throughout the project period, thus allowing for the construction of an accurate and continuous streamflow record during the project period. Successful rating of the Big Springs Creek waterwheel gauge was largely due to the presence of a permanent control structure located immediately downstream. Only the Big Springs Creek waterwheel streamflow data are presented and discussed herein. To facilitate comparison of streamflow characteristics between 2008 and 2009, streamflow statistics (mean, median, maximum, minimum, standard deviation) were calculated from continuous (10-minute interval) discharge records. Small differences between streamflow statistics reported by Jeffres et al. (2009) and in this report for the period of April 1, 2008 through March 31, 2009 are the result of revised discharge-river stage rating relations for the stream gauge at the waterwheel.

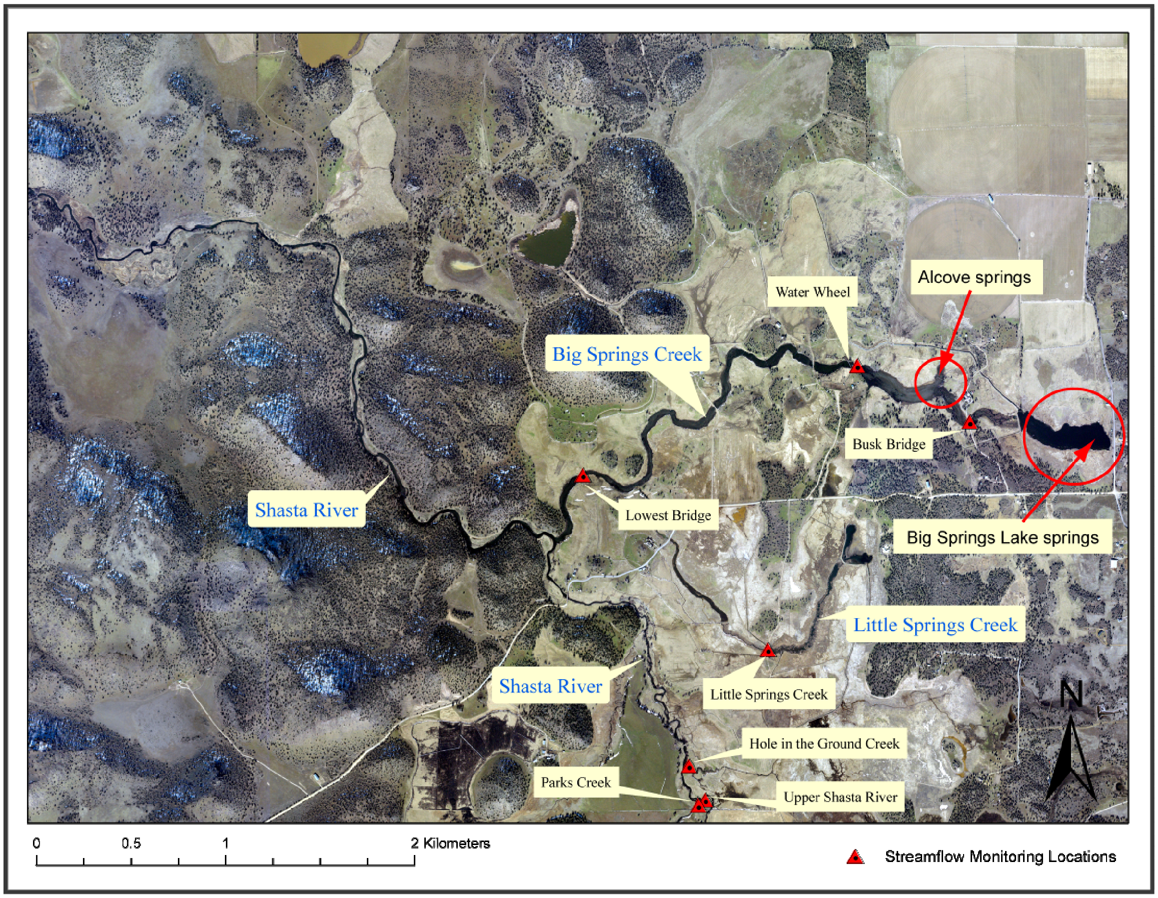

Figure 8: Major hydrologic features and streamflow monitoring locations on the Shasta Big Springs and Busk Ranches

6.2 Data Analysis

Big Springs Creek is hydrologically characterized by fairly stable baseflow derived from discrete and diffuse groundwater sources. Jeffres et al. (2009) identified two large springs within the upper 1.5 kilometers of Big Springs Creek, herein referred to as the "Big Springs Lake springs" and "Alcove springs" (Figure 8). The Big Springs Lake and Alcove springs are comprised of numerous discrete and diffuse springs, and further refinement of the location and character of these discrete springs is provided in Section 8 of this report. The stream gauge along Big Springs Creek at the water wheel is located immediately downstream from the aforementioned springs, that together produced a mean, unimpaired (i.e. non-irrigation season) discharge of 80 ft^3/s ($\sigma = 4$) between October 1, 2009 and March 31, 2010 (Table 1). During the 1 April 2009 to 1 October 2009 irrigation season, the Big Springs Lake springs were periodically impounded behind Big Springs Dam to facilitate irrigation diversions to adjacent properties. The Alcove Springs are located approximately 500 meters downstream from Big Springs Dam and were not diverted or impounded for irrigation purposes during the project period. The Big Springs Creek water wheel stream gauge measured the combined contributions of the Big Springs Lake and Alcove springs, as well as irrigation return flows, during the project period.

Temporally variable surface water diversions from Big Springs Lake, as well as unquantified groundwater pumping, imposed substantial hydrologic variability upon Big Springs Creek, particularly during the 2009 irrigation season (April 1 to October 1). Based on data presented by Jeffres, et al. (2009), it is likely that this variability was principally the result of irrigation diversions from Big Springs Lake, along with presumed (yet largely unquantified) impacts from regional groundwater pumping. Mean irrigation season discharge in Big Springs Creek at the water wheel was 61 ft^3/s ($\sigma = 9$), while minimum discharge during the irrigation season was approximately 44 ft^3/s (Table 1). Discharge magnitudes in Big Springs Creek rebounded rapidly to unimpaired baseflow conditions in early October 2009 following the cessation of upstream irrigation diversions (Figure 9), with mean non-irrigation season discharge magnitudes of 80 ft^3/s ($\sigma = 4$) (Table 1). Large, non-irrigation season deviations between mean 80 ft^3/s ($\sigma = 4$) and minimum 55 ft^3/s discharge magnitudes in 2009 were an artifact of this rapid increase in baseflow magnitude following the cessation of upstream surface water diversions on 1 October 2009, which resulted in an 18 ft^3/s increase in discharge magnitude over a span of three hours on that date (Table 1, Figure 2). Non-irrigation season streamflows in Big Springs Creek were remarkably stable between 1 October 2009 and 31 March 2010, albeit with a gradual increase (~ 10 ft^3/s) in magnitude through the winter months (Figure 9). This seasonal increase in baseflow magnitude in Big Springs Creek was likely in response to increased discharge contributions from both the Big Spring Lake and Alcove spings following the cessation of regional groundwater pumping during the winter and spring.

Table 1: Streamflow statistics for Big Springs Creek at the waterwheel gauge. Statistics were calculated from continuous data collected during both irrigation and non-irrigation seasons between April 1, 2008 and April 1, 2010.

	4/1/2008 to 10/1/2008 (Irrigation season)	10/1/2008 to 4/1/2009 (Non-irrigation season)	4/1/2009 to 10/1/2009 (Irrigation season)	10/1/2009 to 4/1/2010 (Non-irrigation season)
Mean	52	85	61	80
Median	50	87	60	81
Max	85	98	98	87
Min	39	58	44	55
Standard Deviation	9	4	9	4

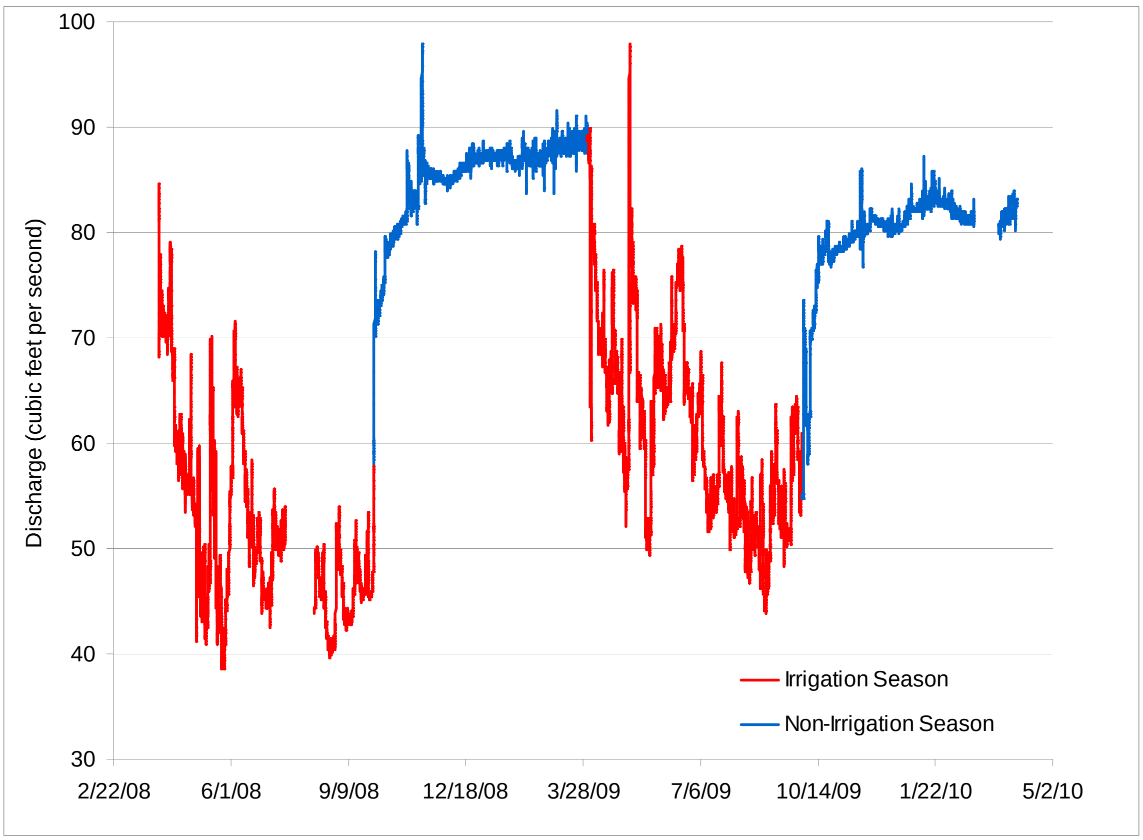

Figure 9: Hydrograph presenting continuous streamflow records obtained from the Big Springs Creek Waterwheel stream gauge for the period 1 April, 2008 through 1 April, 2010. Irrigation season (red line) and non-irrigation season (blue line) periods of record are highlighted.

6.3 Response to Restoration Actions

Restoration actions conducted on Shasta Big Springs Ranch and the Busk Ranch between 1 April, 2009 and 31 March, 2010 principally consisted of: 1) cattle exclusion through riparian fencing; and 2) irrigation water management and tailwater control. The measured hydrologic response to these restoration actions was minimal.

The Big Springs Creek waterwheel stream gauge is located at the eastern boundary of Shasta Big Springs Ranch, and thus quantifies streamflow inherited from groundwater springs emanating on the adjacent Busk Ranch. Comparison of pre-restoration streamflow data with post-restoration streamflow data indentified minimal changes to the magnitude and variability of streamflow in response to restoration actions (Table 1, Figure 9). However, several notable differences were observed, including elevated minimum streamflows (+5 ft^3/s) during the 2009 irrigation season (Table 1), as well as lower baseflows (-5 ft^3/s) during the 2009-2010 non-irrigation season (Table 1). A causal mechanism for elevated minimum streamflow magnitudes during the 2009 irrigation season (post-restoration) could not be identified due to competing and unquantified hydrologic impacts of improved irrigation efficiencies on the Busk Ranch and regional groundwater pumping. It is hypothesized that the lower, post-restoration, non-irrigation season baseflows in Big Springs Creek represent a hydrologic response to reduced groundwater aquifer recharge resulting from drought conditions during the prior three years throughout the Shasta River basin. While small changes in pre- and post-restoration hydrologic conditions in Big Springs Creek were identified, large changes in the magnitude, timing and variability of streamflow were not observed.

6.4 Summary

With the continued use of groundwater-derived spring-flows for irrigation purposes on the Shasta Big Springs and Busk Ranches, as well as the continuance of regional groundwater pumping, the magnitude, timing and variability of streamflow in Big Springs Creek showed minimal response to cattle exclusion. Observed small reductions in mean, non-irrigation season streamflows following cattle exclusion were likely the surface water response to accumulated depletion of regional groundwater recharge during four consecutive years of drought in the Shasta River valley.

7.0 Hydraulics

While groundwater-derived streamflow characteristics (magnitude, timing and variability) in Big Springs Creek remained relatively unchanged following the initiation of cattle exclusion in March 2009, the hydraulic response (i.e. stream depth, wetted cross-sectional area and flow velocities) to cattle exclusion and resultant growth of aquatic vegetation was pronounced, albeit somewhat spatially and temporally variable.

As previously discussed (Section 4), aquatic plants are a critical component of the aquatic ecosystem of Big Springs Creek, creating and/or altering habitat available for fish and aquatic invertebrates. Of critical importance in determining the characteristics of this habitat is the continuous interaction between aquatic macrophyte growth and streamflow - an interaction that produces hydraulic conditions that vary in space and time. Furthermore, such hydraulic conditions are large drivers of numerous physical and chemical riverine processes including flow velocity, nutrient uptake and habitat complexity. During the project period, seasonal trends in hydraulic parameters were explored at several locations along Big Springs Creek to help understand the hydraulic response to cattle exclusion.

7.1 Methods

River stage was monitored continuously at seven stream gauge locations (Figure 8) throughout the Shasta Big Springs and Busk Ranches during the project period. Data was collected at 10-minute sampling intervals using Global Water WL-16 submersible pressure transducers, facilitating analysis of post-restoration changes to seasonal variations in stream depth. Only river stage data collected at the lowest bridge streamflow monitoring site (Figure 1) is presented herein.

Detailed flow velocity transects were conducted every other month at two cross-section locations along Big Springs Creek (Figure 10). Both transects were located approximately 50 meters upstream from monthly aquatic macrophyte sampling sites located at the “Corral” and “Downstream Crossing” (Figure 10), thus allowing quantitative analysis of aquatic macrophyte growth and hydraulic parameters. At each transect location point velocity measurements were collected at approximately 1-meter lateral intervals at 0%, 20%, 40%, 60%, 80% and 100% of the stream depth using a Marsh McBirney Flo-Mate electromagnetic velocity meter. Using the geographic information system (ArcMap 9.3), inverse distance weighted (IDW) interpolation techniques were used to create 2-dimensional velocity contour plots, from which lateral and vertical trends in streamflow velocity and other hydraulic parameters could be identified.

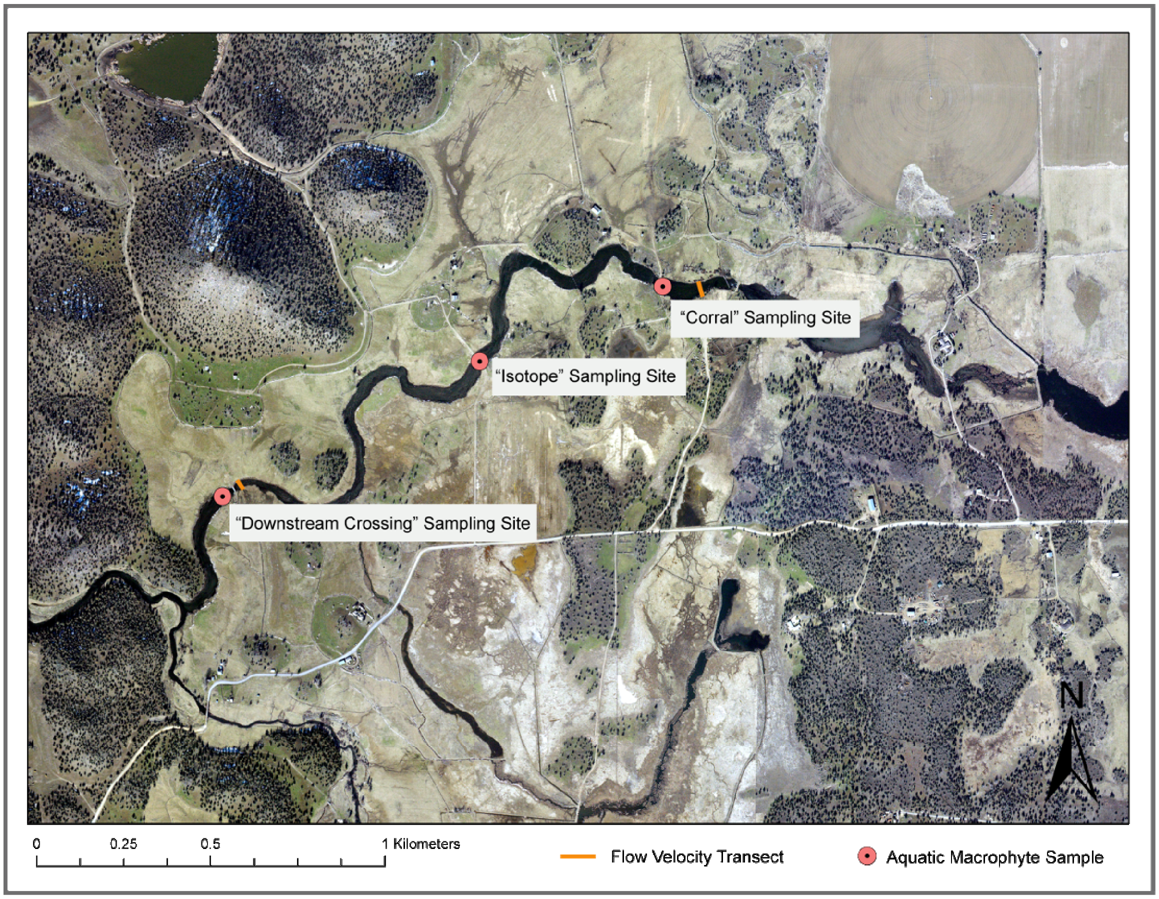

Figure 10: Aquatic macrophyte sampling sites and associated velocity transect locations on Shasta Big Springs Ranch.

7.2 Data Analysis

During the project period, the growth and senescence cycles of aquatic macrophytes and resultant sediment deposition and erosion dynamics (see Sections 4 and 5) played a large role in determining local hydraulic conditions, largely illustrated by changes in stream depth, wetted cross-sectional area and stream velocity. Herein, hydraulic data will be presented for the "Downstream Crossing" and "Corral" study sites (Figure 10).

7.2.1 *Downstream Crossing*

Seasonal changes in hydraulic conditions at the "Downstream Crossing" study site during the project period were principally driven by the growth and senescence of aquatic macrophytes (Figure 4). Seasonal minima of river stage were identified during the late winter/early spring, largely coinciding with the peak senescence (and lowest seasonal biomass) of aquatic macrophytes (Figures 4 and 11). Furthermore, observed non-irrigation season stage minima occurred during periods of maximum streamflow in March 2009 (Figure 11). In contrast, continuously increasing river stage (i.e. depth) conditions through the summer and fall period coincided with both the seasonal growth of aquatic macrophytes (Figure 4) and minimum irrigation season streamflows (Figure 11).

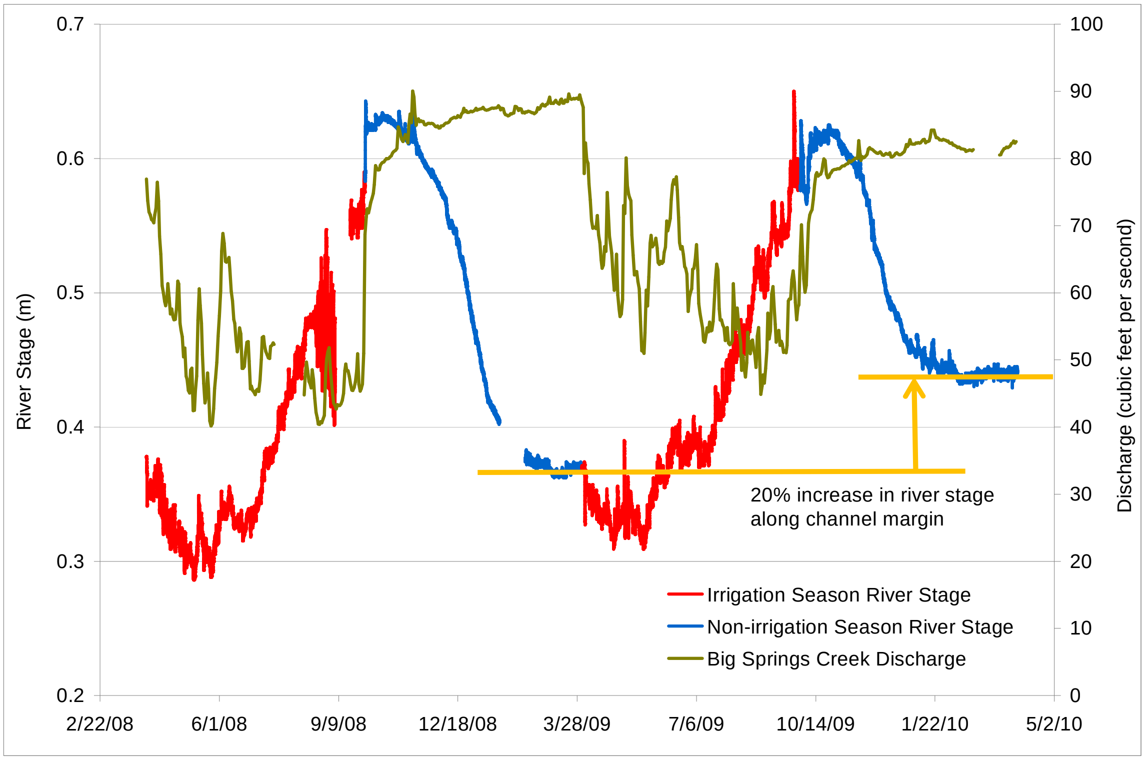

Figure 11: River stage continuously measured at the "lowest bridge" streamflow monitoring station in Big Springs Creek. The grey line represents streamflow magnitudes measured at the upstream waterwheel stream gauge location. Note the approximately 20% increase in late winter/early spring-time minimum river stage following cattle exclusion.

The inverse relationship between river stage (stream depth) and streamflow magnitude at the "Downstream Crossing" study site was principally the result of the increasing hydraulic resistance provided by growing aquatic macrophytes. Comparison of Manning's n values calculated from periodic velocity transects at the study site and measured discharge magnitudes reveal this seasonal trend (Figure 12a). Furthermore, seasonal increases in hydraulic resistance resulted in reduced mean flow velocities, the effects of which were increased summertime river stage (Figure 11) and wetted cross-sectional area (Figure 12b), observations consistent with previous studies of the effects of aquatic plant growth on channel hydraulics (Watson 1987, Bernhardt et al. 2005, De Doncker et al. 2009).

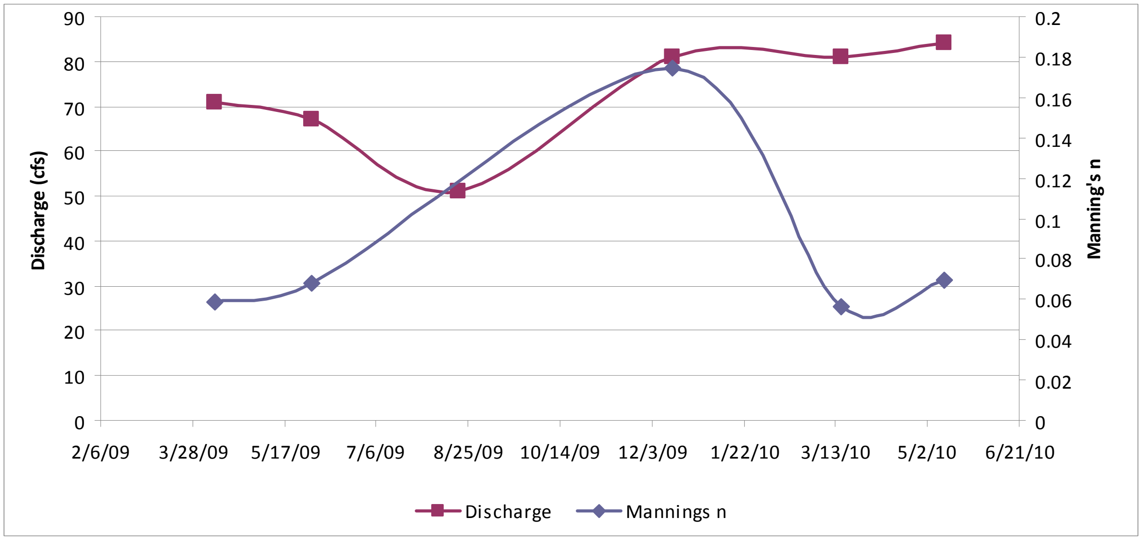

Figure 12a. Seasonal changes in discharge and channel roughness (Manning's n) at the Big Springs Creek Downstream Crossing study site velocity transect.

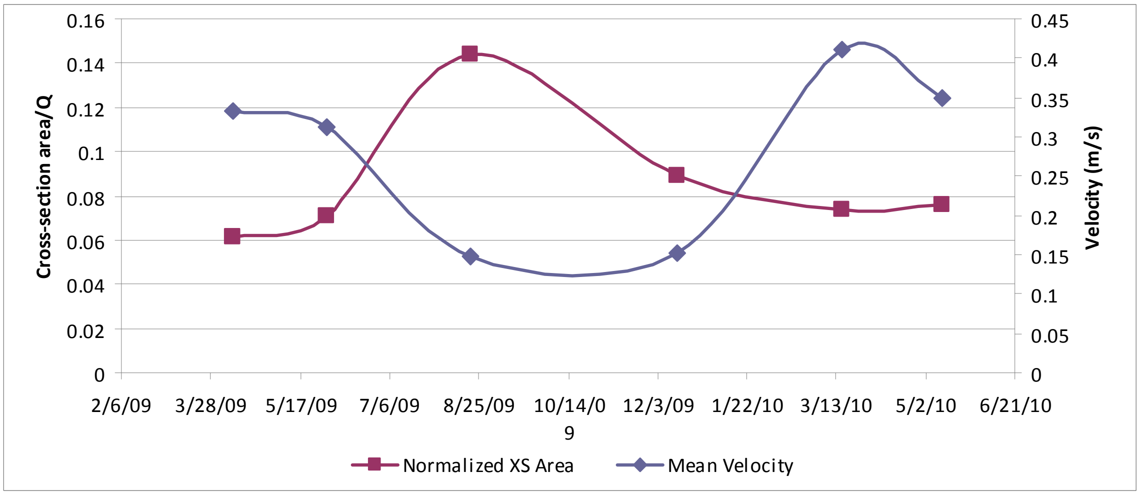

Figure 12b. Seasonal changes in wetted cross section area and mean velocity at the Big Springs Creek Downstream Crossing study site velocity transect. Note that cross-sectional area is normalized by discharge.

Detailed velocity transects conducted at the "Downstream Crossing" study site also revealed lateral and vertical variation of flow velocities associated with seasonal aquatic macrophyte growth (Figure 13). In April 2009, elevated flow velocities (>0.5 m/s) were fairly uniformly distributed across the surveyed transect, principally due to the near absence of aquatic macrophyte growth and associated hydraulic resistance. Through the summer and late fall of 2009, aquatic macrophyte growth increasingly blocked streamflow and reduced flow velocities throughout much of the surveyed transect, restricting elevated flow velocities to unvegetated portions of the transect (Figure 13). These hydraulic conditions persisted through December 2009. Following macrophyte senescence in the winter and early spring of 2010, elevated streamflow velocities once again became more uniformly distributed throughout the surveyed transect in response to reduced streamflow blocking by aquatic vegetation.

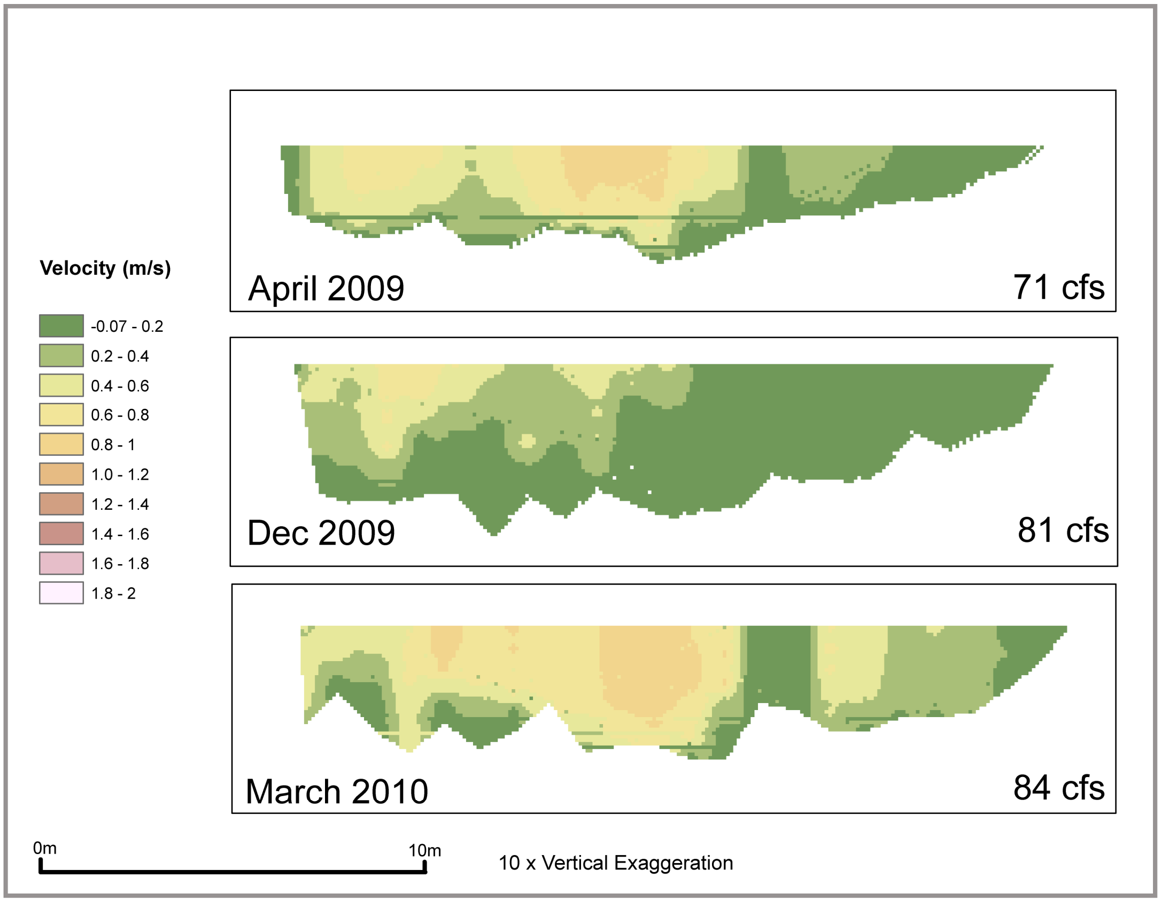

Figure 13: Flow velocity contour plots created from point velocity measurements collected at the Big Springs Creek Downstream Crossing study site transect location. Dark green colors can largely be used as a proxy for cross-section areas blocked by aquatic macrophytes.

7.2.2 *Corral Study Site*

Hydraulic conditions at the "Corral" study site also followed growth patterns of aquatic macrophytes. However, unlike the "Downstream Crossing" study site, where hydraulic conditions were driven by large seasonal fluctuations in aquatic macrophyte biomass, the "Corral" study site experienced minimal variation in aquatic macrophyte biomass (Figure 4). As such, variability in hydraulic conditions appeared to be driven largely by spatial (lateral) variability of macrophyte growth.

Detailed velocity transects performed between April 2009 and December 2009 revealed only small fluctuations (71-75%) in the percentage of the cross-sectional channel area blocked by aquatic macrophytes. Similar consistency in biomass sampled at the study site (Figure 4) was observed during this time period, suggesting that the total size of the macrophyte community varied surprisingly little. However, during this period, mean flow velocities increased, while channel resistance (Manning's n) (Figure 14a) and wetted cross section area (Figure 14b) concurrently decreased. Such trends in hydraulic parameters indicated that while total biomass remained relatively stable during the aquatic macrophyte growing season in the spring, summer and fall of 2009, the spatial distribution of the macrophyte community changed. Observations made during velocity transect surveying revealed that large patches of emergent macrophytes began to block streamflow through portions of the channel transect, thus diverting streamflow laterally through adjacent “corridors” between macrophyte patches, creating pseudo-braided channel conditions. As a result, flow velocities and relative streamflow magnitudes were increased through unvegetated corridors, while flow velocities and relative streamflow magnitudes in vegetated patches were simultaneously reduced (Figure 15). Over the course of the macrophyte growing season, this feedback loop between macrophyte growth and flow velocity ultimately resulted several high velocity corridors transporting up to 90% of the total streamflow, while the remaining streamflow was exported slowly through vegetated portions of the stream channel (Figure 15).

Interestingly, following the low-growth/senescence of aquatic macrophytes in March 2010 (Figure 4), mean flow velocities at the “Corral” study site remained elevated, while Manning’s n values and wetted cross-sectional area remained well below values measured during April 2009. Qualitative observations suggest large volumes of sediment were deposited within the low velocity sediment patches during the summer and fall, creating topographic features in the channel bed, which further diverted streamflow though unvegetated corridors during the winter and spring of 2009.

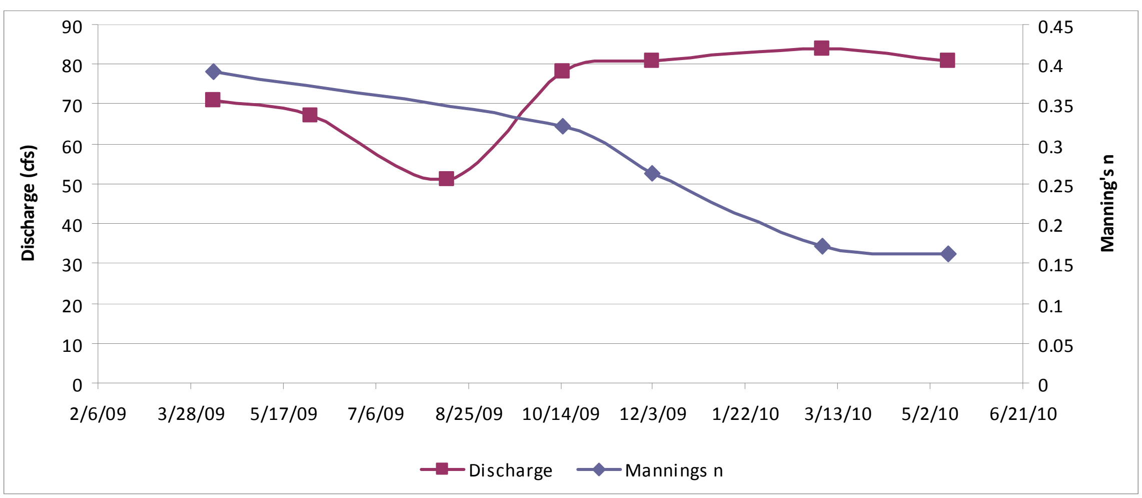

Figure 14a. Seasonal changes in discharge and channel roughness (Manning’s n) at the Big Springs Creek Corral study site velocity transect.

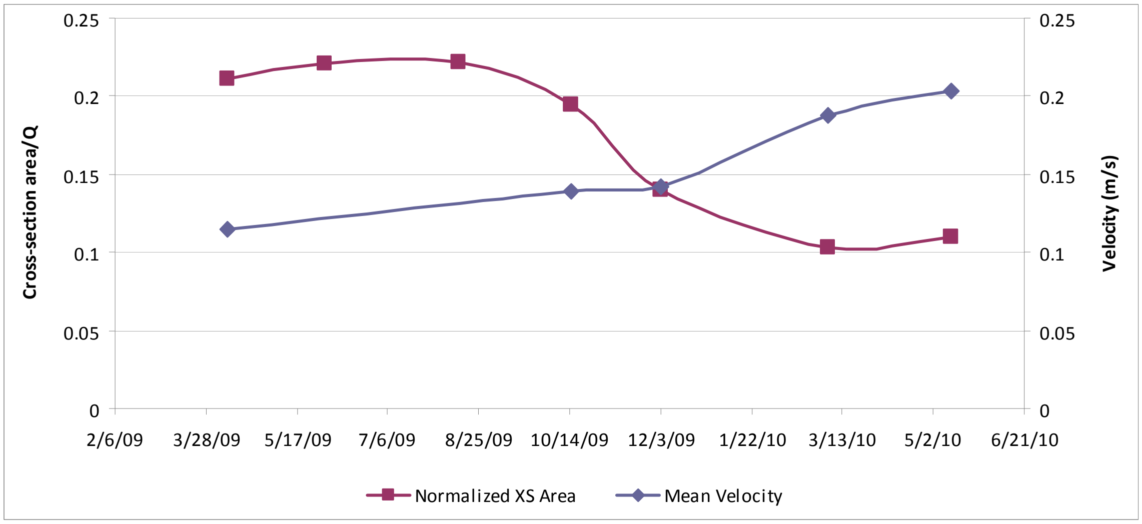

Figure 14b. Seasonal changes in wetted cross section area and mean velocity at the Big Springs Creek Corral study site velocity transect. Note that cross-sectional area is normalized by discharge.

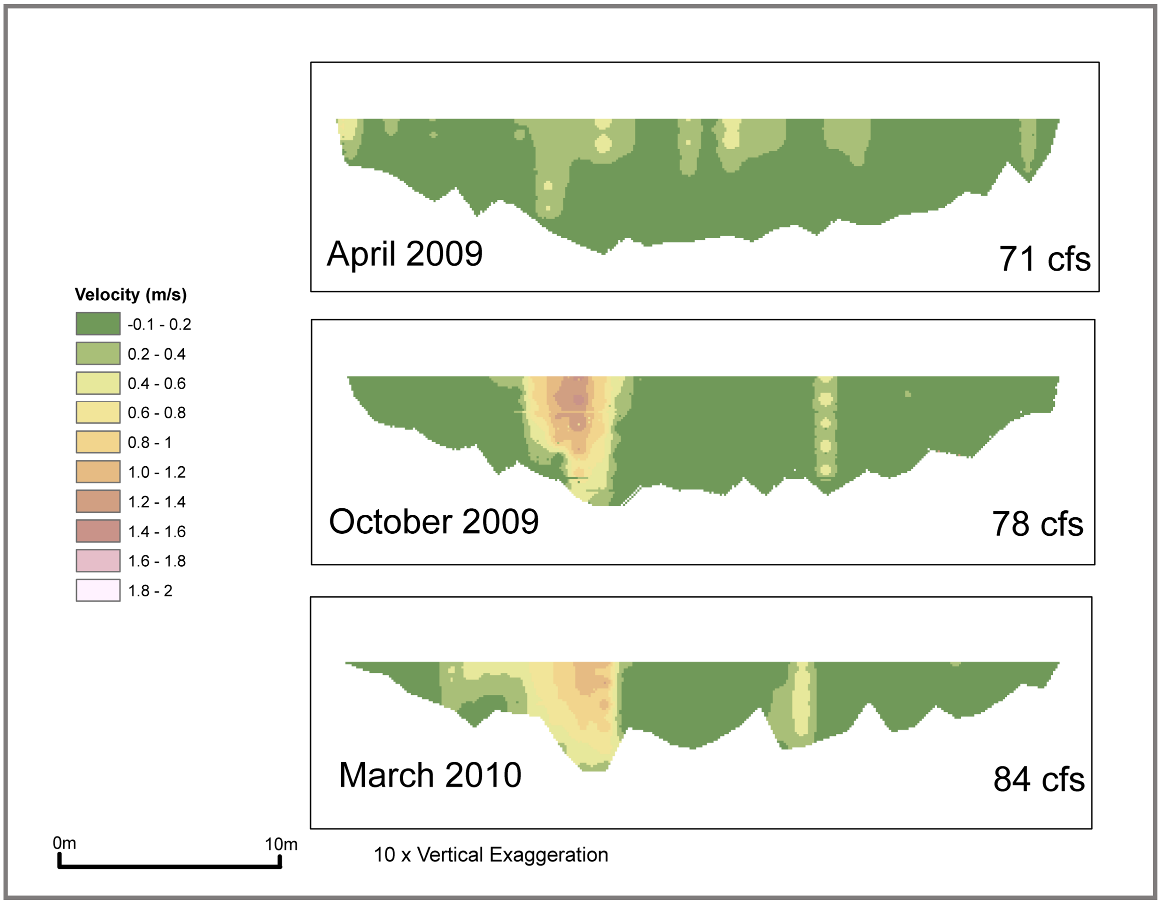

Figure 15: Flow velocity contour plots created from point velocity measurements collected at the Big Springs Creek Corral study site transect location. Dark green colors can largely be used as a proxy for cross-section areas blocked by aquatic macrophytes.

7.3 Response to Restoration Actions

7.3.1 *Downstream Crossing*

Prior to March 2009, in-stream grazing of aquatic macrophytes by cattle resulted in the near elimination of macrophyte biomass at the “Downstream Crossing” study site (Figure 4). Following cattle exclusion in March 2009, submerged aquatic macrophyte species (principally *Myriophyllum sibericum*) began to colonize the channel bed. Concurrent with macrophyte growth were increases in channel resistance and reductions in mean flow velocity - hydraulic effects which forced increases in river stage and cross-sectional area (Figures 11, 12a and 12b). Winter senescence of aquatic macrophytes (Figure 4) forced reductions channel resistance, increases in mean flow velocity, and reductions in river stage and wetted cross-sectional area between December 2009 and March 2010 (Figures 11, 12a and 12b). However, in the absence of in-stream cattle grazing, a small standing crop of submerged aquatic macrophytes was able to persist through the winter/early spring of 2010 (Figure 4). The presence of this standing macrophyte crop increased channel roughness through the winter 2010, and elevated the annual, non-irrigation season river stage and wetted cross-sectional area (normalized by discharge) minimums by approximately 20% from 2009 (Figure 11). Coincidentally, this river stage and cross-sectional area minimum occurred during the spring-time rearing period for juvenile salmonids, thus providing additional habitat area and cover.

Current trends of channel resistance (dominated by macrophyte growth), flow velocity and wetted cross-sectional area at the “Downstream Crossing” study site suggest seasonal patterns of macrophyte growth and senescence, and resulting hydraulic impacts observed during the project period, will continue through 2010. However, in the absence of cattle grazing within the channel, it is hypothesized that macrophyte biomass at the study site will be greater over the 2010 growth season, resulting in more pronounced hydraulic impacts, and greater stream depth and wetted cross-sectional area. Future trends in macrophyte growth and resulting channel hydraulics are unknown.

7.3.2 *Corral Study Site*

In contrast with the “Downstream Crossing” study site, cattle grazing rotation timing on Shasta Big Springs Ranch largely limited in-stream grazing at the “Corral” study site during the summer and fall of 2008. As such, large standing crops of aquatic macrophytes (principally *Polygnum amphibium*) (Figure 4) were present at the study site upon cattle exclusion in March 2009. Thus at the onset of cattle exclusion in March/April 2009, hydraulic conditions at the “Corral” study site were dominated by elevated channel resistance, reduced mean flow velocities and elevated channel cross-sectional area (Figures 14a and 14b). While regions of elevated flow velocities at the “Corral” study site in April 2009 were observed above downstream-bending/flexing patches of aquatic macrophytes, lateral and vertical variability in flow velocity was relatively small (Figure 15).

As the standing crop of macrophytes continued to grow throughout the “Corral” study site velocity transect during the spring/summer of 2009, the vegetation assemblage became dominated by the emergent macrophyte *Polygnum amphibium*. As patches of aquatic macrophytes began to emerge above the water surface, streamflow became blocked through large portions of the surveyed velocity transect, thus routing streamflow around vegetation patches and through unvegetated corridors. The main hydraulic effects of this flow-routing phenomenon were elevated mean flow velocities (driven by substantially elevated flow velocities through unvegetated corridors; see Figure 15) and reduced channel resistance, both of which forced a gradual reduction in wetted channel cross-sectional area (Figures 14a and 14b). Furthermore, qualitative observations indicated large volumes of sediment were deposited within these emergent patches of aquatic macrophytes, further blocking streamflow through large portions of the channel cross-section. In October 2009, this patchy emergent vegetation growth and sediment deposition blocked approximately 76% of the total wetted cross-sectional area, increasing mean flow velocities and ultimately forcing up to 87% of the streamflow through the few unvegetated portions of the channel during the summer and fall of 2009 (Figure 15). Similar observations of dramatic velocity increases and streamflow routing through small, unvegetated portions of stream channels occupied by aquatic macrophytes were observed by Biggs (1996).

Due to the absence of in-stream cattle grazing and associated channel bed trampling, as well as minimally variable streamflows (and absence of flood flows), macrophyte patches and trapped sediments largely remained stable at the “Corral” study site velocity transect throughout the winter macrophyte senescence/low growth period between December 2009 and March 2010. This allowed streamflow to remain concentrated in unvegetated, high velocity corridors – further increasing mean flow velocities and reducing wetted cross sectional areas (Figures 14a, 14b and 15). Observed trends in channel hydraulics at the “Corral” study site velocity transect indicate that hydraulic parameters may be stabilizing at this location, existing in a seasonally-independent, quasi-equilibrium condition only possible because of existing streamflow stability and available nutrients (see Biggs, 1996). Given observed negative relationships between macrophyte biomass and flow velocities above 0.8 m/s (Riis and Biggs 2003), continued routing of streamflow through existing, unvegetated high-velocity corridors at this transect may continue unabated. It is likely that future changes in hydraulic conditions may only be moderated by unpredictable changes in the aquatic macrophyte plant community composition driven by unforeseen hydraulic or biotic forces.

7.4 Summary

The interaction between aquatic macrophyte growth and streamflow produced hydraulic conditions varying in space and time. At the “Downstream Crossing” study site, seasonal growth of predominantly submerged aquatic macrophytes increased channel roughness, thus forcing reductions in mean flow velocities and concomitant increases in river stage and wetted cross-sectional area. In contrast, at the “Corral” study site, the relative stability in the size and composition of the principally emergent aquatic macrophyte community allowed lateral variations in growth (as opposed to seasonal variation) to drive hydraulic conditions. Routing of streamflow through unvegetated portions of the velocity transect, actually reduced channel roughness, increased mean streamflow velocities and reduced wetted cross-sectional area. These data and qualitative observations indicate that hydraulic conditions in Big Springs Creek are principally driven by interactions between streamflow and spatially variable aquatic macrophyte communities.

8.0 Water Temperature

The 2008 baseline assessment of physical, chemical, and biological conditions in Big Springs Creek concluded that water temperature was the key impairment to anadromous salmonid habitat (Jeffres et al. 2009, Nichols et al. 2010). Though the spring sources emerged at water temperatures ideal for anadromous salmonids (e.g. 10-12^{o}C), rapid heating due to degraded habitat conditions (principally illustrated by wide, shallow, and unshaded channel reaches) resulted in elevated water temperatures that made the creek largely unsuitable for over-summering juvenile coho salmon.

The water temperature monitoring program that was initially established to gather data for the baseline assessment was maintained and extended through 2009 to monitor water temperature response to restoration actions. Monitoring locations were also periodically added to the baseline monitoring array as resources permitted to refine the longitudinal thermal profiles and boundary conditions of waterways on the Shasta Big Springs Ranch including individual spring sources in Big Springs Creek as well as include several sites in Little Springs Creek, Hole in the Ground Creek, and the Shasta River.

Water temperature data were examined for the period 1 April, 2009 through 31 March, 2010. This data illustrated that temperature trends shift as Big Springs Creek passes the waterwheel (RKM 2.8), where the stream transitions from a wide, shallow, and flat geometry to a more narrow, deep, and steeper geometry. The period between 1 April and 31 September is concurrent with irrigation season, during which time surface water can be diverted from the creek at Big Spring Dam. This period also coincides with the occurrence of maximum water temperatures that can exceed the threshold at which rearing juvenile anadromous salmonids are stressed. Though the temperature range that is suitable for these fish can change depending on other factors (e.g. the length of time fish experience warmer water temperatures or food abundance), for the purposes of this analysis, the temperature threshold above which rearing juvenile anadromous salmonids are stressed is 18^{o}C.

8.1 Methods

Water temperature data loggers were placed at several locations in waterways throughout Shasta Big Springs Ranch (Figure 16). Water temperature monitoring occurred primarily through the direct deployment of data loggers (spot measurements were also taken periodically throughout the monitoring period). HOBO® Pro v2 Water Temperature Data Loggers from Onset Computer Corporation were used to collect data at 30-minute increments throughout the project area. These loggers have a resolution of approximately 0.02^{o}C (at 25^{o}C), an accuracy of ±0.2^{o}C over the range from 0^{o}C to 40^{o}C, and a 90 % response time of 5 minutes in water (Onset 2009). Remote water temperature monitoring stations were also installed in several locations in Big Springs Creek, including below the Big Springs Dam outlet (RKM 3.6), below the waterwheel (RKM 2.8), and above a tailwater return point discharge (RKM 1.6). Details describing the installation and operation of these remote sensor stations are provided in Willis and Deas (2010) (see appendix).

Monitoring locations in each creek were selected based on project scope and available resources. Sites in Big Springs Creek and Little Springs Creek were selected to monitor both longitudinal temperature trends as well as various spring source water temperatures. Sites in Hole in the Ground Creek were selected to monitor boundary condition temperatures in this Shasta River tributary as it crosses the southern boundary of Shasta Big Springs Ranch, as well as its longitudinal thermal profile. Sites in the Shasta River were selected to establish water temperatures above tributary inflows. Due to resource limitations, partial data sets are available for Little Springs Creek, Hole in the Ground Creek, and the Shasta River. Herein, only water temperature data from Big Springs Creek is presented. Analyses of the water temperature data for Little Springs Creek, Hole in the Ground Creek, and the Shasta River are included in the appendices.

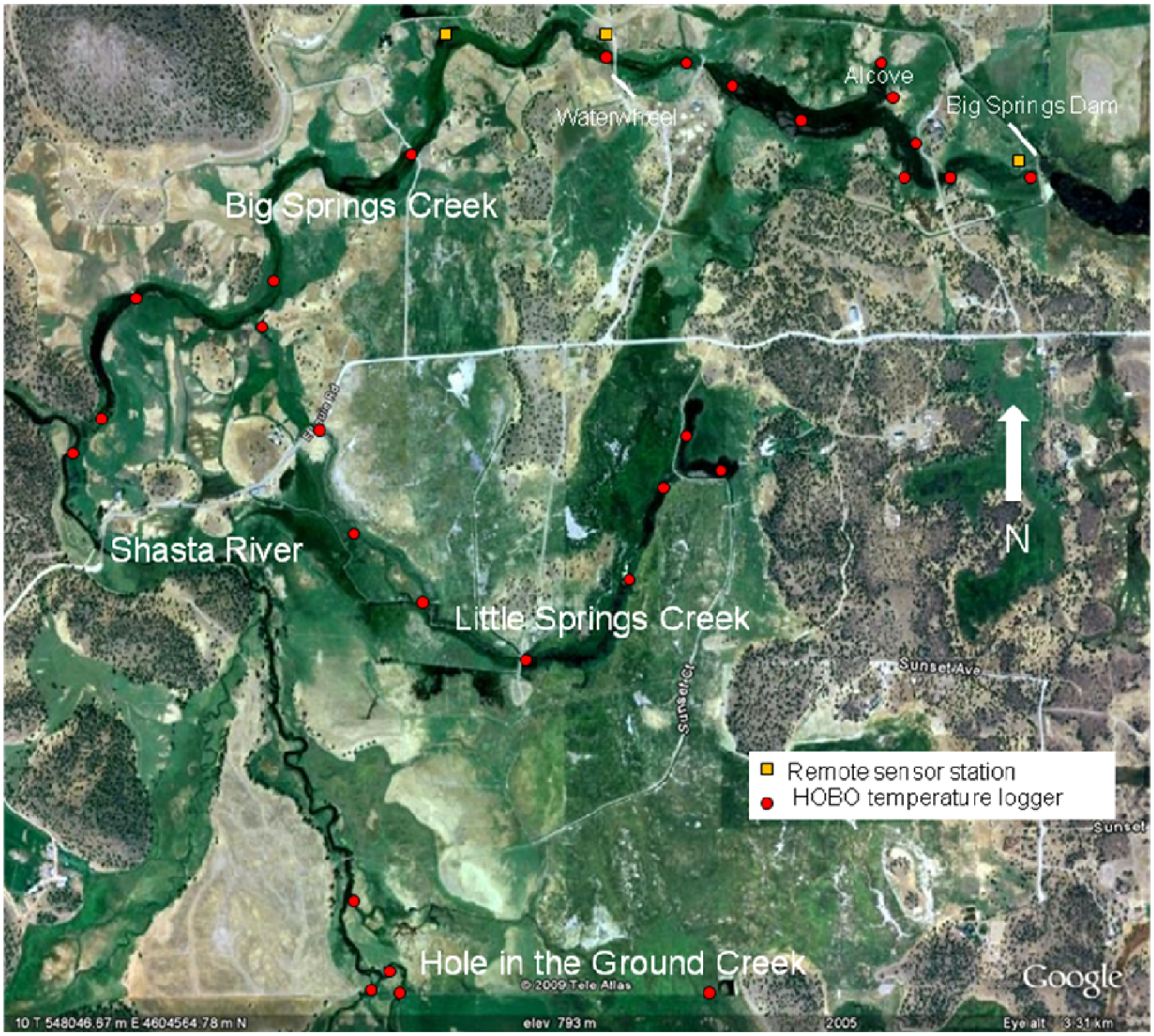

Figure 16. A map of current water temperature monitoring sites in waterways on the Shasta Big Springs Ranch and the Busk Ranch easement.

8.2 Data Analysis

After completing the 2008 baseline assessment, several questions remained about the water temperature characteristics of Big Springs Creek, particularly regarding the water temperature of discrete spring inputs. The monitoring program was refined to address this uncertainty. Discrete spring water temperature data for six sites were examined for sub-daily and seasonal trends. Water temperature data were also examined at 10 sites along the longitudinal profile of Big Springs Creek to characterize water temperatures at each site as well as heating rates between sites. As water temperatures peak during the summer months when irrigation operations concurrently affect flow volumes, the period between 1 April and 1 October, 2009 is focused on for the longitudinal profile.

8.2.1 *Discrete Spring Sources*

During the 2008 baseline assessment, discrete spring sources were identified as the primary source of cool water for Big Springs Creek. These springs were mainly located in the first 0.5 km below Big Springs Dam (though other springs are also located in Big Springs Lake, monitoring them was outside the scope of this project). Emergent water temperatures (i.e. the water temperature as the springs emerge from the ground but before they mix with Big Springs Creek) in these springs were monitored from 1 April 2009 through 31 March 2010; monitoring is currently on-going.

The locations of discrete springs were identified using field observations and thermal imaging (Figure 17). These springs are part of a regional complex called the Big Springs Complex. Though areas of diffuse spring inputs are included in this complex, discrete springs were identified for the purposes of water temperature monitoring (Figure 18). These springs included:

1. The north alcove spring

2. The east alcove spring

3. Below Busk bridge, river right (RR)

4. Below Busk bridge, river left (RL)

River right and river left refer to the streambank direction as one looks downstream. These springs are a sample of those included in the Big Springs Complex and represent a considerable source of inflow to Big Springs Creek.

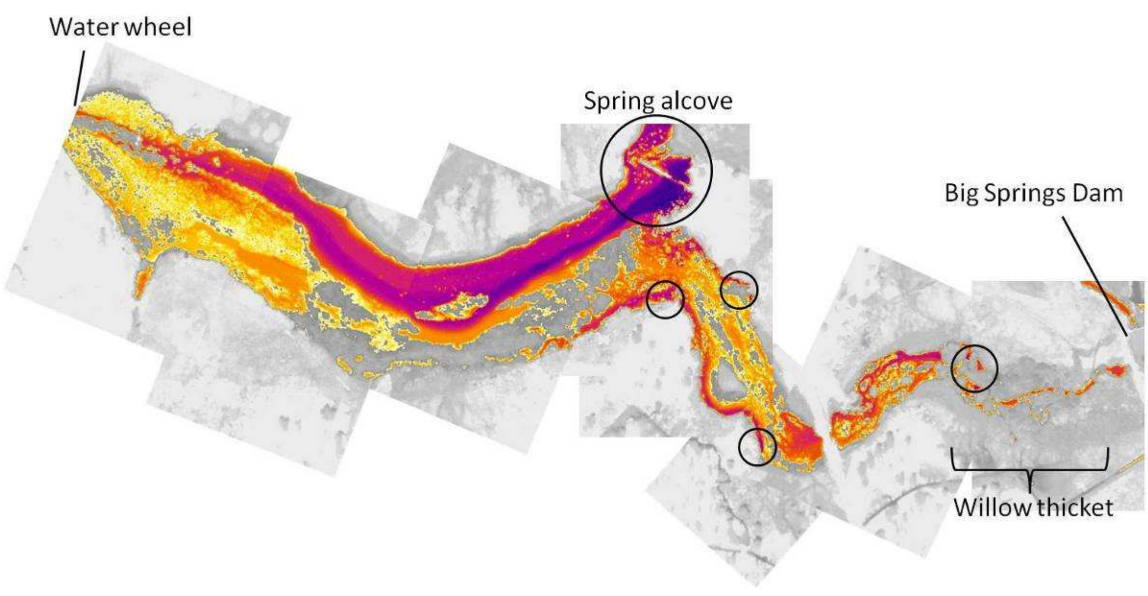

Figure 17. Thermal images stitched together to identify general locations of cool water inflows. Cool water is represented using blue and purple; warmer water is illustrated by yellow and red (Watershed Sciences 2009)

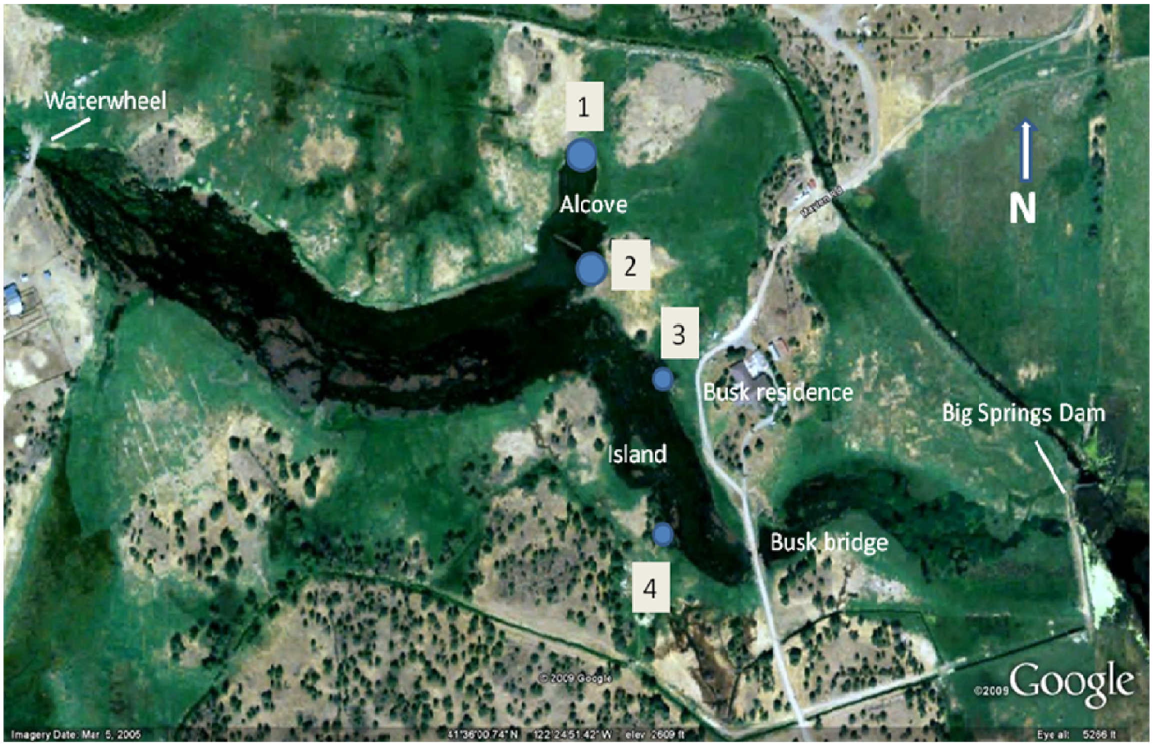

Figure 18. Spring sources monitored for water temperature.

A preliminary analysis of temperature data determined that the springs generally emerge between 10°C and 12°C (Willis and Deas 2009). Additional monitoring supported this initial finding (Table 1). The north alcove spring (RKM 3.1) is the warmest, emerging at temperatures between 11.5°C and 12.5°C. The spring located below the Busk bridge on river right (RKM 3.2), emerges cooler than the other springs, with temperatures ranging from 10.4°C to 10.9°C.

Further monitoring also indicated that each spring illustrated seasonal variations in water temperature, but that compared to Big Springs Creek, the springs' water temperatures were relatively constant (Figures 19, 20, 21, and 22). The springs' seasonal changes ranged between 0.5°C and 1°C, with peak temperatures generally occurring in the late fall-early winter and minimum temperatures occurring in late spring-early summer.

Table 2. Maximum and minimum temperatures for discrete springs in Big Springs Creek between 1 April 2009 and 31 March 2010.

Site*	Spring**	Maximum T (°C)	Minimum T (°C)
1	North alcove spring (RKM 3.1)	12.5	11.5
2	East alcove spring (RKM 3.1)	11.3	10.5
3	Below Busk bridge, RR (RKM 3.2)	10.9	10.4
4	Below Busk bridge, RL (RKM 3.3)	12.2	11.3

*Location based on Figure 18; **RR = river right, RL = river left

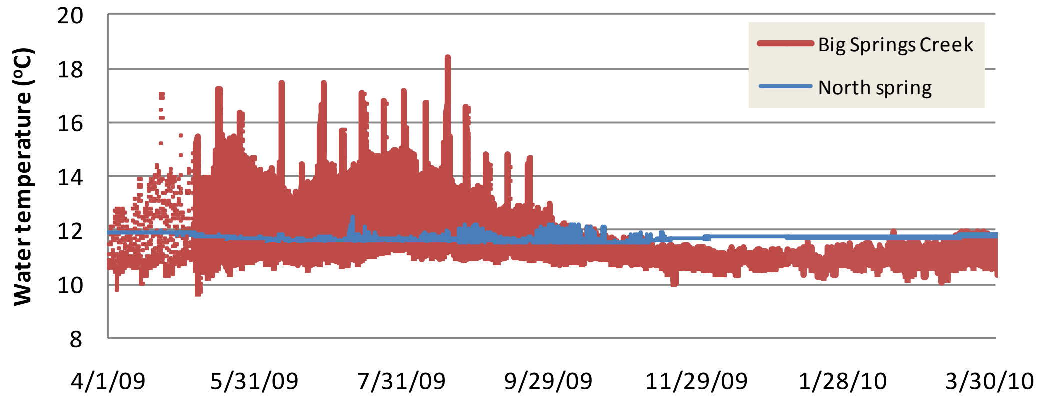

Figure 19. Water temperatures in the north alcove spring relative to the water temperatures in Big Springs Creek at the Busk house bridge (RKM 3.3), upstream of where the spring water mixes with the main channel.

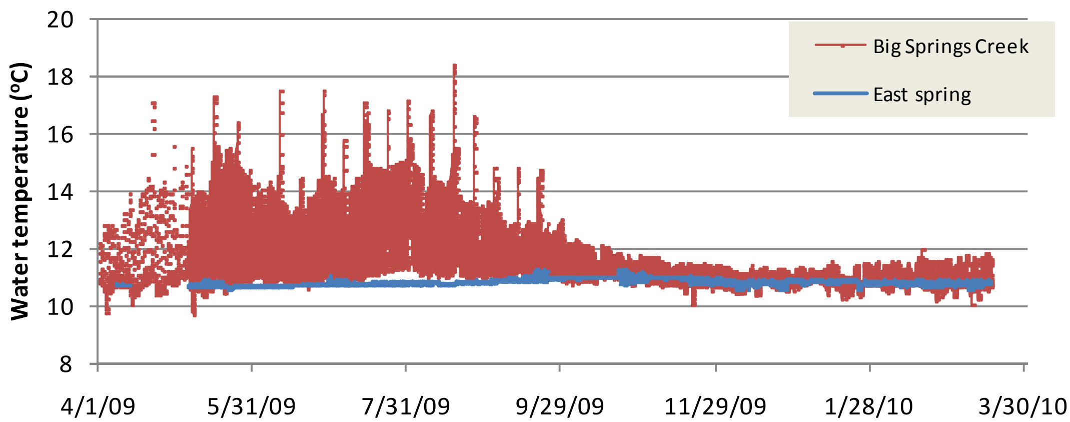

Figure 20.Water temperatures in the east alcove spring relative to water temperatures in Big Springs Creek at the Busk house bridge (RKM 3.3), upstream of where the spring water mixes with the main channel.

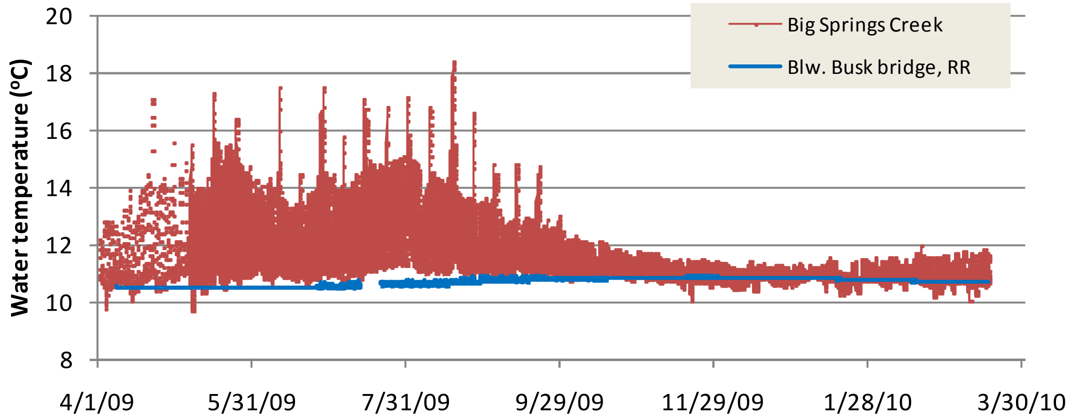

Figure 21. Water temperatures in the spring below the Busk bridge on river right relative to the water temperatures in Big Springs Creek at the Busk house bridge (RKM 3.3), upstream of where the spring water mixes with the main channel.

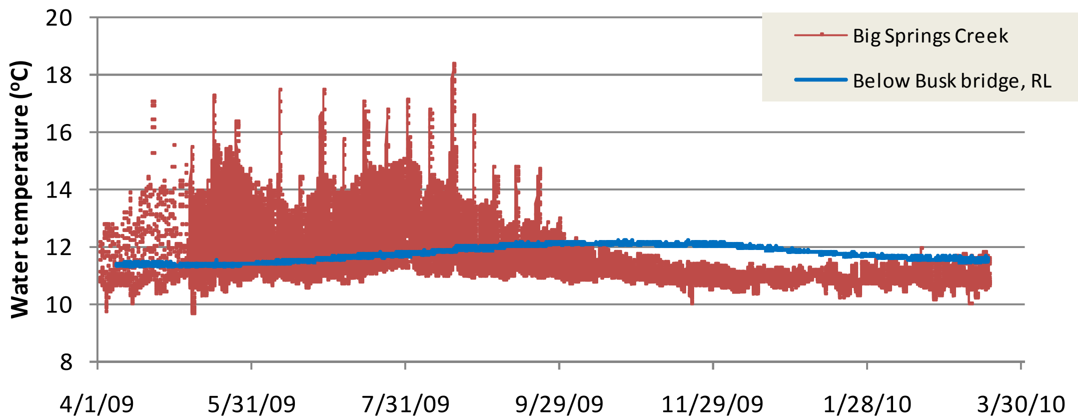

Figure 22. Water temperatures in the spring below the Busk bridge on river left relative to water temperatures in Big Springs Creek at the Busk house bridge (RKM 3.3), upstream of where the spring water mixes with the main channel.

8.2.2 *Longitudinal Profile*

Monitoring discrete springs' water temperatures defined some of the boundary condition thermal inputs to Big Springs Creek. Next, water temperature data from the longitudinal profile were collected to explore downstream temperature trends as well as those at other inflow boundaries (i.e the Big Springs Dam outlet at RKM 3.6). Big Springs Creek was monitored at eight locations from Big Springs Dam (RKM 3.6) to the mouth (RKM 0.0) (Figure 23). Many locations were maintained from the 2008 monitoring program; other locations were added to provide detail as resources permitted. Plotting temperature data along the profile of the creek illustrated both local water temperatures at each monitoring location as well as the rate of thermal loading between sites.

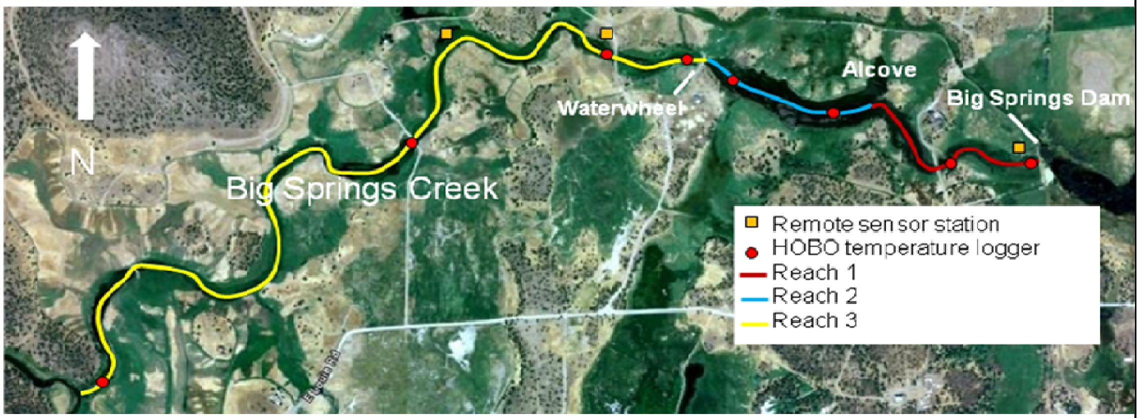

Figure 23. Water temperature monitoring locations along the longitudinal profile of Big Springs Creek. Thermal trends were categorized in three reaches: from the Big Springs Dam outlet to the alcove (RKM 3.6-3.1), the alcove to the waterwheel (RKM 3.1-2.8), and the waterwheel to the mouth of Big Springs Creek (RKM 2.6-0.0).

As discussed in Section 6 of this report, there were two main sources of inflow to Big Springs Creek, which result in two areas of strong thermal inputs. The two types of inflow were from discrete and diffuse springs (discussed in section 8.2.1) and periodic releases from the Big Springs Dam outlet (RKM 3.6). Big Springs Dam impounds Big Springs Lake, which is fed from springs at the east end of the lake (Figure 24). (Monitoring Big Springs Lake was outside the scope of this project). Though water stored in Big Springs Lake emerges as spring water, travel time through the lake results in variable water temperatures as water flows through the dam outlet into Big Springs Creek. Seasonal trends illustrated that water temperatures were warmer during the summer and cooler during the winter (Figure 25). Maximum and minimum water temperatures below the Big Springs Dam outlet were 19.3^{o}C (observed on 21 July, 2009) and 6.8^{o}C (observed on 25 January, 2010), respectively.

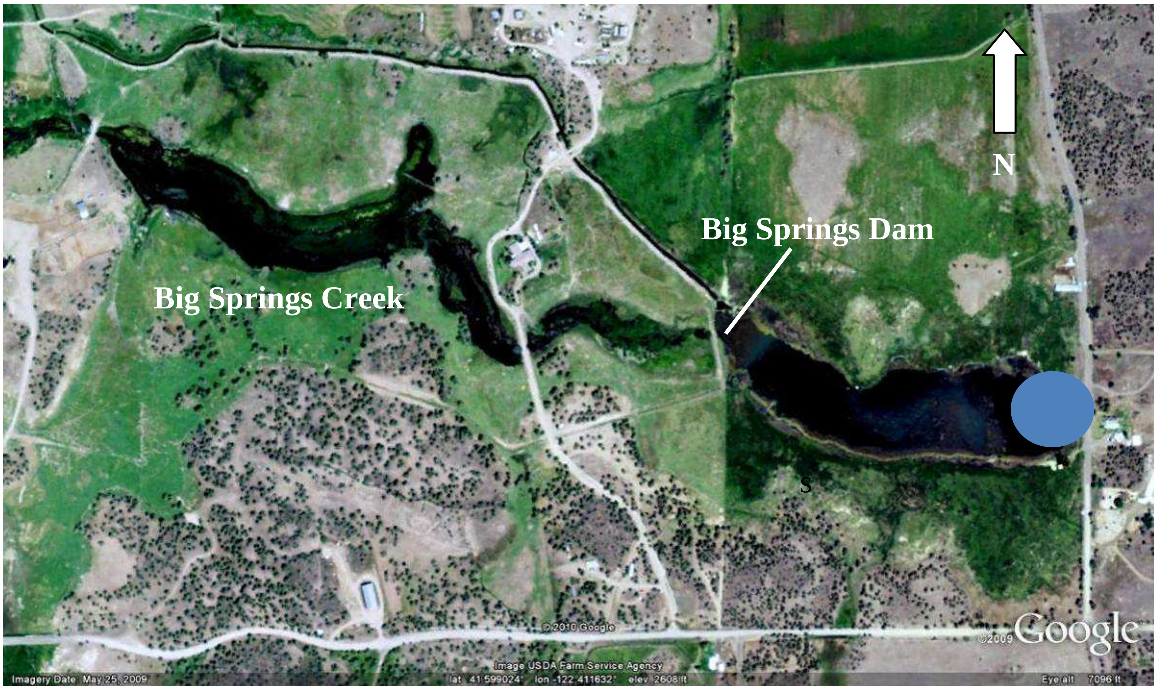

Figure 24. Big Springs Lake is located east of Big Springs Dam and flows into Big Springs Creek. The blue dot indicates the principal location of springs that provided water impounded within Big Springs Lake.

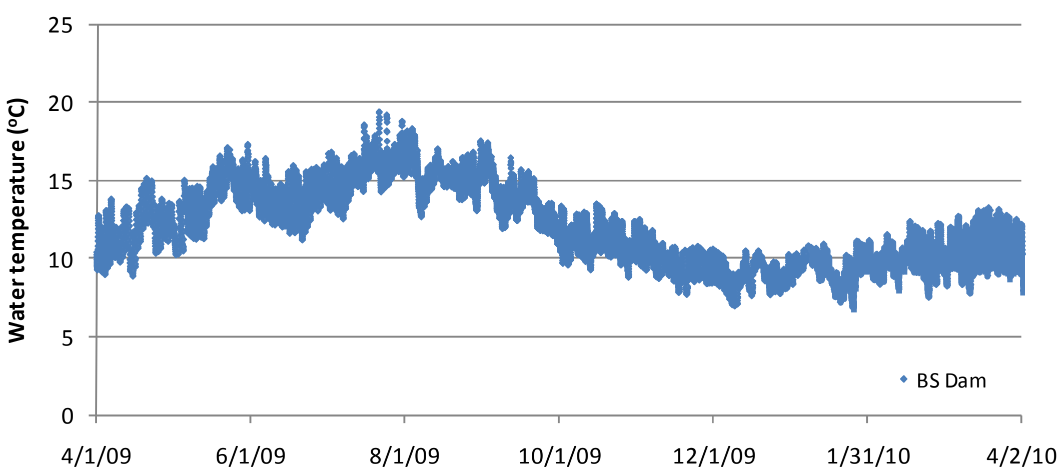

Figure 25. Water temperatures recorded below the Big Springs Dam outlet (RKM 3.6) during the study period.

The second significant flow contribution to Big Springs Creek was made by the diffuse and discrete springs located in the 0.5 km downstream of Big Springs Dam. As previously discussed, the discrete springs downstream of Big Springs Dam emerged at relatively constant temperatures.

Longitudinal temperature plots illustrate how water temperatures change in Big Springs Creek from the Big Springs Dam outlet to the creek's mouth. Heating trends in Big Springs Creek can be divided into three reaches: Reach 1, from Big Springs Dam to the alcove springs (RKM 3.6 to RKM 3.2); Reach 2, from the alcove springs to the waterwheel (RKM 3.2 to RKM 2.6); and Reach 3, from the waterwheel to the mouth (RKM 2.6 to RKM 0.0) (Figure 23). In Reach 1, the main source of water was from Big Springs Dam (accretions were also detected in this reach, though their source was unclear). Water from the Big Springs Dam outlet flows through a complex channel, characterized by irregular channel geometry and a mix of aquatic, emergent, and riparian vegetation. At the alcove springs, water temperatures are strongly influenced by the spring inputs, which contribute a steady source of inflow between 10-12^{o}C. Once the spring water enters from the alcove and other nearby spring sources, Big Springs Creek flows through a remarkably wide and shallow channel reach (Figure 6) for approximately 0.4 km until it reaches the waterwheel. Below the waterwheel, the channel morphology changes again, becoming slightly narrower and deeper, although channel morphologies remain wide and shallow from the waterwheel to the mouth of Big Springs Creek. Both channel reaches extending from the alcove springs to the mouth of Big Springs Creek were occupied by extensive patches of submerged and emergent aquatic vegetation (biomass was seasonally variable – see Section 4). More detail about longitudinal trends in Big Springs Creek channel geometry is presented in Section 5.

Downstream trends in the maximum, mean, and minimum water temperatures throughout Big Springs Creek are presented in Figures 27-30, which illustrate representative seasonal heating and cooling trends during the study period. Water released from Big Springs Dam illustrated gradual heating and cooling until it reached the alcove springs, at which point water temperatures from the springs replaced the thermal signal from the dam. The minimal temperature change observed in the first 0.3 km downstream of the dam outlet is likely due to the stream cover from the heating effects of solar radiation provided by a willow thicket. The temperature shift from this point to the monitoring site below the alcove springs illustrates whether the discrete springs' water temperatures are relatively warmer or cooler than the dam releases water temperatures. During the spring and fall, water temperatures below the alcove were comparable to those below the dam outlet (Figure 28 and Figure 30). During the summer, water temperatures at the alcove were generally cooler than those at the dam outlet (Figure 29). In the winter, water temperatures at the alcove are generally warmer than those at the dam outlet (Figure 31).

Once past the alcove springs, Big Springs Creek entered Reach 2, the 0.4 km reach between the alcove springs and the waterwheel. Big Springs Creek exhibited distinct thermal loading trends in Reach 2 from Reach 1. Through all seasons except winter, peak water temperatures increased along this reach. Furthermore, the fastest rates of heating (spring, summer and fall) or cooling (winter) occurred within this reach. Water temperatures increased by as much as 7^{o}C during the summer and cooled by as much as 4^{o}C in the winter, representing a heating and cooling rate of approximately 35^{o}C/km and 20^{o}C/km, respectively. As discussed in Section 5, this reach is characterized by the highest width-to-depth ratio in the creek and lowest channel slopes. Furthermore, rates of heating were also influenced by instream grazing that occurred from 1 April through 21 July, 2009, which removed much of the aquatic vegetation from the creek channel

(Figure 26). The reduction of vegetation reduced potential shading effects of emergent vegetation and increased travel times, two conditions that can lead to increased heating rates.

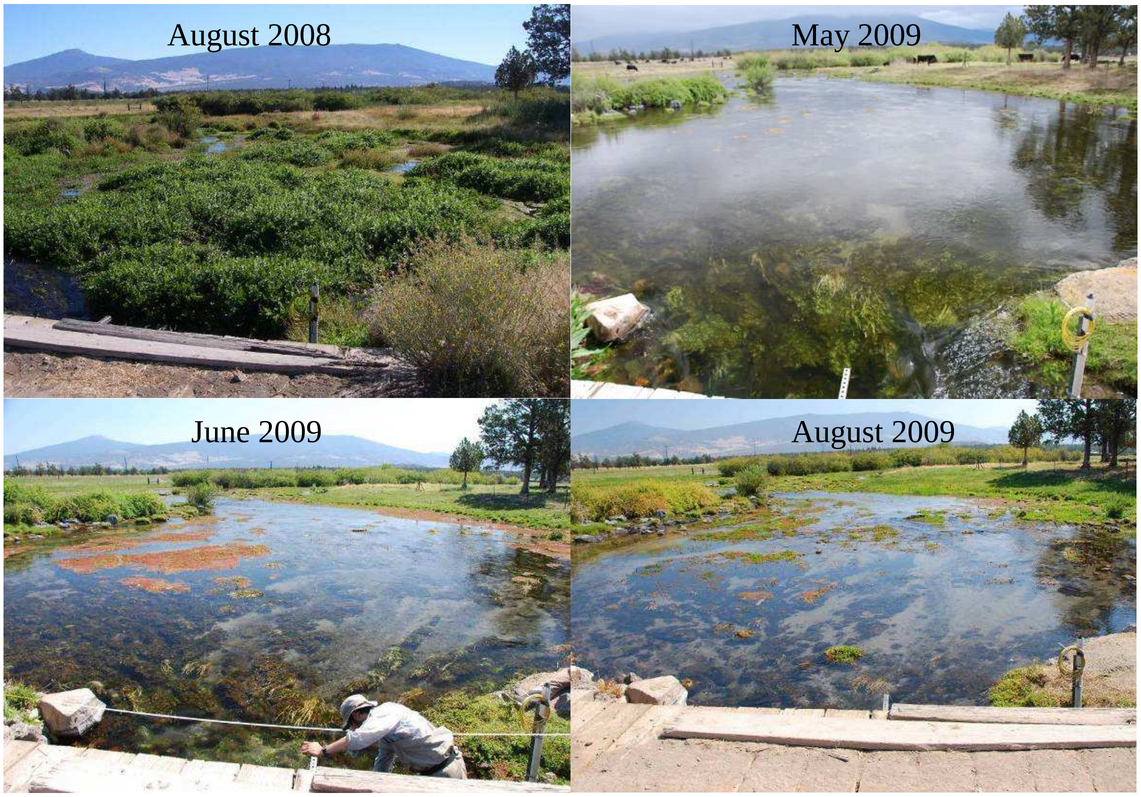

Figure 26. Time series photos showing reduction in vegetation downstream of Big Springs Lake as a result of cattle grazing in the channel.

Big Springs Creek entered Reach 3 with distinct thermal loading trends as it passed the waterwheel. This reach extended approximately 2.7 km from the waterwheel to the mouth. In this reach, the channel geometry was slightly narrower and deeper (although still remarkably wide and shallow); submerged and emergent aquatic vegetation were also present throughout this reach as the summer progressed (Figure 27). The heating rate decreased from that observed in the reach above the waterwheel. Though water temperatures increased as much as 6^{o}C and cooled by as much as 3^{o}C, heating and cooling rates declined to 2.3^{o}C/km and 1.2^{o}C/km, respectively. These reduced heating rates were likely a result of the smaller width-to-depth ratios in this reach and increased channel slopes, which resulted in decreased travel times. Also, unlike in the reach between the alcove and the waterwheel, cattle exclusion below the waterwheel began in March 2009, which allowed vegetation to grow unhindered though the summer. Extensive macrophyte growth occurred in parts of this reach, further increasing potential shade and constricting main flow channels resulting in reduced travel times. Both of these factors contributed to the reduced heating rate observed in the downstream reach.

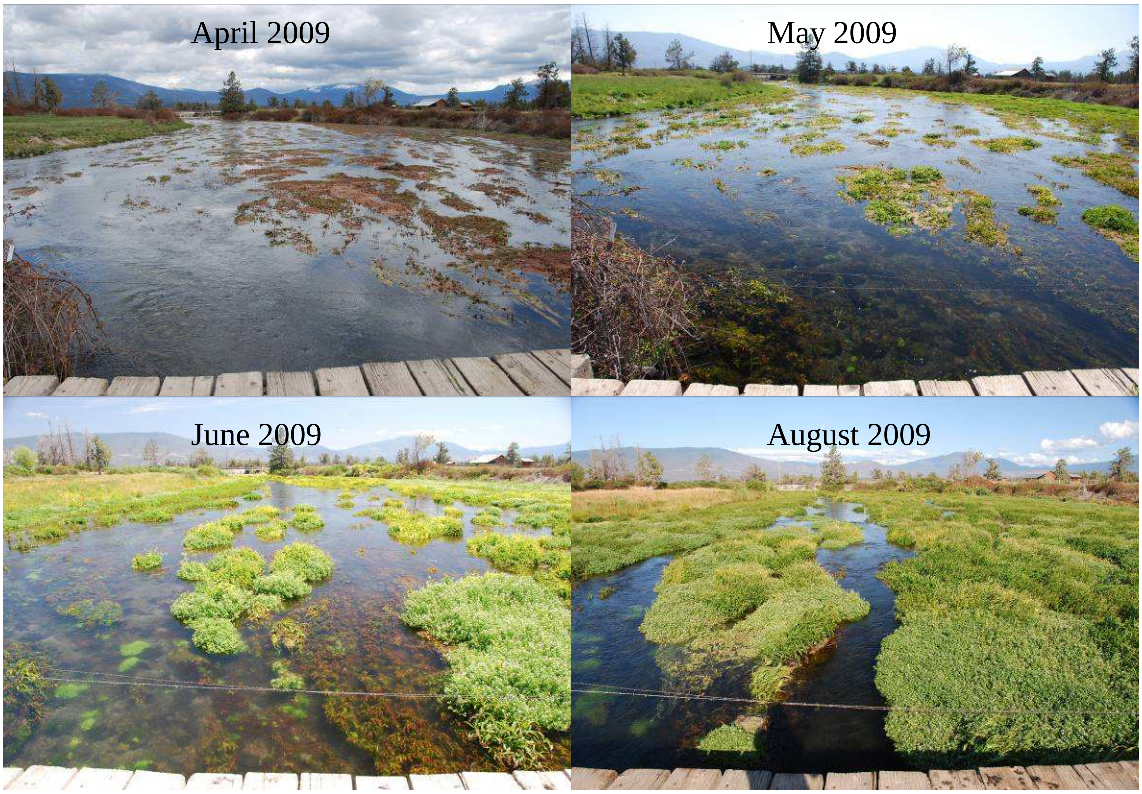

Figure 27. Time series photos showing vegetation growth downstream of the waterwheel (at RKM 2.3) during the 2009 field season.

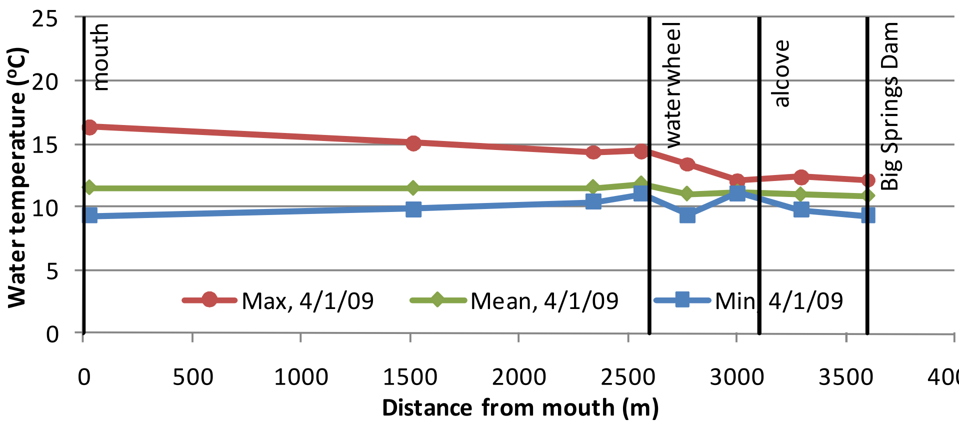

Figure 28. Maximum, mean, and minimum temperatures along the longitudinal profile of Big Springs Creek on 4/1/2009.

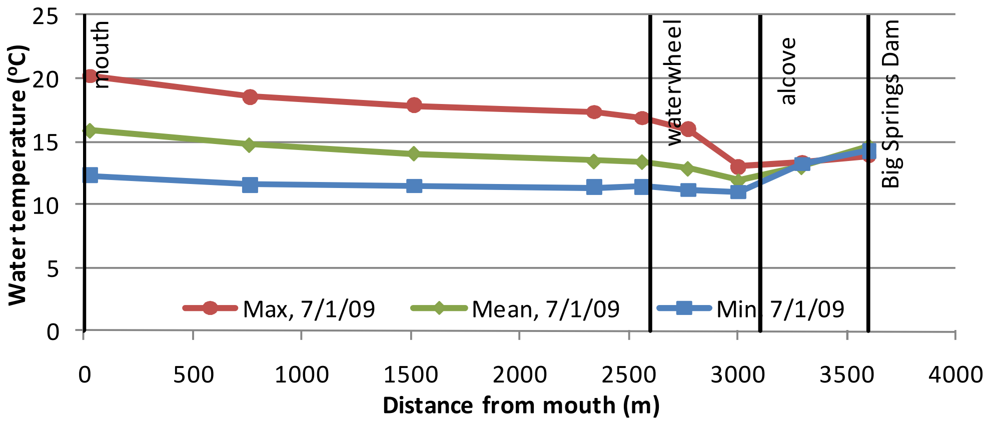

Figure 29. Maximum, mean, and minimum temperatures along the longitudinal profile of Big Springs Creek on 7/1/2009.

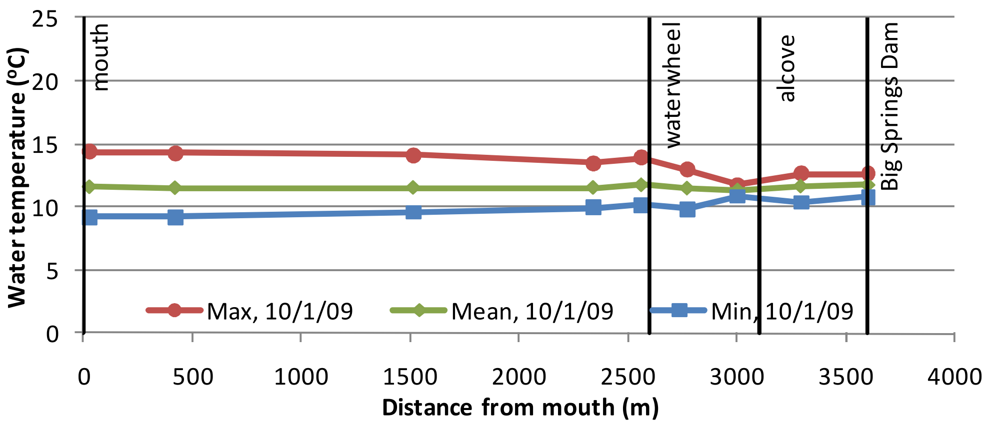

Figure 30. Maximum, mean, and minimum temperatures along the longitudinal profile of Big Springs Creek on 10/1/2009.

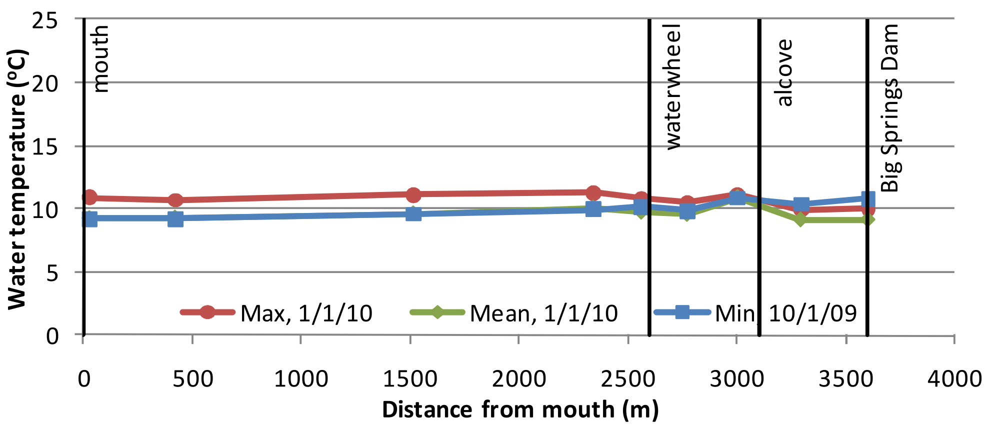

Figure 31. Maximum, mean, and minimum temperatures along the longitudinal profile of Big Springs Creek on 1/1/2010.

Reducing water temperatures at the mouth of Big Springs Creek potentially benefits the Shasta River downstream of the confluence, particularly during the summer when Big Springs Creek contributes substantial streamflow to the Shasta River. Though heating was observed from the waterwheel to the mouth throughout the summer, average daily maximum water temperatures at the mouth declined during that period, when peak temperatures typically increase (Table 2). Average daily maximum temperatures declined from July to August by 2.6^{o}C. Average daily mean and minimum temperatures also declined from July to August by 1.4^{o}C and 0.5^{o}C, respectively. This temperature decline coincided with the extensive growth of emergent aquatic vegetation, which provided shade and decreased travel times through the reach, ultimately reducing the potential solar loading in this reach.

Table 3. Average daily maximum, mean, and minimum water temperatures at the mouth of Big Springs Creek for April-September 2009.

	Average Daily Max (^{o}C)	Average Daily Mean (^{o}C)	Average Daily Min (^{o}C)
April 2009	18.0	12.3	8.6
May	20.7	14.7	8.9
June	20.5	15.5	11.8
July	21.2	16.4	12.3
August	18.6	15.0	11.7
September	16.6	13.7	11.2

8.3 Response to Restoration Actions

Given the availability of baseline assessment data gathered prior to restoration activities and the current data record gathered during the implementation of those activities, the creek's water temperature response to those activities was examined. Water temperature data from 2008 and 2009 were analyzed at each location to determine what effect, if any, one year of passive restoration activities had on local and overall stream temperatures in Big Springs Creek. As the focus of the restoration effort is to reduce elevated water temperatures in Big Springs Creek during juvenile salmonids' oversummering lifestage, water temperatures from 1 April through 30 September were compared from 2008 and 2009.

Daily maximum, minimum, and average temperatures were compared using the paired *t*-test method. This method can be applied to data sets that share some common quality. In this case, the common quality is location. The difference in daily maximums, minimums, and averages were analyzed to determine whether there was a statistically significant shift in mean values for each month. For example, the daily maximum temperatures were determined for each day in April for each year of the study period. The difference was taken for concurrent days; this satisfied one prerequisite for the *t*-test, that the data set be independent. The differences were then analyzed to determine whether the average difference included zero within a 95 % confidence interval (which would indicate that we were 95 % confident that there was no statistically significant difference between the two data sets). In the event that the range of average paired differences did not include zero, we could determine that the seasonal temperatures shifted in a statistically meaningful way and could estimate the magnitude and direction of that shift. By examining the data grouped by month, we reduced the effects of seasonal meteorological differences.

The comparison began at the upstream monitoring sites to determine whether water temperatures that defined the boundary conditions were significantly different from 2008 to 2009. Data gathered from the stream thalweg at the Busk house bridge (RKM 3.3) was used to examine releases from Big Springs Dam (Table 4); similarly, water temperature gathered from the thalweg in Big Springs Creek below the alcove springs (RKM 3.0) was used to examine temperature conditions immediately downstream from the major spring sources (Table 5). While significant differences existed between these two data sets, overall, these differences were small. Water temperatures at the Busk house bridge were 0.1^{o}C cooler in 2009 compared to 2008. Similarly, water temperatures below the alcove springs were 0.03^{o}C cooler in 2009 compared to 2008. The difference at the alcove springs is barely greater than the data loggers' uncertainty range of 0.2^{o}C. Furthermore, while differences were detected between the data sets, these differences were not uniform. For example, at the Busk house bridge, no significant difference existed between water temperatures in April, June, or August of the study period. Also, where differences were significant, the difference was not uniform for daily maximums, means, and minimums. Daily minimum water temperatures increased by 0.5^{o}C on average at the Busk house bridge during September but daily mean water temperatures decreased 0.8^{o}C on average.

Table 4. A summary of the statistical significance of the average monthly difference between 2008 and 2009 daily maximum, minimum, and mean water temperatures at Big Springs Creek at the Busk house bridge (RKM 3.3). Statistically significant changes are indicated with a Y, followed by the average temperature change observed during that month.

	Statistically significant temperature change?		
Month	**Daily Minimum (Average ΔT, ^{o}C)**	**Daily Maximum (Average ΔT, ^{o}C)**	**Daily Mean (Average ΔT, ^{o}C)**
April 2008/2009	N	N	N
May 2008/2009	N	Y(-1.8)	Y(-1.0)
June 2008/2009	N	N	N
July 2008/2009	Y(-1.2)	Y(-1.8)	Y(-1.4)
August 2008/2009	N	N	N
September 2008/2009	Y(+0.5)	Y(+1.2)	Y(-0.8)
Overall data set	**Y(-0.1)**		

While water temperatures were generally 0.1^{o}C cooler at the Busk house bridge, water temperature differences below the alcove springs were even smaller. As previously discussed, the water temperature signal in Big Springs Creek shifted from the dam release thermal signal to the springs' thermal signal as the diffuse and discrete springs contributed to the creek's flow. Generally, no matter what the upstream temperature conditions, water temperatures in Big Springs Creek "reset" to the cool water conditions created by the springs. Similarly to the differences at the Busk house bridge, temperature differences below the alcove springs were not uniform. Each temperature category illustrated significant differences during two months of the study period. For daily minimums, those differences occurred during April and September; for daily maximums, during April and August; for daily means, during June and August. However, the overall difference in data sets was small, near, at or below the uncertainty range of the data loggers. This minimal difference indicates that any significant shift in downstream temperatures may not be related to differences in boundary condition water temperatures between 2008 and 2009.

Table 5. A summary of the statistical significance of the average monthly difference between 2008 and 2009 daily maximum, minimum, and mean water temperatures at Big Springs Creek below the alcove (RKM 3.0). Statistically significant changes are indicated with a Y, followed by the average temperature change observed during that month.

	Statistically significant temperature change?		
Month	**Daily Minimum (Average ΔT, ^{o}C)**	**Daily Maximum (Average ΔT, ^{o}C)**	**Daily Mean (Average ΔT, ^{o}C)**
April 2008/2009	Y(-0.1)	Y(+0.7)	N
May 2008/2009	N	N	N
June 2008/2009	N	N	Y(-0.3)
July 2008/2009	N	N	N
August 2008/2009	N	Y(+0.7)	Y(+0.2)
September 2008/2009	Y(+0.1)	N	N
Overall data set	**Y(-0.03)**		

The first location where a significant shift in temperature regime is observed is at the waterwheel (RKM 2.8). Overall, water temperatures were 0.3°C warmer in 2009 versus 2008, though a closer look at individual trends shows larger shifts (Table 6). In all months except May, daily maximum temperatures increased; July and August illustrated the largest shift, with daily maximum temperatures increasing an average of 1.8°C and 1.9°C, respectively. Daily minimum and average temperatures also illustrated warmer temperatures. Daily minimum temperatures increased the most in May by an average of 1.9°C, though this increase coincided with an overall decrease of daily maximum temperatures. Daily average temperatures increased the most in September by an average of 1.0°C.One difference in the stream between locations upstream of the waterwheel from the other stream sites is that cattle exclusion efforts were delayed. Instream grazing was permitted until late July, at which point vegetation was absent from much of the channel (Figure 26). The lack of vegetation combined with the wide and shallow geometry in this reach resulted in increased heating rates in 2009 compared to 2008.

Table 6. A summary of the statistical significance of the average monthly difference between 2008 and 2009 daily maximum, minimum, and mean water temperatures at Big Springs Creek above the waterwheel (RKM 2.8). Statistically significant changes are indicated with a Y, followed by the average temperature change observed during that month.

	Statistically significant temperature change?		
Month	**Daily Minimum (Average ΔT, °C)**	**Daily Maximum (Average ΔT, °C)**	**Daily Mean (Average ΔT, °C)**
April 2008/2009	N	Y(+0.6)	N
May 2008/2009	Y(+1.9)	Y(-1.8)	N
June 2008/2009	Y(+0.6)	Y(+1.2)	Y(+0.8)
July 2008/2009	Y(-0.3)	Y(+0.8)	Y(+0.2)
August 2008/2009	N	Y(+1.8)	Y(+0.8)
September 2008/2009	Y(+0.4)	Y(+1.9)	Y(+1.0)
Overall data set	**Y(+0.3)**		

Despite increased water temperature at the waterwheel, heating rates between the waterwheel and corral crossing (RKM 2.3) declined in 2009, resulting in comparable water temperatures at the corral crossing in 2009 compared to 2008 (Table 7). Daily maximum temperatures neither increased nor decreased in 2009; except for September, daily average temperatures followed the same trend. Daily minimum temperatures increased during May, June, and September by an average of 0.2 °C, 0.5 °C, and 0.2°C, respectively, though the cause of these increases was not clear. Restoration actions below the waterwheel were implemented in March 2009, allowing passive restoration to begin in the spring and continue through the fall. Though water temperatures were generally comparable, the decreased heating rate demonstrated a beneficial response to restoration actions.

Table 7. A summary of the statistical significance of the average monthly difference between 2008 and 2009 daily maximum, minimum, and mean water temperatures at Big Springs Creek corral crossing (RKM 2.3). Statistically significant changes are indicated with a Y, followed by the average temperature change observed during that month.

	Statistically significant temperature change?		
Month	**Daily Minimum (Average ΔT, °C)**	**Daily Maximum (Average ΔT, °C)**	**Daily Mean (Average ΔT, °C)**
April 2008/2009	N	N	N
May 2008/2009	Y(+0.2)	N	N
June 2008/2009	Y(+0.5)	N	N
July 2008/2009	N	N	N
August 2008/2009	N	N	N
September 2008/2009	Y(+0.2)	N	Y(+0.2)
Overall data set	**Y(+0.1)**		

Below the corral crossing, heating rates in Big Springs Creek continued to decrease. By the lowest drivable bridge crossing, daily maximum and mean temperatures decreased

(Table 8). Daily maximum temperatures showed the strongest response to restoration actions, decreasing by an average of 1.6-2.2°C until September. Daily mean temperatures also decreased by an average of 0.7-0.8°C from June through August. Similarly, daily minimum temperatures also decreased by an average of 0.4-0.5°C from July through September. However, daily minimum temperatures also showed a general increase of 0.4°C in April and June. The cause of increased minimum temperatures was unclear. Overall, water temperatures at this location were cooler by an average of 0.5°C, illustrating a positive and significant response to restoration actions. The cause of decreased heating rates between the corral crossing and the lowest drivable bridge appeared to be the extensive vegetation growth that occurred in this reach.

Table 8. A summary of the statistical significance of the average monthly difference between 2008 and 2009 daily maximum, minimum, and mean water temperatures at Big Springs Creek lowest drivable bridge (RKM 1.5). Statistically significant changes are indicated with a Y, followed by the average temperature change observed during that month.

	Statistically significant temperature change?		
Month	**Daily Minimum (Average ΔT, °C)**	**Daily Maximum (Average ΔT, °C)**	**Daily Mean (Average ΔT, °C)**
April 2008/2009	Y(+0.4)	N	N
May 2008/2009	N	Y(-1.6)	N
June 2008/2009	Y(+0.4)	Y(-2.2)	Y(-0.7)
July 2008/2009	Y(-0.5)	Y(-1.7)	Y(-0.8)
August 2008/2009	Y(-0.5)	Y(-1.6)	Y(-0.7)
September 2008/2009	Y(-0.4)	Y(-1.2)	N
Overall data set	**Y(-0.5)**		

At the mouth of Big Springs Creek, the response to restoration actions was still illustrated, though not as strongly as at the lowest drivable bridge crossing. In April and May, there was no statistically significant shift in any category of water temperatures. In June and July, daily maximum and minimum temperatures did shift, though daily average temperatures did not. This indicated a narrowing of temperature range around a common mean (i.e. a reduced diurnal range, but no diurnal shift), though the reason for this change is unknown. In June and July, daily maximum temperatures decreased by an average of 1.6°C and 0.7°C, respectively; daily minimum temperatures increased by an average of 0.9°C and 0.4°C. However, daily mean temperatures during June and July remained the same. August saw the most significant temperature shift, during which daily maximum, minimum, and mean temperatures shifted. The average changes for daily maximum, minimum, and mean temperatures were -1.7°C, +0.4°C, and -0.8°C, respectively. This indicated that not only did the diurnal range decrease, but that the mean temperature decreased as well, and average creek water temperature conditions were cooler. In September, the average difference between daily maximums and minimums continued to be statistically significant, but the difference in mean temperatures were not. A summary of the statistical significance in the average difference on mouth maximum, minimum, and mean water temperatures is presented in Table 9.

Table 9. A summary of the statistical significance of the average monthly difference between 2008 and 2009 daily maximum, minimum, and mean water temperatures at Big Springs Creek mouth (RKM 0.0). Statistically significant changes are indicated with a Y, followed by the average temperature change observed during that month.

	Statistically significant temperature change?		
Month	**Daily Minimum (Average ΔT, ^{o}C)**	**Daily Maximum (Average ΔT, ^{o}C)**	**Daily Mean (Average ΔT, ^{o}C)**
April 2008/2009	N	N	N
May 2008/2009	N	N	N
June 2008/2009	Y(+0.9)	Y(-1.6)	N
July 2008/2009	Y(+0.4)	Y(-0.7)	N
August 2008/2009	Y(-0.7)	Y(-1.7)	Y(-0.8)
September 2008/2009	Y(+0.4)	Y(-0.8)	N
Overall data set	**Y(-0.1)**		

The average temperature change was plotted at each monitoring location along the longitudinal profile of Big Springs Creek for daily maximum water temperatures. The average change of daily maximum temperatures illustrates the greatest shift of the three temperature categories (Figure 32). From 2008 to 2009, maximum water temperatures at the waterwheel increased 0.8-1.9^{o}C each month except for May, illustrating that the rate of heating generally increased in the wide and shallow reach above the waterwheel. The main difference in this upstream reach was the abundance of aquatic and emergent vegetation in 2008 compared to 2009. Throughout 2008, cattle were generally excluded from the reach above the waterwheel, which allowed aquatic and emergent vegetation to grow. The vegetation provided shade and decreased travel time through the reach by effectively narrowing the main flow channel (the role of vegetation as it affects hydraulics is discussed in Section 6). In 2009, however, all cattle grazing was concentrated in this reach, which effectively eliminated the presence of aquatic vegetation during 2009. The increased exposure to solar radiation combined with the increased travel time through the reach caused heating rates to increase and 2009 daily maximum temperatures to generally exceed those observed in 2008.

However, despite increased daily maximums above the waterwheel, daily maximum water temperatures decreased below the waterwheel. By the time Big Springs Creek flowed past the corral crossing at RKM 2.3, 2009 daily maximum temperatures were comparable to those in 2008 despite the elevated temperatures at the waterwheel. This trend can again be explained by the difference in aquatic vegetation growth between 2008 and 2009. Vegetation growth between the waterwheel and the corral crossing was extensive, providing shade for most of the channel while decreasing travel times by concentrating the flow in narrow, high-velocity channels (Figure 27). The decreased travel time combined with the extensive cover from solar radiation minimized heating opportunities in this reach.

The reduced heating rate continued to lower daily maximum temperatures until the lowest drivable bridge (RKM 1.5), at which point heating rates began to increase. Water temperatures at the mouth of Big Springs Creek were still generally lower in 2009 compared to 2008, though the difference decreased from the lowest drivable bridge to the mouth. This can be explained by the decreased vegetation biomass (and hence flow concentration and shading benefits) in the lower reaches of the creek (data describing vegetation biomass is presented in Section 4). However, by August, shading emergent vegetation was present throughout the creek below the waterwheel. Daily maximum water temperatures at the mouth of Big Springs Creek decreased approximately 1.8°C between 2008 and 2009.

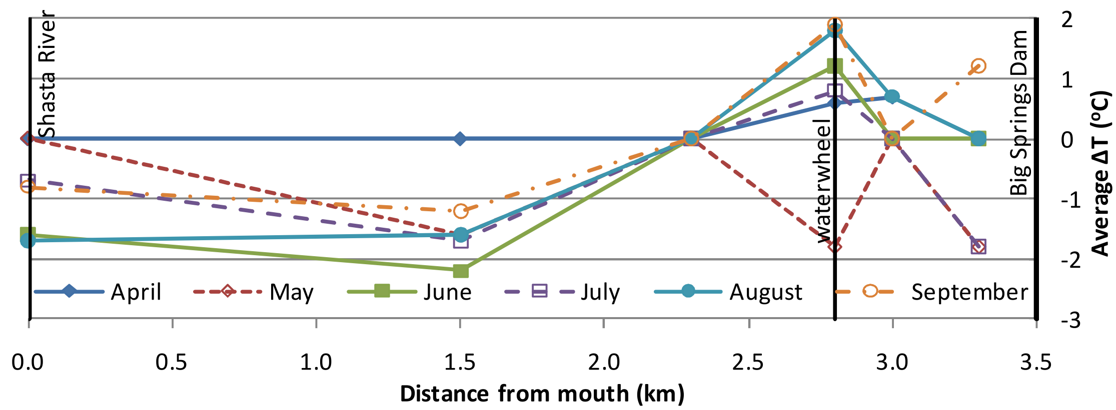

Figure 32. Average change in local daily maximum temperatures from 2008 to 2009 in Big Springs Creek.

8.4 Summary

Restoration actions that began in March 2009 affected Big Springs Creek water temperatures, though local water temperature responses seemed sensitive to the timing of restoration implementation. In the stream reach upstream of the waterwheel, restoration actions were not fully implemented until July 2009. This shortened the recovery period, resulting in less vegetation than was observed in the downstream reaches. Below the waterwheel, cattle were excluded in March 2009. The result was extensive vegetation growth, though growth was not uniform at all locations (the local vegetation response is discussed in Section 4). Where growth was extensive, water temperatures illustrated the strongest response. Where growth was less extensive, heating rates still declined, though not to the extent of other locations with more vegetation. The greatest response was observed at the lowest bridge crossing (RKM 1.5), located at the downstream end of a reach that contained the most extensive vegetation growth in the creek in 2009. Above the waterwheel (RKM 2.8), where restoration actions were delayed, water temperature conditions actually degraded. Overall, water temperatures in Big Springs Creek decreased by the time water reached the creek's mouth, resulting in cooler water flowing into the Shasta River.

9.0 Water Quality

Water quality of Big Springs Creek varied seasonally and longitudinally. Some of this variability was due to the influence of springs that entered the creek at different locations along the course of the creek en route to the Shasta River. There was also seasonal variability along the length of Big Springs Creek due to sources and sinks. Major sources included return flow from adjacent irrigated lands, and sinks included uptake by plants.

To develop a more comprehensive understanding of water quality conditions in the creek, and to develop a baseline data set to guide and evaluate restoration actions, a water sampling program was developed to augment other elements of the baseline study. Discussions herein are focused on nutrients (nitrogen, phosphorus, and carbon) because of their biological importance in aquatic systems and the potential role of these constituents in restoration actions.

9.1 Methods

Water samples were collected at four principal locations in Big Springs Creek on a biweekly to monthly basis. Samples were collected in acid-washed 125 ml high-density polyethylene bottles. Bottles were rinsed with the local water three times prior to collection of the sample. Samples were placed in a cooler and transported back to University of California Davis where samples were refrigerated throughout completion of processing. Samples were analyzed for pH, electrical conductivity (EC), total N, NO_3^-N, NH_4^+-N, total P, soluble-reactive PO_4^{3-} (SRP), dissolved organic carbon (DOC), turbidity, and major cations (Ca^{2+}, Mg^{2+}, K^+, Na^+) and anions (Cl^-, SO_4^{2-}).

9.2 Data Analysis

The unique water quality attributes of Big Springs Creek is largely borne out of largely stable springs-dominated hydrology, where geology plays a dominant role. Examination of springs throughout the Shasta Valley indicated that those spring complexes that emanate on a roughly north-south line along the contact between the Cascades and the underlying Paleozoic sedimentary and metamorphic rocks had elevated concentration of both inorganic nitrogen (as NO_3^--N) and phosphorus (as soluble reactive phosphorus (SRP) PO_4^{3-}-P). Specifically, the combination of ancient marine sediments overlain by volcanic rock in the Shasta Valley allowed for natural sources of nitrogen (N) and phosphorus (P) to be incorporated into the groundwater that eventually emerge as springs. The project team has investigated several springs, including the headwater of Big Springs Creek, and found levels of nitrate and orthophosphate (Figure 33). Although some of the variability in the concentration, particularly nitrate, may be from irrigation operations, there were clearly elevated levels of both nutrients present.

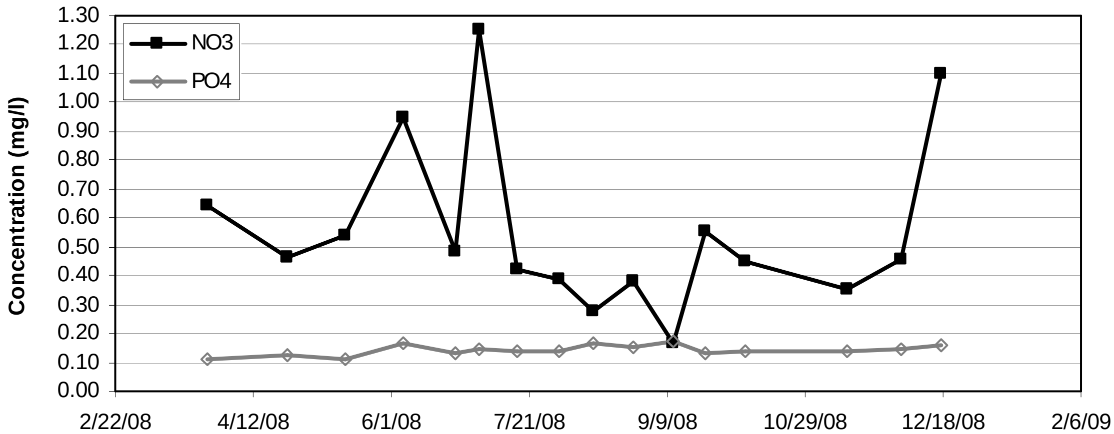

Figure 33. Nitrate and orthophosphate concentration in Big Springs Creek at the waterwheel, 2008 (Nichols et al, 2010).

Nitrogen and phosphorous are key components of primary productivity and one or the other are often limiting in natural aquatic ecosystems (when both limit primary productivity, the condition is termed colimitation). When N and P are available in sufficient quantities, primary production in aquatic systems can be appreciable. System status in terms of nitrogen, phosphorus, and carbon, as well as nutrient limitation is presented below on a site-by-site, seasonal, and longitudinal basis. For purposes of this discussion the following site names and abbreviations are used:

- Busk House Bridge refers to Big Springs Creek at the bridge to the Busk Residence (RKM 3.3)
- East Alcove Spring refers to a spring in the large springs complex below the Busk residence (RKM 3.1)
- Waterwheel refers to Big Springs Creek at the waterwheel crossing (RKM 2.8)
- Downstream Xing refers to Big Springs Creek at the lowest crossing (RKM 0.4)

To assess water quality conditions in the creek, data were examined from March 2008 through March 2010. For comparing pre- and post-restoration conditions, March 2008-2009 and March 2009-10 were employed.

9.2.1 *Nitrogen*

Nitrogen is an essential nutrient for plant growth, yet is often described as a pollutant (e.g., from fertilizers and animal wastes) in many freshwater systems and is subject to total daily maximum loads (TMDLs) due to its role in eutrophication. In rivers with elevated nutrient levels (N & P), abundant primary productivity often results in a high biological oxygen demand (BOD), which can lead to undesirable dissolved oxygen concentrations. Both total nitrogen (organic and inorganic) and inorganic nitrogen are examined herein. Inorganic nitrogen is available to uptake by aquatic plants and consists of ammonium, nitrite, and nitrate. Because nitrite is largely absent under aerobic conditions, total inorganic nitrogen is calculated herein as ammonium plus nitrate.

Overall, the creek had elevated levels of inorganic nutrients, of which a large part was derived from spring contributions. Background levels of total inorganic nitrogen were 0.24 mg/l. Longitudinal differences in concentration were not clear due to the various springs inputs and uptake by vegetation. Typically, the most upstream site at the Busk house bridge (RKM 3.3) had low concentrations of inorganic nitrogen. This was probably due to the modest spring inputs (in terms of flow) and the extensive aquatic vegetation in Big Springs Lake, which impounds the actual headwaters of Big Springs Creek. The east alcove spring enters the creek, as do several other springs, in the reach between the Busk house bridge and the waterwheel, and several-fold increases in inorganic nitrogen occurred due to these spring inputs. The age of water (travel time from source to the existing spring) in some of these springs has been quantified and they differ considerably, particularly considering their close proximity. Two springs on Big Springs Creek have been identified to have a water age of 24 years, and 44 years (unpublished data). These differences in age, and associated exposure to geologic formations, may have marked impacts on constituent concentrations. Total inorganic nitrogen concentrations decreased between the waterwheel and the mouth of Big Springs Creek by about a third, most likely due to the extensive aquatic vegetation growth. Between 2008-09 (pre-restoration) and 2009-10 (post restoration), total inorganic nitrogen concentrations were reduced from 0.26 mg/l to 0.21 mg/l (17.7 %) over the annual period (March to March). During winter, concentrations increased slightly, from 0.22 mg/l to 0.24 mg/l (6.1 %). Comparison of spring, summer, and fall, indicate reductions of 44.9 %, 10.4 % and 24.0 %, respectively. These findings suggest that post-restoration, the increase in aquatic vegetation associated with the removal of extensive in-stream grazing resulted in a decrease in inorganic nitrogen. Total nitrogen showed the same pattern – annual reductions from pre- to post-restoration conditions (0.35 mg/l to 0.31 mg/l, respectively), with slightly higher concentrations in winter (0.30 mg/l to 0.39 mg/l, respectively) and lower values in all other months (0.34 mg/l to 0.28 mg/l spring-fall average). Data are limited to only two years, so no firm conclusions can be drawn. This reduction may be due to natural inter-annual variability or may be due to initial restoration actions. In the latter case, such a reduction may be a short-term effect, as carry-over or stored nutrient concentrations in Big Springs Creek attain equilibrium with a restored condition (i.e., this may not be a long-term reduction).

9.2.2 *Phosphorus*

Like nitrogen, phosphorus is an essential nutrient for plant growth, is often described as a pollutant (e.g., from fertilizers, pesticides, detergents) in many freshwater systems, and is subject to total daily maximum loads (TMDLs) due to its role in eutrophication. As noted above, in combination with nitrogen, phosphorus can lead to abundant primary productivity, which can lead to undesirable dissolved oxygen concentrations. Both total phosphorus (organic and inorganic) and inorganic phosphorus are examined herein. Inorganic nitrogen is available for uptake by aquatic plants and consists of orthophosphate.

Overall, the creek had elevated levels of inorganic phosphorus, of which a large part was derived from spring contributions. Background levels of total inorganic nitrogen were 0.16 mg/l. Longitudinal and seasonal differences in inorganic and total phosphorus concentration were sufficiently small that no clear conclusions can be drawn at this time. Similarly, differences on a site-by-site basis between 2008-09 and 2009-10 were small. Given the level of phosphorus in the system (inorganic or total forms), the system, appeared to be systematically (in space and time) nitrogen limited.

9.2.3 *Nitrogen:Phosphorus Ratio*

Nitrogen and phosphorus in algal tissues typically occur in a 16:1 molar ratio (or 7:1 by mass), known as the Redfield ratio (Redfield et al. 1934). Carbon can be limited, but due to the ubiquitous nature of carbon (e.g., CO_2), such limitation is generally transitory versus systematic over periods such as a season. Generally, a ratio less than 7:1 by mass is associated with a nitrogen limitation and greater than 7:1 translates to phosphorus limitation (Kalff 2002), although local conditions can lead to deviations in these ratios.

Using inorganic forms (denoted with subscript *i*), those available for plant uptake, the nitrogen to phosphorus ratio (by mass) was calculated. Throughout the project area the N_i:P_i ratio was well under 7, averaging 1.56, indicating severe nitrogen limitation. This condition did not change appreciably by location.

9.2.4 *Carbon*

Carbon is an essential nutrient for plant growth and dissolved organic carbon (DOC) lends insight into the fate and transport of organic matter in a riverine system. Dissolved organic carbon (DOC) in Big Springs Creek was low, averaging approximately 0.65 mg/l in the winter and fall to approximately 1.0 mg/l in the spring and summer. DOC values are expected to be low in spring systems because groundwater sources are typically low in organic nutrients (contamination being an exception). The values are not smaller because there was contribution of organic matter (and organic carbon) from Big Springs Lake and upstream creek reaches. Further, some of this seasonal increase may be due to land use practices in the Big Springs Creek watershed as well as increases in primary production in summer and fall.

9.3 Downstream Implications

Water quality in terms of nitrogen, phosphorus, and carbon, as well as nutrient limitation, was explored in Nichols et al. (2010) on a site-by-site, seasonal, and longitudinal basis for the Shasta River from above Dwinnell Dam to the Klamath River – a distance of over 60 km. Seven locations were included in Nichols et al. (2010) (Table 10). In addition to Big Springs Creek near the mouth, two locations were located above Big Springs Creek, and four locations were located below Big Springs Creek. This broad spatial representation of water quality provided the basis for assessment of the impact of Big Springs Creek contributions, as well as characterizing longitudinal conditions. Longitudinal information from this previous study is summarized herein to illustrate that Big Springs Creek has a considerable influence on the Shasta River downstream of the confluence. Abbreviations for site locations in the graphics are listed in Table 10.

Table 10. Sampling sites on Big Springs Creek and the Shasta River for longitudinal assessment (Nichols et al. 2010).

Sampling Site	Rkm	Abbr.
Shasta River at Fontius Ranch (above Dwinnell Dam)	76.8	SR-F
Shasta River above Parks Creek	56.2	SR-abP
Big Springs Creek at the lowest crossing (near mouth)	54.2 (0.4)*	BSC
Shasta River at the top of the Nelson Ranch	52.0	SR-TN
Shasta River at the top of the Freeman Ranch	32.7	SR-TF
Shasta River at the top of the Manley Ranch	21.1	SR-TM
Shasta River Canyon site	2.6	SR-Cyn
*Big Springs Creek enters the Shasta River at Rkm 54.2, while the sampling site in Big Springs Creek is located 0.4 miles upstream.		

9.3.1 *Nitrogen and Phosphorus*

Total inorganic nitrogen concentrations during winter periods showed a general increase from upstream to downstream, while in the spring and summer there was considerable depletion of total inorganic nitrogen due to extensive macrophyte growth (Figure 34). Systematic, significant reductions occurred during these seasons in the Shasta River from below Big Springs Creek to the Klamath River. During fall, concentrations recovered in response to decreased demand from plant uptake and fall senescence of seasonal algal standing crop. Winter concentrations suggested that upstream of Big Springs Creek the background concentrations were on the order of 0.1 mg/l, while downstream of Big Springs Creek background concentrations were on the order of 0.2 to 0.25 mg/l. These concentrations were assumed to represent the approximate levels of available nutrients when primary production was at an annual minimum and fall senescence had abated. Unlike total inorganic nitrogen, inorganic phosphorus (with the exception of the uppermost site above Dwinnell Reservoir) showed almost no longitudinal or seasonal variability (Figure 35). These findings were similar to conditions local to Big Springs Creek, and N_i:P_i ratios throughout the Shasta River from spring through fall (with the exception of the upstream-most site above Dwinnell Dam, SR-F) were overall less than 2.0.

Nitrogen limitation appeared to be a dominant element in the Shasta River, with the Big Springs Complex contributing elevated levels of phosphorus to the system. This seasonal limitation is clearly seen as nitrate depletion in the Shasta River from Big Springs Creek to the Klamath River in Figure 36. This plot shows seasonal depletion longitudinally for March 2008 through March 2010, where from spring into fall, higher concentrations (shown in green and yellow) in the upper-most reach give way to lower concentrations (blue) in downstream reaches. The “ridge” running down the middle of the plot (green) illustrates winter recovery of nitrate levels when primary production was at a seasonal minimum. When comparing the pre-restoration (2008-09) and post-restoration period (2009-2010), careful examination of the data suggested that the period of severe nitrate depletion (when values fall below about 0.01 mg/l) was notably longer in the post-restoration period. The pre-restoration period extended from approximately mid-June to early October, while the post-restoration period extended some 5 weeks longer, from approximately 1 June to the end of October (denoted by white arrows in Figure 36). This may be the result of inter-annual variability, or it may be consistent with the findings noted above – that sequestering of nitrogen in Big Springs Creek associated with increased aquatic vegetation growth led to an extended period of nitrogen limitation in downstream reaches.

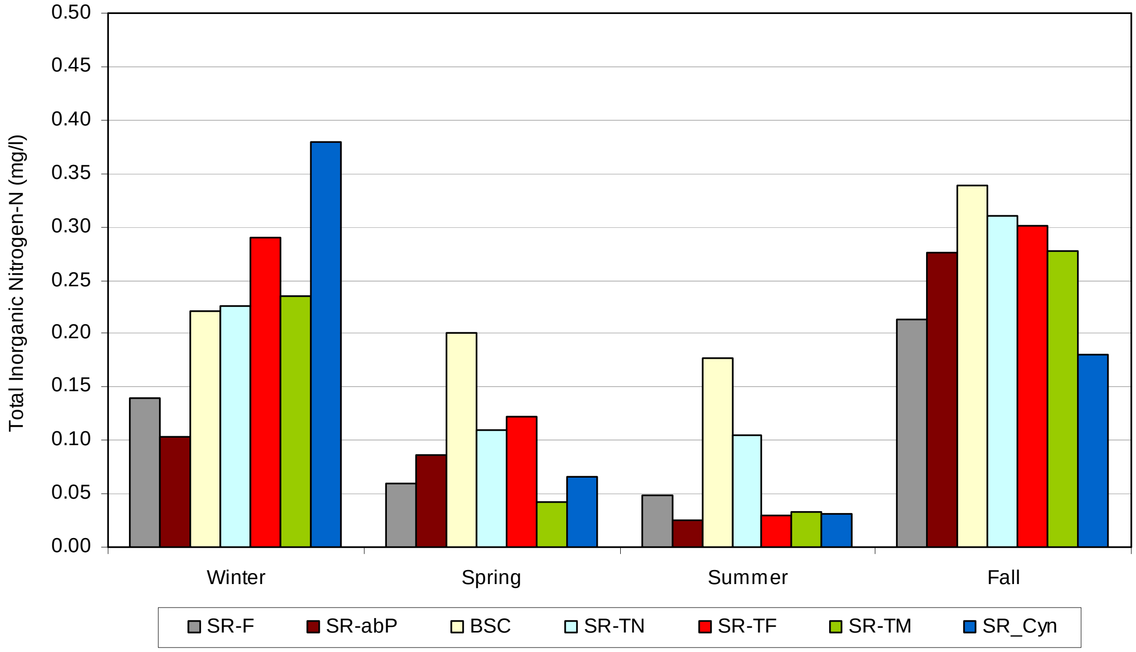

Figure 34. Total inorganic nitrogen concentration by location and season in the Shasta River and Big Springs Creek, 2008. Data are arranged within each season from upstream to downstream (left to right).

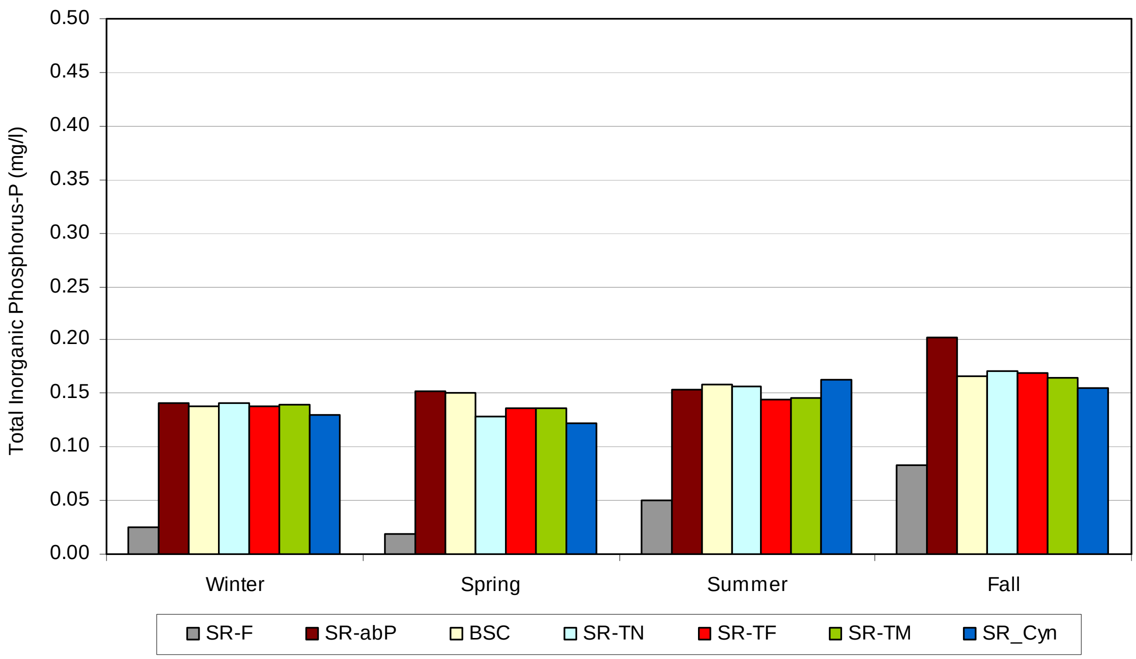

Figure 35. Total inorganic phosphorus concentration by location and season in the Shasta River and Big Springs Creek, 2008. Data are arranged within each season from upstream to downstream (left to right).

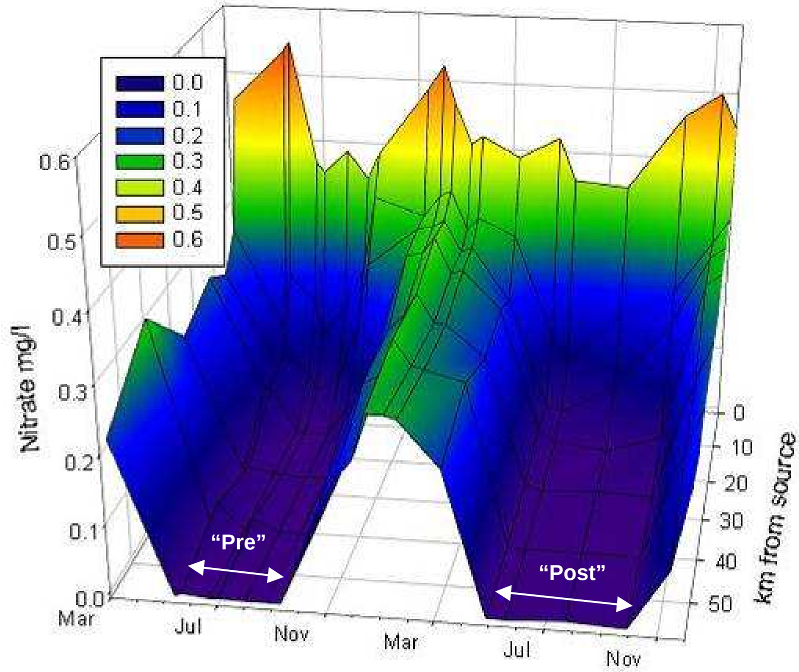

Figure 36. Seasonal and longitudinal fluctuation in Nitrate (NO_3^--N) from the spring source in Big Springs Creek (0 km) to the confluence with the Klamath River (58 km) from March 2008 through December 2009.

9.4 Response to Restoration

Analysis of Big Springs Creek data suggested that post restoration, the increase in aquatic vegetation associated with the removal of extensive in-stream grazing resulted in a decrease in inorganic nitrogen and total nitrogen. Data were limited to only two years, but the impact on nitrogen appeared to be a reduction following initial restoration actions. Phosphorus contributions from the springs were relatively high compared to nitrogen sources, leading to nitrogen limitation in the system. This condition changed slightly, with the post-restoration N_i:P_i ratio being lower (1.38) versus the pre-restoration N_i:P_i ratio (1.74). Due to the considerable nitrogen limitation, phosphorus concentrations also changed little from pre- to post-restoration conditions. DOC concentrations were low and pre- and post-restoration comparisons did not yield significant insight at this early stage of restoration. As aquatic vegetation communities evolve to include more colonial stream margin species (e.g., *Scirpus*, *Typha*) and woody vegetation species (e.g., *Salix, Betula*) take hold, some changes may become evident. Downstream implications of a restored Big Springs Creek have not been explored at this time.

9.5 Summary

As data from study sites in Big Springs Creek illustrate, water quality in Big Springs Creek was defined largely by the spring complexes and their geologically derived nutrients. Nitrogen and phosphorus in spring waters were at sufficient concentrations to support extensive aquatic vegetation growth. The system was nitrogen limited. Based on available field data, it appears that removal of in-stream grazing reduced nitrogen concentrations (i.e., post-restoration concentrations are lower than pre-restoration concentrations). Whether this is natural inter-annual variability or a more persistent result of restoration has yet to be determined. Additional field data from ongoing monitoring supported by NFWF during the summer of 2010 will add useful data to further assess post-restoration response.

Below Big Springs Creek, nitrogen and phosphorus were notably higher than the Shasta River upstream of Big Springs Creek. Field data identified that the springs that form a vital portion of the Shasta River baseflow were natural sources of this nutrients. These nutrients provided enhanced growth rates at ever higher trophic levels in the food web from primary producers up through salmonids. In sum, spring contributions

- formed a vital aspect of baseflow and associated habitats in Big Springs Creek and the Shasta River,
- provided relatively warm water in the winter and cool water thermal refugia in the summer; and
- provided nutrients that drive a highly productive food web that are critical to salmonid production.

As such, restoration prescriptions in the Shasta River should consider each of these factors, recognizing that actions that do not maintain spring baseflows may be considerably less effective than those that retain these essential, unique, and interrelated processes.

10.0 Fish Abundance and Salmonid Habitat Surveys

Fish surveys were conducted throughout Big Springs Creek as part of both pre-restoration and post-restoration assessment activities throughout the Shasta Big Springs and Busk Ranches. Pre-restoration baseline assessments of fish abundance were conducted between April 2008 and March 2009 (Jeffres et al. 2009), while post-restoration assessments were conducted between April 2009 through March 2009. Survey data collected prior to and following the initiation of restoration actions facilitated analysis of the fisheries response to cattle exclusion (Jeffres et al. (2009).

The April through March period of observation for both pre-restoration and post-restoration snorkel surveys allowed for the continuous observation of each freshwater life-stage of juvenile salmonids in the Big Springs Creek (coho and Chinook salmon and steelhead trout) for the year prior to and the year following restoration actions. Observed juvenile life stages extended from emergence through out-migration, which is the critical period of salmonid mortality in the Shasta River basin (Nichols et al. 2010). Furthermore, snorkel surveys allowed observations of the juvenile salmonid population response to previous adult spawning seasons during which cattle were either allowed to graze within the creek (2008) or were excluded from the creek and surrounding riparian areas (2009). When cattle were allowed in the creek in 2008-2009, they trampled redds, browsed on aquatic macrophytes, and mobilized fine sediment, therefore reducing the quality of the spawning gravels (Jeffres et al. 2009).

While snorkel surveys conducted throughout Big Springs Creek determined relative fish abundance and habitat usage for all species of fish observed, only data/observations pertaining to salmonids are discussed herein. Below, a brief discussion of Shasta River/Big Springs Creek salmonid life history strategies is provide to facilitate subsequent presentation of snorkel observation data and discussions pertaining to the juvenile salmonid population response to cattle exclusion.

10.1 Shasta River Salmonid Life History Strategies

A fish's life history strategy and physiological tolerances ultimately determine which species will be affected the most by anthropogenic alteration of the environment. Current alteration of the Shasta River has resulted in reduced stream flows and increased water temperatures during the spring and summer. Chinook salmon are able to much better tolerate these conditions than coho because they have higher thermal tolerances and leave the Shasta River for the ocean just as in the spring, just as conditions begin to degrade. Steelhead on the other hand have a high thermal tolerance relative to coho salmon and are able to make use of the abundant habitat and food resources that the Shasta River provides, even under severely altered conditions. Understanding how salmonids utilize the Shasta River watershed both temporally and spatially will help to prioritize restoration and recover salmonid populations.

Steelhead and/or rainbow trout (*Oncorhynchus mykiss*) are the most thermally tolerant year-round salmonid in the Shasta River. Steelhead and rainbow trout are the same species and are not obligated to go to the ocean to mature. Some fish remain in fresh water where they mature and can spawn with other mature fish that return from the ocean environment. Ocean going adults return to the Shasta River to spawn November through March. Resident rainbow trout also participate in spawning activities with the returning sea-run adults. The majority of the steelhead spawning takes place in March. Juvenile steelhead begin to emerge in April where they can either leave the Shasta River during their first year or any year thereafter to go to the ocean.

Chinook salmon (*Oncorhynchus tshawytscha*) primarily use the Shasta River from September through June each year. Adult Chinook return to spawn between September and November, with the peak of spawning taking place in October. Juveniles emerge from the gravels beginning in late January, with emergence continuing through March. Emergence timing depends upon both adult spawning timing and the proximity of spawning to groundwater spring sources. Thermally stable groundwater springs in the vicinity of Big Springs Creek allow nearby waterways to remain relatively warm during the winter, facilitating increased developmental rates, resulting in earlier emergence from the gravels. Juvenile Chinook remain in the Shasta River and its tributaries (e.g. Big Springs Creek) until April when emigration begins. Juveniles will emigrate through June with only a very small number remaining in the Shasta River to over-summer.

Coho salmon (*Oncorhynchus kitsuch*) have been in decline in the Shasta River and are the principal driver of restoration activities within the basin. Adult coho return to spawn during late fall and winter when streamflows are at the seasonal high and water temperatures have cooled from summer irrigation season low-flow periods. Shasta River coho spawn predominantly in two locations: 1) the Shasta River canyon, which extends approximately 13 km upstream from the confluence with the Klamath River; and 2) the Big Springs complex – portions of the Shasta River and several tributaries (including Big Springs Creek) in the immediate vicinity of large groundwater spring sources. During the late fall and winter coho spawning period, there is little difference in the apparent quality of the two aforementioned spawning locations, and thus spawning activities likely coincide with reproductive opportunity and not environmental cues.

Juvenile coho emerge from the gravels in March and April - again, depending on spawning timing and proximity to relatively warm water spring sources. However, during the spring and the onset of basin-wide water withdrawls for irrigated agriculture, rearing habitat and migration conditions for coho in the primary spawning (and thus emergence) locations differ considerably. As irrigation season begins, reductions in streamflow and seasonal thermal loading lead to increased water temperatures, particularly downstream of Big Springs Creek. Further, flashboard dams are installed throughout the Shasta River to support irrigation water diversion, and these features can form upstream migration barriers (Jeffres et al. 2008, Jeffres et al. 2009). Summer water temperatures in the Shasta River canyon spawning location often exceed 27°C, forcing outmigration or mortality. However, water temperatures in waterways throughout the Big Springs Complex spawning location remain relatively cool (10-18°C), leading to beneficial rearing conditions. This longitudinal and seasonal gradient in water temperature, along with migration barriers ultimately determines if and where juvenile coho will survive in the Shasta River.

10.2 Methods

Snorkel surveys were used as a non-invasive method to determine relative abundance and habitat usage and should not be used as a surrogate for population estimates. Because of the presence of coho (a federally threatened species), snorkel surveys were determined to be the method with the lowest level of impact when determining habitat usage by fishes. To conduct snorkel surveys, reaches were selected at each of the study sites (Figure 37). Within Big Springs Creek, snorkel surveys were conducted among the various habitat/cover types available. Each survey was completed moving upstream and fish were only counted within one meter of each side of the surveyor. Repeat snorkel surveys were conducted twice per month on Shasta Big Springs Ranch, and once per month on the easement property on the Busk Ranch throughout the study period. Reaches varied between 22 and 114 meters in length. During all surveys, the surveyor identified fish species and age class, and recorded the information on a wrist slate. After a reach survey was completed, instream cover, substrate type and exposed substrate were qualitatively estimated and recorded.

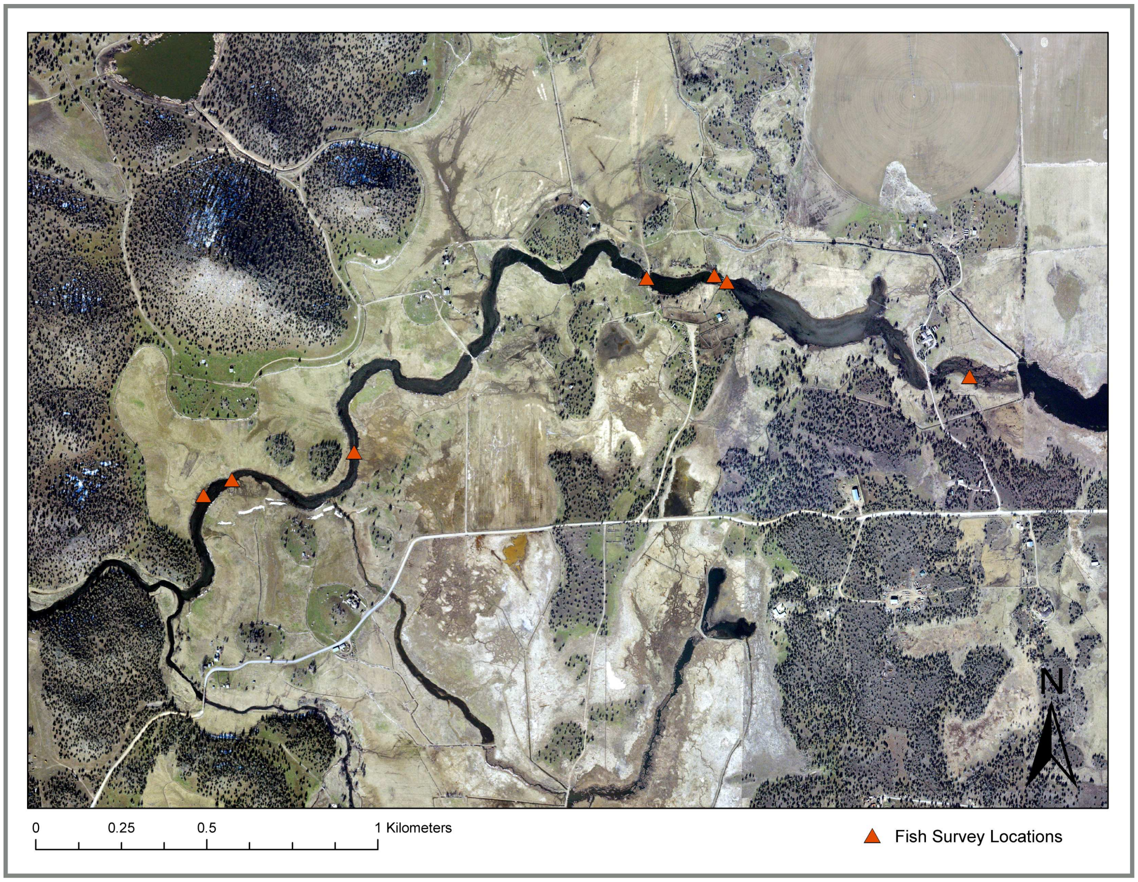

Figure 37: Snorkel survey locations through Big Springs Creek

10.3 Data Analysis

10.3.1 Coho Salmon

In 2008, few juvenile coho were found in Big Springs Creek prior to a warm water event in May. When water temperatures increased in late May, approximately 225 juvenile coho from Big Springs Creek and the Shasta River migrated to the pool at the outlet of Big Springs Lake, where they remained throughout the summer and fall. This was the only location where juvenile coho were observed in Big Springs Creek during the summer months. During this time, very little habitat was available throughout the rest of the creek due to the aforementioned habitat degradation by cattle having access to the stream channel.

Unfortunately, it was not possible to compare the habitat usage in Big Springs Creek by juvenile coho from the 2008-2009 and 2009-2010 sampling periods due to such small numbers. This was in large part due to the small number of adult returns (28) to the Shasta River during 2008-2009 sampling effort compared to 249 the previous year (CDFG unpublished data). In 2008-2009 greater than 200 juvenile coho were found in the outlet of Big Springs Lake throughout the summer (Jeffres et al. 2009). In 2009-2010 only three juvenile coho were observed throughout the entire sampling effort despite conditions much more conducive to successful over-summering.

10.3.2 *Chinook Salmon*

In October 2008, adult Chinook returned to Big Springs Creek and began spawning in the lower portion of the creek (RKM0 to RKM1.6). Cattle were allowed access to the river following the spawing season and were observed trampling redds while walking in the channel. Trampling of eggs and fry while they are in the gravels can be a significant source of mortality. Additionally, removal of aquatic and emergent vegetation increased the amount of fine sediment mobilized in the creek. Increased fine sediment reduced the quality of spawning gravels, while the removal of aquatic macrophytes reduces the amount of rearing habitat for those fish that did emerge from the gravels (Jeffres et al. 2009). In the 2009-2009 sampling effort, only three juvenile Chinook were observed in Big Springs Creek. The timing of cattle having access to the channel after adults selected spawning habitat ultimately resulted in adults selecting habitat that would not be suitable for juveniles, and thus the likely loss of production from Big Springs Creek.

During the following spawning season (2009), cattle were excluded from Big Springs Creek through Shasta Big Springs Ranch in March 2009. Consequently, juvenile Chinook were protected from egg deposition to emergence and rearing. Furthermore, the exclusion of the cattle allowed for redds to remain intact and mostly free from fine sediment. Seventy-eight (78) and 101 redds were counted in Big Springs Creek in 2008 and 2009 respectively (CDFG unpublished data). These redd counts are relatively similar, yet the apparent productivity between the two years is significantly different (Figure 38). In the 2008-2009 sampling period .0004 juvenile Chinook were observed per linear meter surveyed, while during the 2009-2010 sampling period .086 juvenile Chinook were observed per linear meter surveyed (Table 11). This increase in juvenile Chinook production can be attributed almost solely to the exclusion of the cattle from the creek channel. Not only were the redds not trampled or smothered with fine sediment, but once the juvenile Chinook emerged, abundant habitat was available due to the growth of aquatic macrophytes, which provided cover, velocity refuge and adequate depth. Juvenile Chinook that reared in Big Springs Creek appeared to grow at a rapid rate due to abundant food resources and the high quality habitat found in Big Springs Creek.

Table 11. 0+ steelhead, 1+ steelhead, and 0+ Chinook observed during snorkel surveys in Big Springs Creek.

	0+ Steelhead per linear meter surveyed	1+ Steelhead per linear meter surveyed	0+ Chinook per linear meter surveyed
April 2008-March 2009	0.131	0.067	0.000
April 2009-March 2010	0.301	0.172	0.086

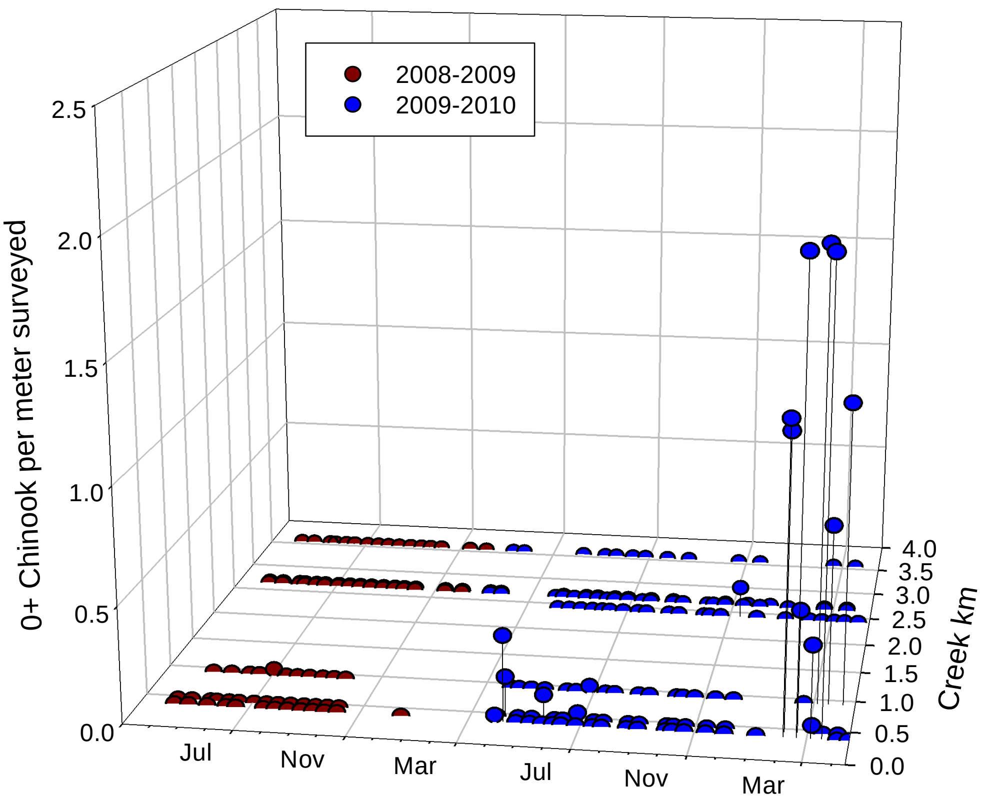

Figure 38. 0+ Chinook observed per linear meter during surveys on Big Springs Creek.

10.3.3 *Steelhead*

Steelhead are the most abundant year-round resident salmonid in Big Springs Creek. As presented in this report, 0+ steelhead are young of the year fish and 1+ steelhead are all fish greater than one year old. Fish size during a specific time of year is the primary factor when determining age class.

In 2008-2009, very little habitat was available for both 0+ and 1+ steelhead in Big Springs Creek. Because of the aforementioned removal of aquatic habitat, little cover and depth was available for 0+ steelhead when they emerged from the gravels. For the same reasons as the 0+ steelhead, 1+ steelhead were primarily found in a single location above the waterwheel, where adequate depth and cover were present.

In the 2009-2010 sampling season 0+ steelhead were greater than two times more abundant than during 2008-2009 (Table 11; Figure 39). Similar to Chinook, the exclusion of the cattle was likely the primary cause for the increase in the 0+ steelhead numbers. The removal of the cattle allowed for successful spawning and provided rearing habitat for small juvenile steelhead.

The 1+ steelhead in Big Springs Creek benefited in 2009-2010 from the increased growth of aquatic macrophytes which increased depth and provided cover (Figure 11). Observations of 1+ steelhead more than doubled between the pre and post restoration activities. Survey locations where 1+ steelhead were observed also increased in the 2009-2010 sampling effort. In February 2010, adult steelhead were observed building redds in the lowest 1.6 km of Big Springs Creek. Both large ocean-run fish and resident fish were in the redd while spawning activities were taking place. During the previous year, no large ocean-run steelhead were observed in Big Springs Creek. This may have been because of the poor condition of the spawning gravels from cattle still present in the creek.

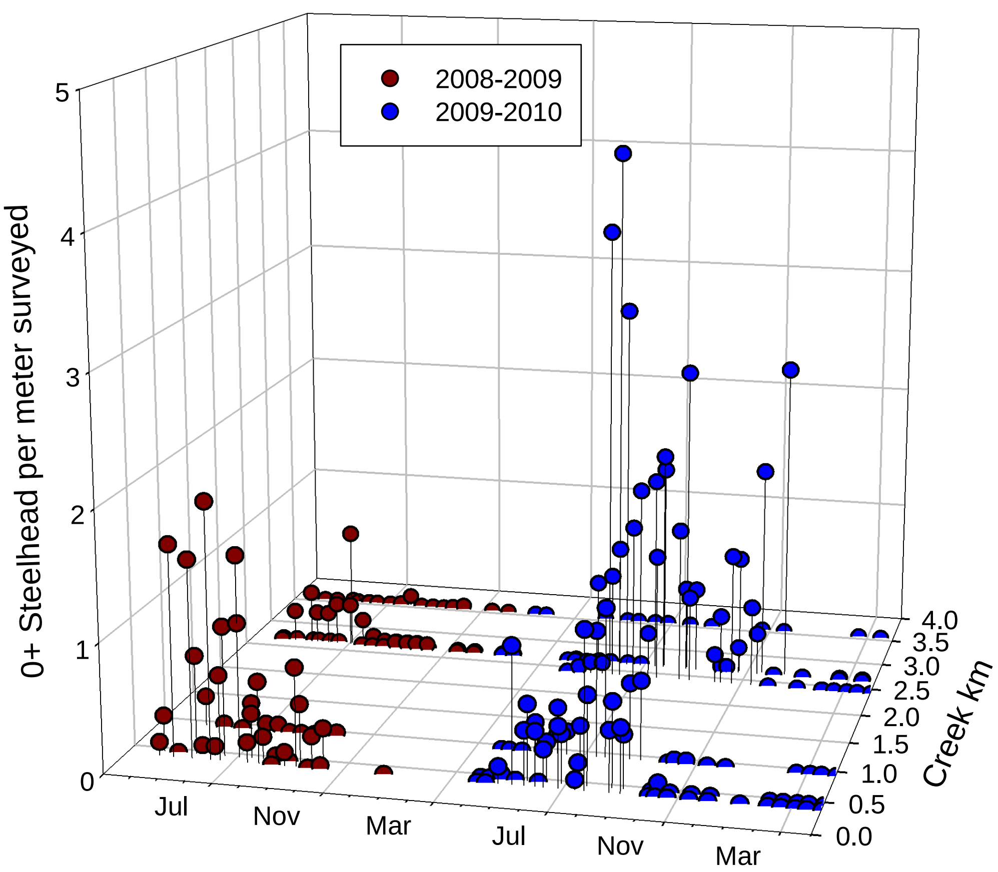

Figure 39. 0+ steelhead observed per linear meter during surveys on Big Springs Creek.

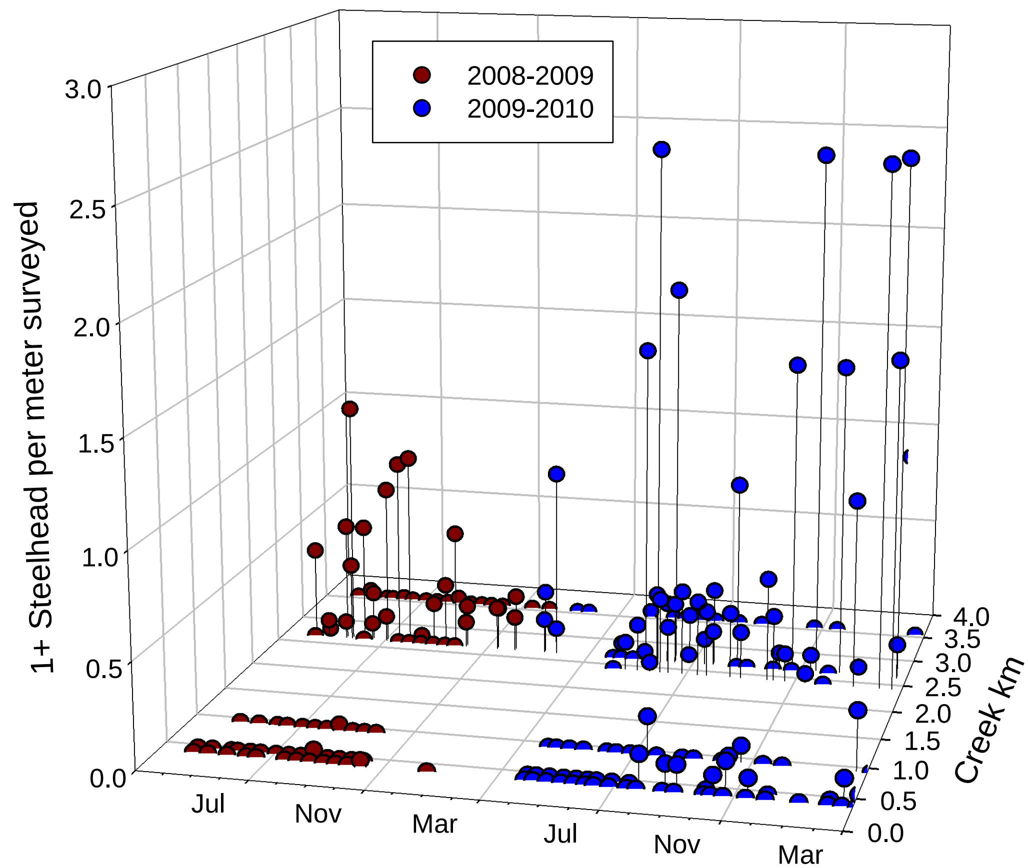

Figure 40. 1+ steelhead observed per linear meter during surveys on Big Springs Creek.

10.4 Summary

Juvenile Chinook salmon (0+) and steelhead (0+ and 1+) abundance throughout Big Springs Creek increased considerably following cattle exclusion. Increased juvenile Chinook and steelhead abundance was principally driven by: 1) increased egg to fry survival through the elimination of redd trampling by cattle; and 2) reduced out-migration or mortality due to increased rearing habitat quality and quantity following unhindered growth of aquatic macrophytes. Due to low numbers of returning adult coho in 2009, the juvenile coho population response to improved habitat conditions was unable to be assessed. After cattle were excluded, 215 times more juvenile Chinook salmon were observed rearing in Big Springs Creek than the previous year, despite similar numbers of adult salmon spawning. Young of the year and 1+ steelhead utilization of habitats in Big Springs Creek doubled after restoration actions were implemented. With continued cattle exclusion from Big Springs Creek and initiation of riparian planting efforts, salmonid populations are expected to increase in response to habitat improvements.

11.0 Conclusions and Conceptual Linkages

Initial restoration actions have largely focused on initiating riparian recovery through exclusion fencing along Big Springs Creek. This measure alone has led to remarkable, short-term change in abiotic stream conditions (hydraulics, geomorphic processes, water temperature and quality) and biotic community structure (aquatic macrophytes) – all to the benefit of salmonid habitat. Past land management practices in Big Springs Creek resulted in a disturbance regime associated with cattle grazing. Cattle grazing within the channel and along the creek margins removed both aquatic and herbaceous riparian vegetation and degraded banks and channel form. This disturbance regime was inconsistent with typical spring creek aquatic systems, which generally have stable flow regimes and channel forms, low rates of thermal loading, climax vegetation communities, and, in this case, diverse salmonid habitat. By removing the disturbance (elimination of cattle in the riparian and riverine zone), a natural succession of vegetation has begun, and will ideally lead to a climax community assemblage that will re-attain aquatic system attributes consistent with a spring creek.

The role of aquatic vegetation in this system is critical. Observed feedbacks between seasonal growth of aquatic vegetation and abiotic stream conditions indicate aquatic macrophytes act not only as geomorphic agents with impacts to hydraulic processes, but also modify the thermal regime (through hydraulic effects and shading), impact water quality (principally through nutrient retention), and directly benefit salmonid habitat by providing food resources and refuge. Under existing management conditions, a natural evolution of aquatic plant communities and hydrogeomorphic conditions will likely occur, a process sometimes referred to as "fluvial biogeomorphic succession" (Corenblit et al. 2007). It is anticipated that the initial phase of this succession regime will be dominated by the continued seasonal growth and senescence of aquatic macrophytes. In the absence of grazing disturbances, macrophyte root masses and more resilient stem materials will likely remain in place throughout the year, allowing the capture of mobile sediments and organic material sourced from upstream macrophyte senescence. This feedback between macrophyte growth/senescence and hydraulic conditions favorable to sediment deposition may ultimately create a peat/marsh habitat (dominated be emergent vegetation) along the channel margins and low-velocity channel areas adjacent the main flow paths. This hypothesized outcome is consistent with the original condition at Big Springs Creek documented during initial (1856) public land surveys, wherein Big Springs Creek was described as a wide marsh with a several meters wide freshwater creek flowing through it.

It is anticipated that physical conditions and biological community structure will continue to evolve throughout Big Springs Creek as restoration actions mature across annual to decadal time scales. Expected changes include: temporal succession in vegetation assemblages from principally submerged aquatics to a mixture of submerged and emergent aquatics within the channel and along the channel margins; a reduction in the functional cross-section area of the stream; reduced water residence times through increases in streamflow velocities; and decreased water temperatures. These hypothesized abiotic responses to changes in aquatic vegetation assemblages will be the principal drivers of continued improvements to salmonid habitat throughout Big Springs Creek.

12.0 Recommendations

Restoration actions throughout Big Springs Creek are on-going. The establishment of permanent exclusion fencing initiated rapid changes to hydrogeomorphic processes and the biologic community structure. With planned riparian and emergent vegetation plantings in 2010, continued monitoring and analysis of the trajectory of abiotic and biotic changes in response to cattle exclusion, planting efforts and water management throughout Big Springs Creek are critical components of the evaluation and future planning of restoration efforts.

Herein, recommendations for continued monitoring and assessment efforts are provided. Execution of these recommendations will provide a comprehensive set of physical, chemical and biological data from which to understand evolving adjustments between physical processes and biological communities as restoration actions progress throughout Big Springs Creek.

<u>Aquatic Vegetation</u>

The rapid response of aquatic vegetation growth to exclusion fencing was the primary driver of observed short-term changes to physical processes and biological community structure. Understanding the evolving relationship between aquatic vegetation growth cycles and physical, chemical and biological conditions in Big Springs Creek is necessary to adaptively manage restoration efforts. Aquatic vegetation monitoring recommendations include:

- Continued assessment of spatial and temporal trends in aquatic macrophyte community biomass and species composition;
- Mapping of aquatic vegetation cover to determine seasonal and interannual variability;
- Quantification of seasonal variability of shade characteristics of aquatic, seral, and woody vegetation;
- Given the abundant macrophyte growth and its effect on nutrient concentrations, a food web analysis should be repeated to determine whether any critical energy pathways to the salmonids’ food sources have been affected.

<u>Geomorphology</u>

Observed feedbacks between aquatic vegetation growth and fluvial geomorphic process and channel morphology conditions, as well as channel morphology influences on thermal loading indicate continued geomorphic monitoring in a necessary component of restoration assessment. Monitoring recommendations include:

- Annual monitoring of channel cross-section channel morphologies to assess deposition and erosion patterns associated with aquatic macrophyte growth and senescence;

- Assess changes in channel geometries in response to passive (exclusion fencing) and active (emergent and riparian planting) restoration actions.

Hydrology

Understanding temporal trends in hydrologic conditions remains a necessary component in managing restoration actions throughout Big Springs Creek. Quantifying streamflow magnitude, timing and variability in Big Springs Creek is critically important to understanding trends in water quality and temperature. Furthermore, streamflow monitoring allows continued assessment of the hydrologic responses to restoration actions comprised of on-going irrigation water management. Recommended actions include:

- Continued monitoring of streamflow in Big Springs Creek;
- Examination of temporal variability of groundwater spring contributions to streamflow in Big Springs Creek;
- Assessment of the connections between regional groundwater use and streamflow.

Hydraulics

Complex interactions between aquatic macrophyte growth and hydraulic conditions suggest on-going monitoring of reciprocal adjustments between plant growth and hydraulic (and dependent geomorphic) conditions is necessary to understand the fluvial geomorphic response to restoration actions. Furthermore, hydraulic conditions have substantial influences on rates of thermal loading, and must be understood to assess changing water temperature conditions/trends in throughout Big Springs Creek.

- Continue the local velocity transects and biomass sampling locations to evaluate seasonal and inter-annual trends in the hydraulic response to aquatic vegetation growth and potential community assemblage changes;
- Maintain river stage gauges along Big Springs Creek to continually quantify temporal changes in stream depth conditions (a proxy for habitat area) driven by growth cycles of aquatic macrophytes and corresponding changes to geomorphic conditions.

Water Temperature

Water temperature remains the limiting factor affecting available salmonid habitat in Big Springs Creek and the Shasta River below. As such water temperature is the most critical abiotic metric used to assess the response of Big Springs Creek to salmonid restoration efforts. Recommended actions include:

- Continue existing a water temperature monitoring network throughout Big Springs Creek;
- Assessment of water temperature impacts of water management activities (return flow/tailwater control) initiated as part of on-going restoration actions;
- Provide more detailed descriptions of thermal characteristics along principal heating reaches (i.e. 0.4 km upstream of the waterwheel) to inform restoration activities in high priority locations along Big Springs Creek.
- Develop the remote monitoring station network to phase out data logger array and provide real-time data regarding water temperature conditions in Big Springs Creek, the Shasta River, and related waterways on Shasta Big Springs Ranch.

Water Quality

Water quality at the spring sources is likely not to change, but downstream parameters are likely to change as a result of restoration actions. With increased aquatic macrophyte biomass there will be more potential for increased uptake, but at the same time if residence time is reduced, then there will be less water-plant interaction and more potential for increased nutrient export. Recommended actions include:

- Continued longitudinal sampling to determine spatial and temporal changes in water quality not only in Big Springs Creek, but downstream in the Shasta River.

Fish habitat and assemblage

Quantifying coho, Chinook and steelhead production and habitat utilization from Big Springs Creek and the upper watershed with a combination of snorkel surveys, mark and recapture, and general population estimates will allow for a quantification of restoration actions in upstream reaches. Recommended actions include:

- DFG screw trap be reinstalled on the Nelson Ranch and that sampling of the fyke net also remain in place;
- Redd counts and adult telemetry of both coho and Chinook should continue to be made on Big Springs Creek as well as in the Shasta River and Parks Creek to get an estimate of adult spawning above the canyon reach;
- Wild coho should be discouraged from spawning in the canyon section of the Shasta River;
- Identify locations with highest long-term potential habitat to support/inform active restoration activities.

These recommended monitoring and assessment actions will provide a foundation of information from which to understand complex spatial and temporal interactions between physical stream conditions and biotic community structure and behavior. Understanding such interactions is necessary to effectively and adaptively manage on-going restoration actions in an effort to meet to the principal objective of increasing the spatial extent of habitat suitable to salmonids throughout Big Springs Creek and the Shasta River below.

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14.0 Appendices

Technical Memorandum

Date: 12/29/2009

To: Amy Hoss, The Nature Conservancy
George Stroud, The Nature Conservancy
Ada Fowler, The Nature Conservancy
Chris Babcock, The Nature Conservancy
Amy Campbell, The Nature Conservancy

Copies: Carson Jeffres, University of California, Davis
Drew Nichols, University of California, Davis

From: Ann Willis, Watercourse Engineering, Inc.
Mike Deas, Watercourse Engineering, Inc.

Re: Springs temperature monitoring in Big Springs Creek

Abstract

Big Springs Creek is predominantly supplied by a complex of springs that are distributed throughout the upper 0.5 miles of the creek. This reach extends from Big Springs Lake to the channel constriction at the waterwheel. Within this complex, spring sources emerge at approximately 10^{o}C – 12^{o}C, an optimal temperature range for anadromous salmonids. Water temperature devices were deployed at the source of six springs. Results indicate that spring temperatures remain relatively static, warming slightly through the summer and cooling slightly in the winter with the exception of the north alcove spring, which illustrates the opposite trend. These stable sources should be protected to maintain quality thermal baseline conditions in Big Springs Creek.

Introduction

Big Springs Creek is supplied by spring sources that are distributed throughout the upper 0.5 miles of the creek from Big Springs Lake to the constriction at the waterwheel (Figure 1). As the primary flow source for the creek, these springs define initial temperature conditions of source waters. The premise of restoration activities on Big Springs Creek is that by restoring the riparian corridor, channel form, and general geomorphic structure, water temperatures will decrease in downstream reaches to optimal levels for anadromous salmonids (of principal interest is the juvenile rearing lifestage through the spring and summer periods). However, if temperatures of the springs are not stable, then restoration potential may be limited. To learn about the thermal patterns of the spring sources, HOBO Water Temp Pro v2 loggers were deployed at six spring sources. The results indicate that the springs generally emerge at a constant temperature, warming slightly in the summer and cooling slightly in the winter. Variations detected during the irrigation season had three primary causes: reduced spring flow volumes, reduced water surface levels, and return flows mixing with spring flow sources.

Spring temperature monitoring

Several spring sources were initially identified using FLIR data gathered during a 2003 thermal imaging flight over Big Springs Creek, Little Springs Creek, Parks Creek, and the Shasta River. A second FLIR study occurred in 2008 that took thermal images during a morning and an evening in July. This flight provided estimates of several spring temperatures at their sources. However, these data only provided a snapshot of the spring's thermal characteristics. They gave limited or no indication of diurnal or seasonal temperature trends. To develop a better understanding of these characteristics, HOBO Water Temp Pro v2 loggers were deployed in or near six spring sources. These locations were (Figure 1):

1. Below the Busk bridge on river left (RL) (directions are relative to the downstream view of the river),
2. In front of the Busk residence on river right (RR)
3. Above the alcove, RL
4. Above the alcove, RR
5. In the alcove, east spring
6. In the alcove, north spring.

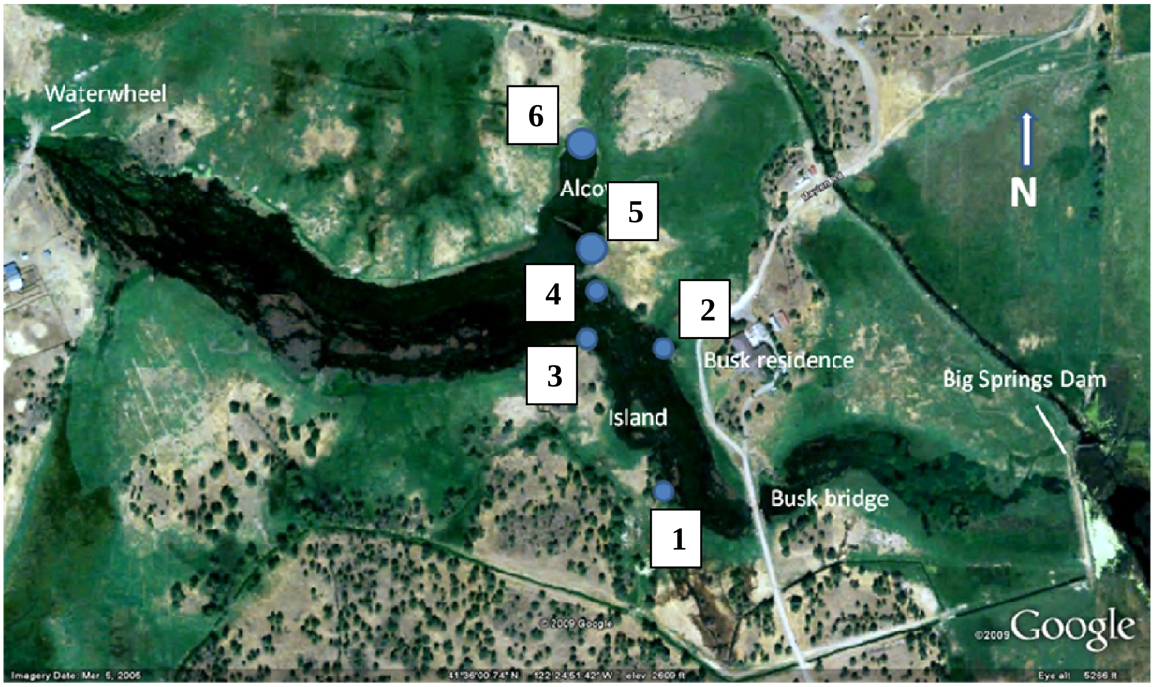

Figure 1. Locations of the spring monitoring sites in Big Springs Creek.

Four loggers were deployed, to the extent possible, directly into spring sources (locations 1, 2, 5, and 6). These springs produced the most constant temperatures (Figure 2, Figure 3, Figure 4, and Figure 5). Though some variations were observed, temperature changes ranged within the 0.2^{o}C accuracy range of the data logger. Larger variations, such as month-long period of warm temperatures in the east spring, generally coincided with periods when water levels in the creek dropped, partially exposing some of the loggers. Due to restricted access to this easement area, the placement of these loggers could only be adjusted once a month. Once the loggers were relocated into lower spring sources, the relatively static thermal signal was maintained. Generally, these springs indicated a seasonal response, with warmer waters in summer. An exception is the north alcove spring which showed slightly cooler temperatures as the summer progressed. Further, variability in the summer of 2009 at this location may be from return flow "contaminating" the temperature signal.

The loggers in locations 3 and 4 were deployed in an area where cool thermal signals were detected by the FLIR, but discrete springs were not found using field observations. These thermal signals recorded by loggers placed in the proximity of cool water sources detected by the FLIR illustrated pronounced diurnal variations and do not seem to indicate appreciable cool water sources (Figure 6) or diffuse cool water contributions (Figure 7).

Temperature monitoring in the north alcove spring has been ongoing for the past year and observations present an interesting signal – warmer in winter and cooler in summer (Figure 8). This signal appears to be the inverse of the smaller springs near the Busk residence (locations 1 and 2). A longer record will provide greater insight into these interesting thermal dynamics.

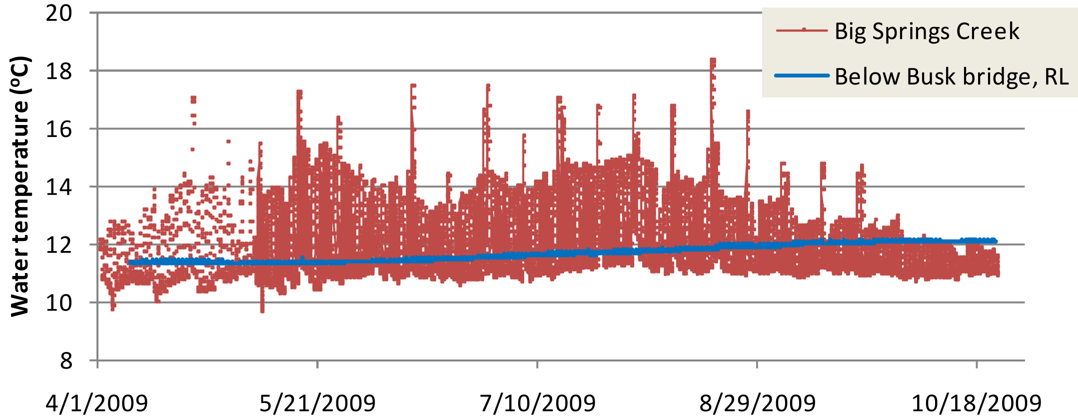

Figure 2. Water temperature data for the spring located on river left below the Busk bridge compared to mainstem water temperatures in Big Springs Creek.

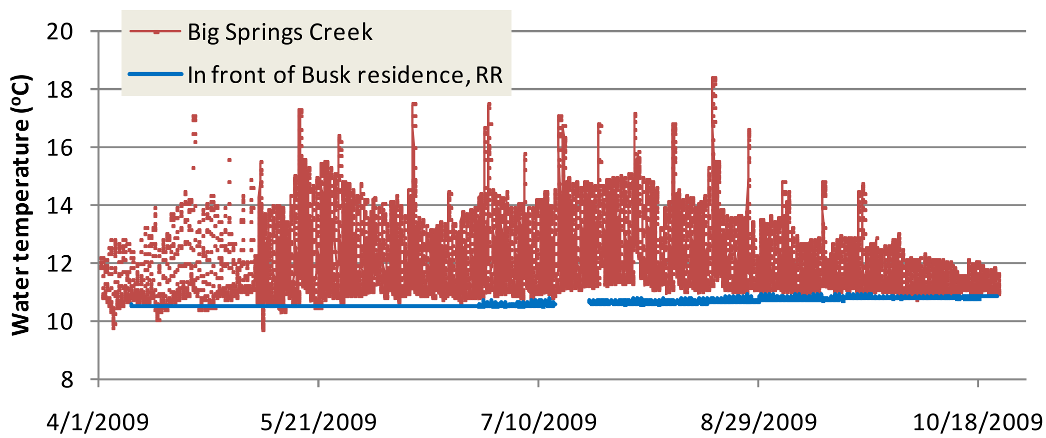

Figure 3. Water temperature data for the spring located in front of the Busk residence on river right, compared to mainstem water temperatures in Big Springs Creek.

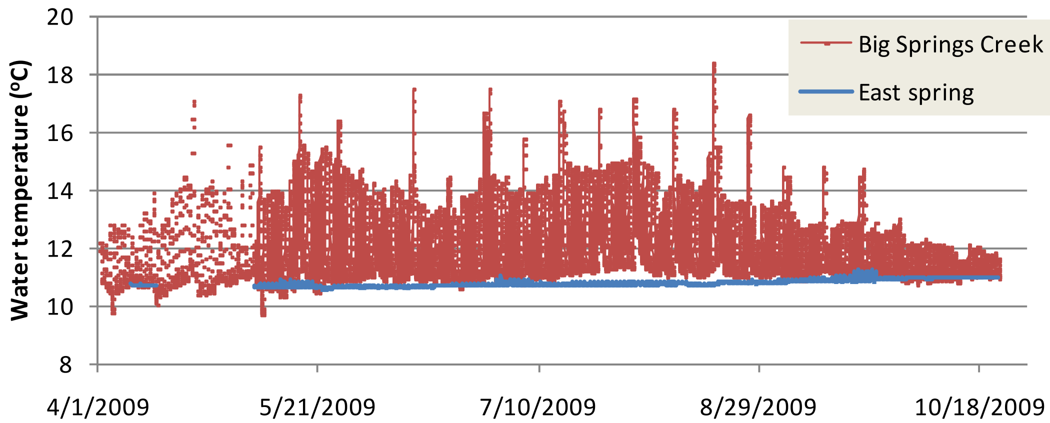

Figure 4. Water temperature data for the spring located on the east side of the alcove compared to mainstem water temperatures in Big Springs Creek.

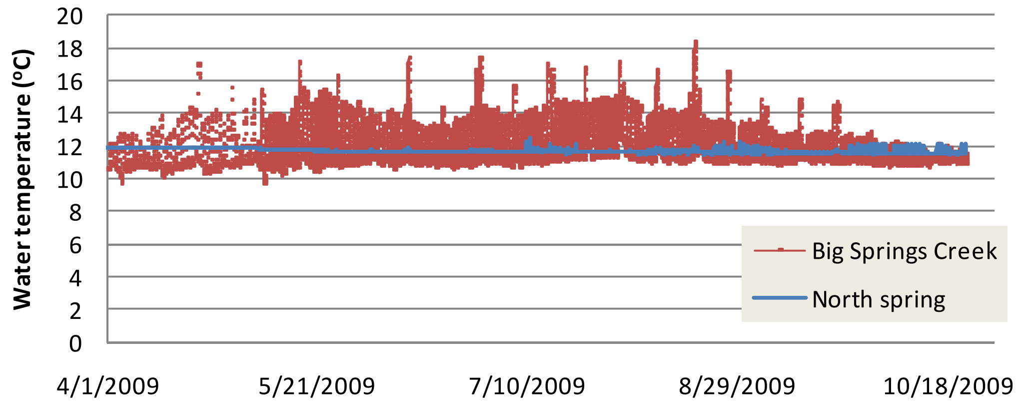

Figure 5. Water temperature data for the spring located on the north side of the alcove compared to mainstem water temperatures in Big Springs Creek.

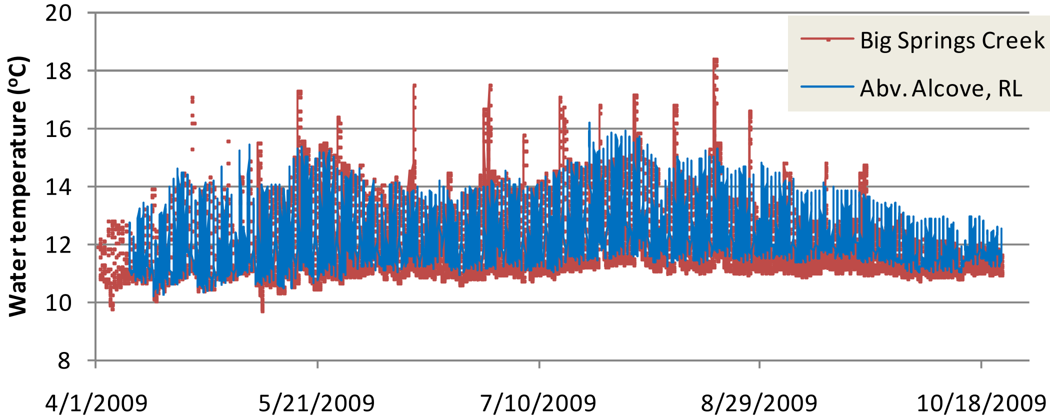

Figure 6. Water temperature data for the spring located on river left, below Big Springs Island compared to mainstem water temperatures in Big Springs Creek.

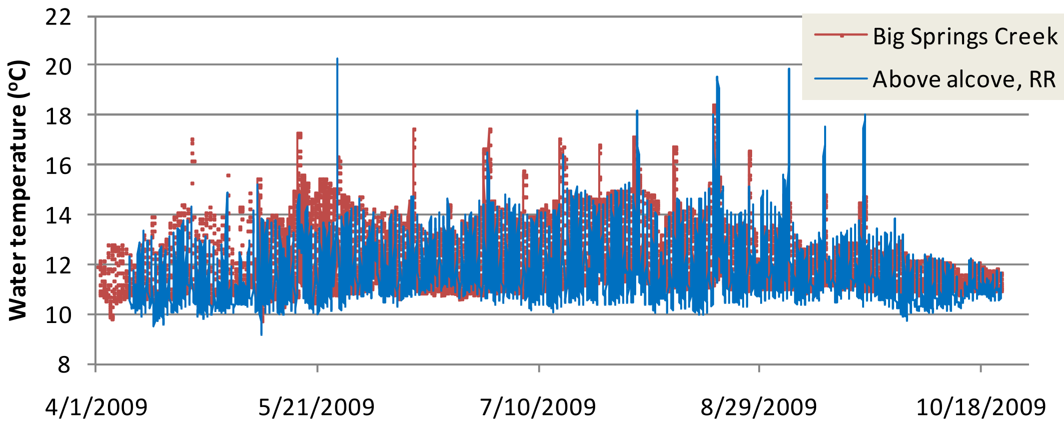

Figure 7. Water temperature data for the spring located on river right, upstream of the alcove compared to mainstem water temperatures in Big Springs Creek.

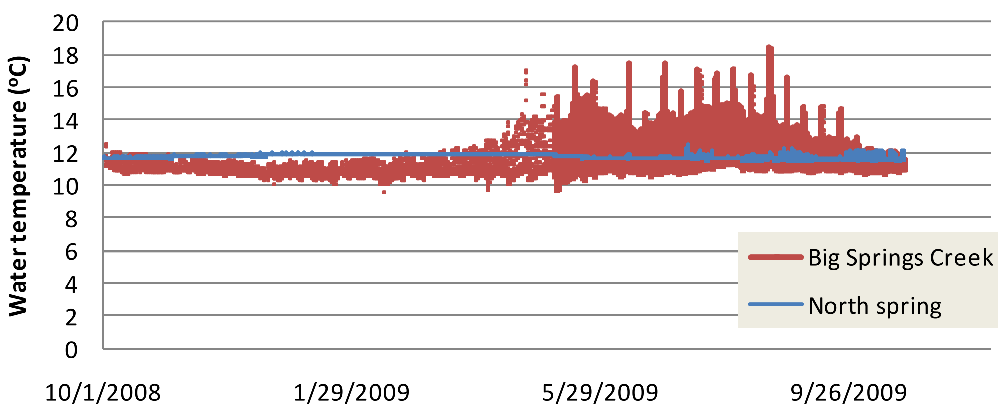

Figure 8. Water temperature data for the spring located on the north side of the alcove compared to mainstem water temperatures in Big Springs Creek.

Conclusion and Recommendations

The spring sources to Big Springs Creek provide a relatively constant source of cool water to the creek throughout the year. While some of the springs detected by the FLIR were identified, the diffuse nature of others made them difficult to locate. Falling water surface levels exposed some of the loggers during irrigation season; relocating the loggers to spring flow closer to the creek margins recovered the spring's thermal signal. The regular cool water supply provided by these springs makes Big Springs Creek a key area that could support anadromous salmonids populations at all life stages given proper water temperature management.

Ongoing monitoring of a select number of springs is recommended to further explore the variability of spring sources. An intriguing element of this work is that there is notable variability in springs that are in a relatively close spatial proximity.

Watercourse Engineering Inc.

Technical Memorandum

Date: 1/29/2010

To: Amy Hoss, The Nature Conservancy
George Stroud, The Nature Conservancy
Amy Campbell, The Nature Conservancy

Copies: Carson Jeffres, University of California, Davis
Drew Nichols, University of California, Davis

From: Ann Willis, Watercourse Engineering, Inc.
Ada Fowler, The Nature Conservancy
Chris Babcock, The Nature Conservancy
Mike Deas, Watercourse Engineering, Inc.

Re: Little Springs Creek temperature monitoring

Abstract

Little Springs Creek is a 1.25-mile long tributary to Big Springs Creek that is used to irrigate several grazing fields south of Big Springs Creek. While evaluating the irrigation strategy for Shasta Big Springs Ranch, The Nature Conservancy (TNC) has the opportunity to reorganize its irrigation infrastructure to reduce or eliminate the need for Little Springs Creek water during all or part of the irrigation season as part of its water efficiency strategy. The Nature Conservancy (TNC) coordinated with Watercourse Engineering, Inc. (Watercourse) and ranch managers to conduct a preliminary free flow experiment over several days during the summer to examine longitudinal heating patterns in Little Springs Creek. Heating rates show that water temperatures increase between 7^{o}C and 10^{o}C from the source to the mouth, with the greatest rate of heating between the second headgate and the mouth.

Introduction

Little Springs Creek is a 1.25 mile tributary to Big Springs Creek that flows through the southern grazing fields of Shasta Big Springs Ranch (SBSR). During irrigation season, water is diverted from Little Springs Creek into an irrigation system as part of the flood irrigation that is applied throughout much of Shasta Big Springs Ranch. The adjudicated diversion right from Little Springs Creek is 7 cfs and is applied to about 400 acres of irrigated pastures. At times, flow at the mouth of Little Springs Creek can fall to insignificant levels. Subsequent to purchasing SBSR, TNC has been exploring multiple options for restoring anadromous salmonid habitat, including reassessing irrigation practices to seek a balance between land use and aquatic system requirement. Part of modifying irrigation practices may include relieving irrigation demands on Little Springs

Creek while implementing a more efficient application of Hole in the Ground Creek water or other sources. However, Little Springs Creek is currently only valuable as anadromous salmonids habitat under certain, very limited, thermal conditions. Because limited water temperature data existed in Little Springs Creek, TNC coordinated with ranch managers and collaborated with Watercourse to monitor water temperatures during a free flow experiment. Watercourse deployed loggers at multiple locations to collect temperature data along the longitudinal profile of Little Springs Creek during a period when ranch managers opened all headgates to allow the creek water to flow unimpeded from Little Springs source to its mouth. Water was allowed to flow freely over a period of several days, once from June 27th through July1st, and again from August 23rd through August 30th. A plot of the water temperatures along the longitudinal profile indicate that rates of heating are largest in the reach between the most downstream headgate and the mouth.

Water temperature monitoring

Water temperature data were recorded using HOBO® Pro v2 Water Temperature Data Loggers from Onset Computer Corporation were used to collect information at 30 minute increments throughout the project area. These loggers have a resolution of approximately 0.03^{o}C (0.02^{o}C at 25^{o}C) and an accuracy of ±0.2^{o}C over the range from 0^{o}C to 40^{o}C, and a 90% response time of 5 minutes in water (http://www.onsetcomp.com). Eight temperature loggers were deployed along the longitudinal profile of Little Springs Creek as shown in Figure 1 and described in Table 1.

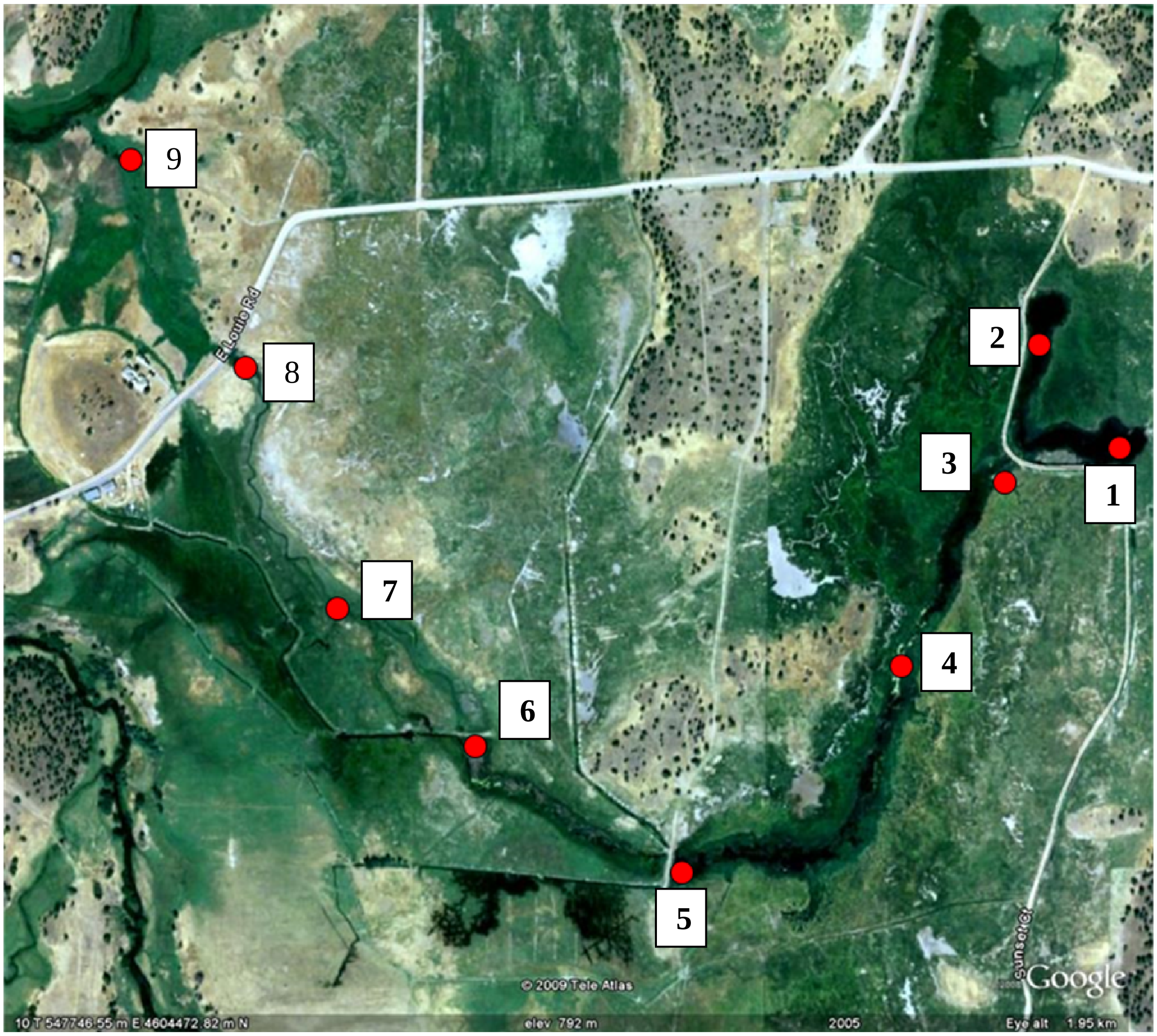

Figure 1. Map of the Little Springs monitoring locations.

Table 1. Location description for each monitoring site.

Location number	Location description	River mile
1	Little Springs Lake, east arm near property boundary	0.00
2	Little Springs Lake, north arm	0.05
3	Below lake culvert	0.10
4	½-way between culvert and 1st headgate	0.25
5	1st headgate	0.50
6	2nd headgate	0.70
7	½-way between 2nd headgate and Louie Rd.	0.85
8	Louie Rd.	1.00
9	mouth	1.25

Water temperatures were highest during the June free flow experiment, reaching peaks above 25^{o}C at the mouth (Figure 2). During this period, the two reaches that illustrated the highest heating rates were between the spring sources of Little Springs Creek and the culvert that functions as the outlet for Little Springs Lake as well as the reach between the second headgate and Louie Rd. In the 0.1-mile reach between the spring sources and the lake outlet, maximum daily water temperatures increased approximately 3^{o}C. Over the next 0.4 miles, maximum daily water temperatures gradually increased until the second headgate, at which point maximum daily temperatures increased between 3^{o}C and 8^{o}C over 0.3 miles (Figure 3). Daily minimum temperatures in Little Springs Creek indicated modest heating, but were typically less than 2^{o}C warmer than the lake outlet (i.e., typically less than 15^{o}C). This indicates that during non-heat loading period (e.g., night), cool waters dominate the creek from source to mouth. Therefore, restoration strategies that notably limit heat loading during the daytime periods could result in stream temperatures amenable to anadromous fish.

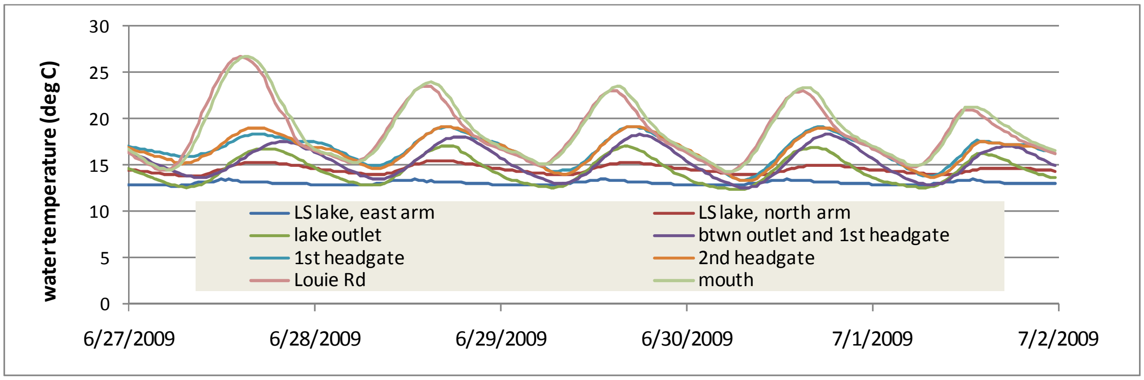

Figure 2. Water temperatures at each monitoring point in Little Springs Creek during the June free flow period.

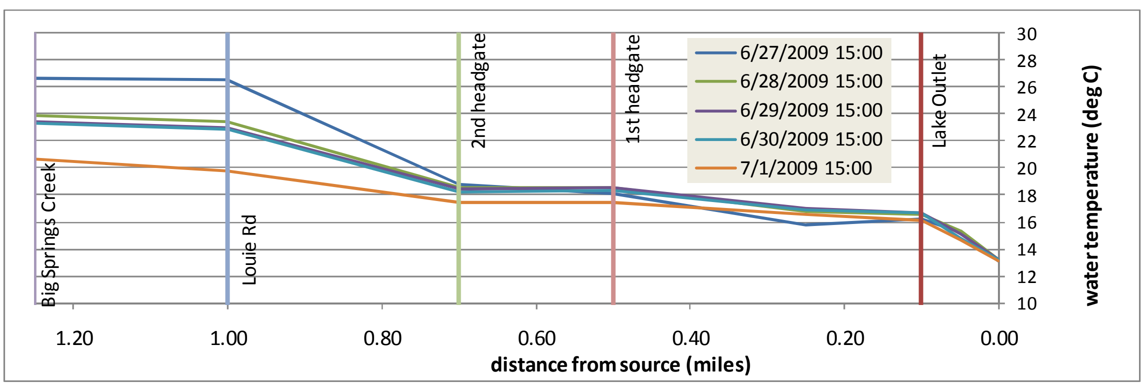

Figure 3. Maximum daily water temperatures along the longitudinal profile of Little Springs Creek during the June free flow experiment.

For each day during the June flow experiment, maximum daily temperatures at the mouth of Little Springs Creek exceeded simultaneous temperatures in Big Springs Creek (Figure 4). As a result, Little Springs Creek was a heat source to Big Springs Creek during this period.

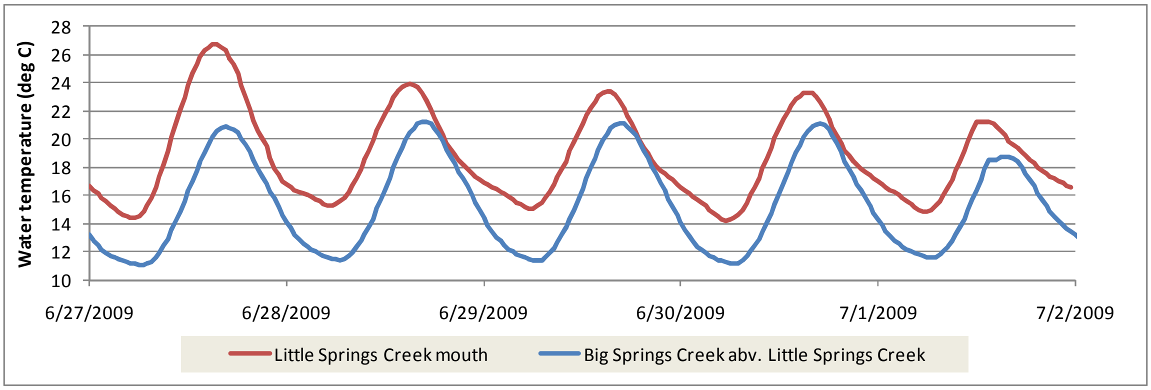

Figure 4. Water temperatures in Little Springs Creek compared to those in Big Springs Creek during the June flow experiment.

Similar trends were observed during the August free flow experiment, though peak temperatures did not reach the same maximums as in June. Maximum daily water temperatures at the mouth of Little Springs Creek were approximately 20^{o}C (Figure 5). The two reaches with the highest rate of heating were in Little Springs Lake between the spring source and the lake outlet as well as the reach between the second headgate and Louie Rd. In Little Springs Lake, maximum daily water temperatures increased approximately 2^{o}C in the 0.1-mile reach; between the second headgate and Louie Rd, maximum daily water temperatures increased between 2^{o}C and 4^{o}C in the 0.3 miles (Figure 6).

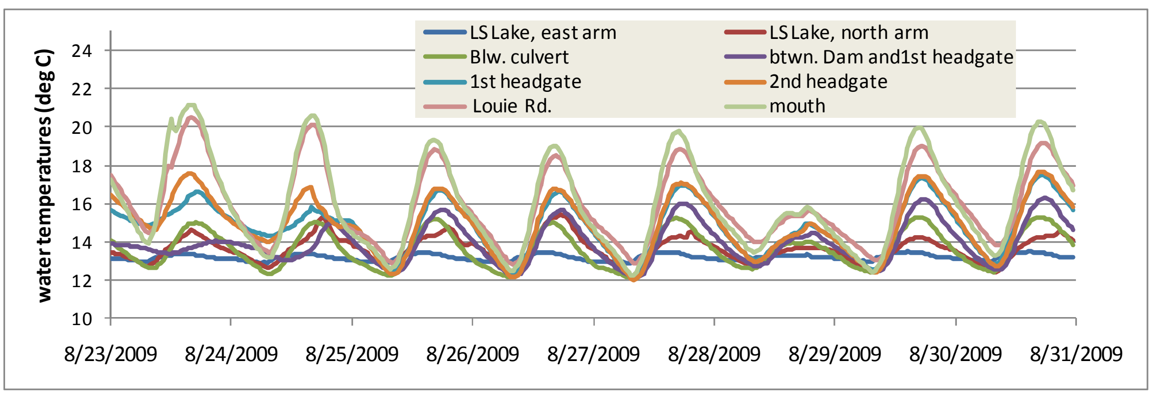

Figure 5. Water temperatures at each monitoring point in Little Springs Creek during the August free flow experiment.

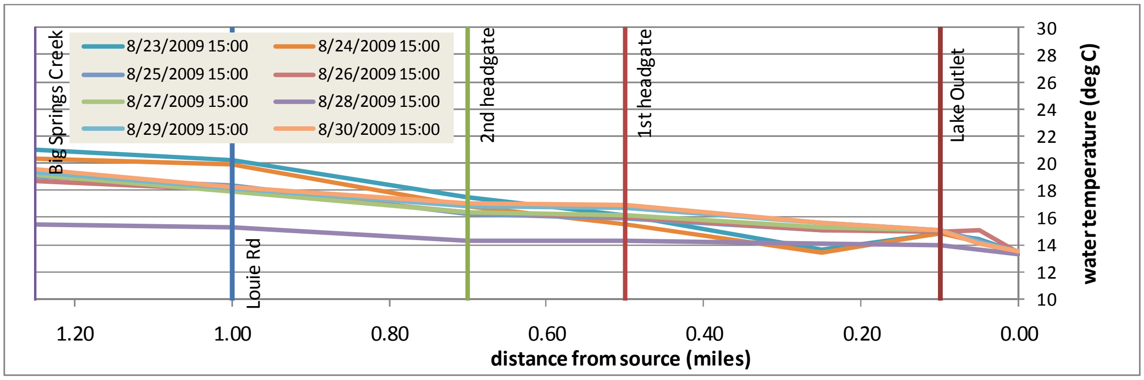

Figure 6. Peak water temperatures along the longitudinal profile of Little Springs Creek during the August free flow experiment.

Similarly to the June flow experiment, water temperatures in Little Springs Creek were generally warmer than those in Big Springs Creek, though there were some periods when the temperature difference was negligible. During periods when a temperature difference was observed, it was not as large as it was during the June experiment.

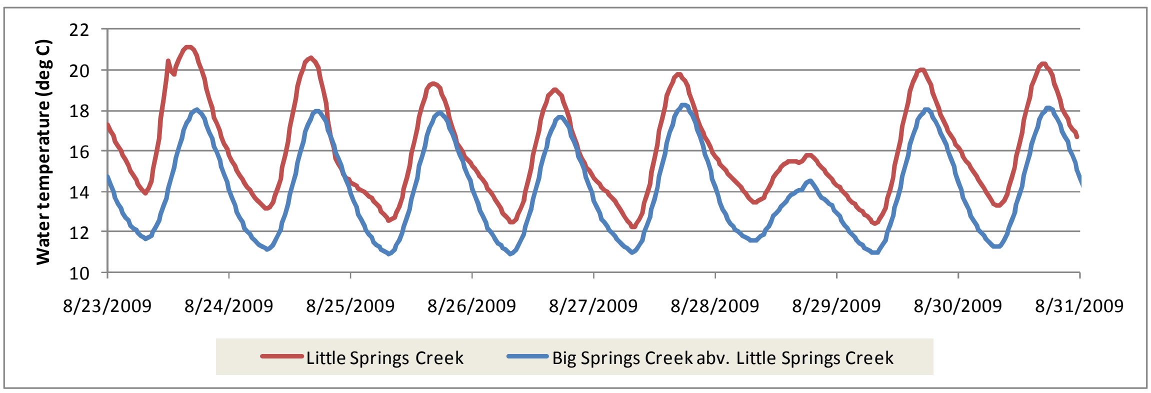

Figure 7. Water temperatures in Little Springs Creek compared to those in Big Springs Creek during the August flow experiment.

Conclusion

Though Little Springs Creek emerges from its spring source near 13^{o}C, maximum daily water temperatures during the summer can sometimes exceed 25^{o}C after water has traveled approximately 1.25 miles to the creek's mouth. The two reaches that illustrate the highest rates of heating are in Little Springs Lake between the spring source and the lake outlet as well as the creek channel between the second headgate and Louie Rd. Generally, by the time Little Springs Creek water reaches Big Springs Creek, its temperatures are higher than those in Big Springs Creek just upstream of the confluence.

Recommendations

Additional experiments should be performed to develop a more complete understanding of the creek's thermal characteristics for a wider array of meteorological conditions and flow quantities. Better communication between the science and ranch management staff as to periods of releases would facilitate maximum participation of science staff. Among the additional recommended studies included quantifying channel morphology (slope, current cross section form) and flowrates. Other investigations of the current soil and vegetation conditions, land use activities, irrigation demands, and alternative source waters would provide the necessary information to identify and test potential restoration strategies for Little Springs Creek. The existing creek form is the byproduct of over a century of grazing and presents an adverse thermal loading condition. Initial results suggest that cattle exclusion, strategic planting, barrier considerations (at Louie Road) and flow management may provide additional opportunities for further expanding over-summering habitat for anadromous fish on SBSR.

Technical Memorandum

Date: 1/29/2010

To: Amy Hoss, The Nature Conservancy
George Stroud, The Nature Conservancy
Ada Fowler, The Nature Conservancy
Chris Babcock, The Nature Conservancy
Amy Campbell, The Nature Conservancy

Copies: Carson Jeffres, University of California, Davis
Drew Nichols, University of California, Davis

From: Ann Willis, Watercourse Engineering, Inc.
Mike Deas, Watercourse Engineering, Inc.

Re: Remote sensor temperature monitoring at Shasta Big Springs Ranch

Abstract

Remote temperature sensors were introduced into the Shasta Big Springs Ranch temperature monitoring plan to aid with water and return flow management decisions. Part of the remote sensor array includes three monitoring locations in Big Springs Creek: at the outlet of Big Springs Dam, below the water wheel, and upstream of the lowest drivable bridge. These remote sensors allow for continuous temperature monitoring and enable on-site and off-site managers to make real-time decisions. Further, remote sensor stations provide water temperature with considerable less field staff time, leading to more efficient use of funds and restoration resources. Recommendations are provided that identify potential additional locations on Big Springs Creek and the Shasta River.

Introduction

One of the priorities during the first year of restoration on the Shasta Big Springs Ranch was to improve management of tailwater and return flows that enter Big Springs Creek. To support this effort, Watercourse Engineering (Watercourse) partnered with Eyasco Inc. (which specializes in data collection and management) to install remote sensors at five locations. Data from these sensors can be viewed online, allowing off-site managers to monitor on-the-ground conditions in real time and make ranch management decisions with on-site personnel. Remote sensors are employed to monitor water temperatures at three locations in Big Springs Creek and two locations in the North Ditch. One sensor was also programmed to monitor air temperature at Big Springs Dam. After an initial test period during which remote sensor data was compare to HOBO logger data, the remote sensors appear to work well. The success of this initial effort indicates that additional remote sensor installations would provide invaluable data and be an efficient use of resources, while establishing an infrastructure to support future long-term monitoring efforts.

Remote Sensor Performance

Five remote sensors were installed on the Shasta Big Springs Ranch and Busk Ranch easement to monitor water temperature. Three sensors were installed in Big Springs Creek at the following locations:

1. Big Springs Dam outlet,
2. Below the water wheel, and
3. Upstream of the tailwater return channel above the lowest drivable bridge.

Two sensors were installed on the North Ditch:

1. At the Busk-TNC property boundary before the return flow diversion below the waterwheel, and
2. At the outlet of the tailwater collection pond.

A sixth sensor was installed at Big Springs Dam outlet to monitor air temperature.

Data collected by the remote sensors were validated using HOBO Watertemp v2 loggers and spot measurements. These loggers have a resolution of approximately 0.03^{o}C (0.02^{o}C at 25^{o}C) and an accuracy of ±0.2^{o}C over the range from 0^{o}C to 40^{o}C, and a 90% response time of 5 minutes in water (http://www.onsetcomp.com). Spot measurements confirmed that the remote sensors were gathering accurate water temperature data. Comparison with a HOBO logger shows that the sensor and the HOBO logger followed similar temperature trends, but did not record the same maximums and minimums. Due to access restrictions, the site could not be examined until 20 August 2009, one month after the sensors were initialized. Upon inspection, the HOBO logger had been buried under a mat of vegetation. The vegetation was cleared and the logger was redeployed. Subsequent results show that the logger and remote sensor recorded temperatures within 0.5^{o}C of each other (Figure 1).

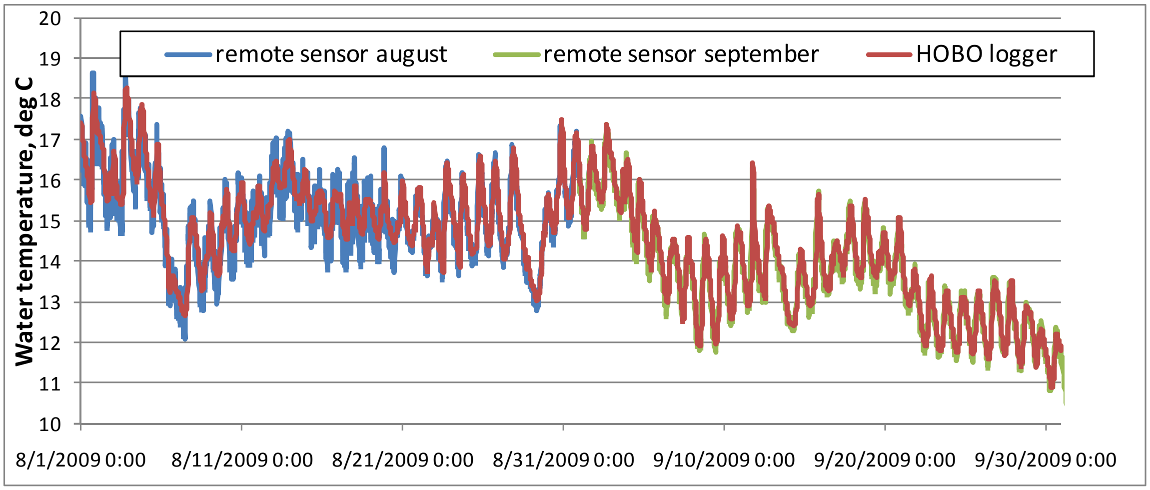

Figure 1. Comparison of remote sensor water temperature data to HOBO logger water temperature data.

Remote sensor application

Initially, remote sensors were deployed to allow irrigation managers to determine optimal times to release tailwater or return flows back into Big Springs Creek. A user interface is available on the internet that indicates the location of each sensor, wherein the location symbols provide a link to each data set (Figure 2).

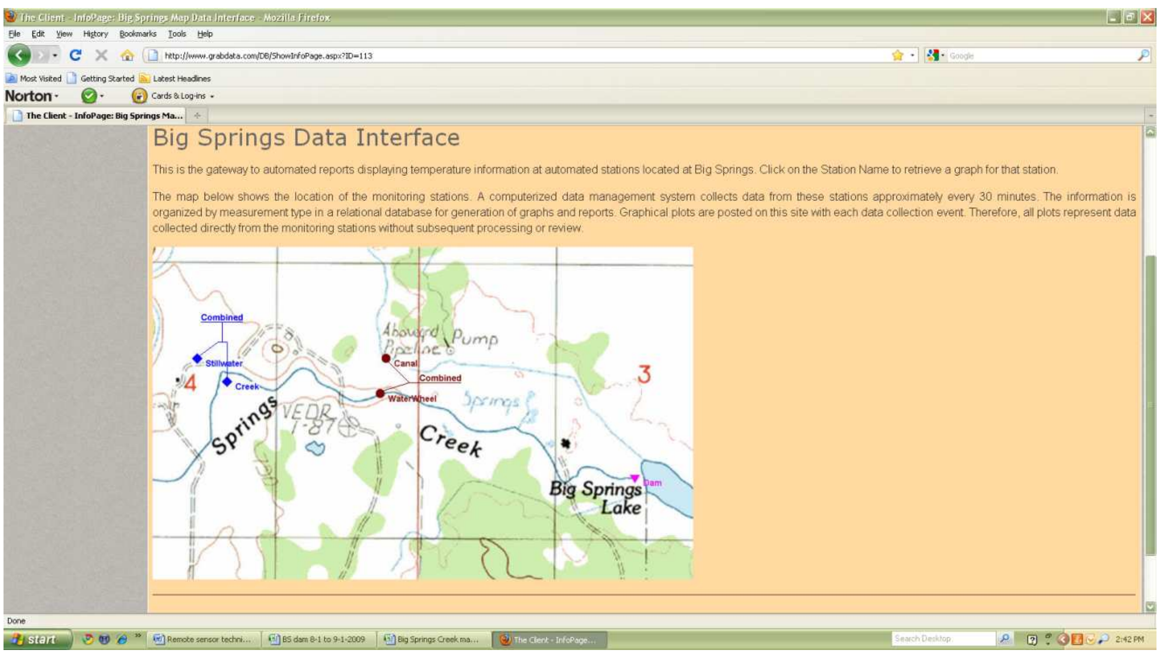

Figure 2. The online user interface for the remote sensor array.

Monitoring at the “paired” sites, listed as “Combined” in Figure 2, includes

- “Canal” and “Waterwheel” representing the main canal north of Big Springs Creek and Big Springs Creek below the waterwheel, respectively.

- “Stillwater” and “Creek” representing the return flow sources

These paired sites have been specifically designed to assist resource managers on water use decisions regarding water temperature of discharges from the main canal back to Big Springs Creek (near the waterwheel) and from the tailwater pond (Stillwater) to Big Springs Creek. For example, both the main canal data and waterwheel data are displayed when the user clicks on the “combined” link that connects them (Figure 3). Ranch managers can easily confer with off-site managers to determine whether flows should be released back into the creek or whether to wait until water temperatures in the canal and creek are more amenable at another time, e.g., to prevent increasing creek temperatures. Previous data are displayed so the user can track the history of temperatures as well.

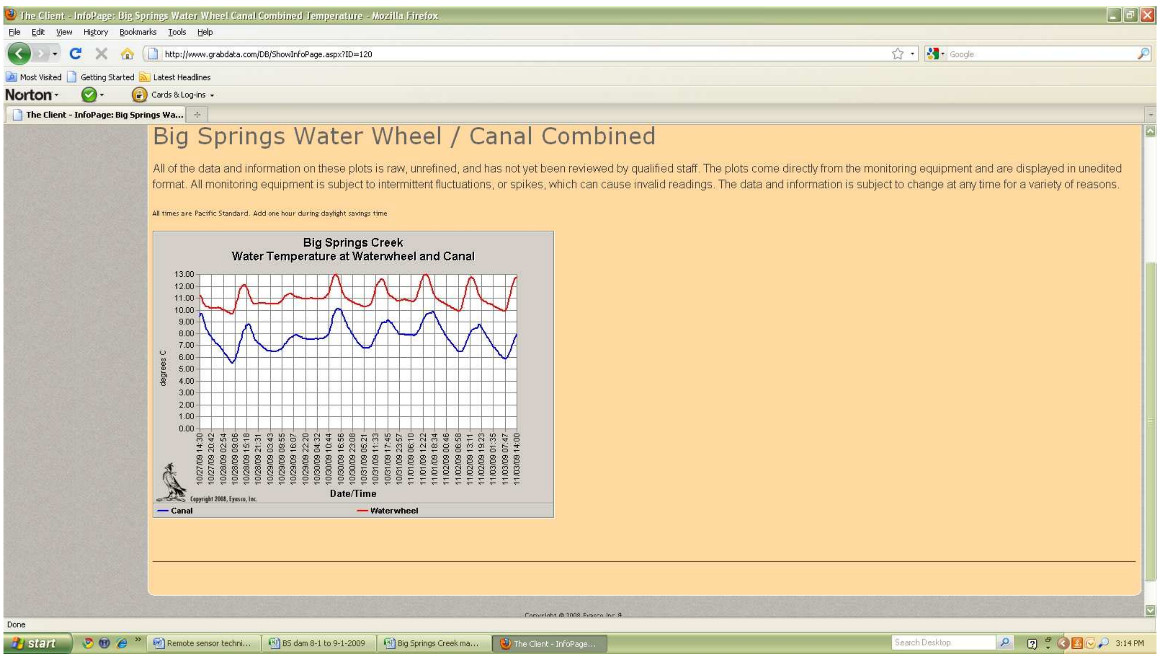

Figure 3. The interface that displays linked data for the creek and the canal.

Conclusion and Recommendation

The remote sensor array allows on-site and off-site managers to make decisions in real-time with on-the ground ranch managers regarding temperature management of discharges and tailwater releases to Big Springs Creek. This tool also supports temperature monitoring while conserving restoration funds and resources that can be redistributed to support other restoration activities by reducing travel and associated.

Given the success of the preliminary remote sensor installation, Watercourse recommends extending the array to include additional locations. Recommended locations include three downstream locations in Big Springs Creek, three locations in the Shasta River, and one location on Parks Creek. Further, a complete meteorological station could be added to the network to track local conditions at SBSR, which may aid ranch managers in water requirements for pasture irrigation.

Technical Memorandum

Date: 03/31/2010

To: Amy Hoss, The Nature Conservancy
Chris Babcock, The Nature Conservancy
Amy Campbell, The Nature Conservancy
Ada Fowler, The Nature Conservancy
George Stroud, The Nature Conservancy

Copies: Carson Jeffres, U.C. Davis
Andrew Nichols, U.C. Davis

From: Ann Willis, Watercourse Engineering, Inc.
Mike Deas, Watercourse Engineering, Inc.

Re: Hole in the Ground water temperature monitoring

Abstract

Hole in the Ground Creek water temperatures at the Shasta Big Spring Ranch (SBSR) boundary are higher during the summer months than water temperatures in both the Shasta River at the SBSR boundary and the diffuse springs system. Because these unfavorable temperatures occur during critical periods of the year, efforts could be considered to manage these waters to minimize undesirable thermal conditions. A more comprehensive data set that identifies specified periods when Hole in the Ground Creek water is used to irrigate should be acquired to ensure effective prescriptive measures are developed.

Introduction

Hole in the Ground Creek begins at its spring source on Hole in the Ground Ranch and flows approximately 2.5 km (1.5 mi) to the boundary of TNC's Shasta Big Springs Ranch (SBSR) (Figure 1). Historically, after Hole in the Ground Creek crossed the south property boundary, it flowed north-west for 0.8 km (0.5 mi) until it reached the Shasta River. Beginning in 2009, from April 1 to October 1 (irrigation season), the majority of this flow was diverted into an irrigation pipe that runs approximately 0.5 km (0.3 mi) along the SBSR southern property boundary to the Shasta River. A portion of this water is used to irrigate the southern areas of pastures LS6 and LS7. The remaining water was historically passed over the Shasta River and Parks Creek via a flume to irrigate a portion of land on the west side of Parks Creek and the Shasta River (known as the "island"). This flume is currently non-functional and the pipeline leading to the siphon is in disrepair. Presently, water from Hole in the Ground Creek that is diverted into the pipe leaks out at numerous locations before flowing out of a break and into the Shasta River through a down-cut channel approximately 0.02 km (0.01 mi) from the southern property boundary. Hole in the Ground Creek water also reaches the Shasta River during irrigation season in the form of tailwater from pastures LS6 and LS7. This tailwater flows into a well-defined channel that also contains considerable diffuse spring inflow. Subsequently, the combined tailwater and spring inflows are conveyed to the Shasta River approximately 0.4 km (0.25 mi) downstream of the property boundary. Outside of irrigation season, Hole in the Ground Creek flows north and then west from the property boundary, and eventually commingles with the diffuse spring system before flowing into the Shasta River.

One aspect of the recent recently funded NOAA Fisheries stimulus project is to improve irrigation efficiencies. To that end, a water temperature monitoring program was implemented to quantify the thermal conditions of Hole in the Ground Creek and inform potential prescriptions for improving management of these waters. To quantify thermal conditions in this area, temperature measurements were collected at:

(a) the point where Hole in the Ground Creek enters the SBSR property,

(b) the down-cut channel where flow from the broken pipe enters the Shasta River,

(c) the mouth of the diffuse spring system, and

(d) the Shasta River upstream of all these inflows (at the SBSR property boundary).

These locations are illustrated in Figure 1. Data from these locations lend insight to the potential thermal habitat conditions in Hole in the Ground Creek and inform management decisions on potential irrigation practices. Monitoring occurred from April 2009 until February 2010, and preliminary data analyses indicate that Hole in the Ground Creek at the SBSR property boundary is consistently warmer than the Shasta River at the SBSR property boundary until the irrigation season ends on October 1.

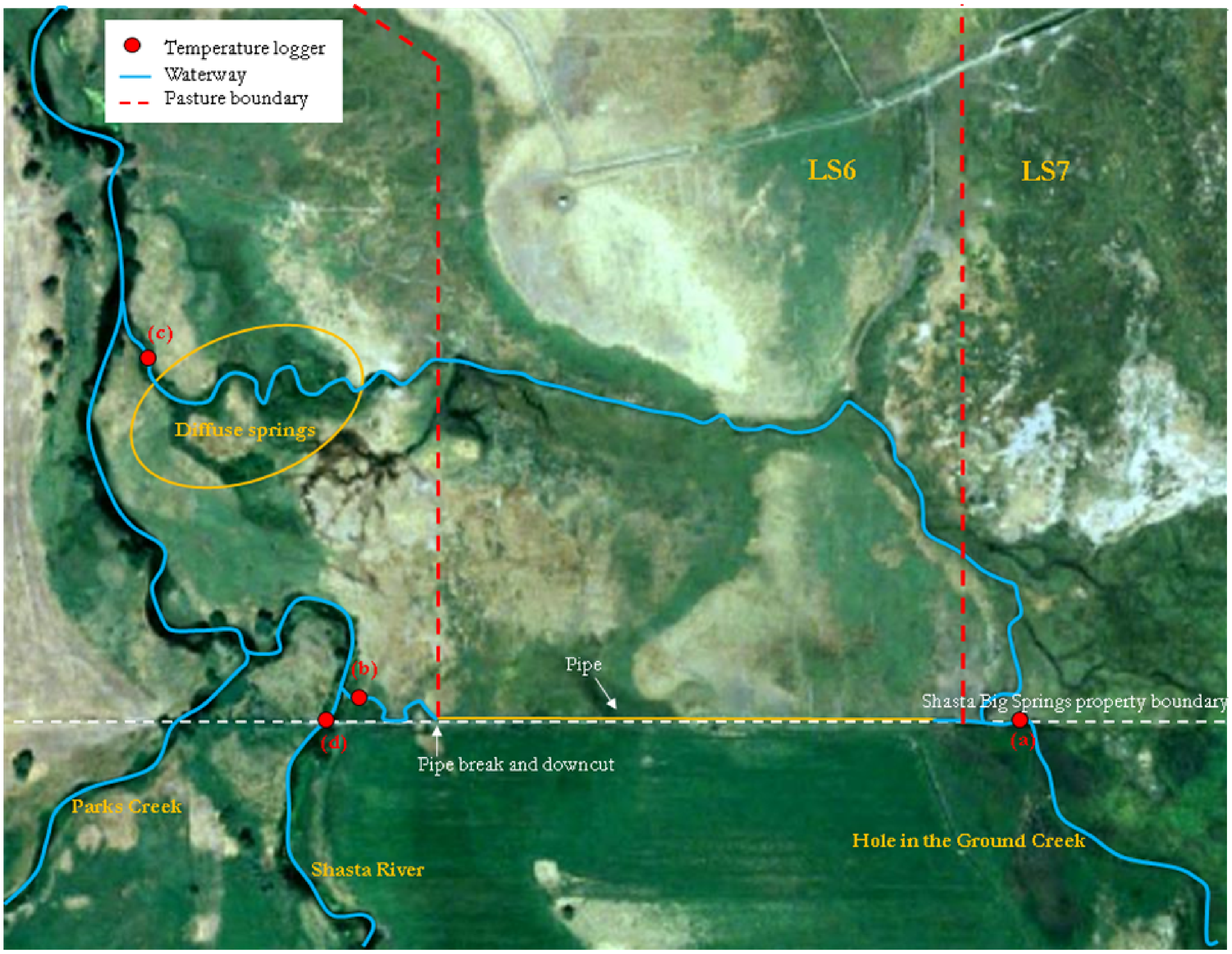

Figure 1. A map of the southern areas of LS6 and LS7, the two fields currently irrigated using Hole in the Ground Creek. Each monitoring point is labeled according to the locations described above.

Water temperature

Temperature loggers were placed at several locations in and around Hole in the Ground Creek (Figure 1). Water temperature field monitoring occurred primarily through the direct deployment of data loggers (spot measurements were also taken periodically throughout the monitoring period). HOBO® Pro v2 Water Temperature Data Loggers from Onset Computer Corporation were used to collect data at 30-minute increments throughout the project area. These loggers have a resolution of approximately 0.02^{o}C (at 25^{o}C), an accuracy of ±0.2^{o}C over the range from 0^{o}C to 40^{o}C, and a 90 percent response time of 5 minutes in water (Onset 2009). Instruments were deployed consistent with protocols developed on the Nelson Ranch (Jeffres et al. 2008). Data was collected at all Hole in the Ground Creek sites from 15 April 2009 to 18 February 2010; after October 1 (the end of irrigation season), water was no longer diverted into the pipe, but rather released into its natural channel where it eventually commingles with the diffuse spring system. Therefore no data was collected in the downcut after October 1. In the Shasta River, data was collected from 6 May 2009 to 18 February 2010.

14.1 Hole in the Ground Creek and the Shasta River

Hole in the Ground Creek undergoes little temperature change from the point where it enters the Shasta Big Springs Ranch to the pipe break where it flows into the Shasta River (Figure 2). The period when differences are notable (i.e. July through September) coincide with when Hole in the Ground Creek water was used to irrigate pastures LS6 and LS7, and was not diverted down the pipe to the Shasta River. Thus, water temperature data from the pipe outlet during that period does not represent Hole in the Ground Creek water, but rather the temperature of tailwater, small seeps, and other subsurface flow in the down-cut channel. As the temperature change through the pipe is negligible, comparing water temperatures from Hole in the Ground Creek at the south property boundary to the Shasta River provides a representative comparison of the two systems.

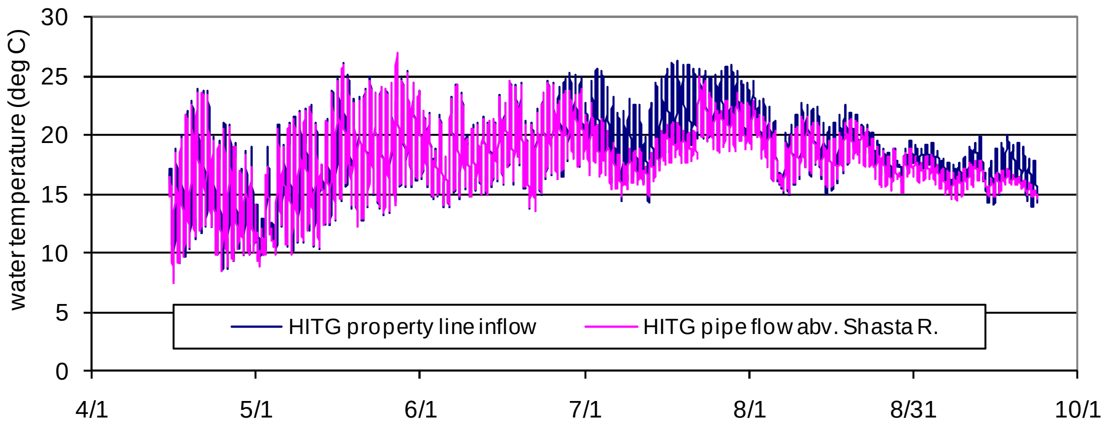

Figure 2. Hole in the Ground (HITG) water temperatures at the point of entry to Shasta Big Springs Ranch and pipe outflow.

Maximum temperatures in Hole in the Ground Creek at the property boundary exceed 25^{o}C several times from mid-May through July, while maximum water temperatures in the Shasta River were approximately 2^{o}C to 5^{o}C cooler (Figure 3). When maximum daily temperatures in Hole in the Ground Creek are compared to maximum daily temperatures in the Shasta River, those in the creek are generally warmer than those in the Shasta River. At times, particularly during summer months, minimum temperatures in Hole in the Ground Creek at the property boundary also exceed those in the Shasta River. Therefore, water diverted through the pipe that ultimately reaches the Shasta River can contribute to increased temperatures. From August through September, seasonal temperatures decline in both the Shasta River and Hole in the Ground Creek; the water temperature difference between the two streams diminishes steadily until October 1(Figure 4).

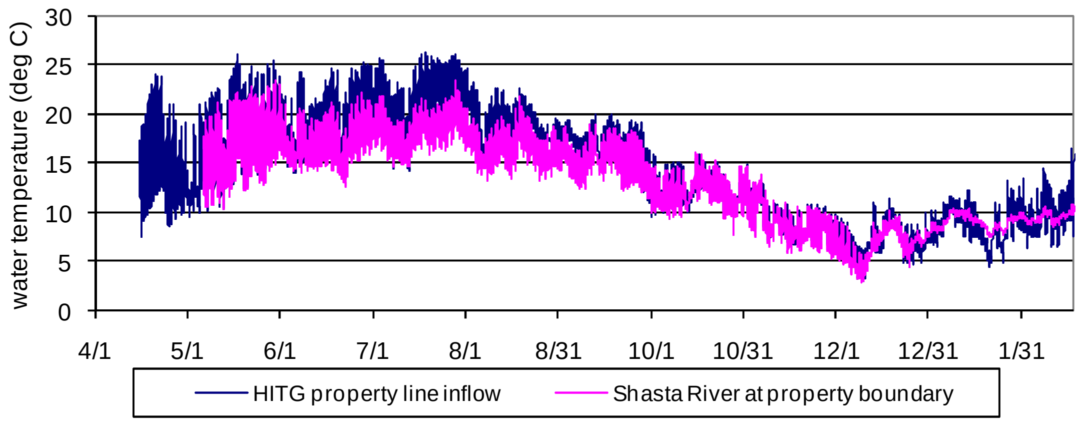

Figure 3. HITG water temperatures at pipe outflow and the Shasta River water temperatures above its confluence with the HITG pipe flow.

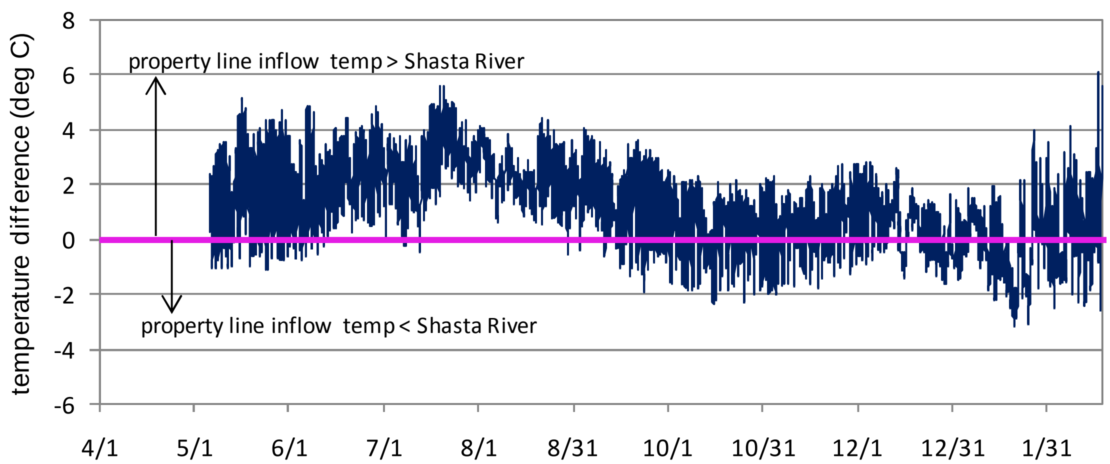

Figure 4. The temperature difference between Hole in the Ground at the south property boundary and the Shasta River at the south property boundary. The zero line indicates that water temperatures in the two waterways are equal at that time.

14.2 Irrigation Tailwater and Diffuse Springs Inflow

Periodically during irrigation season (April 1 to October 1), a portion of the water diverted down the pipe is used to irrigate the southern areas of two pastures: LS6 and LS7. Some of this water runs off as tailwater into a channel system that eventually flows into the Shasta River. As well as conveying tailwater runoff, this channel also contains a diffuse spring system that augments the flow with cold water inputs. Though the source and variability of the volume of water supplied by these springs is unknown, on 20 May 2009, approximately 3 ft^3/s was supplied by these diffuse springs.

Between May and September, the thermal signal from the diffuse spring system and Hole in the Ground Creek at the property line are distinct (Figure 5). Periodic field observations indicate that little tailwater reached the diffuse spring system during this time; temperature data illustrates that tailwater did not generally alter the springs thermal signal. Two periods when the springs' thermal signal is altered occur during April 2009 and September 2009. Water temperatures in the diffuse spring system during these periods shift from the relatively constant average diurnal signal observed through the summer and more closely track the trends illustrated in Hole in the Ground Creek. These alterations may indicate that some tailwater was commingling with the diffuse spring system. Beginning in October, irrigation ended and all Hole in the Ground Creek water flowed into its natural channel, which eventually flowed into the diffuse spring system. The diffuse spring system thermal signal tracks the Hole in the Ground Creek thermal signal; however, at this point, maximum daily temperatures were below those considered stressful for salmonids. During winter, the springs seemed to buffer minimum daily temperatures recorded at the Hole in the Ground property line inflow, as is illustrated by higher minimum temperatures detected in the diffuse spring system than in Hole in the Ground Creek at the property line.

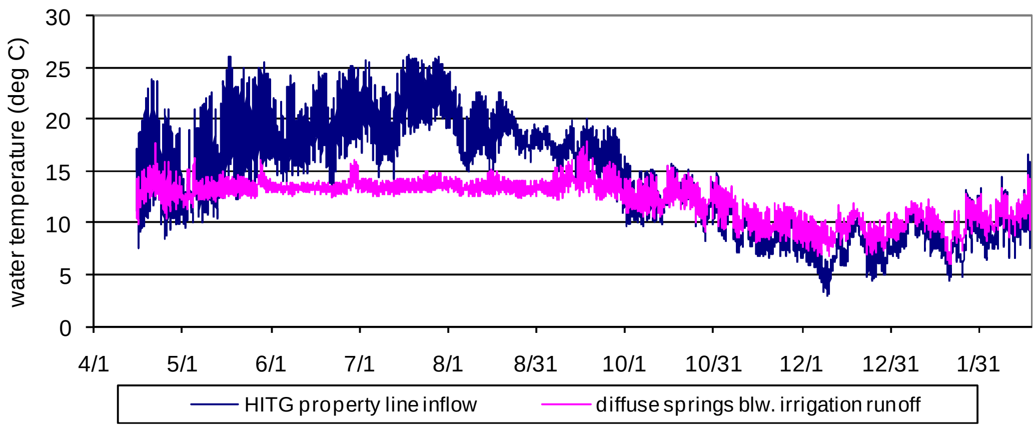

Figure 5. Hole in the Ground water temperatures at the point of entry to SBSR and water temperatures below the diffuse spring inputs below tailwater runoff.

The difference in temperatures between the diffuse spring system and Hole in the Ground Creek illustrate that during the summer, Hole in the Ground Creek is generally warmer than the diffuse spring system (Figure 6). Water temperatures in the diffuse spring system were as much as 12^{o}C cooler than water temperatures measured in Hole in the Ground Creek at the property line. Until mid-May, minimum water temperatures at the property line often cooled to water temperatures lower than those of the diffuse spring flow; however, after that time, minimum temperatures at the property line rarely cooled to the maximum temperatures reached by the diffuse spring system. From June to September, water temperatures from Hole in the Ground Creek exceeded those in the diffuse springs. During this time, vegetation growth in the diffuse spring system increased to cover the entire channel (Figure 7a-c). This cover lasted until fall, when Hole in the Ground Creek was no longer diverted into the irrigation pipe and instead flowed into the diffuse springs system. The combination of the increased flow volume, combined with seasonal vegetation senescence, likely reduced cover as illustrated in Figure 7c. After October 1, when Hole in the Ground Creek flowed into the diffuse spring system, water temperatures in the diffuse springs were consistently warmer than those measured at the property line. This indicates that in the winter, the diffuse spring system was relatively warm compared to Hole in the Ground Creek.

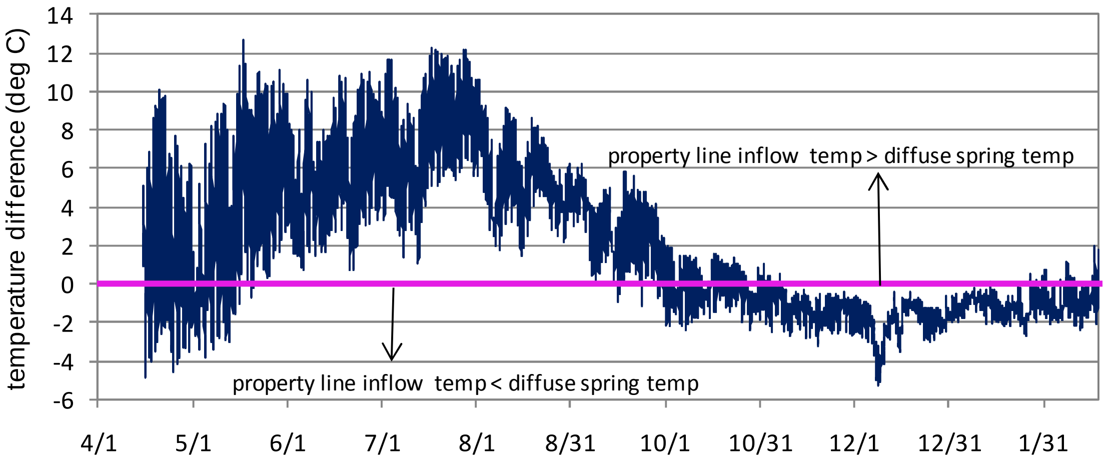

Figure 6. The temperature difference between Hole in the Ground Creek at the property line and in the diffuse springs. The zero line indicates that water temperatures in the two waterways are equal at that time.

Figure 7(a-c). Progression of vegetation grown and senescence in the diffuse springs from (a) 19 May 2009, (b) 25 June 2009, and (c) 19 February 2010.

Conclusions and Recommendations

Hole in the Ground Creek surface water seasonally contributes warm waters to the Shasta River. Management of this water for irrigation purposes and minimizing thermal impacts associated with return flow and tailwater may be a prudent action. Tailwater from pastures LS6 and LS7 mixes with water flowing from diffuse springs prior to reaching the Shasta River. The diffuse springs have a distinct thermal signal from the Hole in the Ground Creek at SBSR's property line. These springs do not exhibit the same heating and cooling trends as the surface water and maintain a relatively constant diurnal signal and daily mean temperature through the summer. When this signal is disrupted, likely the disruption is due to commingling tailwater that modifies the springs' natural signal. The source of these springs is unknown, but may be seasonal precipitation recharge of shallow groundwater that surfaces on the channel margins, subsurface return flow from Hole in the Ground Creek from local irrigation practices, or other sources. Flows and temperatures appear to persist in the springs through the summer season; however, more data are needed to determine if this is a potential thermal refuge for anadromous fish (e.g. coho salmon).

Field monitoring suggests that tailwater return flow was well-managed during summer 2009. An additional monitoring element that would assist in assessing the impacts of Hole in the Ground Creek water use and thermal management would be to track the irrigation schedule and rotation to identify when water is diverted. An example of a record sheet is provided at the end of this document (Table 1). Furthermore, investigation of the water source for the diffuse spring system should also be made to determine the inter- and intra-annual persistence of the diffuse springs and their potential as thermal refugia.

Table 1. Example format for irrigation data log.

IRRIGATION SCHEDULE DATA SHEET

Irrigator ______________________ **Rotation Date** ________________________

Begin *End*

Method __**flood/fixed line/wheel line/center pivot**______________________

Pastures ____

Waterway	Pasture	Irrigation start date	Irrigation end date
Big Springs Creek	BS1		
	BS2		
	BS3		
	BS4		
	BS5		
	BS6		
Little Springs Creek	LS1		
	LS2		
	LS3		
	LS4		
	LS5		
	LS6		
	LS7		
Hole in the Ground Creek	LS6		
	LS7		