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Scott River Beaver Dam Analogue Program
2015 Interim Monitoring Report

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A Chinook salmon passes through a beaver dam analogue and into the deep resting pool above. Photo: P. Thamer.

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"Community-based collaboration to conserve watershed resources"

EXECUTIVE SUMMARY

The Scott River Watershed Council constructed experimental beaver dam analogues (BDAs) on the Scott River, and two tributaries, Sugar Creek and Miners Creek, for the purposes of creating slow water habitat to benefit coho salmon. These were the first BDAs constructed in California.

Physical and biological parameters at some of the BDAs were monitored to assess the effects of the structures. For logistical reasons, most of the monitoring occurred at the Sugar Creek site.

During the summer, thousands of mostly 0+ juvenile salmonids (coho, Chinook and steelhead/rainbow trout) utilized the slow water habitat upstream of the Sugar Creek BDAs. Mark and recapture data using PIT tags indicate that juvenile salmonids remained in the ponds throughout the summer and put on growth during that time. In April, most of the 1+ juvenile salmonids emigrated downstream out of the ponds in a concentrated pulse.

Adult salmon spawned above all of the BDAs. Chinook salmon spawned above the BDAs in the mainstem, while coho salmon spawned above the BDAs in the tributaries.

Summertime temperatures in the Sugar Creek BDA ponds were suitable for juvenile salmonids at most times and in most locations, but there were some very low flow conditions that resulted in high temperatures. These temperature spikes are correlated with unusually rapid drops in surface flow upstream. The reason for these rapid streamflow drops is not immediately apparent.

Dissolved oxygen levels in the Sugar Creek BDA ponds were suitable for juvenile salmonids at most times and in most locations. There were a total of 10 instances of DO levels briefly dropping below 4 ppm; all of these occurred at night and were likely due to plant respiration.

Water surface elevations and temperatures were measured with a network of groundwater and surface water monitoring wells in and near the Sugar Creek BDAs. These data suggest that the BDAs have elevated groundwater levels, and thus increased groundwater storage in the Sugar Creek alluvial aquifer during the high flow periods in winter and spring. This storage and subsequent discharge during the summer likely contributed to creating perennial streamflow in lower Sugar Creek, in contrast to the year prior to BDA installation, in which lower Sugar Creek dried up over the summer. Relative to upstream reaches, the BDA ponds have stable diurnal and seasonal temperatures, suggesting that the most of the surface flow is derived from groundwater.

At the mouth of Sugar Creek, an additional 700 feet of a Scott River side channel retained flow throughout the year in an area that had previously dried up in the summer. This was the only observed perennial flow in the tailings reach of the Scott River. Water surface elevation data, temperature data and other observations suggest that the likely source of this flow was upwelling from the Sugar Creek alluvial aquifer.

Overall, approximately 1600 linear feet of stream above and below the BDAs retained flow throughout the summer, in reaches that previously ran dry. During the summer, juvenile salmonids were observed using most of the available habitat that had sufficient depth and cover, inclusive of the side channel.

Juvenile coho production capacity estimates for the Sugar Creek BDA ponds is > 7000. This assumes that the ponds remain full throughout the summer and are not drained.

Outline/Table of Contents

List of Figures

List of Tables

INTRODUCTION

Report Purpose and Overview

The Scott River Watershed Council received funds from the Klamath River Coho Enhancement Fund to use beaver dam analogues to create slow water habitat for coho salmon, and to monitor physical and biological effects of these structures. An interim report summarizing those monitoring efforts to date is due April 1st, 2016.

Data collection efforts are extensive and ongoing, and as such so are the data analysis and interpretation. Thus this is a "living" report which will continue to be updated and revised as additional data are collected and additional analyses are performed. Ultimately this report will be converted into a manuscript or manuscripts for submission to a peer-reviewed scientific journal.

This current report also fulfills the reporting requirements for the California Department of Fish and Wildlife Streambed Alteration Permit and the California Department of Water Resources Permit which were provided to the Scott River Watershed Council for the purposes of constructing experimental beaver dam analogues. The California Department of Fish and Wildlife issued a Lake and Stream Alteration Agreement for the project "Scott River Juvenile Coho Habitat Enhancement through Beaver Dams 1600-2014-0094-R1". The North Coast Regional water Control Board permitted the project as "Scott River Juvenile Coho Habitat Enhancement through Beaver Dams WDID No. 1A14055WNSI, ECM PIN No. CW-806806."

The report outline follows standard scientific format and as such, includes the following sections: an Abstract (or Executive Summary), Introduction, Site Description, Methods, Results, a Discussion which interprets the results, along with any conclusions, followed by Acknowledgments and a Bibliography.

The introduction provides an overview of coho salmon in the Scott River watershed, along with a brief history of restoration and monitoring efforts within the watershed. There is an impressive history of salmon habitat restoration and monitoring within the watershed and we felt it essential to acknowledge those past and ongoing efforts and to help provide context for this current restoration effort.

Much of the data presented in this report was gathered from agencies and organizations with whom the Scott River Watershed is collaborating. While we describe the methods we used to collect data, describing the data collection methodologies used by these outside organizations is beyond the scope of this report, but interested readers can generally find that information online or elsewhere.

Coho Salmon In The Scott River Watershed

The Scott River supports a Core, Functionally Independent Population of Southern Oregon Northern California Coast (SONCC) coho salmon (*Oncorhynchus kisutch*) that is one of the most productive natural stock in the Klamath River basin. The Scott River coho salmon population is likely above the depensation threshold with a moderate extinction risk (NMFS, 2014). The SONCC coho salmon were listed as threatened under the Federal Endangered Species Act in 1997 and the California ESA in 2004. The Scott River coho salmon population consists of a relatively strong adult brood year (2,752 adults documented at RM 18 video weir in 2013) and two weak brood years (355 adults documented in 2011 and 201 adults documented in 2012) (Knechtle & Chesney, 2015) (Figure 1).

Adult spawning ground surveys have been performed annually in the Scott River since 2001 to document the distribution and relative abundance of adult coho salmon spawners (Maurer, 2002 & Yokel, 2014). The majority of adult coho spawning occurs in the western tributaries of the Scott River during a normal water year with the highest observed abundance occurring in three primary areas in all brood years: the Shackleford-Mill Creek system in the Quartz Valley, the French-Miners Creek system and Sugar Creek (Figure 2). The distribution of adult spawners during the strong brood is significantly greater than during the weaker brood years with spawning observed in tributaries to the Scott River Canyon Reach (Scott Bar - Mill Creek, Tompkins Creek, Canyon Creek and Kelsey Creek), western tributaries (Kidder Creek, Patterson Creek and Etna Creek) and the South and East Fork of the Scott River. Limited spawning of adult coho has been observed in the mainstem Scott River during average water years. A severe drought in water years 2013 and 2014 impacted the ability of the strong brood of adult coho salmon to access the tributaries of the Scott River due to low stream flows and lack of connectivity that persisted through the migration period. Virtually the entire run of adult coho salmon spawned in the mainstem Scott River during the winter of 2013-14, with most of the spawning occurring late in the season (Yokel, 2014).

Summer time juvenile distribution surveys have been performed in select reaches of the Scott River watershed since 2005 (Maurer, 2005 & Yokel, 2006). The observed relative abundance of juvenile coho salmon correlates with the abundance of adult spawners on a reach level. Meso-habitat units offering areas of deep low velocity water had significantly higher densities than habitat units with shallow and higher velocity water. The highest densities of juvenile rearing were observed in meso-habitats that had complex micro-habitat features that partition habitats and offer fish cover. These micro-habitats are created by instream coarse woody debris, undercut banks, overhanging and instream terrestrial vegetation and aquatic vegetation. Efforts to perform direct observation surveys in the winter months to document juvenile coho salmon distribution have been unsuccessful because of high flows and cold temperatures. Little is known regarding the wintertime density and distribution of juvenile coho salmon. The documented distribution of coho salmon in the Scott River watershed is illustrated in Figure 2.

A limiting factor analysis for coho salmon in the Scott River identified a lack of suitable rearing habitat during the summer and winter months as a probable limitation to smolt production (SRWC, 2006). The legacy of historic watershed management and channel alteration has limited channel form and function, habitat complexity, floodplain connectivity and riparian forest condition in much of the range of coho salmon in the Scott River (SRWC & SRCD, 2014). Surface water rights and groundwater used for irrigation of the agricultural lands in the Scott Valley decrease the magnitude of instream summer base flow. Water temperature impairments in the Scott River due to limited riparian canopy in conjunction with the decreased instream flows and altered channel morphology limit the volume of suitable habitat during the base flow period. Excessive sediment loads and altered stream form and function in conjunction with an altered hydrologic regime has created disconnected reaches in the main stem Scott River and in the low gradient reaches of the tributaries (NCRWQCB, 2006). The dry reaches impede adult and juvenile migration, fragment habitats, decrease habitat volume and strand fish.

The lack of floodplain connectivity and associated off channel habitats throughout the Scott River limits the volume of slow water habitat refuge during the period of winter rearing. Historically, there was an abundant beaver population in the Valley that provided slow-water rearing habitat. Currently, there are few concentrations of beaver dams, but where they are found, primarily in the Mill-Shackleford and French-Miners Creeks systems, is coincident with consistently abundant coho salmon populations. It is likely that restoration activities that increase the availability of low velocity habitats with suitable water quality and improve the condition of the riparian forests will ameliorate the limiting factors to juvenile coho salmon during the summer and winter months (NMFS, 2014).

The Scott River watershed supports anadromous fish runs for two other salmonid (*Oncorhynchus*) species: Chinook salmon (*O. tshawytscha*) and steelhead trout (*O. mykiss*). The Scott River produces a significant population of Chinook salmon (Figure 1-bottom). Chinook salmon spawn primarily in the main stem Scott River with high densities observed in the Valley Reaches from the confluence of Sugar Creek to Etna Creek and at the mouth of Shackleford Creek. During periods of severe drought (2001, 2002 and 2015) low flows and dry reaches have precluded access to spawning grounds in the Valley. The majority of juvenile Chinook salmon out-migrate in early summer as the Scott River approaches the base flow regime. Steelhead trout have the largest distribution and most varied life history strategies of the salmonids in the watershed.

The role of the Scott River coho salmon population in the Upper Klamath River and Middle Klamath River population is not well understood. Significant numbers of young of the year (YOY) juvenile coho salmon have been observed at an out migrant trap operated in the lower Scott River (Chesney & Yokel, 2003). The fate of these juvenile salmon is unknown but is hypothesized that some survive by occupying available habitat in the tributaries of the Klamath River. Two juvenile coho that were PIT tagged in Sugar Creek were subsequently captured in Waukell Creek; a tributary of the Klamath River at Rkm 53.0 that produce a significant amount of non-natal out migrant coho salmon (Olswang, 2015).

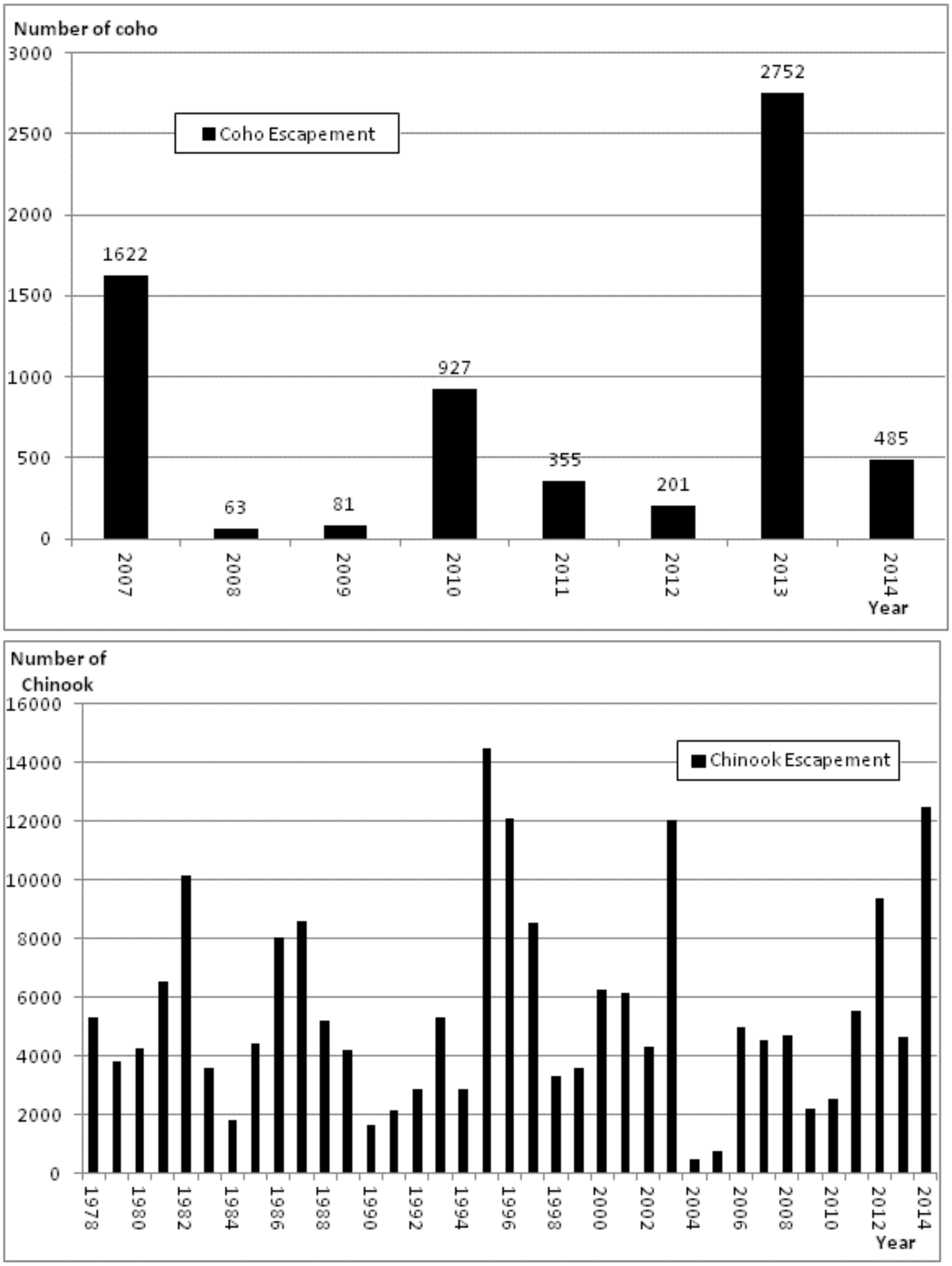


Figure 1. Top: Estimated Scott River coho natural spawner escapement (Knechtle & Chesney, 2015). Coho escapement abundance is underestimated in 2012 and 2014 due to a shortened survey season as a result of higher river flows Bottom: Estimated Scott River Chinook natural spawner escapement (Knechtle & Chesney, 2015). Average Chinook natural spawner escapement (age 2-5) in the Scott River is 5,502 (1978 – 2014). The Scott River Chinook escapement represents an average of 9% of the Klamath Basin natural Chinook escapement (Knechtle & Chesney, 2015).

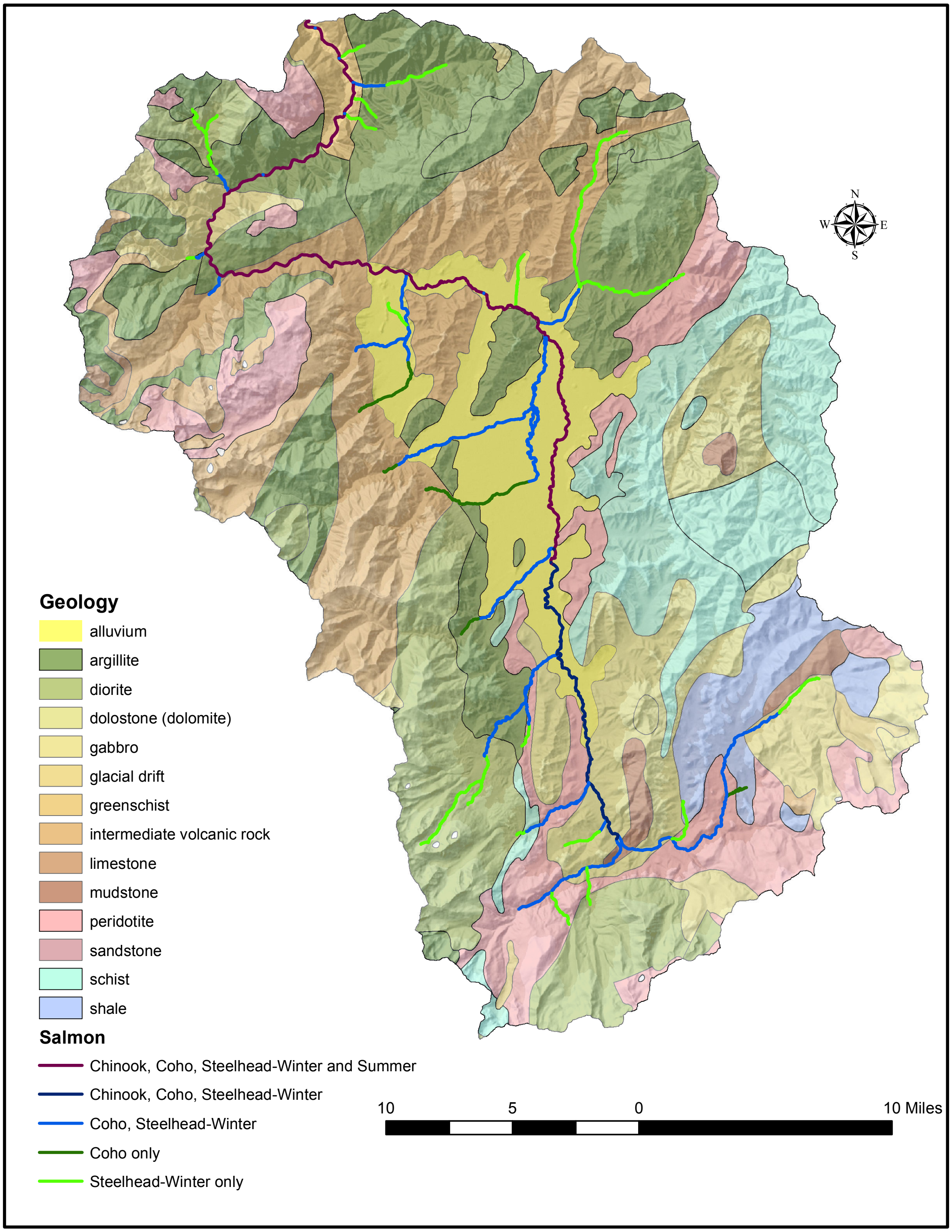


Figure 2. Geology and distribution of salmon in the Scott River watershed. Most of the salmon-bearing streams are on the west side of the watershed, where snowpack, precipitation and stream flows are greater, relative to the drier east side. In addition to the mainstem of the Scott River, major salmon-bearing tributaries are Mill Creek-Shackleford Creek, French Creek, Sugar Creek, Kidder Creek-Patterson Creek, South Fork of the Scott River and the East Fork of the Scott River. Etna Creek and Moffett Creek and are other producers.

Coho and Coho Habitat Monitoring Efforts

Efforts to document the population, distribution and condition of coho salmon in the Scott River have been performed by multiple groups including the California Department of Fish and Wildlife, the United States Forest Service, the United States Fish and Wildlife Service, NOAA Fisheries, the United States Geologic Survey, the Siskiyou Resource Conservation District, Northern California Resource Center, the Quartz Valley Indian Reservation and the Karuk Tribe.

Efforts to document the water supply, water quality, water quantity, stream morphology, riparian and floodplain condition, and fish habitat in the Scott River have been performed by the above groups, the California Department of Water Resources, the North Coast Regional Water Quality Control Board, the Scott River Water Trust, Sari Sommarstrom, PhD and other private consultants, and the University of California, Davis.

Adult Chinook salmon spawning ground surveys were initiated in the Scott River upon the creation of the California Department of Fish and Wildlife (CDFW) Klamath River Project in 1978. Cooperative adult coho spawning ground surveys were initiated in 2001. The CDFW has operated an out migrant trap in the Scott River above Scott Bar (RM 4.5) since 2000 to document run timing and estimate the smolt population of all three anadromous species. The CDFW installed a video weir in the Scott River at RM 18.2 in 2007 that is operated through the period of adult Chinook and coho salmon migration, except during high flows. The CDFW uses the adult escapement and smolt production estimates to assess the production and survival of coho salmon in the Scott River. Estimates of the smolt production per adult female coho in the Scott River for Brood Years 2007 – 2012 have a range of 6.7-78.6 with an average of 56.4 smolts produced per female adult (Knechtle & Chesney, 2015).

The CDFW has previously performed a study on juvenile coho salmon utilization and movement in a natural beaver dam in Sugar Creek (RM 0.4) from June 2011 through June 2012 (Olswang, 2015). Multiple direct observation surveys above, below and within the pond were performed to identify the distribution and relative abundance of rearing coho from June to August 2011. 371 juvenile coho were trapped and marked with a PIT tag in the beaver pond and adjacent habitats from August 2011 – May 2012. A PIT tag detection array was installed in Sugar Creek above the confluence with the Scott River. 28% of the tagged fish were detected at the downstream array from January – June 2012. This one year study was the first concerted effort in the Scott River to document the distribution of juvenile coho salmon in a reach with a beaver dam and pond and to apply PIT tags to mark and track the timing of out migration. Olswang, 2015 recommends that "Future and multiple years of studies are needed to understand some of the observations made in this single season".

Fish passage at beaver dams and beaver dam analogues

Successful fish passage at channel spanning obstructions depends on the swimming and leaping capabilities of fish and the hydraulics present at the obstruction. Considerable research has been conducted on fish passage at culverts and other hydraulic control structures (e.g. dams and weirs) which has lead to established passage criteria for these structure types (Powers and Osborn 1985, Bates 1991, NMFS 2001, CDFW 2002, NMFS 2008).

However, research and guidance for managers and practitioners to properly evaluate barrier status of natural channel obstructions such as beaver dams and logjams, and to effectively design and maintain man-made analogues is limited. Prior to the mid-1990's, channel obstructions were evaluated and routinely removed. Removal criteria was based primarily on the potential of the obstruction to induce overbank flooding and the assumption that the obstruction posed a barrier to fish migration (California Resources Agency 1982, SRGC 1983, Wooster and Hilton 2004). Over the last three decades the role and significance of channel obstructions for ecological purposes has gained popularity as a subject of research and restoration practice (Cluer and Thorne, BOR & USACE 2015, Pollock et al. 2015).

Hydraulics at beaver dams and BDAs are complex, spatially and temporally dynamic, with a multiplicity of passage opportunities available as hydrologic and hydraulic conditions change in response to fluctuations in flow stage and transport of sediment and wood. This hydraulic diversity creates a variety of distinct hydraulic features that fish can use to move past these structure types. Lokteff (2015) showed native trout movement was not inhibited by beaver dams in two small tributaries in northern Utah. Adult salmon and redds have been observed upstream of BDAs in the Scott River and natural beaver dams in tributaries of the Lower Klamath River (SRWC this report; YTFP Unpublished Data). More importantly, Coho fry less than 60 mm are commonly found in the Lower Klamath beaver ponds (YTFP Unpublished Data). Juvenile fish rearing in the Spruce Creek beaver pond (Lower Klamath) are non-natal and must pass through or over the beaver dam. The non-natal status of the juvenile fish in Spruce Creek pond is certain because spawning habitat is absent upstream of the beaver dam and adult fish have not been observed in over ten years of monitoring in that system.

NMFS (2001) and CDFW (2002) recommend a maximum hydraulic drop of 0.5 feet, velocity of 1.0 feet per second, and a minimum flow depth of 0.5 feet as the culvert passage criteria for juvenile salmonids. Fish presence above beaver dams, logjams and analogue structures with hydraulics that exceed these criteria illustrates that additional research is needed to i) evaluate the barrier status of natural and analogue structures, and ii) improve BDA design and maintenance guidelines.

To increase our understanding of fish passage conditions at BDAs we examined the potential hydraulics juvenile salmonids may encounter at a two flow paths present at a typical BDA structure, orifice and side channel flow. A goal of the analysis was to identify which flow path would most likely provide passage for juvenile fish according to NMFS (2001) and CDFW (2002) criteria.

History of Stream Restoration Projects

The Scott River and tributaries have been significantly altered since the first fur trappers discovered the watershed in the 1830's. Beaver removal and gold mining were the first significant landscape altering practices in the 19th century. Massive placer mining in the tributaries and main stem Scott River created a legacy of tailing piles that significantly reduce flood plain connectivity and riparian forest condition (Figure 3. The main stem Scott River was straightened, cleared and leveed in the late 1930's to reduce the frequency of flooding in the Scott Valley downstream of Etna Creek. The second largest flood for the period of record for the USGS gage below Fort Jones (established 1941) occurred on December 22nd, 1955 (38,500 cfs) causing significant bank and soil degradation in the Scott River. The largest flood in the period of record occurred on December 22, 1964 (54,600 cfs) and the fourth largest and latest historic flow event occurred on January 1, 1997 (34,300 cfs). A concerted effort to stabilize the banks of the Scott River using large rock was led by the Soil Conservation Service (now Natural Resources Conservation Service) and landowners to protect the prime agricultural land of the Scott Valley following the 1955 and subsequent floods (SRWC & SRCD, 2014).

Riparian restoration in the Scott River began in the early 1990's and has continued to date. A large riparian restoration effort was implemented in the southern portion of the main stem Scott River downstream of the tailings pile in 1998 to accelerate the recovery of the riparian forest following the 1997 flood. Grazing exclusion fencing has been installed throughout the watershed to protect riparian areas and stream banks that could be impacted by livestock. Assessments of riparian restoration projects and the current morphology of the Scott River's channel, banks and floodplain led to the development of a strategy to continue riparian and stream channel restoration (SRWC & SRCD, 2014).

Surface water diversions within the range of coho salmon have fish screens to prevent loss of fish into the irrigation ditches. Observations of adult coho spawning in the South Fork Scott River in 2001 were the first documentation of coho in this higher gradient stream. Several unscreened surface water diversions in the South Fork were immediately screened upon the discovery that coho utilize the South Fork. The Siskiyou RCD has worked with landowners in the Scott River Watershed to protect and enhance riparian and stream habitat for anadromous salmonids.

Figure 3. The tailings reach in the upper mainstem of the Scott River, showing the overturned substrate and the lack of riparian vegetation and aquatic habitat simplification. River flow is from left to right. The tailings are the symmetrical mounds of cobble on river left. There is about 6 linear miles of such habitat.

Overview Of Restoration Project

The Scott River Watershed Council's restoration project expands on existing landowner efforts to work with beaver to create more juvenile coho salmon rearing habitat in the Scott Valley. The complex, slow-water habitat created by beaver dams is ideal for juvenile coho salmon (Figure 4). Numerous studies have shown improved survival, smolt production and growth of juvenile salmon in beaver ponds and other slow water habitat (e.g. see Roni et al. 2006, Rosenfeld et al. 2008).

The Scott Valley was once so abundant with beaver that it was initially named the Beaver Valley. In the 19^{th} century, beginning in 1836, trappers removed many thousands of beaver from the valley until the beaver were extirpated and the ponds and wetlands that they sustained largely disappeared (Figure 4). Today slow-water rearing habitat, such as that formed by beaver dams, is limited to a few isolated locations in the Scott Valley and this severely reduces coho salmon production potential. However, there is still tremendous potential to for beaver to recolonize miles of stream reaches within the Scott Valley and increase coho salmon smolt production potential by several orders of magnitude. Doing this should measurably increase overall coho salmon production in the Klamath River system.

Coho smolt production from slow water habitat of all kinds averages about $0.37/m^2$, with active beaver ponds tending to be on the higher end of the production range (Roni et al. 2006, Rosenfeld et al. 2008). Smolt survival estimates from the Scott River range from 1.5%-18% (Knechtle and Chesney 2013), suggesting around 1500 smolts and 22-270 adult coho salmon could be produced per acre of slow water habitat created, with the smolt production numbers increasing as the quality of the slow water habitat improves. In recent years, California Department of Fish and Wildlife (CDFW) estimates that Scott River adult coho salmon returns range from 62-1622 (Knechtle and Chesney 2013), suggesting that creation of a relatively small number of beaver ponds or other slow water habitat could significantly increase the coho salmon population (typical beaver colonies flood 1-2 acres). Beaver dams and similar structures also improve streamflows through groundwater recharge and decrease temperatures through increased hyporheic exchange, thus improving coho salmon habitat through multiple mechanisms.

This habitat restoration project has been working with a growing list of cooperating landowners in the Scott Valley who want to use beaver to improve habitat conditions for coho salmon and in doing so provide an example of public-private partnerships that cost-effectively restore salmon habitat.

This project utilized the beaver habitat restoration tools developed by Pollock et al. (2012) and adopted by the National Marine Fisheries Service, the United States Forest Service and the Bureau of Land Management as a preferred restoration approach on federal lands in the Pacific Northwest (NMFS 2013). This restoration approach works to help beaver build and maintain stable dams that will provide rearing habitat for juvenile salmonids where possible. Where conditions are not yet suitable for beaver colonization, the restoration approach uses beaver dam analogues (see methods section), to create habitat for juvenile salmonids in the short-term, and habitat for beaver and juvenile salmonids in the long term.

Community Engagement—Interest in using beaver and beaver dam analogues to restore coho salmon habitat has arisen organically from within the Scott Valley community and local community groups and landowners are partners in this project. The Scott River Watershed Council formed a beaver working group to learn from and to educate landowners on how to live with and utilize beaver to achieve desired land use objectives. The Scott Valley Beaver Working Group and the Scott Valley Groundwater Advisory Committee have held several public meetings on the subject of using beaver to improve stream habitat conditions, and the reception has been generally positive from landowners, natural resource agencies and Indian tribes, including the Scott River Water Trust, the Scott river Watershed Council, the North Coast Regional Water Quality Control Board, the Karuk Tribe, the Quartz Valley Indian Tribe, the California Department of Fish and Wildlife, the National Marine Fisheries Service and the United States Fish and Wildlife Service. There is growing interest in and enthusiasm for the use of beaver and beaver dam analogues to restore stream habitat because it is a very affordable restoration technique that has a demonstrated track record of success. Ongoing planning efforts include identification of additional landowners willing to participate in the pilot study and using hydrologic and geomorphic features of streams to identify and rank all coho salmon stream based on their potential for using beaver and beaver dam analogues to create high quality habitat.

A total of 8 beaver dam analogues were installed at four sites in the Scott River watershed, although two of them are no longer functional (Figure 5). The four sites are (1) on the Scott River at and just upstream from the confluence with Etna Creek, (2) the Scott River just upstream from the confluence with French Creek, (3) Sugar Creek just upstream from the confluence with the Scott River, and (4) Miners Creek, just upstream from the confluence with French Creek. The details of the permitting, design and construction are available upon request.

Figure 4. Top: Beaver dams create complex habitat both upstream and downstream that is beneficial. Bottom (a) an 1852 USGS map of the Scott Valley, showing that historically, wetlands were abundant from Etna to Fort Jones. Trappers from the Hudson's Bay Company removed thousands of beaver from the valley, beginning in 1836; (b) Historic photograph of the Scott River (in the background) near Fort Jones in the early 20th century, showing the river still had extensive hydrologic connectivity with expansive floodplain wetlands. Historical accounts indicate that many thousands of beaver once occupied the valley, creating habitat ideal for coho salmon.

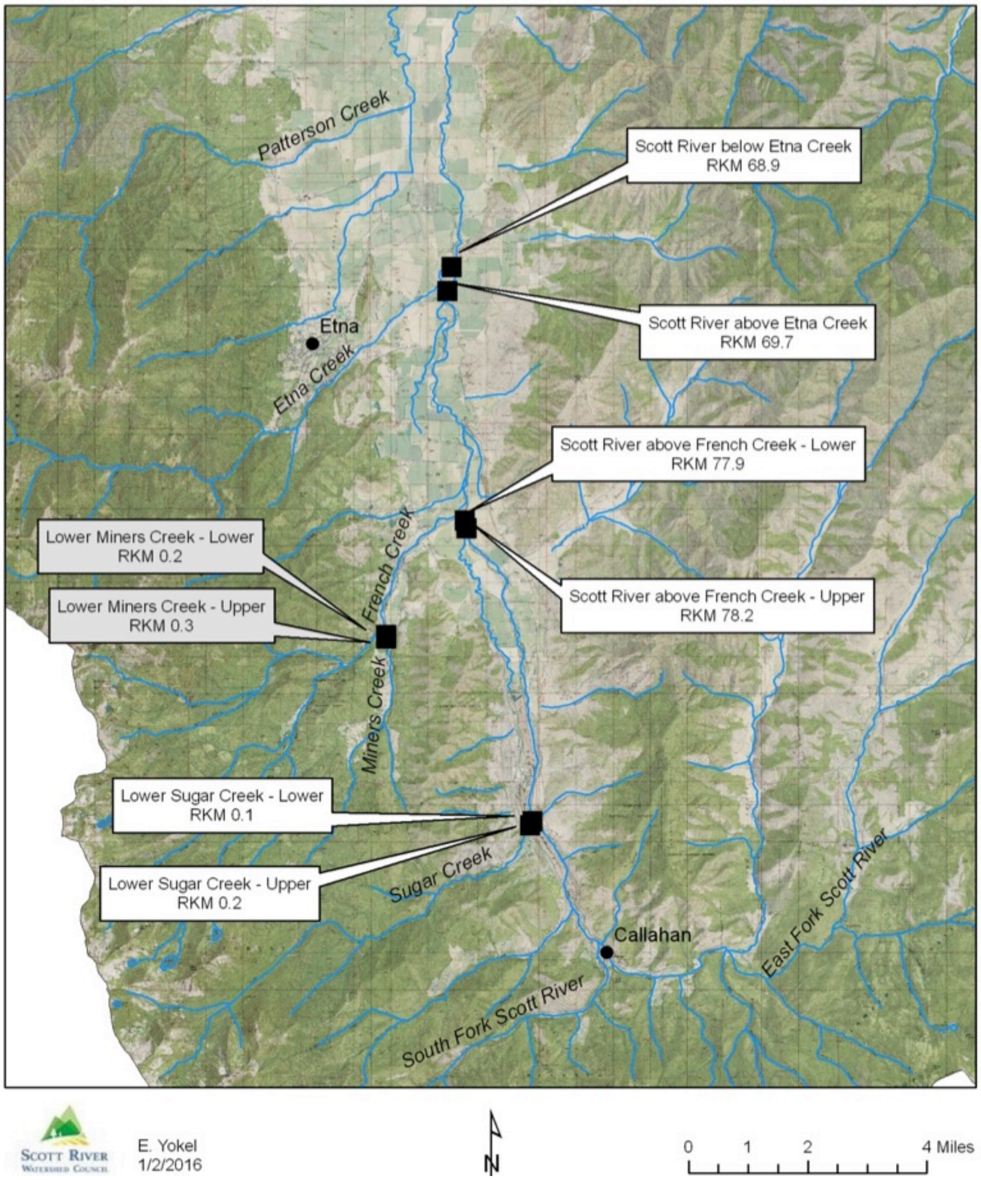


Figure 5. Location of installed beaver dam analogues (BDAs) in the Scott River watershed. Rkm = river kilometer, which refers to the distance upstream from the mouth of a river or creek.

Site Description

The Scott River is located in the Klamath and Marble Mountains of Western Siskiyou County in Northwest California. The Scott River watershed is approximately 520,000 acres (813 square miles) and is a major tributary to the Klamath River (Figure 6). The East Fork and the South Fork of the Scott River merge at Callahan to form the Scott River. From Callahan the Scott River flows to the northwest about 60 miles where it joins the Klamath River 2 miles above Hamburg The watershed has a north-south length of about 25 miles and extends in an east-west direction for about 10 miles at its widest part. The area has a human population of about 8000, with "major" population centers in Etna, Fort Jones, Greenview and Callahan. The major industries are agriculture, cattle, timber and recreation. The Pacific Crest Trail passes near the town of Etna and as such, is a major resupply point for hikers. Hay, largely alfalfa, is the chief agricultural crop and is dependent upon surface-water irrigation for successful production. Agricultural activities are concentrated on the wide valley floor, while timber harvest is focused on private lands on the hillslope immediately above the valley, while recreational activities, as well as summer grazing, occur mostly on the National Forest lands at higher elevations (Figure 7).

Geology and Groundwater Hydrology

The bedrock in the area, dating from pre-Silurian to Late Jurassic and possibly Early Cretaceous time, consists of consolidated rocks whose fractures yield water to springs at the valley margins and in the surrounding upland areas. The oldest rocks are the Salmon hornblende schist and Abrams mica schist, a sequence of completely recrystallized sedimentary and volcanic rocks of pre-Silurian age (Figure 1). Overlying these rocks with profound unconformity along the eastern part of Scott Valley are beds consisting of more than 5,000 feet of sandstone, chert, slate, and limestone of probable Silurian age. Along the northern part of the area, the Salmon and Abrams schists are unconformably overlain by andesitic and basaltic volcanic rocks altered to greenstone and greenstone schist. Beginning in Late Jurassic and perhaps continuing into Early Cretaceous time, the Klamath Mountains were the scene of profound orogeny. The rocks were strongly folded and faulted and were invaded by a series of magmas which solidified into rocks ranging in composition from peridotite, now largely altered to serpentine, to granodiorite (Figure 1). The granodiorite is the youngest of all the consolidated rocks in the area (Mack 1958).

The valley alluvial fill consists of a few isolated patches of older alluvium (Pleistocene) found along the valley margins and of younger alluvium which includes stream-channel, flood-plain, and alluvial-fan deposits of recent age. The recent deposits underlie and form the alluvial plains of Scott and Quartz Valleys, the valley of Oro Fino Creek and the fans at the valley margins, and extend in tongues up the valleys of tributary streams (Figure 1). Thickness of the recent alluvial deposits reaches a maximum of more than 400 feet in the wide central part of the valley between Etna and Greenview. The most permeable alluvium underlies the flood plain of the Scott River. The major irrigation wells in the area, which yield from 1,200 to 2,500 gallons per minute (gpm), are on the Scott River flood plain between Etna and Fort Jones. The average specific yield of the flood-plain sediments is estimated at15 percent. The alluvial deposits along the west side of the valley comprise the fans deposited by the major western tributary streams and the deposits forming the gently sloping zones of ground-water discharge near the base of the fans. Hydrologic data indicate that these deposits are of much lower permeability than the flood-plain deposits with which they merge to the east. Specific yield of the alluvium underlying the fans and discharge zones is estimated to range from 5 to 7 percent (Mack 1958).

Hydrology

In the Scott Valley, the average seasonal precipitation is 21.7 inches, but may exceed 70 inches annually in the western mountains, and exceed 30 inches in the eastern mountains (Figure 8). The average annual temperature in the Valley is 50.3° F. Streamflow in the Scott River is primarily driven by fluctuations in snowpack and the quality of the water year. Much of the Scott Valley consists of highly permeable sediment that creates significant connectivity between the stream surface water and the underlying aquifer. During normal precipitation years, the aquifer is recharged during the winter and spring, with groundwater accretion supplementing surface water during periods of low flow. The river and tributaries flow subsurface in some locations during the summer months and in years with low levels of precipitation. The Scott River experiences significant flooding. The largest flood at the USGS gage below Fort Jones (established 1941) occurred on December 22, 1964 (54,600 cfs) The second largest flood occurred on December 22nd, 1955 (38,500 cfs) and the fourth largest and most recent major flow event occurred on January 1, 1997 (34,300 cfs). Within the past two decades, few flows have exceeded 15,000 cfs. Although there is extensive rip rap along the mainstem, virtually all large floods cause significant bank erosion. As recently as 2015, a > 15,000 cfs flood initiated an avulsion in the tailings reach, breaching a levee and creating a new flow path that extended for miles before returning to the mainstem just above French Creek.

Snow surveys have been performed in the Scott River Watershed since 1946 at Middle Boulder 1 (Elev. 6600 ft) in the Scott Mountains. The Scott River is dependent on the snow pack during the summer months and the April 1st snow surveys are used by water managers to forecast the water supply. The 2015 April 1st snow survey documented an average snow depth and equivalent water content of less than one percent at the eight surveyed snow courses (USFS-KNF, 2015). The winter of water year 2015 (October 1, 2014-September 30 2015) was the warmest in California's recorded history causing most of the precipitation to fall as rain. Water year 2015 was the fourth year of drought in the Scott River watershed. The watershed was classified as D2 (Severe Drought) by the United States Drought Monitor on March 31, 2015 (NDMC, et al., ND). The watershed was classified as D2 on April 1, 2014, as D0 (Abnormally Dry) on April 2, 2013 and was split between D0 and D1 (Moderate Drought) on April 3, 2012.

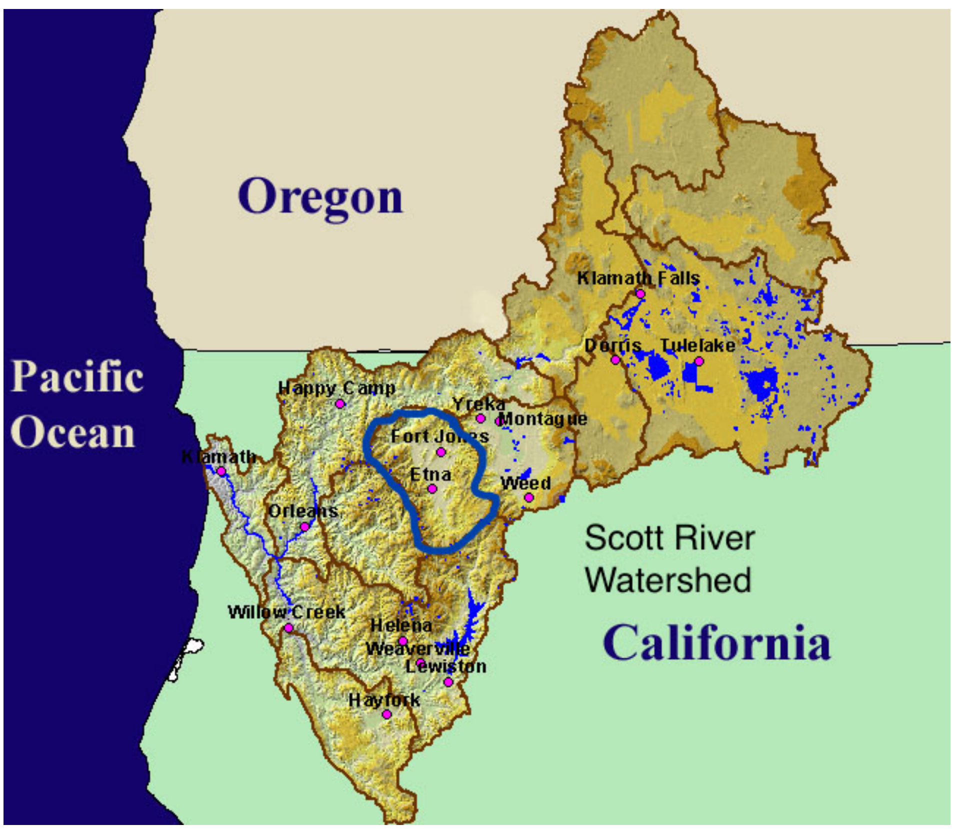


Figure 6. Location of Scott River watershed (circled in blue) within the Klamath River basin. Red lines delineate other major watersheds within the Klamath River basin.

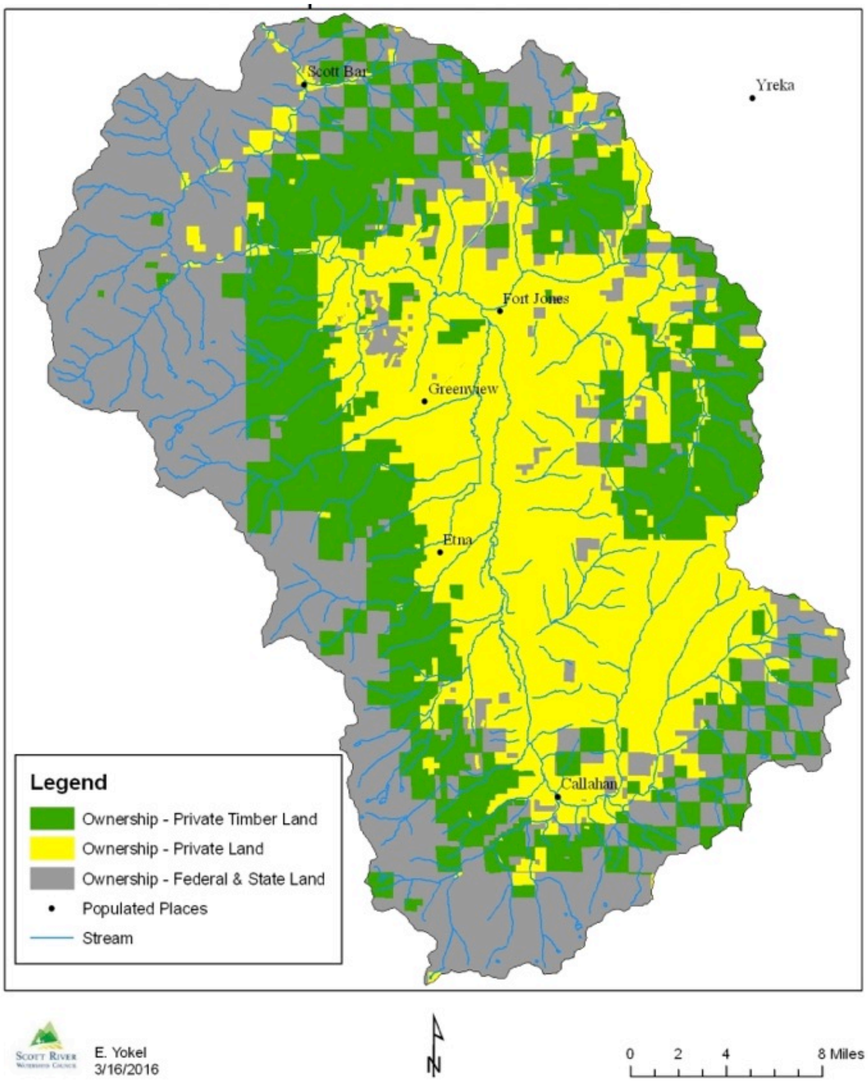


Figure 7. Public and private land ownership patterns in the Scott River watershed. Private and mostly agricultural ownership is concentrated on the valley floor, while public ownership and private timber ownership is concentrated on the steeper hillslopes.

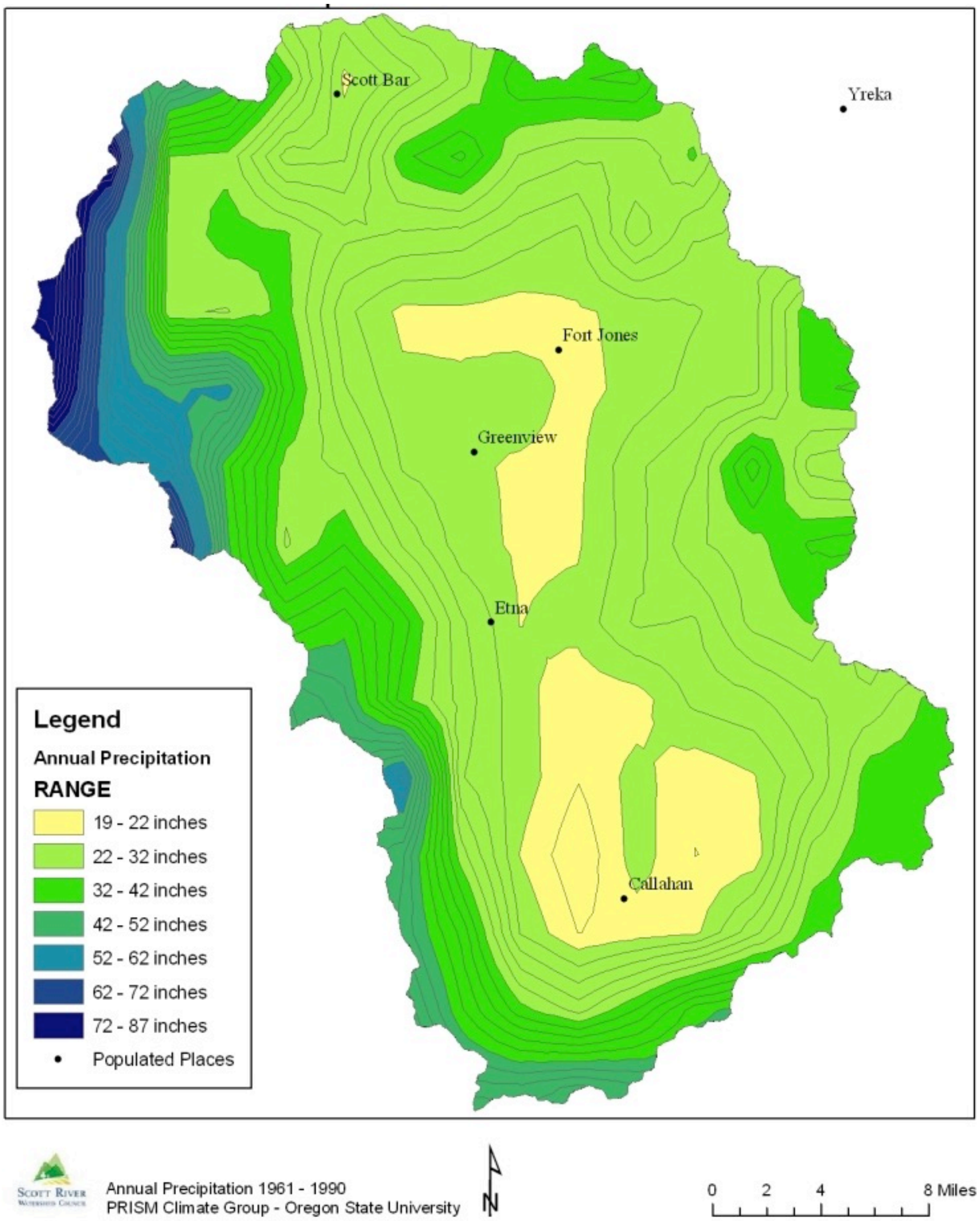


Figure 8. Annual precipitation patterns in the Scott River watershed from 1961-1990, as estimated using the PRISM model. The west side mountains get the bulk of the precipitation from the moist winter storms coming in off of the Pacific Ocean. The western mountains create a rain shadow such that very little precipitation reaches the eastern mountains.

METHODS

Overview Of Monitoring Strategy

The purpose of the monitoring effort was to document physical and biological effects of BDA placement at select locations within the Scott River watershed. Because the primary intended beneficiary of the structures was coho salmon, biological monitoring focused on salmon. Specific questions intended to be answered through monitoring include:

- Are juvenile salmon utilizing the habitat created by the structure? which species and at what densities.
- What are the growth rates of the juvenile salmon? Are they thriving or just surviving?
- Are juveniles able to pass over the structures?
- Are adult salmon able to pass over the structures?
- What is the juvenile salmon rearing capacity of the habitat created?
- What is the temperature regime of the habitat created relative to conditions suitable for salmon?
- What are the dissolved oxygen conditions of the habitat created relative to conditions suitable for salmon?
- How have the structures affected groundwater levels? Are there indications of elevated groundwater and increased summer flow?

Fish Monitoring

Adult Coho and Chinook Salmon Surveys

Annual spawning surveys (carcass and redd counts) performed by the Siskiyou Resource Conservation District were used to assess adult fish passage over BDAs. Adult fish passage and spawning ground surveys were performed during the spawning period of Chinook salmon and coho salmon in the main stem Scott River and tributaries in 2014-2015 and 2015-2016. Two technician crews walk reaches of the stream and identify live fish and spawning sites (redds) and collect sample from carcasses. All recovered carcasses were identified by species, sex and fork length. Otoliths and tissue are collected on a subsample of Chinook salmon and all coho salmon. Location of spawning (redds) is documented utilizing a hand held GPS receiver. The SRCD publishes the spawner survey data at the end of each spawning season (March).

After BDA installation, the spatial distribution of redds and carcasses upstream and downstream of each structure were quantified and compared to distributions in previous years to assess whether the structures are affecting spawning patterns within the watershed, and specifically, if there are any indications that structures are reducing upstream spawner densities. When adult Chinook and coho salmon are present (November – January) we visited each 2x/week to ensure they are passable. If fish were present below a structure and unable to pass, we planned to breach the structure sufficient to allow fish passage, however at no time were fish present that were not able to cross the structure, making breaching unnecessary.

The CDFW also estimates adult returns on the Scott River using a video counting system near the mouth of the Scott Valley. The USGS also maintains a streamflow monitoring station that measures discharge and stage height on the Scott River near Fort Jones (USGS #11519500). These data were used to place the spatial distribution of redds relative to BDA locations in the context of total run size and hydrologic regime during the spawning season, since year-to-year variation in the spatial distribution of spawning is affected by these variables.

Juvenile Salmon PIT tagging

In order to obtain information on fish movement, survival, and growth in Sugar Creek and other locations in the Scott River watershed, CDFW in collaboration with the Siskiyou RCD, and the SRWC, have been individually marking fish with passive integrated transponder tags and operating in-stream antenna stations to remotely detect the tagged fish. Elements of this monitoring effort that are related to the Sugar Creek BDA location in 2014 and 2015 are presented here.

A number of methods were used to capture fish for PIT tagging. In 2014 a fish relocation effort took place in the Scott River and part of this effort included releasing fish in Sugar Creek that were removed from drying pools elswehere in the Scott River. Relocated fish were captured with seines and transported to Sugar Creek via truck and aerated water tank. Capture efforts in Sugar Creek were carried out using seines, fyke nets, and unbaited minnow traps. For PIT tagging purposes, captured juvenile salmonids that met the minimum size criteria (60 mm fork length) were anesthetized with CO_2 and scanned with a hand-held PIT tag reader to determine if they had been previously tagged. The PIT tags and 14 gage needles were disinfected with isopropyl alcohol prior to use. An incision was made approximately 10 mm anterior to the base of the left pectoral fin with the needle and the PIT tag was then inserted by hand. Fish were measured for fork length, sampled for scales then held in aerated recovery containers before releasing them.

The PIT tag antenna stations were operated near the downstream BDA on Sugar Creek and at several other locations in the Scott River watershed (Figure 9). Juvenile fish passage at BDAs was assessed through placement of PIT tag monitoring station with two antennae, one upstream and one downstream of the lower BDA on Sugar Creek. These antenna systems were custom built in collaboration with Mauro Engineering (Mt. Shasta California). Antennas were made of a wire conductor threaded through PVC pipe for structure and secured to t-post driven into the river bottom. A variety of antenna dimensions were used depending on channel characteristics at a given site. A data logger powered by a solar panel and batteries recorded PIT tag detections onto an SD card along with a date and time stamp. Data was uploaded to a Microsoft Access database for analysis.

The Sugar Creek PIT tag antenna station was checked on a weekly basis to verify operation and perform any needed maintenance. During each visit the antenna station performance was rated on a 0-3 scale based on the portion of the rivers transect that was covered by a PIT tag detection field (Figure 9). This served to qualitatively track detection efficiency throughout the study. Several high water events in the winter caused some periods of non-operation because equipment was damaged or removed to avoid damage.

Figure 9. Map of the PIT tag arrays in lower Sugar Creek in relation to BDAs; PAWS = BDAs.

Juvenile Salmon Population Estimates-Aquatic Surveys

Direct observation dives were performed in lower Sugar Creek and the mainstem Scott River during the late spring and summer of 2015 to document distribution and estimate the population of juvenile salmonids. Juvenile salmonids are identified and enumerated by species. Direct observation surveys were performed on May 28th and June 19th, 2015.

On May 28th 2015, a snorkel survey was completed from the mouth of Sugar Creek upstream approximately 0.45 miles (as measured by Google Earth) to the State Highway 3 bridge (Figure 10). This length of stream encompasses the BDAs. The purpose of this survey was to assess relative fish abundance by species and age class in lower Sugar Creek. At the time of the survey the CA Dept. of Water Resources stream gage at the Fay Ditch (SGN) recorded a stage from 3.27 to 3.25 feet, which correlates to a discharge of 10.5 to 10.0 cubic feet per second. There was complete surface water connectivity through this reach of stream and the water clarity/visibility was good to excellent. Water temperatures during the survey were 13 -14 °C.

On June 19th, 2015, a second snorkel survey was completed from the mouth of Sugar Creek upstream approximately 0.37 miles (as measured by Google Earth) through the BDAs project site (Figure 10). The purpose of this survey was to assess relative fish abundance by species and age class through the length of Sugar Creek influenced by the structures. At the time of the survey the CA Dept. of Water Resources stream gage at the Fay Ditch (SGN) recorded a stage of

2.76 feet, which correlates to a discharge of 2.26 cubic feet per second. There was complete surface water connectivity through this reach of stream and Sugar Creek was confirmed to be flowing into the Scott River. The north-western side channel of Sugar Creek was dry at its two access points (inflow and outflow) and was therefore not surveyed. Water temperatures during the survey were 16 -18 °C.

Figure 10. The blue line marks the length of Sugar Creek surveyed on May 28th (left) and June 19th. The shorter survey in June was due to the fact that there was no surface flow just below the Highway 3 bridge. The Scott River was not surveyed. Note that the 2014 ortho imagery shown below does not reflect current the channel configuration.

Juvenile Salmon Habitat Capacity

Habitat volume surveys (e.g. slow water habitat surveys) were performed in the areas with functional BDAs during the spring and summer of 2015. Slow water surveys were performed at established cross sections upstream of the BDA. Each cross section was divided into twenty cells from edge of water to edge of water. The water depth, available cover type and dominant substrate were documented in each cell. Velocity measurements were recorded in a sub sample of representative cells.

A limited topographic survey of lower Sugar Creek was performed using a real-time kinematic global navigation satellite systems (RTK GNSS) survey. A longitudinal profile and water surface elevations were performed during the period of base flow.

Fish Passage

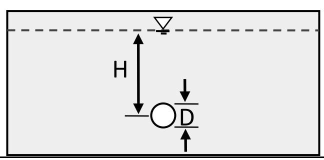
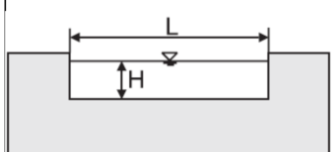
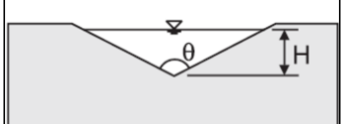
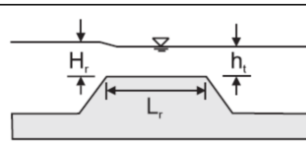
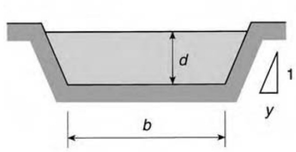
We used a combination of direct observation, field measurements and application of hydraulic first principles to evaluate BDA passability for juvenile salmonids. We identified six types of hydraulic flow paths that typically occur at beaver dams and BDAs within the Klamath Basin. Table 1 provides a basic description of each path type with a comparison to the nomenclature used by Lokteff (2015).

We solved equations for orifice and side channel flow iteratively to achieve a minimum passage depth of 0.5 ft. and velocity of 1.0 ft/s by adjusting the hydraulic coefficients C and n and other parameters. An overview of the hydraulic structures and equations used is provided in Table 2.

Table 1. Hydraulic flow paths at beaver dams and beaver dam analogues.

Hydraulic Flow Path (Lokteff et al. 2015)	**Hydraulic Flow Path** (Fiori et al. 2016)	**Description**	**Hydraulic Model**
Under/Through	Interstitial	Flow leaking through the entire structure	Flow through storm grate or rock weirs
Through	Orifice	Flow through the bottom or face of the dam	Orifice flow equation
Through	Pipe	Flow through the bottom or face of the dam, or through the streambank	Manning's equation for pipe flow
Over	Gap	Small pour point over the top of the dam	V-notch weir
Over	Weir	Large pour point over the top of the dam	Sharp & broad crested weir
Side Channel	Side Channel	Surface flow that circumvents the dam structure	Manning's equation For open channel flow

Table 2. Standard hydraulic control structures and associated discharge rating equations.

Hydraulic Structure		**Geometry**	**Equation**	**Standard Coefficient(s)**
Orifice			$Q = CA\sqrt{(2gH)}$	C = 0.61
Sharp Crested Weirs	Rectangular		Contracted $Q = C(L-0.1iH)H^{3/2}$ Suppressed $Q = CLH^{3/2}$ i = number of iterations	Metric C=1.84 English C = 3.3367
	V-Notch		$Q = C(8/15)\sqrt{(2g)}\tan\theta\,(H/2)^{3/2}$	C varies between 0.611 and 0.57 depending on H and Q
Broad Crested Weirs	Broad (side view)		$Q = C_dLH_r^{3/2}$	C_d is a function of H_r, h_t and L_r ranging between 1.25 and 3.1
Open Channel Flow			$Q = (1.486/n)A\,R^{2/3}\,S^{1/2}$	n can vary between 0.011 and 0.1 for man-made and natural channels

Physical Habitat Monitoring

Stream Temperature

Onset tidbit dataloggers ((Pro v2 and Tidbit v2-accuracy ± 0.2 °C) were used to measure stream temperatures at 15 minute intervals above and below BDAs. Because of the high spatial variability of temperature in the complex habitat surrounding BDAs, we employed multiple dataloggers at each site during the summer. We measured the spatial variation in stream temperatures for the purposes of identifying the extent of "thermally available" habitat, relative to control sites. Temperature dataloggers were used in a rotating panel design to measure spatial variability at control and treatment sites, while others were used to continuously monitor stream temperatures at each of the sites throughout the year.

Stream temperature was monitored in the mainstem Scott River at multiple long term trend sites and above and below BDAs at Rkm 69.7 and Rkm 78.2 (Figure 11). All water temperature dataloggers were deployed in riffle habitats in late May, 2015 to document the ambient temperature of well mixed water with the exception of the logger at Rkm 78.2 which was placed in the pond upstream of the BDA. Two water level dataloggers (Onset U20) placed in pool habitats (Rkm 56.5 and Rkm 75.0) to gauge pool stage for discharge monitoring performed by the Siskiyou RCD recorded water temperature.

Temperature dataloggers were placed in lower Sugar Creek within, above and below the BDA Rkm 0.1 & 0.2 ponds and above a natural beaver dam (Rkm 0.7) at Rkm 1.0 (Figure 12). Temperature dataloggers in Sugar Creek were placed in riffle habitats at Rkm 0.05, 0.4 and 1.0 and in BDA pond habitats at Rkm 0.1 and 0.2.

A network of water temperature dataloggers was established in lower Sugar Creek on 8/18/2015. Temperature dataloggers were placed at stations located at a 50 foot interval with STA 0+00 at the post line of BDA Rkm 0.1. The temperature dataloggers at Rkm 0.1, Rkm 0.2 and Rkm 0.4 were located at STA 0+50, STA 4+22 and STA 11+00, respectively. A logger was placed in the bottom of the water column attached to the streambed in the channels thalweg at all stations. Water depth was measured at each station when deploying and retrieving the temperature dataloggers. An additional water level logger was suspended at a depth of approximately 80% from the bottom in the water column at stations with water depth greater than 1.5 feet (Table 3).

The continuous water temperature (Celsius) data at all locations was analyzed to determine if the datalogger was in a dry channel at any period of the deployment. The continuous data was converted to daily average, daily minimum, daily maximum and moving weekly average temperature (MWAT) for further analysis and presentation. The period of dry channel (if applicable) and the date and magnitude of the maximum MWAT was documented for each location.

Air Temperatures

To provide context for the observed water temperatures, air temperature was monitored in three locations in the study area. Two Onset Water level dataloggers utilized for barometric compensation were deployed in a white PVC tube in lower Sugar Creek and at the trunk of a large riparian tree in the flood plain of the Scott River at Etna Creek. A third air temperature was retrieved from the weather station at the USFS Guard Station in Callahan (retrieved from CDEC).

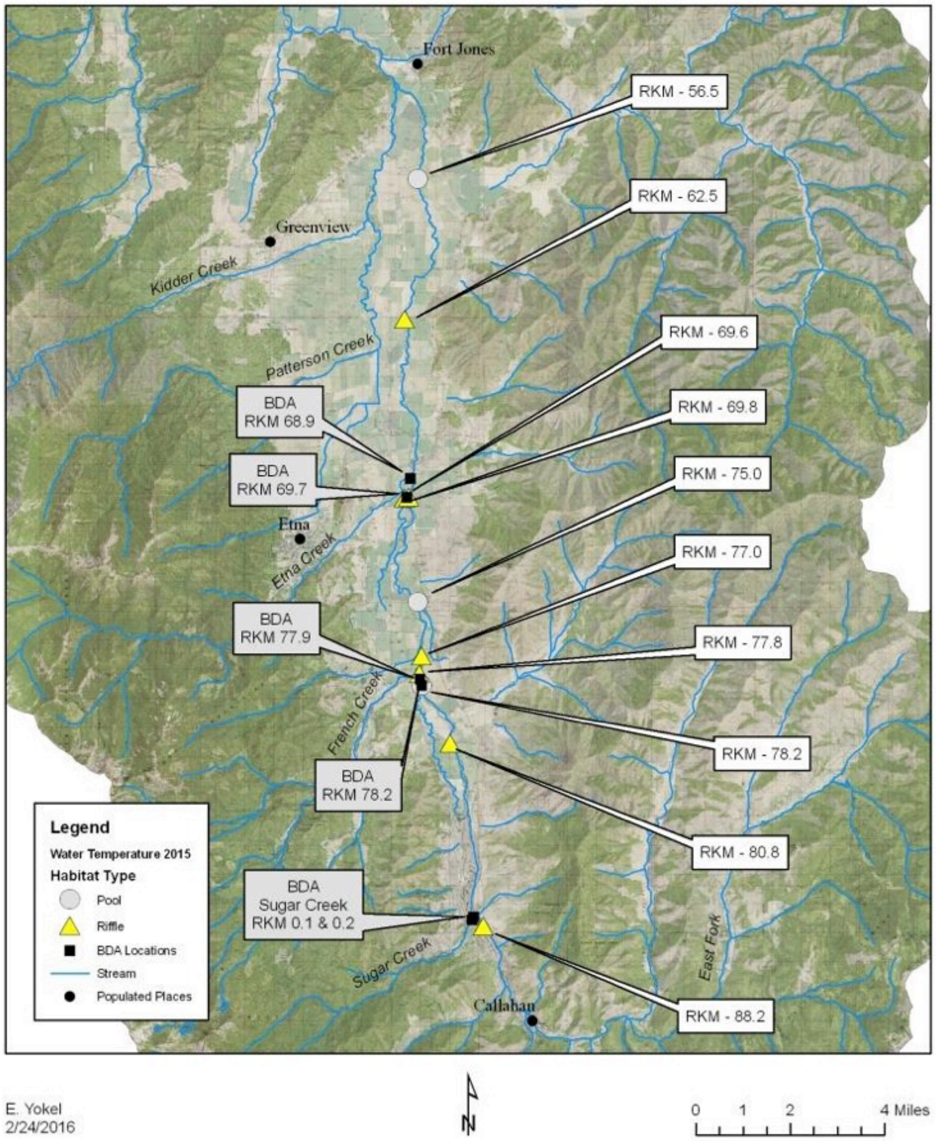


Figure 11. Location and habitat type (e.g. pool or riffle) of surface water temperature monitoring stations in the Scott River watershed, used in this study, in relation to the beaver dam analogues which were installed. Rkm = river kilometer, which refers to the distance upstream from the mouth of a river or creek.

Figure 12. Location of surface water temperature monitoring stations in lower Sugar Creek, used in this study, in relation to the beaver dam analogues which were installed (thin black lines). Rkm = river kilometer, which refers to the distance upstream from the mouth of a river or creek.

Table 3.Location of water temperature dataloggers in lower Sugar Creek.

	Logger 1	Logger 2		
	Distance	Distance	Water Column - Depth	
Station	from bottom	from bottom	8/18/2015	10/21/2015
0+50	0	1.5	1.9	3.0
1+00	0	1.5	2.0	3.0
1+50	0		2.5	3.5
2+00	0	2	2.5	3.3
2+50	0	1.5	2.0	3.0
3+00	0	1.3	1.6	3.2
3+50	0		1.1	2.2
4+00	0		1.1	2.1
4+50	0		1.2	2.2
5+00	0		0.6	
5+50	0		0.6	1.7
6+00	0		0.8	1.9
6+50	0		0.8	1.8
7+00	0		0.7	1.8
7+50	0		0.8	1.9
8+00	0	2	2.6	3.4
8+50	0		0.6	1.3
9+00	0		0.9	1.7
9+50	0	2	2.8	3.4
10+00	0		0.4	1.2
10+50	0		1.2	1.7
11+00	0		0.3	0.5
			8/18/2015	11/4/2015
SC 0+00	0		1.2	2.4
SC 0+50	0		1.0	2.2
SC 0+88	0		0.9	2.2

Dissolved Oxygen

Two Dissolved Oxygen (DO) Loggers (Onset U26-001) were used to document the dissolved oxygen and temperature in lower Sugar Creek. The DO dataloggers were calibrated to saturation and 0% DO in the lab. A hand held DO meter (YSI 550A) was used upon deployment and retrieval of the logger to document temperature and DO. The schedule for datalogger retrieval and maintenance (cleaning of membrane) was a maximum of two weeks to minimize the probability of membrane fouling and erroneous DO data. This goal was not always achieved. The dataloggers were placed in four locations in lower Sugar Creek (Table 4 & Figure 13).

Both DO dataloggers were initially placed in the BDA ponds on 6/27/2015. The logger above BDA Rkm 0.2 was moved to a shallow pool below a riffle above the influence of the BDAs to document the DO of the water entering the BDA ponds. The DO logger in the BDA Rkm 0.1 pond was moved during the period of minimal water surface elevation and habitat volume from

STA 0+50 to STA 2+00. STA 2+00 was a deeper habitat with a significant number of observed rearing salmonids during the direct observation effort of 8/31/2015 and observed cold water input. The DO meter at STA 10+83 was moved to STA 0+50 to simultaneously document DO and temperature at STA 0+50 and 2+00. On November 18th, the DO meter at STA 2+00 was removed from lower Sugar Creek and relocated in Miners Creek in the newly constructed BDA Rkm 0.3 pond.

Table 4. Locations and monitoring dates for dissolved oxygen dataloggers.

Site	Begin Date	End Date
BDA RKM 0.1 Pond - STA 0+50	6/27/2015	9/1/2015
BDA RKM 0.1 Pond - STA 2+00	9/1/2015	11/18/15
BDA RKM 0.1 Pond - STA 0+50	9/28/2015	12/22/2015
BDA RKM 0.2 Pond - STA 4+00	6/27/2015	8/4/2015
RKM 0.4 - STA 10+83	8/4/2015	9/28/2015

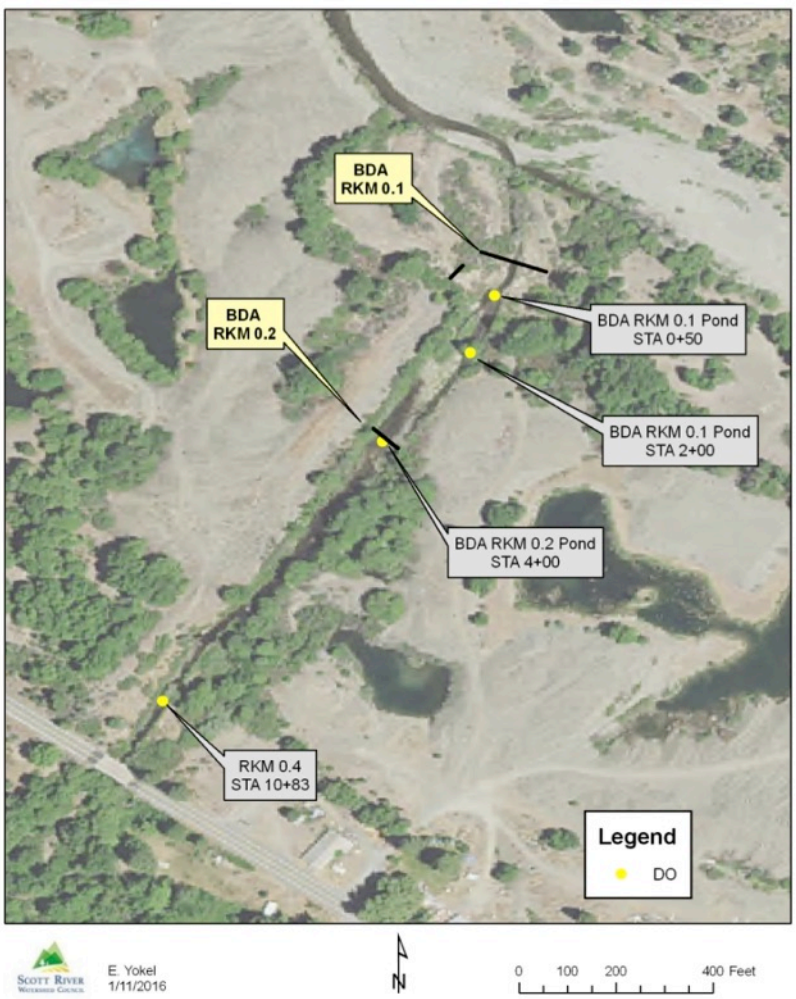


Figure 13. Location of dissolved oxygen monitoring stations in lower Sugar Creek, used in this study, in relation to the beaver dam analogues which were installed (thin black lines). STA x+xx = distance upstream from BDA 1 or 2, where x+xx = distance in feet (e.g., 2+00 = 200 feet).

Water Surface Elevation

Networks of groundwater monitoring wells were established at four locations – Scott River at Etna Creek (68.9 – 69.3 Rkm) – Figure 14 and Table 5, Scott River above French Creek (77.7 – 78.5 Rkm) (Figure 15 and Table 6), Scott River above Fay Lane and lower Sugar Creek (Figure 16 and Table 7).

Monitoring wells were established using 10 foot sections of vented PVC placed in an excavated pit and backfilled at the two groundwater sites on Sugar Creek. The monitoring wells on the main stem Scott River were established using a vented steel pipe with a welded point on the end that was pounded into the ground using heavy equipment. Several surface water elevation stations were initially established using a t-post pounded into the substrate of the Scott River and side channel and slough locations. Surface water stations consisting of vented PVC tubes attached to t-posts were initially established in the surface water of Sugar Creek and a disconnected pond to the south of Sugar Creek. Vented tubes and staff gages were added to several of the surface water stations in early June 2015 and a surface water elevation station was established in the pond above the BDA Rkm 78.2 above French Creek (FRMW12s).

Pressure transducers (Onset HOBO U20 and U20L water level dataloggers) were placed in the majority of the monitoring wells and surface water stations at the Scott River at Etna Creek, Scott River above French Creek and lower Sugar Creek networks. Two pressure transducers were deployed at the Scott River at Etna Creek and Sugar Creek locations to record barometric pressure.

The distance from an established reference point to the water surface elevation (wse) in the monitoring wells is measured and recorded using a hand held well depth sounder.

The wells' reference points and adjacent ground surface elevations were surveyed using an RTK GNSS survey system (Trimble R8). The coordinates were georeferenced utilizing post processing from the Online Positioning User Service (OPUS) of the National Geodetic Survey (NGS) using the NAD83 horizontal datum and NAVD88 vertical datum and computed using Geoid12B model (http://www.ngs.noaa.gov/OPUS/).

The pressure signal from the water level dataloggers is converted to a water depth using "Barometric Compensation" in Onset HOBOware Pro. The water depth measurements are converted to water surface elevations using the periodic measurements in conjunction with the reference point survey.

The 15 minute data was converted to daily minimum, average and maximum for QA/QC, analysis and presentation.

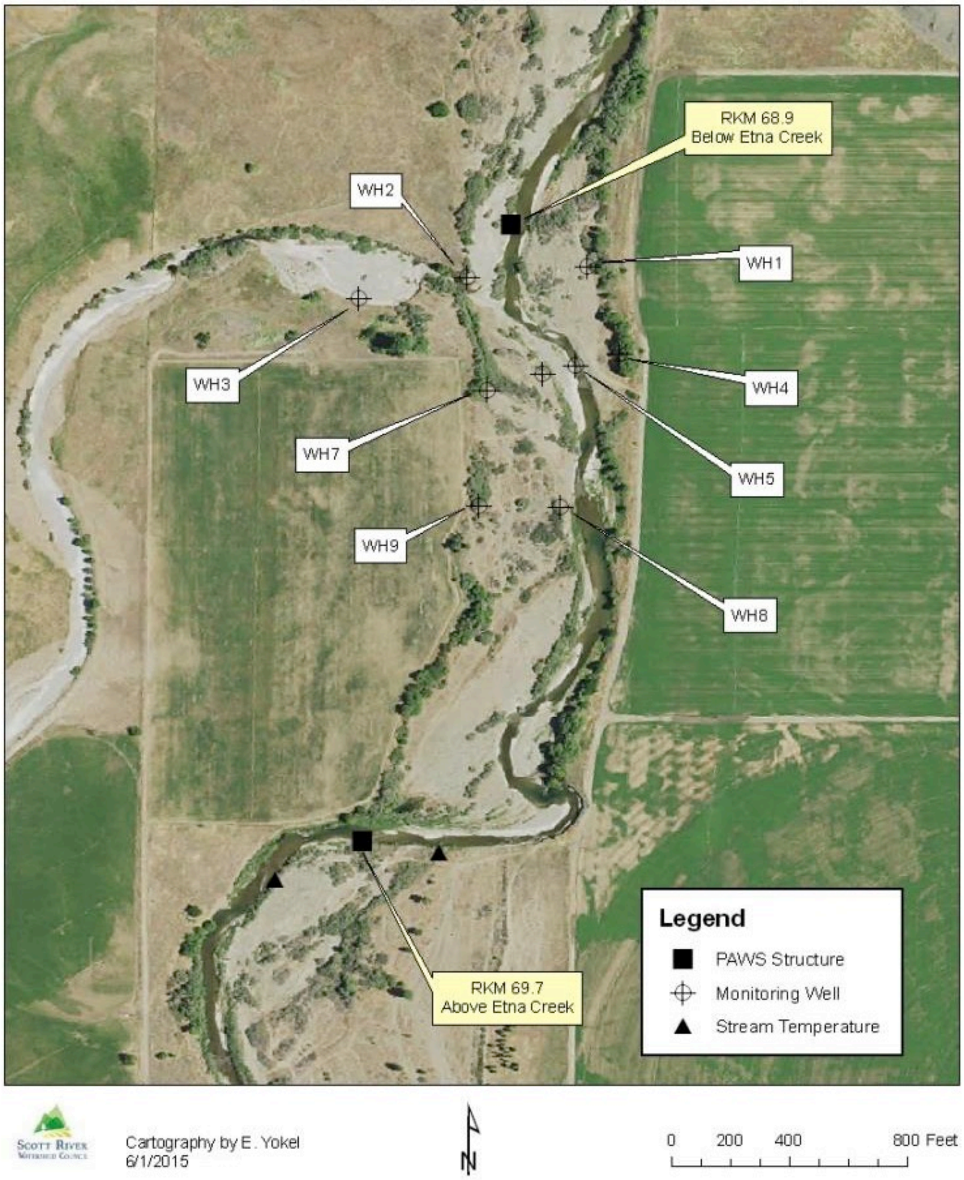


Figure 14. Diagram of the network of groundwater monitoring wells (water level and temperature) and surface water temperature monitoring stations at the confluence of Etna Creek and the Scott River. Etna Creek flows in from the left, direction of flow on the Scott River is from bottom to top of figure. PAWS = post assisted wood structure, which is synonymous with beaver dam analogue (BDA); WH = monitoring well; Rkm = river kilometer above the mouth of Scott River.

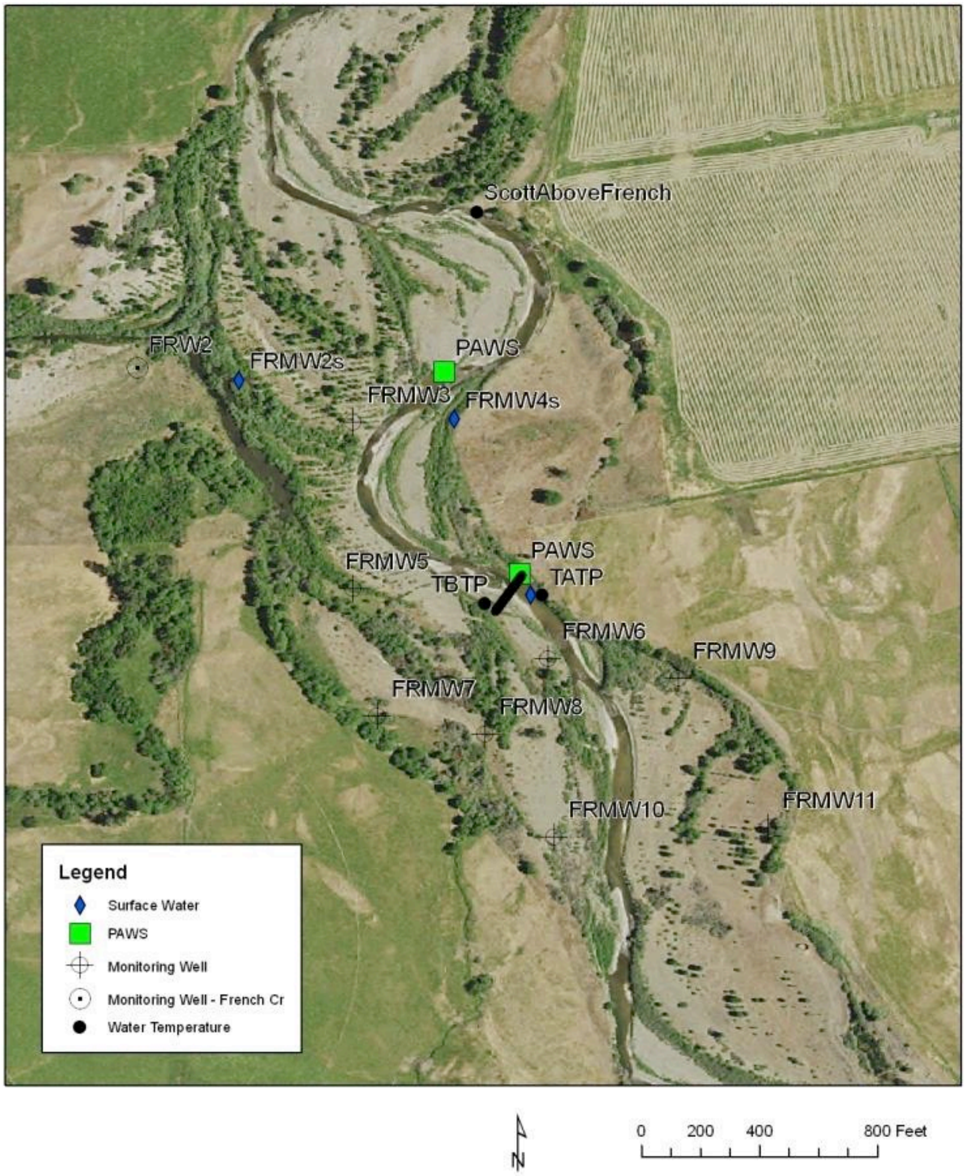


Figure 15. Diagram of the network of groundwater monitoring wells (water level and temperature) and surface water temperature monitoring stations at the confluence of Etna Creek and the Scott River. Etna Creek flows in from the left, direction of flow on the Scott River is from bottom to top of figure. PAWS = post assisted wood structure, which is synonymous with beaver dam analogue (BDA); WH = monitoring well; Rkm = river kilometer above the mouth of Scott River.

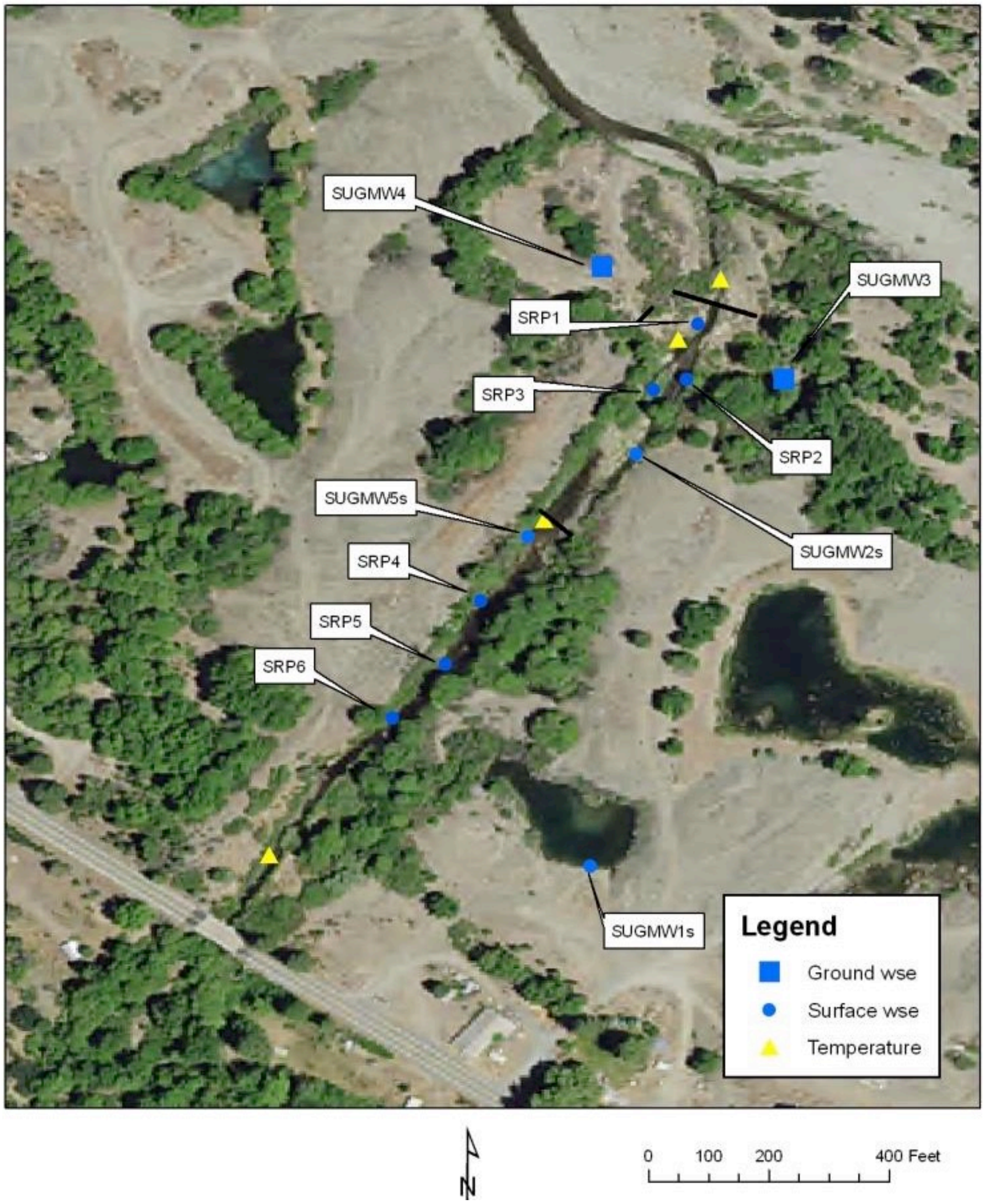


Figure 16. Diagram of the network of groundwater monitoring wells (water level and temperature) and surface water temperature monitoring and water surface elevation stations at the confluence of Sugar Creek and the Scott River. Sugar Creek flows in from the lower left, direction of flow on the Scott River is from right to left of figure. Note the distributary side channel of Sugar Creek on river left. WSE=water surface elevation.

Table 5. The UTM coordinates and ground and reference point (RP) elevations of monitoring wells at Scott River at the confluence of Etna Creek.

Monitoring Well	Northing (m)	Easting (m)	RP Elevation (ft)	Ground Elevation (ft)
WHMW1	4591669.8	512614.6	2761.2	2759.6
WHMW2	4591660.7	512520.2	2756.6	2756.6
WHMW3	4591636.3	512435.0	2760.5	2756.3
WHMW4	4591579.8	512635.8	2765.1	2763.1
WHMW5	4591570.6	512605.8	2757.3	2756.0
WHMW6	4591562.4	512576.9	2761.3	2759.6
WHMW7	4591546.8	512536.2	2763.0	2761.0
WHMW8	4591426.4	512595.4	2761.2	2760.1
WHMW9	4591424.4	512531.2	2765.8	2763.6

Table 6. The UTM coordinates and ground and reference point (RP) elevations of monitoring wells at Scott River at the confluence of French Creek.

Monitoring Well	Northing (m)	Easting (m)	RP Elevation (ft)	Ground Elevation (ft)
FRMW2s	4584860.9	512732.1	2824.2	2820.0
FRMW3	4584821.8	512824.1	2824.9	2824.3
FRMW4s	4584821.0	512900.4	2822.7	2818.6
FRMW5	4584654.1	512817.4	2824.6	2823.2
FRMW6	4584574.6	512974.7	2828.3	2826.7
FRMW7	4584513.2	512843.0	2827.5	2825.8
FRMW8	4584505.6	512930.2	2826.8	2825.5
FRMW9	4584545.5	513076.7	2829.1	2827.8
FRMW10	4584395.2	512983.8	2830.0	2828.8
FRMW11	4584398.7	513144.9	2831.2	2829.5
FRMW12s	4584641.0	512966.3	2825.5	2821.0

Table 7. The UTM coordinates and ground and reference point (RP) elevations of monitoring wells at Scott River at the confluence of Sugar Creek.

Monitoring Well	Northing (m)	Easting (m)	RP Elevation (ft)	Ground Elevation (ft)
SUMW1s	4576464.5	514686.0	3004.6	2997.5
SUMW2s	4576672.3	514704.2	3005.5	3000.2
SUMW3	4576714.0	514762.2	3006.6	3003.8
SUMW4	4576767.3	514687.9	3005.0	3002.8
SUMW5s	4576633.6	514663.4	2999.2	2999.2

Geomorphic Change

Topographic surveys were not performed in the reaches in which BDA were installed in 2014 and 2015. A topographic survey using a RTK GPS survey was performed at the BDA Rkm 78.2 site to document the elevation of the installed posts and the stream bed in the area of the BDA pond in 2014. A more extensive survey was performed using a RTK GNSS survey of the Scott River's channel and floodplain above and below BDA Rkm 77.9 & BDA Rkm 78.2 in 2015.

Comparison of the stream bed elevations upstream of BDA Rkm 78.2 documents the change in morphology after the high flow events of water year 2015.

Comparison of stream bed features (e.g. top of bank and thalweg) captured in the 2015 survey to the 2014 National Agriculture Imagery Program (NAIP) ortho imagery was used to document lateral stream migration on the meander downstream of BDA Rkm 78.2. The next scheduled acquisition of NAIP ortho imagery is 2016. High resolution ortho imagery of the main stem Scott River and select tributaries was acquired on October 30th, 2015 to document the geomorphic condition. The ortho imagery has not been post processed or georeferenced at the time of the writing of this report.

RESULTS

Adult Salmon

Chinook

In fall 2014, abundant Chinook salmon spawning occurred in the mainstem Scott River, with spawning well distributed throughout the reaches where spawning has occurred in the past (Figure 17). The majority of Chinook salmon spawned above the first set of mainstem BDAs on the Whipple property, while a sizeable minority spawned above the mainstem BDAs above French Creek. No adult Chinook salmon were observed spawning above the Sugar Creek BDAs, consistent with observations from previous years. However, there were numerous visual observations of live adult Chinook salmon entering the ponds above the BDAs, and moving upstream as far as the Highway 3 Bridge crossing, indicating that the BDAs were passable.

In 2015, the fourth year of drought, disastrously low flows that persisted into early December created flow barriers that prevented adult Chinook salmon migrants from accessing the Scott Valley, and most spawning occurred in the canyon reach below the valley, where conditions for successful spawning are suboptimal due to redd scour from the confined flows.

Coho

In fall and early winter of 2014-15, coho salmon were observed spawning in their usual spawning grounds in the tributaries of the Scott River. However, the vast majority of live fish, carcasses and redds observed was in the Mill-Shackleford Creek system. Very few coho made it to the upriver spawning tributaries inclusive of French-Miners Creek and Sugar Creek. A total of 23, 63 and 10 live fish, redds and carcasses were observed, respectively (Table 8). As is typical for most years, much of the coho salmon spawning occurred during high flows, and the spawning is generally dispersed, making accurate counts challenging, so more fish may have spawned in the upriver tributaries than was indicated by the surveys. In spite of the limited observations, the surveys indicate that most of the coho salmon that did make it upriver spawned above the BDAs that were installed (Figure 17). That is, 19 of 24 of the observations of upriver live or dead coho salmon or coho salmon redds were upstream of BDAs.

In the fall of 2015, a precipitation event on December 7th – 8th allowed for the initial migration of coho salmon to the tributaries of the Scott Valley, and the observations of passage at the CDFW fish weir suggest that the bulk of the coho run occurred at this time. Live adult coho salmon and coho salmon redds were observed above the BDAs in lower Sugar Creek and lower Miners Creek (Figures 18-19). Three adult female coho carcasses were recovered in the reach above the BDAs in Miners Creek.

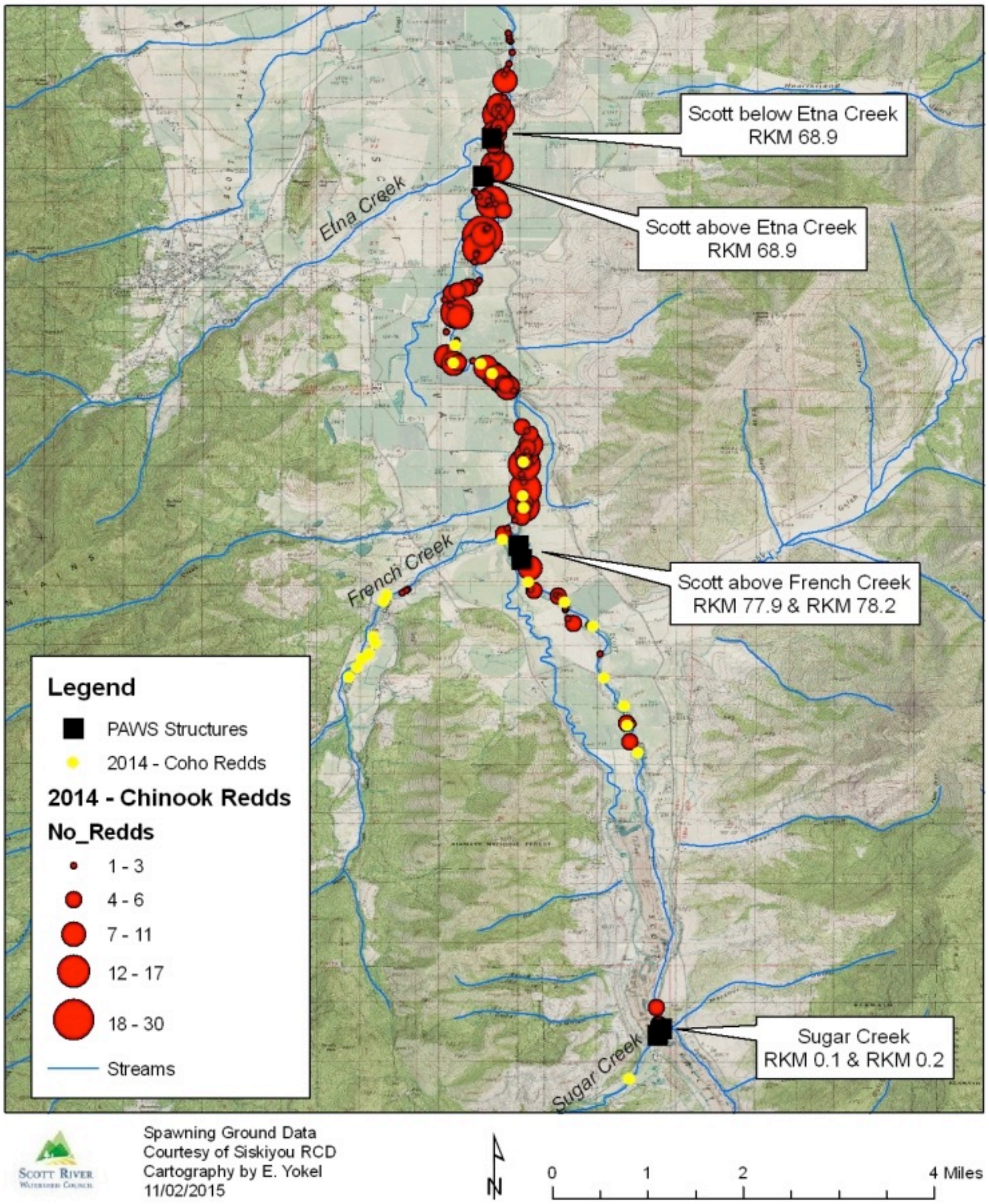


Figure 17. Chinook and coho spawning observed in fall and winter of 2014-2015. Figure 7. PAWS = post-assisted wood structure which is synonymous with beaver dam analogue. Rkm = river kilometer, which refers to the distance upstream from the mouth of a river or creek. The spatial distribution of Chinook salmon redds is relatively consistent from year to year, but coho salmon redd locations are dispersed and variable.

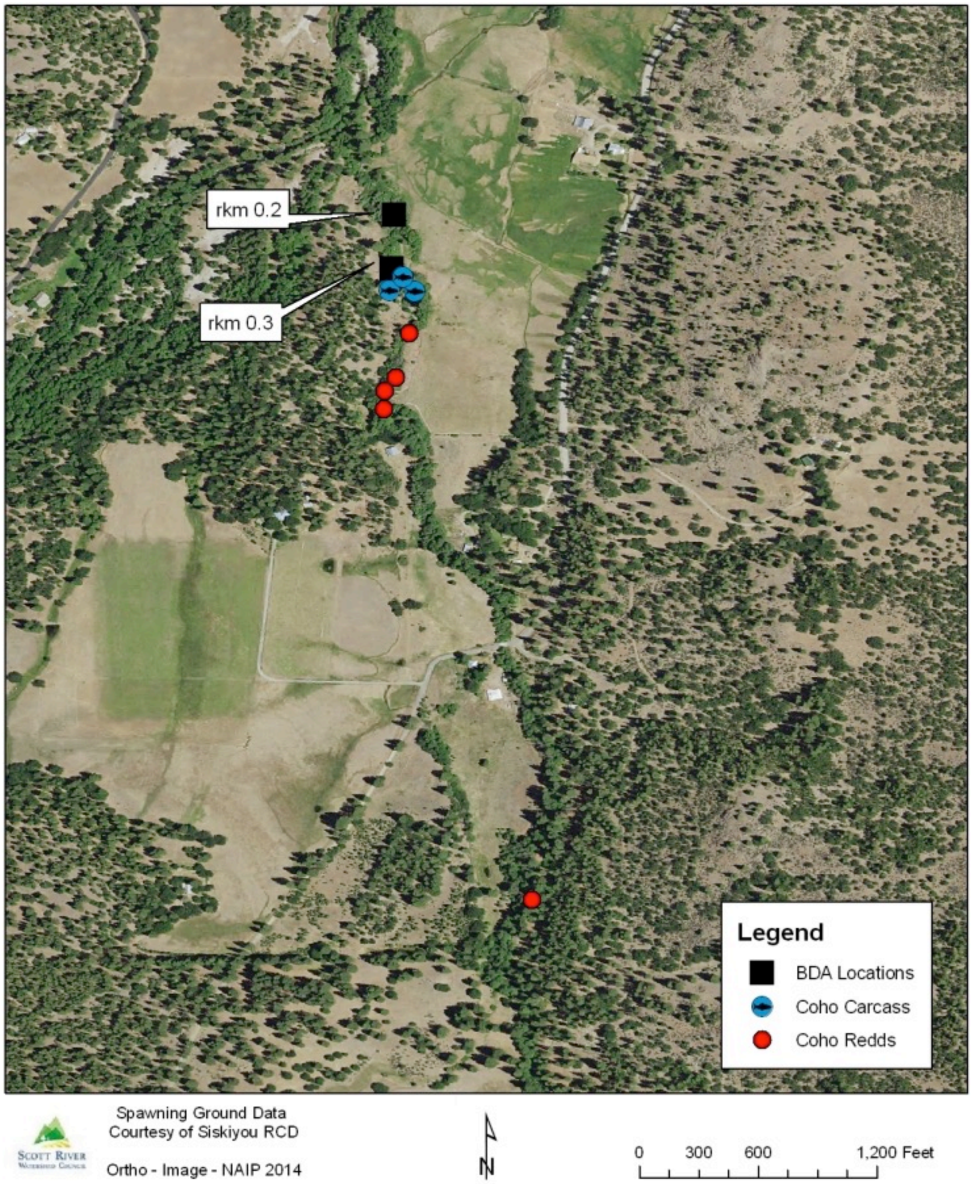


Figure 18. Coho spawning and carcasses observed in Miners Creek in the fall and winter of 2015-2016. Figure 7. BDA = beaver dam analogue. Rkm = river kilometer, which refers to the distance upstream from the mouth of a river or creek, in this case with the confluence of Miners Creek with French Creek, at top left of figure. Flow direction of Miners and French Creeks is towards the top of figure.

Figure 19. Coho spawning and carcasses observed in Sugar Creek in the fall and winter of 2015-2016. Figure 7. BDA = beaver dam analogue. Rkm = river kilometer, which refers to the distance upstream from the mouth of a river or creek. There is no fish blockage at the highway, but the gradient rapidly steepens above the highway and is not ideal for spawning.

Table 8. 2015-2016 Scott River coho salmon spawning ground surveys – (preliminary data, provided by L. Magranet – Siskiyou RCD).

Stream	# Live Fish	# Redds	# Carcasses
Shackleford Creek	5	7	3
Mill Creek	10	44	3
Kidder Creek	0	0	0
Patterson Creek	0	0	0
Etna Creek	0	0	0
French Creek	1	3	1
Miners Creek	7	5	3
Sugar Creek	0	4	0
South Fork Scott	0	0	0

Juvenile Salmon

Pit Tagging

As part of the 2014 CDFW fish relocation effort in the Scott River, an estimated 3,321 coho were released at Sugar Rkm 1 and an estimated 4,709 released at Sugar Creek Rkm 2 in July and August 2014. A sample of the relocated fish were also PIT tagged, which included 149 of the coho released at Sugar Rkm 1 and 90 of those released at Sugar Rkm 2. On September 5 2014, 47 BY2013 coho were captured and tagged at Sugar Rkm 1 (upstream of Hwy 3 bridge) and 60 were PIT tagged between Hwy 3 and the upstream BDAs, which was the downstream most pool in Sugar Creek at that time (dry channel downstream).

Sugar Creek between the two BDAs was dry in the summer of 2014, but when the creek became connected again in the fall of 2014 coho were observed in that location. Several capture efforts took place between the two BDAs from December 2014 to April 2015, resulting in the PIT tagging of 67 BY2013 coho, 89 juvenile steelhead, and two adult steelhead. Fork length of all BY2013 coho tagged and released in Sugar Creek is shown in Figure 20. Capture efforts continued between the two BDAs from May 2015 to Augst 2015 to capture and tag BY2014 coho and additional juvenile steelhead and Chinook salmon. These efforts resulted in the capture and tagging of 124 BY2014 coho, 26 juvenile steelhead, and 10 juvenille Chinook.

Detections of BY2013 coho at the Sugar Creek antenna station began immediately upon reconnection of the creek. The number of individuals detected increased each month as fish from the upstream release locations moved down, and as additional fish were tagged between the two BDAs (Figure 9). The number of individuals detected was highest in April and May, as tagged coho in Sugar Creek outmigrated as age-1 smolts, passing the antenna station on their way out (Figures 21 and 22). Four coho detected upstream of the BDAs from December 2014 through February 2015 were tagged outside of Sugar Creek, indicating that they moved upstream past the downstream BDA (Table 9). All four of those fish were detected in Sugar Creek as late as May 2015, suggesting that they survived to outmigrate as age-1 smolts.

During the winter and spring of 2015, 22 BY2013 coho and 17 juvenile steelhead were detected at both the Sugar Creek PIT station and the PIT station at Scott Rkm 76 (near the French Creek confluence), verifying that those individuals succesfully moved downstream past the BDAs. Fish that leaft Sugar Creek earlier tended to have a longer travel time to reach Rkm 76 (approximately 40 days), wheras fish that left in April and May tended to reach Rkm 76 in less than 5 days (Figure 23).

A total of 124 BY2014 age-0 coho were tagged in Sugar Creek in 2015 (Figure 21). In September, October, and November, 57, 53, and 44 of those fish have been detected at the Sugar Creek antenna station, respectively (Figures 24 and 25), indicating that they are successfully rearing in that location. This cohort is still at large and additional information will be obtained after their smoltification period occurs in the spring of 2016. Due to an eror occurring in the data logging device, we are currently unable to differnetiate between detections at anntenna 1 (downstream of lower BDA) and antenna 3 (upstream of lower BDA) from July through December 2015. Because of this we are unable to conclude whether thagged fish passed the BDAs during that time. All fish captured between the two BDAs either passed downstream over/through the upstream BDA or upstream over/through the downstream BDA, since the location was dry in 2014 and no spawing in known to have occurred in that location.

A total of 115 juvenile steelhead were tagged in Sugar Creek in 2014 and 2015 (Figures 26 and 27). Most of those fish appear to have outmigrated in the spring of 2015, based on their date of last detection at the Sugar Creek antenna station (Figure 28 and 29). Of the 10 Chinook tagged in Sugar Creek, four were detected at the antenna station as late as October and November 2015 (Table 10). Growth data for physically recaptured PIT tagged fish is summarized in Table 11.

During the course of the study the following events occurred which the limited our ablity to assess upstream passage of the BDAs:

Flow around/through the downstream BDA occupied two separate channels which entered the Scott River at different locations. Only one of these channels was fitted with a PIT tag antenna, therefore fish moving up or down the un-monitored channel (north channel) were not detectable.

The BDAs were manually breached on several occasions, and it is unknown if movement past the BDAs occurred while the BDAs were breached.

No fish were tagged downstream of the downstream BDA and no fish were sampled upstream of the upstream BDA.

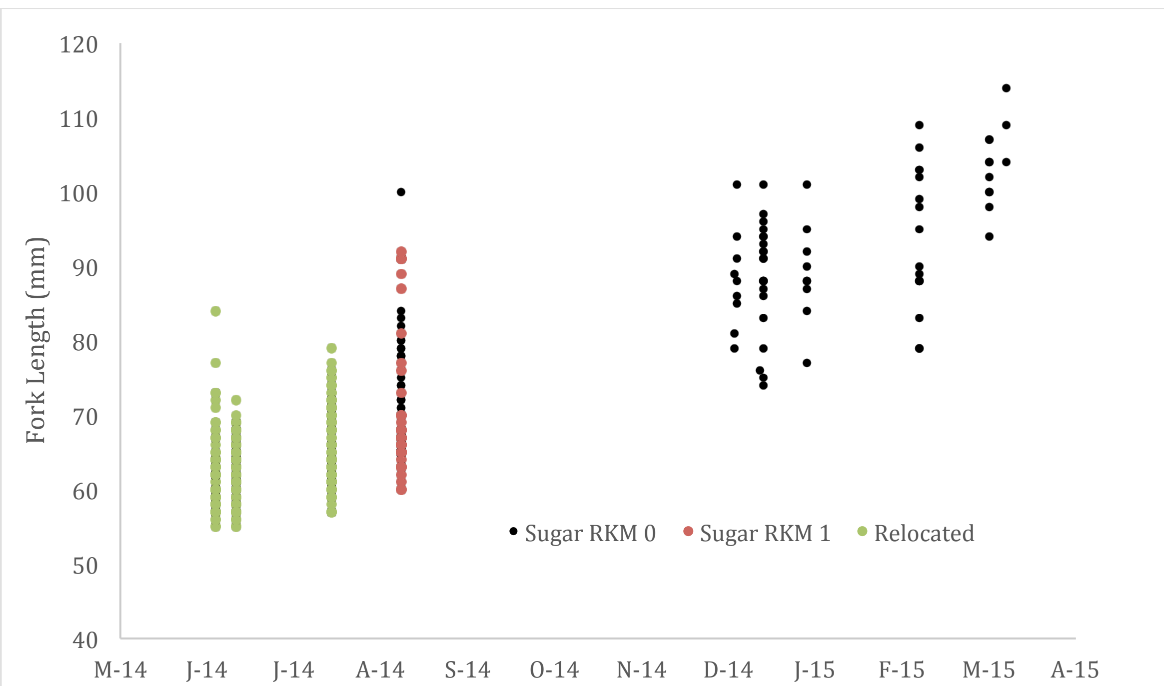


Figure 20. Fork length of brood Year 2013 coho tagged and released in Sugar Creek. Relocated fish were brought form other areas of the Scott River and releases at Sugar Rkm 1 and sugar Rkm 2.

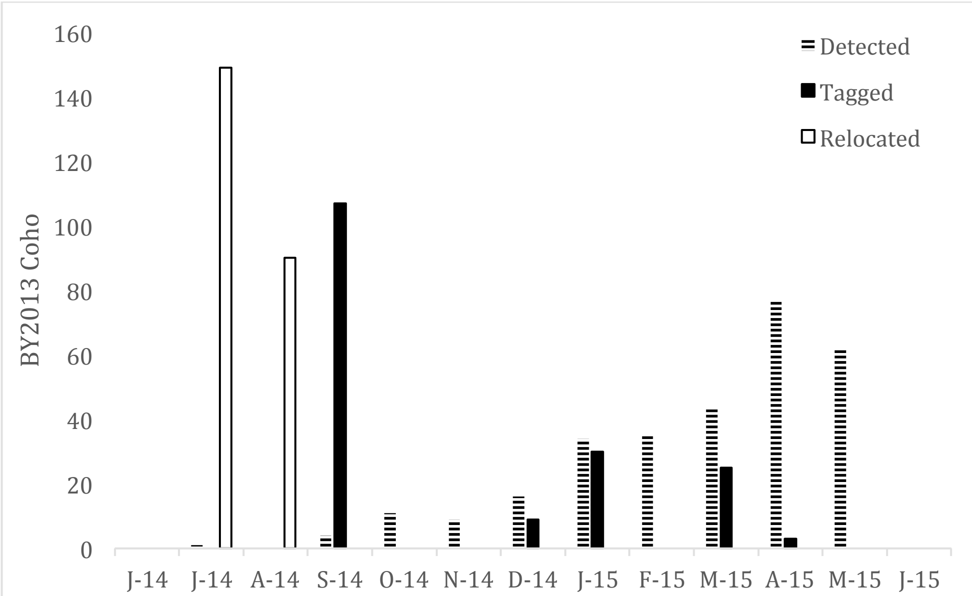


Figure 21. Total monthly number of BY2013 coho tagged and detected in Sugar Creek.

Table 9. Coho detected upstream of the downstream BDA that were tagged outside of Sugar Creek.

Pittag	Species	Date	StationName	MinOfcontactdatetime	MaxOfcontactdatetime
985153000362767	Coho Salmon	6/4/2014	Scott RKM 74	1/6/2015	5/10/2015
989001003304748	Coho Salmon	7/1/2014	South Fork	12/3/2014	5/10/2015
989001003425777	Coho Salmon	7/10/2014	South Fork	1/13/2015	5/3/2015
989001003427058	Coho Salmon	8/7/2014	South Fork	2/16/2015	5/3/2015

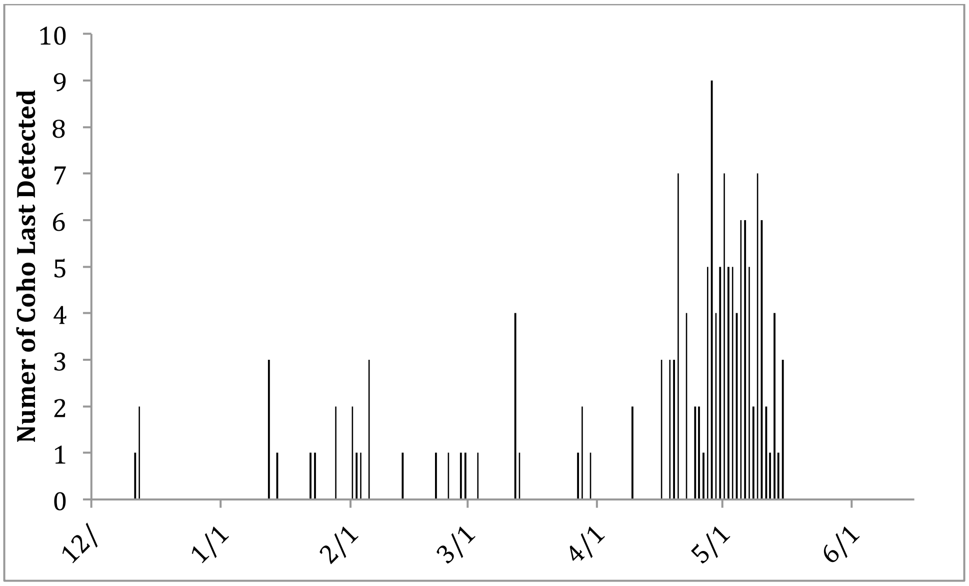


Figure 22. BY2013 coho date of departure from Sugar Creek based on their date of last detection at the Sugar Creek Rkm 0 antenna station.

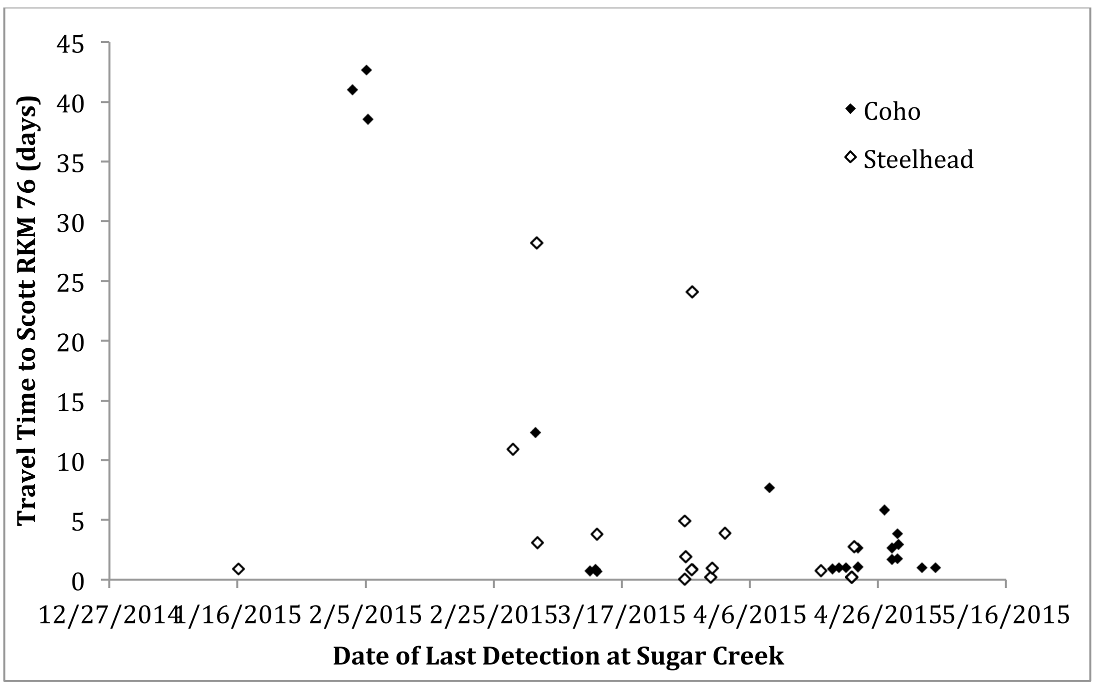


Figure 23. Travel time from Sugar Creek to Rkm 76 (near French Creek confluence) based on last date of detection at Sugar Creek and first date of detection at Rkm 76.

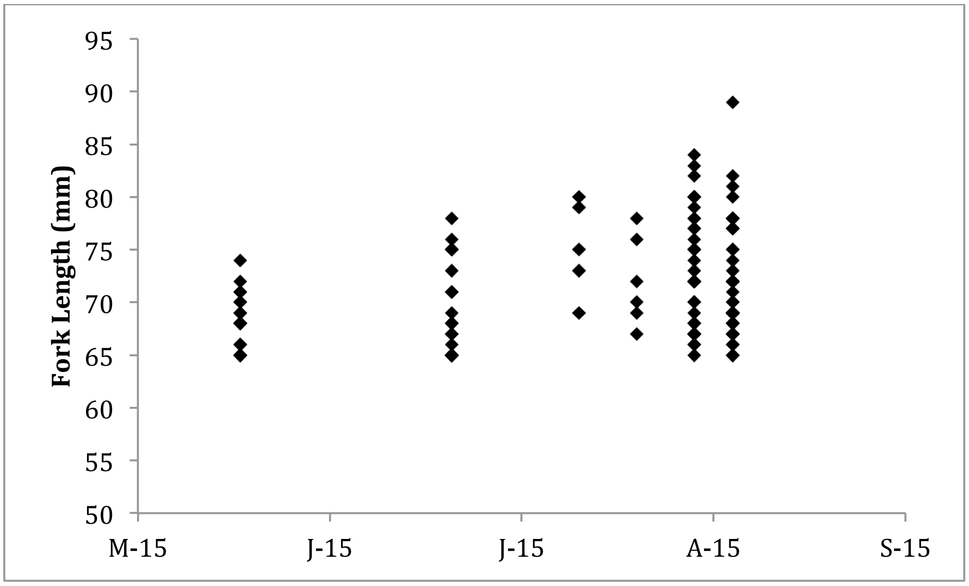


Figure 24. Fork length of BY2014 coho tagged and released in Sugar Creek.

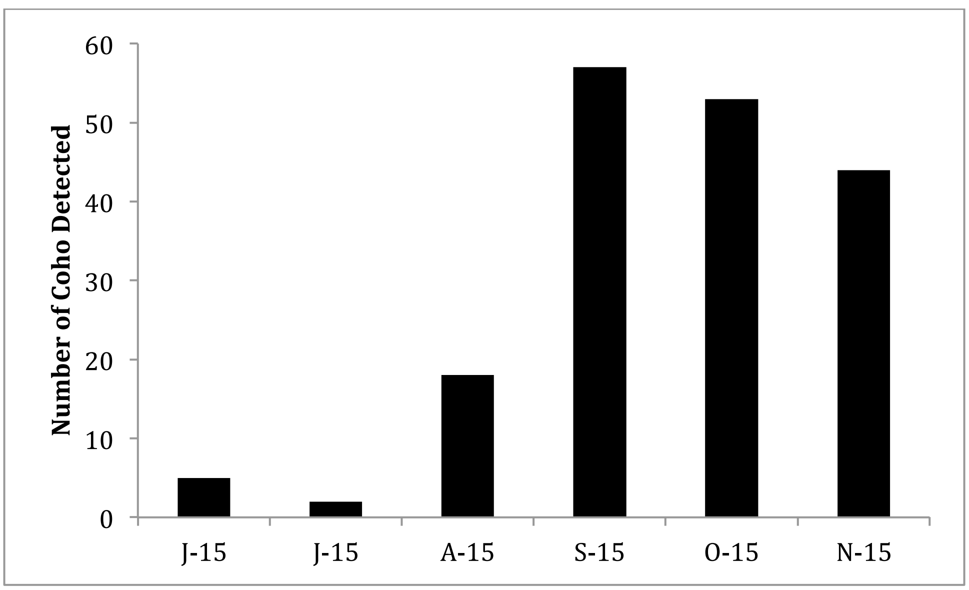


Figure 25. Monthly total number of BY2014 coho detected at the Sugar Creek Rkm 0 antenna station.

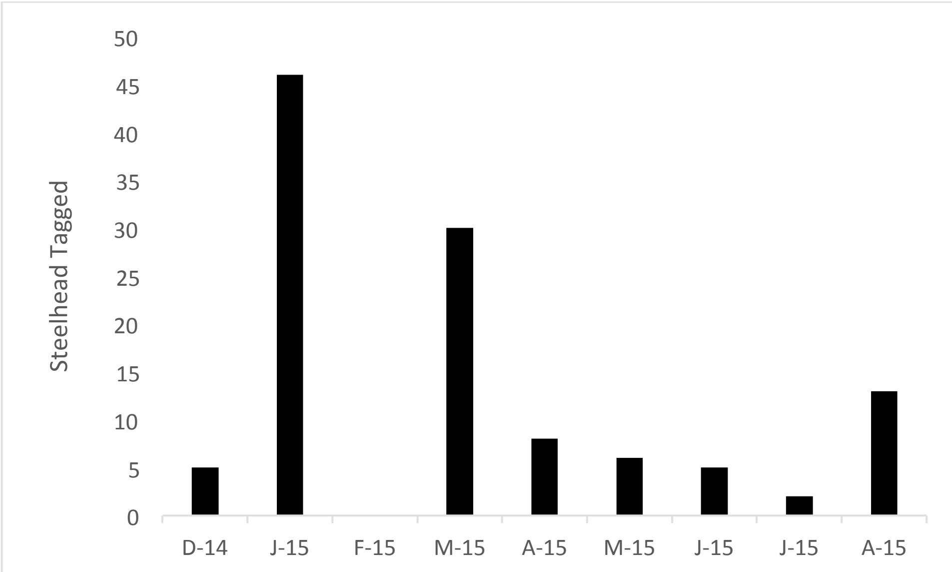


Figure 26. Monthly total number of juvenile steelhead tagged at Sugar Creek in 2014 and 2015.

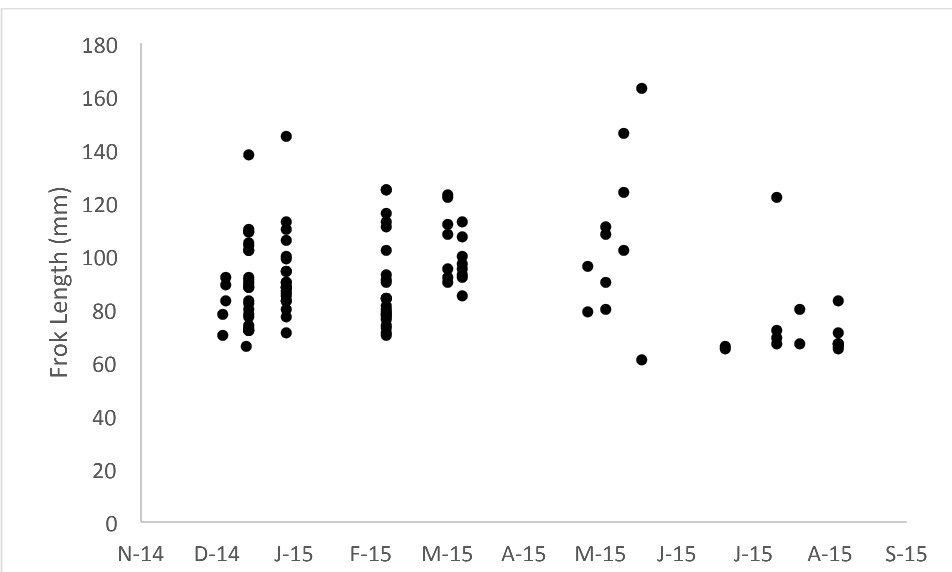


Figure 27. Fork length of juvenile steelhead tagged and released in Sugar Creek in 2014 and 2015.

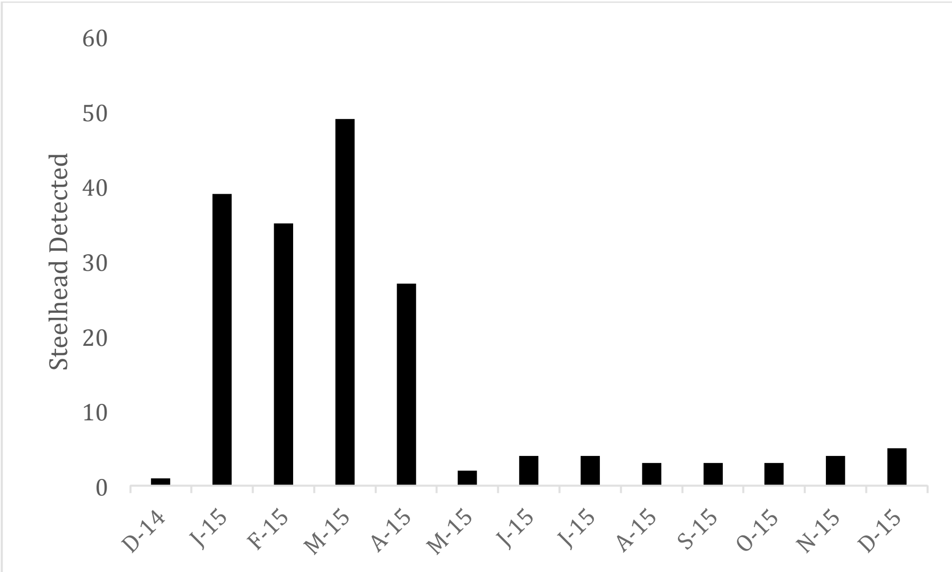


Figure 28. Monthly total number of juvenile steelhead detected at the Sugar Creek Rkm 0 antenna station.

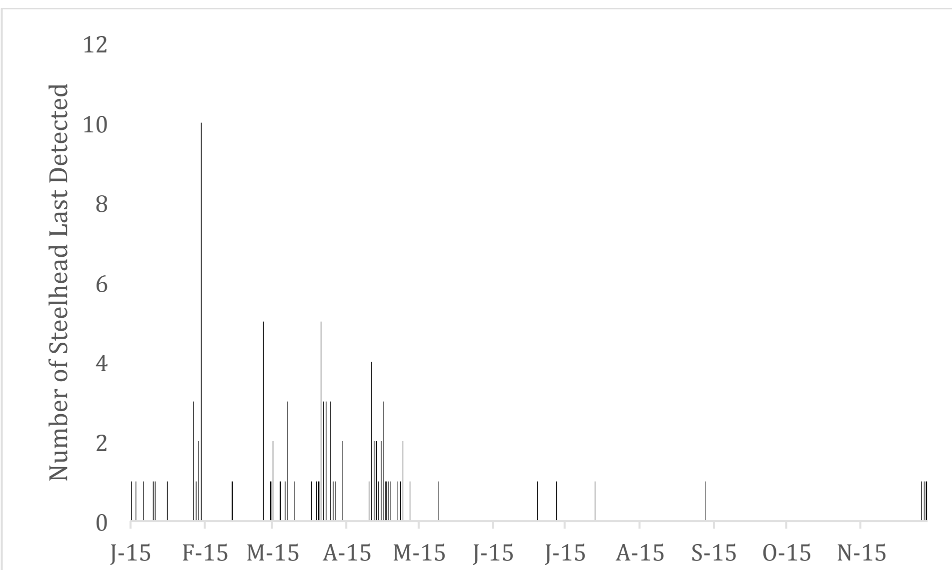


Figure 29. Juvenile steelhead date of departure from Sugar Creek, based on date of last detection at the Sugar Creek Rkm 0 antenna station.

Table 10. Chinook salmon PIT tagged in Sugar Creek in 2015 and their date of last detection.

PIT	Tag Location	Species	Date	Fork Length (mm)	Last Detection (Sugar Rkm 0)
989001001356958	Sugar Rkm 0	Chinook Salmon	7/14/2015	87	11/12/2015
989001001952053	Sugar Rkm 0	Chinook Salmon	7/14/2015	69	

989001001953391	Sugar Rkm 0	Chinook Salmon	7/14/2015	84	11/8/2015
989001003465735	Sugar Rkm 0	Chinook Salmon	8/3/2015	75	
989001001955105	Sugar Rkm 0	Chinook Salmon	8/21/2015	69	10/28/2015
989001001955252	Sugar Rkm 0	Chinook Salmon	8/21/2015	69	10/14/2015
989001001955442	Sugar Rkm 0	Chinook Salmon	8/21/2015	90	
989001003467287	Sugar Rkm 0	Chinook Salmon	8/27/2015	94	
989001003467348	Sugar Rkm 0	Chinook Salmon	8/27/2015	65	
989001003467429	Sugar Rkm 0	Chinook Salmon	8/27/2015	70	

Table 11. Growth data for tagged fish recaptured in Sugar Creek in 2014 and 2015.

	Tag Data			**Recapture Data**					
Species	**Location**	**Date**	**FL(mm)**	**Location**	**Date**	**FL(mm)**	**Days**	**Growth (mm)**	**mm/day**
Coho Salmon	Sugar Rkm 0	9/5/2014	61	Sugar Rkm 0	1/8/2015	94	125	33	0.26
Steelhead Trout	Sugar Rkm 0	12/30/2014	92	Sugar Rkm 0	3/27/2015	106	87	14	0.16
Coho Salmon	Sugar Rkm 0	12/30/2014	91	Sugar Rkm 0	1/23/2015	95	24	4	0.17
Steelhead Trout	Sugar Rkm 0	1/8/2015	89	Sugar Rkm 0	1/23/2015	91	15	2	0.13
Coho Salmon	Sugar Rkm 0	1/8/2015	101	Sugar Rkm 0	3/27/2015	108	78	7	0.09
Coho Salmon	Sugar Rkm 0	1/8/2015	75	Sugar Rkm 0	3/3/2015	92	54	17	0.31
Steelhead Trout	Sugar Rkm 0	1/23/2015	88	Sugar Rkm 0	3/3/2015	96	39	8	0.21
Steelhead Trout	Sugar Rkm 0	1/23/2015	94	Sugar Rkm 0	3/3/2015	105	39	11	0.28
Steelhead Trout	Sugar Rkm 0	1/23/2015	88	Sugar Rkm 0	3/27/2015	97	63	9	0.14
Steelhead Trout	Sugar Rkm 0	3/3/2015	125	Sugar Rkm 0	4/2/2015	138	30	13	0.43
Steelhead Trout	Sugar Rkm 0	3/27/2015	112	Sugar Rkm 0	4/2/2015	113	6	1	0.17
Coho Salmon	Sugar Rkm 0	6/11/2015	71	Sugar Rkm 0	8/21/2015	80	71	9	0.13
Coho Salmon	Sugar Rkm 0	7/14/2015	65	Sugar Rkm 0	8/21/2015	66	38	1	0.03
Coho Salmon	Sugar Rkm 0	8/21/2015	78	Sugar Rkm 0	8/27/2015	78	6	0	0.00

Juvenile Salmon Population Estimates-Aquatic Surveys

May 28th Survey—Juvenile salmonids were found throughout this reach of stream utilizing various aquatic environments including pools, glides and low gradient riffles. The habitat in the PAWS impoundments was found to be very complex with multiple types of instream shelter including overhanging banks, woody debris, emergent and aquatic plants. The diver made every effort to provide thorough fish counts by surveying narrow pathways through aquatic vegetation and wetland areas (Table 12). It is important to point out that the number of fish observed upstream of the upper PAWS structure was not separated at the time of the survey between the impoundment and the channel to the bridge, however, the surveyor reports that most of the observed fish were above the project site.

Juvenile coho and Chinook were close in size and developmental stage (Figure 30). However, young-of-the-year trout had recently emerged from the gravel and were found to be less than 30 mm (Figure 31). A snake was observed emerging from woody debris along the bank of the upper PAWS impoundment and capturing an age 1+ trout. None of the fish observed were handled.

June 19th Survey—Juvenile salmonids were encountered in all habitat units surveyed and were found utilizing various aquatic environments including pools, glides and low gradient riffles. Fish were observed utilizing elements of cover (e.g. overhanging banks, woody debris, emergent and aquatic plants) but were also found in open slow flat water or riffle currents. Steelhead/rainbow trout were the most numerous fish with individuals ranging in size from recently emerged (20-30 mm) to one year residents (around 100 -150+ mm).

Coho were generally found to be right around 60 mm with several larger individuals noted (approximately 80-100 mm) however, it is unclear whether these juveniles are large age 0 or small age 1 fish. None of the fish observed were handled.

The high density of emergent plants within the BDA impoundments provided thick cover that precluded the ability of a diver to obtain complete fish counts (Figure 32 and 33). Therefore, total abundance reported within the project area (the two impoundments) is assumed to be low.

The three sections of this survey (as listed in Table 13) displayed a wide variation in habitat characteristics and water quality. Sugar Creek below the project site is composed of a cobble streambed with a relatively narrow wetted channel and a noticeable current at times. Visibility was excellent through this section (Figures 34-35) and well mixed water temperatures were recorded at 16 °C. For comparison, the upper BDA impoundment is made up of a small substrate (primarily decomposed granite) with fine sediment layers that are easily disturbed. Water clarity through this glide was cloudy and visibility could be considered fair. Fresh beaver scat was noted. Water temperatures were recorded at 18 °C.

Visible distortions in water clarity were observed as a result of the variations in water quality. This could be seen at locations of subsurface inputs from the tailings piles on the South bank of Sugar Creek and near the surface of flat water glides possibly resulting from thermal stratification.

Due to the width of the stream channel in the project area and the complexity of the environment it is recommended that dual divers are employed to survey the two impoundments. Furthermore, it would be valuable to measure the dimensions of each habitat unit at the time of the survey so that volume estimates could be made and salmonid densities calculated.

Table 12. Number of salmonids observed-May 28th survey.

Age Class and Species	0+ Coho	1+ Coho	0+ Chinook	1+ Chinook	0+ Trout	1-2+ Trout
Downstream of Project Site	1	0	32	0	38	2
Lower BDA Impoundment	1	0	3	0	26	1
Upper BDA Impoundment to Bridge	770	0	13	0	70	0
Total Fish Counted	**772**	**0**	**48**	**0**	**134**	**3**

Table 13. Number of salmonids observed-June 19th survey.

Age Class and Species	0+ Coho	1+ Coho	0+ Chinook	1+ Chinook	0+ Trout	1+ Trout
Downstream of Project Site	255	0	95	0	1,005	15
Lower BDA Impoundment	350	0	20	0	500	5
Upper BDA Impoundment	320	0	0	0	500	0
Total Fish Counted	**925**	**0**	**115**	**0**	**2,005**	**20**

Figure 30. Juvenile coho and Chinook salmon on May 28th, 2015, showing the similarity in size (photo: L. Magranet).

Figure 31. Steelhead/rainbow trout fry on May 28th, 2015 (photo: L. Magranet).

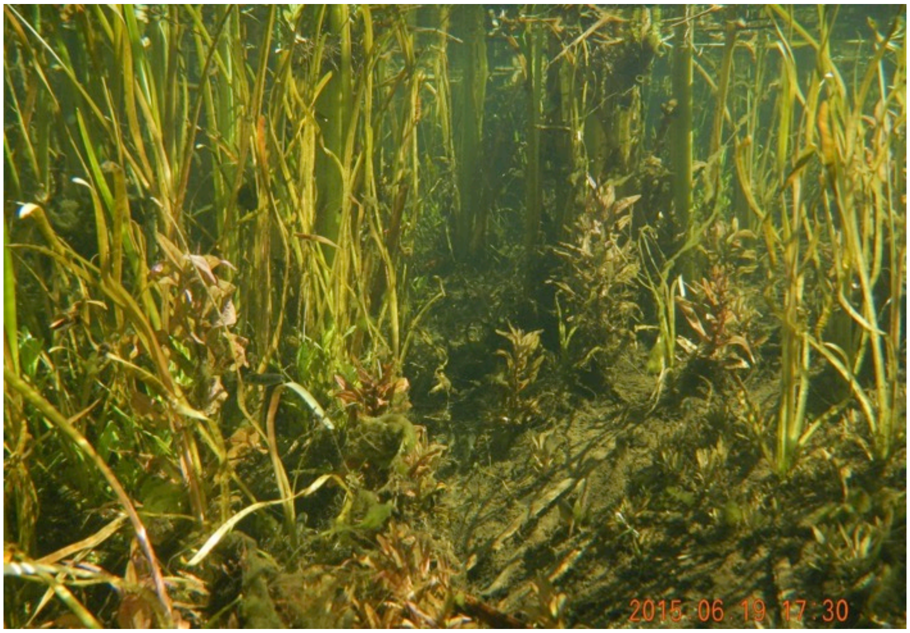


Figure 32. Emergent plants within the BDA impoundments that provide ample cover for rearing salmonids, June 19th, 2015. Compare with photo (below) of Sugar Creek below the BDAs (photo: L. Magranet).

Figure 33. Coho and trout young of the year utilizing the lower BDA impoundment, June 19th, 2015 (photo: L. Magranet).

Figure 34. Sugar Creek in the foreground entering the Scott River on June 19th, 2015 (photo: L. Magranet). Note the lack of pools and generally simplified habitat structure. Compare with deep pools with complex habitat created by the BDAs (above).

Figure 35. Chinook young-of-the-year encountered in Sugar Creek, in the limited habitat downstream of the project area, June 19th, 2015.

Habitat Capacity

The estimated habitat capacity of coho salmon production potential for the Sugar Creek BDA ponds (when completely full) and downstream side channel habitat are provided in Table 14. The capacity estimates of Roni et al. (2008) and Beechie et al. (2015) are based primarily on the variables of depth, velocity and cover and do not take into account water quality parameters that may limit production such as high temperatures and low dissolved oxygen.

Table 14. Estimate of juvenile coho production potential for the Sugar Creek BDA ponds and the downstream side channel habitat. Estimate 1 is based on Beechie et al. 2015 Comparison of potential increases in juvenile salmonid rearing habitat capacity among alternative restoration scenarios, Trinity River, California, and Beamer et al. unpublished.; Estimate 2 is based on Roni et al. 2008. Global Review of the Physical and Biological Effectiveness of Stream Habitat Rehabilitation Techniques.

Sugar Creek BDA Habitat	Area (m^2)	Estimate 1	Estimate 2
Main linear pond			
Edge area (1.28 f/m^2)	600	768.0	
non-edge area (0.32 f/m^2)	17400	5541.1	
Total area (0.37 f/m^2)	18000		6660.0
Total pp main pond		6309.1	6660.0
Shallow (40 m) vegetated "side" wetland			
Total area (0.73 f/m^2 or 0.37 f/m^2)	1500	1095.0	555.0
Subtotal BDA ponds production potential		7404.1	7215.0
Side Channel at Sugar Creek mouth			
Edge area (1.28 f/m^2)	215	275.2	
Non-edge area (0.32 f/m^2)	200	64.0	
Total area (0.37 f/m^2)	415		153.6
Subtotal side channel production potential		339.2	153.6
Total production potential		7743.3	7368.6

Fish Passage

Orifice Passage—Our simple passage analysis shows that a BDA with a headwater depth (H) of 2.0 feet would likely have a velocity (V) at least six times greater than the allowable culvert passage criteria for juvenile salmonids (see Test 1 in Table 15). Considering the standard orifice coefficient (C) of 0.61 is representative of a relatively smooth hydraulic opening compared to a BDA, we explored what changes in C and H would be required to attain a V= 1.0 ft/s. For Test 2, C was reduced to 0.09, while keeping H at 2.0 ft. and for Test 3, H had was reduced to 0.5 ft in order to approximate V equal 1.0 ft/s. This analysis shows that orifice flow paths at the bottom of a dam can only be effective fish passage under low head conditions or with an unrealistic discharge coefficient (Table 15).

Side Channel Passage—Our analysis evaluated a small trapezoidal side channel that could be configured to circumvent a BDA similar to the Sugar Creek site. This hypothetical side channel was configured to have 1:1 side slopes, a bottom width of 0.5 feet, a minimum flow depth of 0.5 feet, and channel slope of 0.5%. This simple calculations show small channels have the hydraulic conditions need to provide adequate juvenile passage.

Table 15. Evaluation of orifice and side channel hydraulics for juvenile fish passage.

Hydraulic Parameters	Units	Hydraulic Flow Path				
		Orifice			Side Channel	
		Test 1	Test 2	Test 3	Test 4	Test 5
Headwater or flow depth (H)	ft	2.00	2.00	0.05	0.50	0.50
Channel width or diameter (D)	ft	0.71	0.71	0.71	0.50	0.50
Cross-sectional area (A)	ft^2	0.39	0.39	0.39	0.50	0.50
Wetted Perimeter (WP)	ft	0.19	0.19	0.19	1.91	1.91
Hydraulic Radius (R)	ft	2.13	2.13	2.13	0.26	0.26
Slope (s)	ft/ft	na	na	na	0.005	0.005
Hydraulic Coeffient (C, n)	varies	**0.61**	**0.09**	**0.61**	**0.035**	**0.045**
Velocity (V)	ft/s	**6.92**	**1.02**	**1.09**	**1.2**	**0.96**
Discharge (Q)	ft^3/s	**2.73**	**0.40**	**0.43**	**0.62**	**0.48**

Physical Habitat-Water Quality

Surface Water Temperatures

2015 was the fourth year of drought with snow depth and equivalent water content in the surveyed courses of the Scott River Watershed at less than 1% of the historic average (USDA – KNF News Release – No date). A significant portion of the mainstem Scott River became dry with the connected areas having the highest maximum MWATs during the period of record for the Scott River temperature monitoring program 1998 to present.

Mainstem—Stream temperature was recorded at ten sites in the mainstem Scott River (Table 16 and Figure 36). Five locations were dry during a period of base flow and it is unknown if the pool location below Young's Dam (Rkm 75) was connected throughout the season. A temperature logger was deployed directly below BDA Rkm 78.2 that failed to collect data. The temperature logger deployed above BDA Rkm 78.2 was placed in the pond. In the future, a logger deployed in a riffle habitat directly above the pond is necessary to document the effect of the BDA pond on stream temperatures.

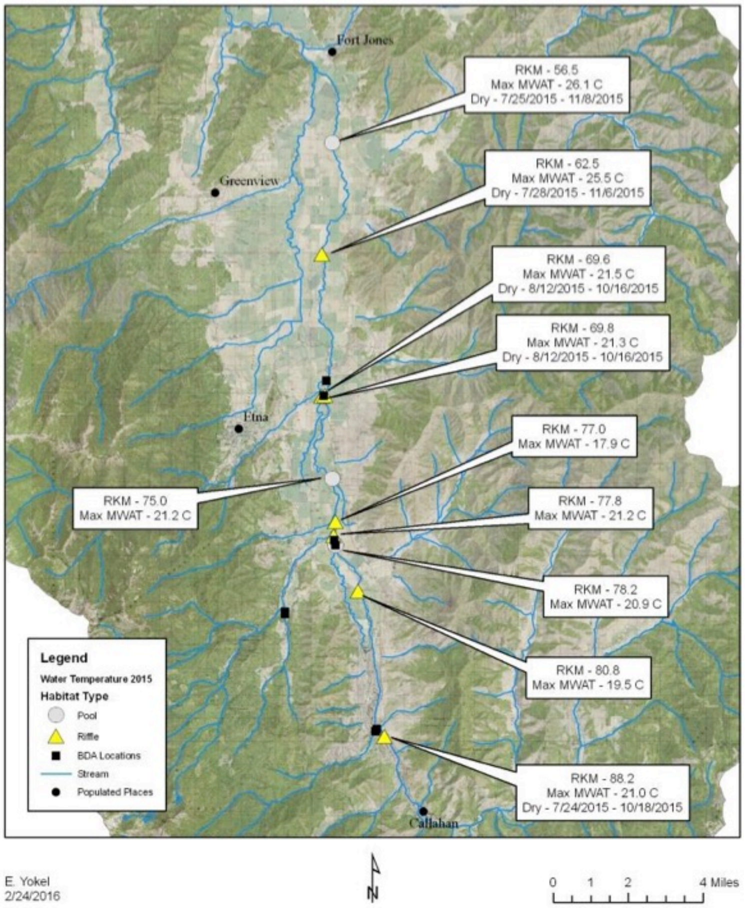


Figure 36. Maximum moving weekly average temperatures (MWAT) at surface water monitoring locations on the mainstem of the Scott River. Rkm = river kilometer, which refers to the distance upstream from the mouth of a river or creek.

Table 16. Scott River Water Temperature – Maximum MWAT at ten locations in the mainstem Scott River. Rkm = river kilometer upstream from the mouth of the Scott River.

Site	RKM	Max MWAT	Date	Dry Begin	Dry End
Scott Tailings - RM 36	88.2	21	7/7/2015	7/24/2015	10/18/2015
Scott River above Fay Lane	80.8	19.5	7/22/2015		
Scott River above BDA RKM 78.2	78.2	20.9	7/7/2015		
Scott River above French Creek	77.8	21.2	7/7/2015		
Scott River below French Creek	77	17.9	7/6/2015		
Scott River below Youngs Dam	75	21.2	7/7/2015		
Scott River above BDA RKM 69.7	69.8	21.3	7/22/2015	8/12/2015	10/16/2015
Scott River below BDA RKM 69.7	69.6	21.5	7/7/2015	8/12/2015	10/16/2015
Scott RM 39	62.5	25.5	7/7/2015	7/28/2015	11/6/2015
Scott River above Serpa Lane	56.5	26.1	7/7/2015	7/25/2015	11/8/2015

Sugar Creek—The maximum MWAT was calculated for each stream temperature site in the lower Sugar Creek temperature monitoring network deployed on 8/18/2015 (Table 17). Temperatures generally increased from an upstream to downstream direction, and as the stream moved from a steeper, narrower stream with a closed canopy to a wider, low-gradient stream with limited canopy coverage as it moved through the tailings reach below the highway. For example, the maximum MWAT stream temperature increased from 16.4° C at the upstream station (STA 11+00) to 17.9° C at STA 6+00 located above a dry reach that extended through STA 5+50 and 5+00. The pool at STA 4+50 above the BDA Rkm 0.2 (STA 4+17) exhibited the highest MWAT in the monitored reach (21.4° C). The stream temperature rapidly cooled to 18.2° C at STA 3+00 and 18.0° C at STA 2+50 and 2+00 (location of the majority of observed salmonids during the lowest flow period in the BDA Rkm 0.1 pond) and warmed slightly to 18.4°C at STA 0+50 (Table 17).

Temperatures were also compared between the bottom of the water column and mid water column. No appreciable differences were observed between temperatures mid column and at the stream bed surface (Table 17 and Figure 37).

The daily average water temperature of the four permanent temperature dataloggers in Sugar Creek (Rkm 1.0 – Rkm 0.1) is displayed in Figure 38. Daily average water temperatures are similar at all four stations from early April through early July, a time that includes the peak temperatures for 3 of the 4 sites, roughly coincident with day length. (Figure 38). Beginning in mid-July, significant warming is observed between Rkm 0.4 and Rkm 0.1 in the reach that flows through the tailings . The riffle below the BDA Rkm 0.1 (Rkm 0.1 logger) was observed to be disconnected on 8/24/2015 and the datalogger was moved from the riffle habitat downstream to a disconnected pool. The Rkm 0.1 datalogger was returned to the riffle location on 9/21/2015. The daily average water temperature of the Rkm 0.1 and Rkm 0.2 dataloggers in the exposed tailings reach was warmer than the daily average at Rkm 0.4 and Rkm 1.0 from late July and the difference extended through mid November (Figure 38).

Throughout the winter months, the downstream locations had more stable and warmer temperatures than the upstream station at Rkm 0.4 suggesting a stronger groundwater influence. The off channel pond near Rkm 0.3 is completely groundwater fed and it had the warmest and most stable winter stream temperatures (Figure 39).

This effect is more clearly illustrated in Figure 40, which shows temperature fluctuations over the course of 9 months for surface water and groundwater monitoring stations. The surface water stations that are dominated by stream flow (Rkm 10 and 0.4) fluctuate the most, both day to day and seasonally, while the groundwater-fed pond (SUMW1), a Sugar Creek at Rkm 0.2 near a groundwater spring (SUMW2) and the groundwater well near Rkm 0.1 (SUMW3) fluctuate the least.

Table 17. Maximum moving weekly average temperatures (MWAT) documented in Sugar Creek.

Station	Location	Max MWAT (C)	Max MWAT Date
0+50	Bottom	18.4	8/29/2015
0+50	1.5 ft from bottom	18.4	8/29/2015
1+00	Bottom	18.4	8/29/2015
1+00	1.5 ft from bottom	18.3	8/29/2015
1+50	Bottom	18.2	8/29/2015
2+00	Bottom	18	8/29/2015
2+00	2.0 ft from bottom	18.2	8/26/2015
2+50	Bottom	18.2	8/31/2015
2+50	1.5 ft from bottom	18	8/30/2015
3+00	Bottom	18.2	8/30/2015
3+00	1.3 ft from bottom	18.2	8/30/2015
3+50	Bottom	18.5	8/29/2015
4+00	Bottom	20.1	8/29/2015
4+50	Bottom	21.4	8/29/2015
5+00	Bottom		dry
5+50	Bottom		dry
6+00	Bottom	17.9	8/27/2015
6+50	Bottom	17.7	8/27/2015
7+00	Bottom	17.4	8/29/2015
7+50	Bottom	17.5	8/29/2015
8+00	Bottom	16.9	8/29/2015
8+00	2.0 ft from bottom	17.1	8/29/2015
8+50	Bottom	17.1	8/29/2015
9+00	Bottom	17.1	8/29/2015
9+50	Bottom	16.6	8/29/2015
9+50	2.0 ft from bottom	16.3	8/29/2015
10+00	Bottom	16.6	8/29/2015
10+50	Bottom	16.6	8/29/2015
11+00	Bottom	16.4	8/29/2015
SC 0+00	Bottom	18.6	8/29/2015
SC 0+50	Bottom	18.5	8/30/2015
SC 0+88	Bottom	18.1	8/31/2015

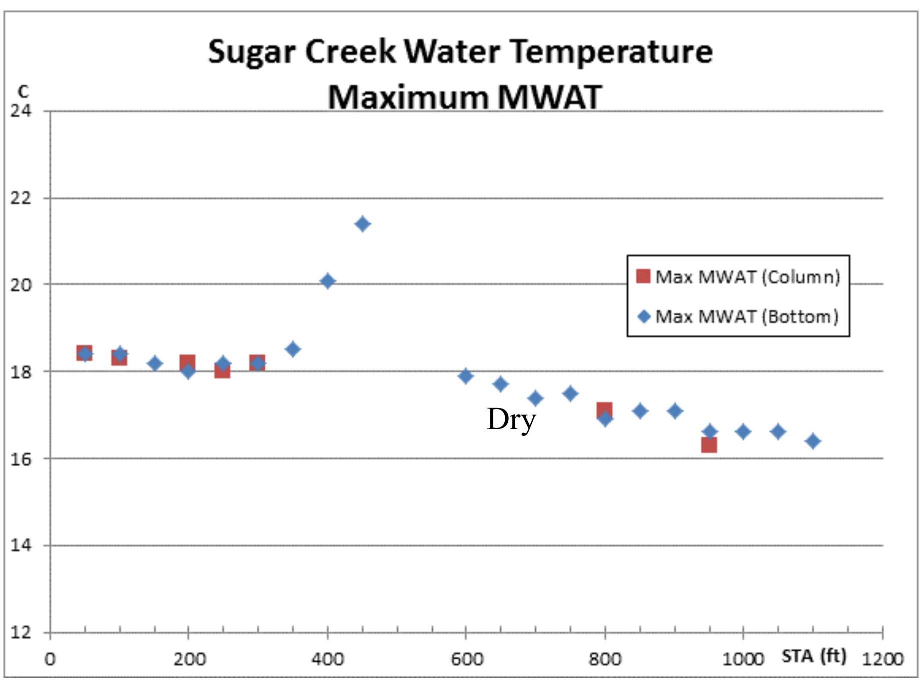


Figure 37. Maximum moving weekly average temperatures (MWAT) documented in Sugar Creek in the middle of the water column and at the bottom. Temperatures are in degrees Celsius. Distances (feet) are upstream from the mouth of Sugar Creek.

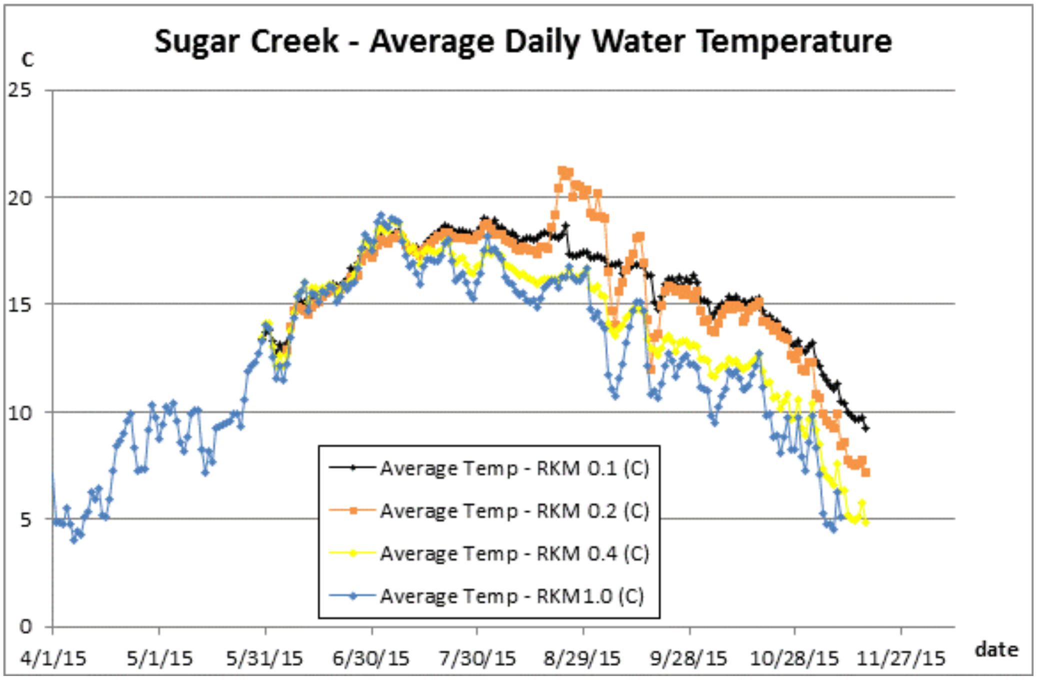


Figure 38. Daily average water temperature for four temperature monitoring stations on Sugar Creek. Rkm 1.0 and Rkm 0.4 are in narrow reaches with or just below extensive canopy cover, while Rkm 0.2 and 0.1 are located in the tailings reach, where the canopy cover is limited and the stream is wider. Within this reach, the banks consist of steep piles of coarse cobble that make establishment of riparian vegetation difficult.

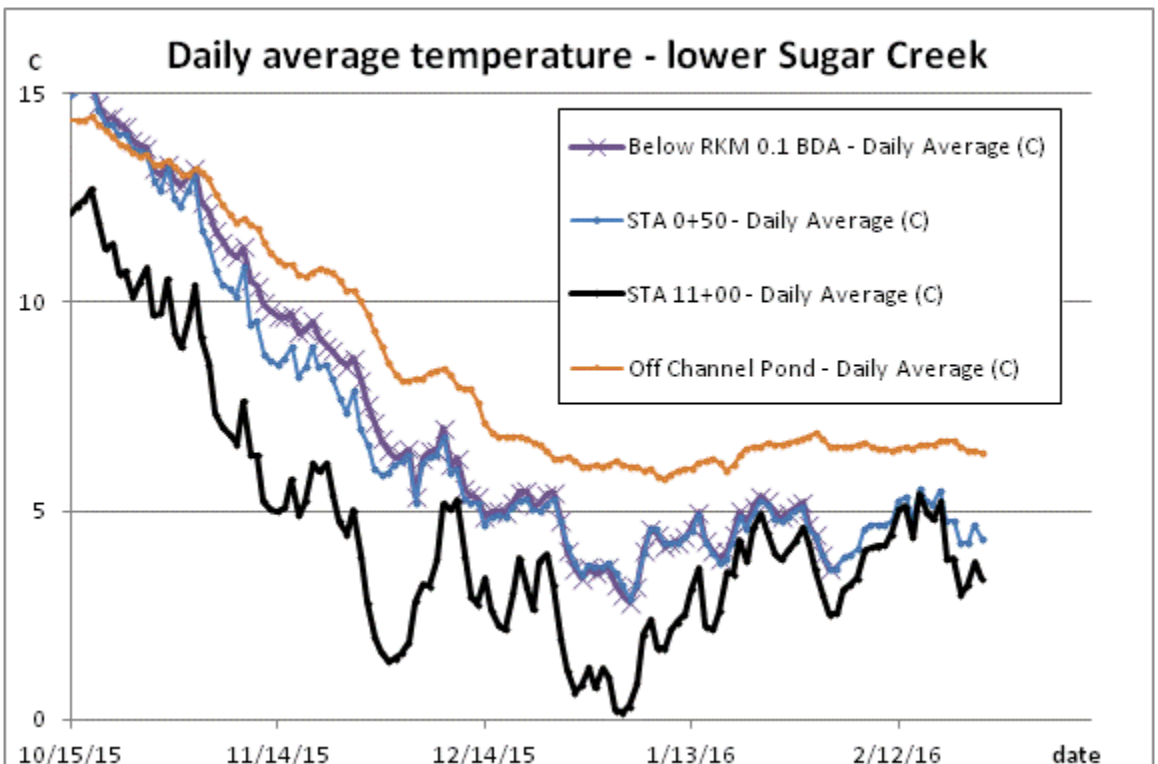


Figure 39. Daily average winter time water temperature (^{0}C) fluctuations of surface water stations in lower Sugar Creek compared with the nearby off channel pond. STA0+50 = Rkm 0.1, STA 11+00 = Rkm 0.4. Off channel pond is near Rkm 0.3 on river right (see Figure 12).

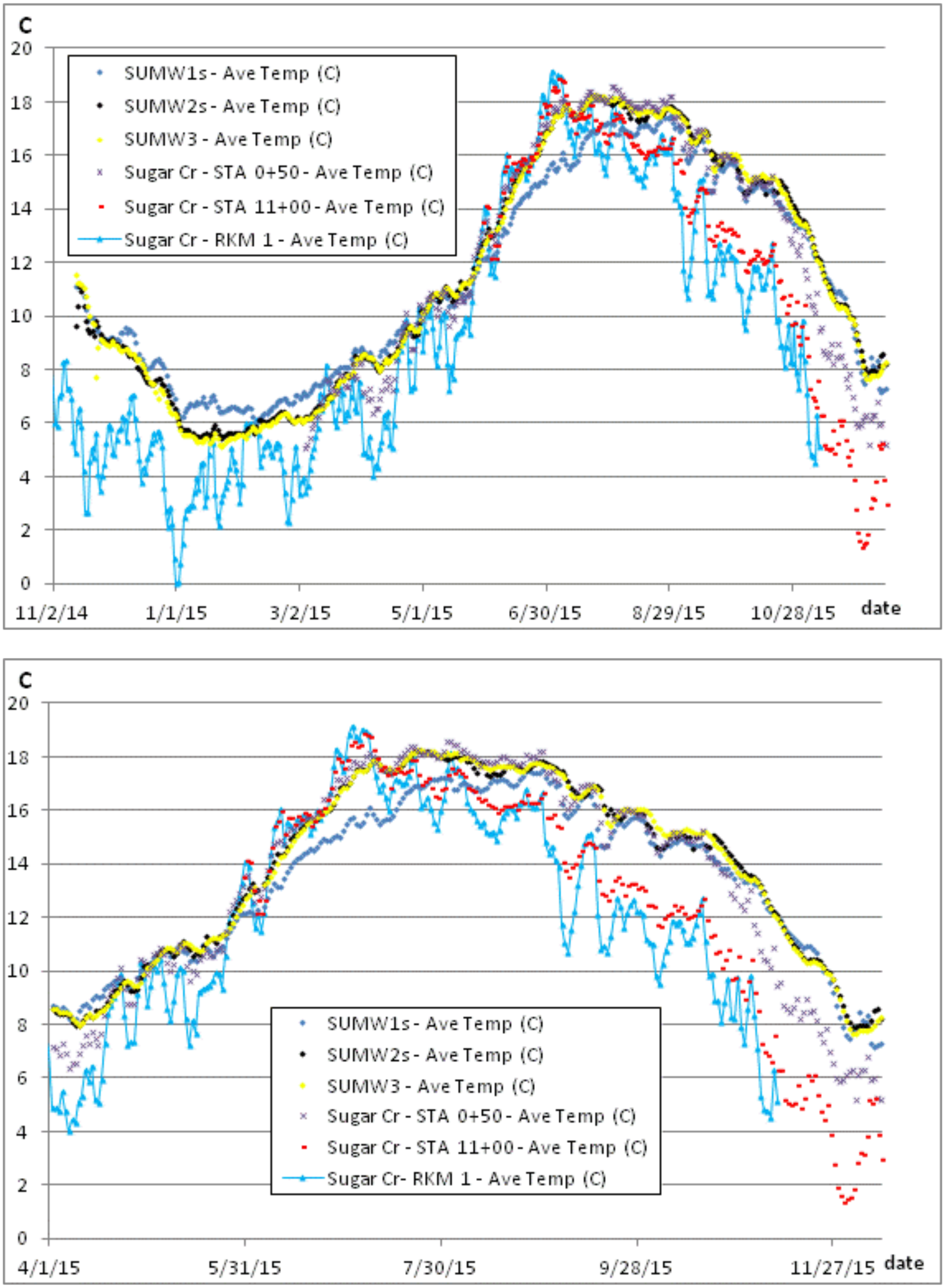


Figure 40. Comparison of average daily water temperatures (^{0}C) between groundwater (SUMW3 & SUMW2s) and surface water stations in Sugar Creek. Top: from11/2/14-11/30/15; Bottom: From 4/1/15-11/30/15, to provide additional detail.

Air Temperatures

Daily air temperatures for Sugar Creek and Callahan are provided in Figures 41 and 42. These are helpful for providing context to the stream temperatures observed. Air temperatures peaked in June, coincident with the longest days of the year. Average daily temperatures were usually above 18 ^{0}C and often above 20 ^{0}C until the beginning of September.

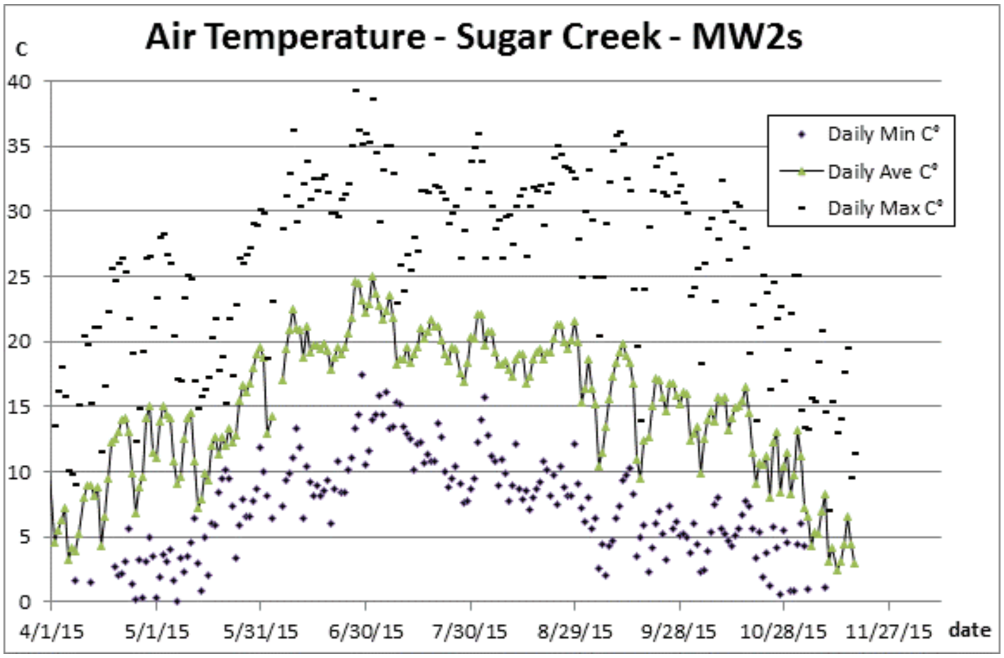


Figure 41. Average air temperatures at Sugar Creek Monitoring Well 2.

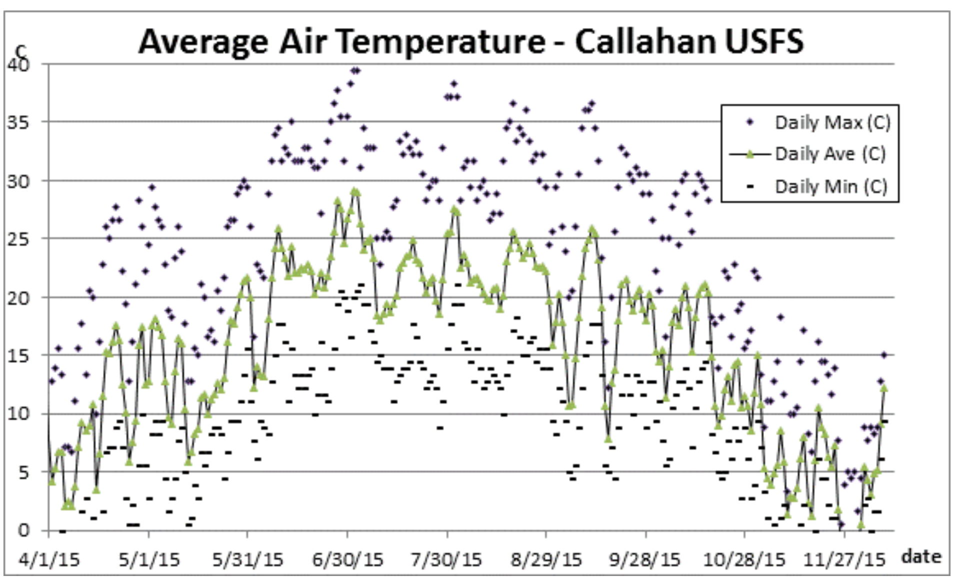


Figure 42. Average daily air temperature at the Callahan USFS Station.

The maximum MWAT for the air temperature at all three stations occurred on the same date – July 2nd, 2015 (Table 18).

Table 18. Air temperature – Maximum MWAT

Site	Max MWAT	Date
Callahan Air Temperature	27.6	7/2/2015
Sugar Creek Air Temperature	23.7	7/2/2015
Scott River at Etna - Air Temperature Riparian	25.1	7/2/2015

Dissolved Oxygen

The dissolved oxygen (DO) dataloggers in lower Sugar Creek were non stationary in order to document the DO levels in a wide range of representative habitats of the reach. The pond above BDA Rkm 0.1 was monitored for the entirety of the season- the logger was initially placed at STA 0+50 – an area of relatively deep water with little fish cover elements but a population of observed juvenile salmonids. As the water surface elevation (WSE) declined towards the nadir the majority of the juvenile salmonids were observed at the deeper water habitat extending through STA 2+00 – STA 2+50. The DO logger was moved from STA 0+50 to STA 2+00 during the period of lowest surface water WSE when the fish were observed to be concentrated on this location and there was concern that STA 0+50 would become disconnected.

The second logger was initially deployed in the BDA Rkm 0.2 pond (STA 4+00). This logger was moved upstream to STA 10+83 in a shallow pool (d = 0.95 feet on 8/18/2015) directly downstream from a riffle (STA 11+00, Rkm 0.4 temperature logger).

The DO concentration (mg/L) observed at STA 10+83 above the ponding of the BDAs was above 4 mg/L throughout the monitoring period. The location was below 4.5 mg/L on 8/26 and 8/27/2015 with a minimum DO of 4.3 mg/L observed on 8/27/2015. A total of ten occurrence of DO levels less than 4 mg/L occurred (Table 19). Two of the ten occurrences of observed DO less than 4.0 mg/L extended to an entire hour. Only one occurrence on 8/28/2015 at STA 0+50 lasted more than an hour with a minimum DO level of 2.1 mg/L.

Table 19. Duration of Instances of DO less than 4.0 mg/L in lower Sugar Creek. Two of the ten occurrences of observed DO less than 4.0 mg/L extended to an entire hour. Only one occurrence on 8/28/2015 at STA 0+50 lasted more than an hour with a minimum DO level of 2.1 mg/L.

Date	Site	Begin Time DO < 4.0 mg/L (PST)	End Time DO < 4.0 mg/L (PST)	Time DO < 4.0 mg/L (hours)	Minimum DO (mg/L)
7/30/2015	STA 4+00	22:40	22:55	0.3	3.6
7/31/2015	STA 4+00	2:30	2:35	0.1	3.8
8/19/2015	STA 0+50	5:50	6:35	0.8	3.7
8/20/2015	STA 0+50	4:30	4:55	0.4	3.8
8/22/2015	STA 0+50	5:15	6:15	1.0	3.6
8/25/2015	STA 0+50	5:55	6:10	0.3	3.3
8/28/2015	STA 0+50	4:10	6:50	2.7	2.1
9/12/2015	STA 2+00	1:35	2:10	0.6	3.6
9/16/2015	STA 2+00	3:55	3:55	0.1	3.8
9/17/2015	STA 2+00	0:05	0:10	0.1	3.8

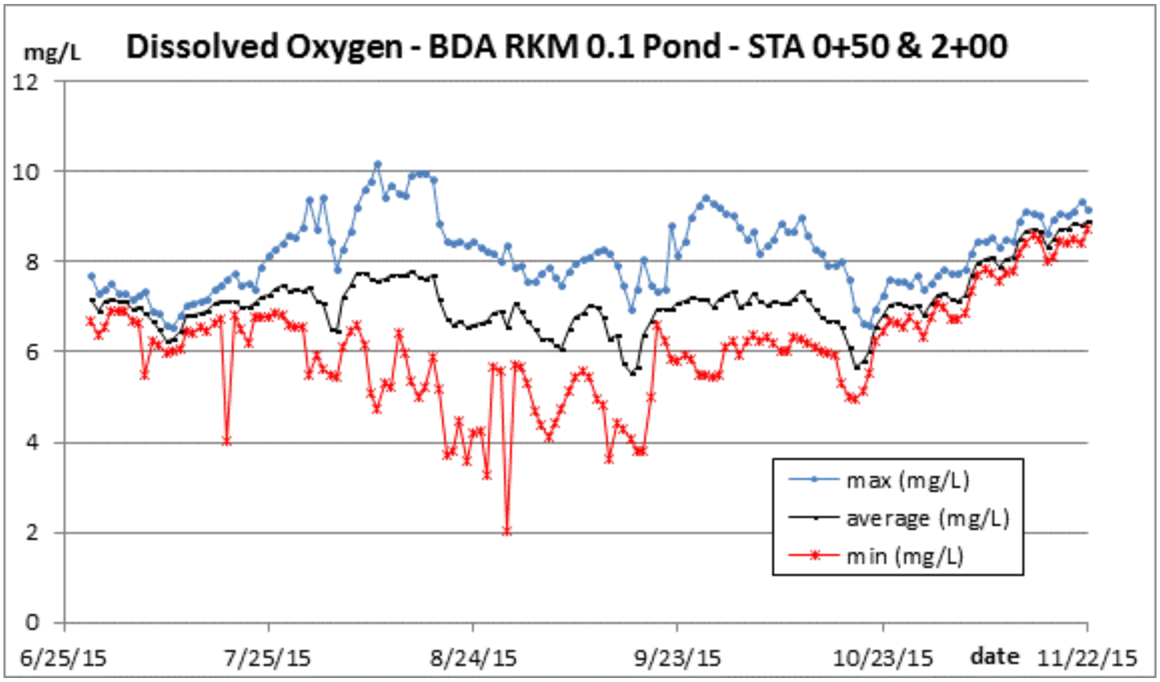


Figure 43. Daily average, maximums and minimums for Dissolved Oxygen (mg/L) in BDA Rkm 0.1 pond.

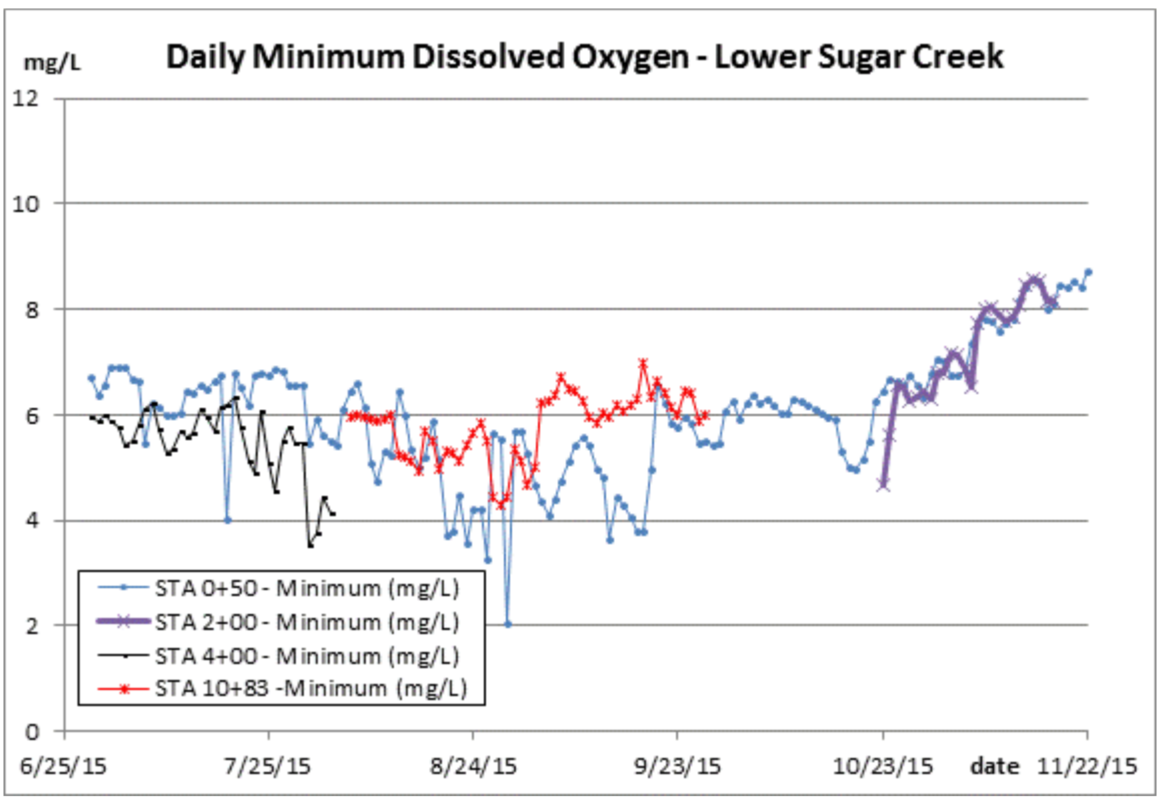


Figure 44. Daily minimum Dissolved Oxygen (mg/L) – all sites lower Sugar Creek.

Physical Habitat-Water Quantity

Hydrographs and rainfall- Scott River near Fort Jones

Stream discharge graphs for the USGS gage station on the Scott River near Fort Jones are provided in Figures 45-48, while precipitation graphs are provided in Figures 49-50.. These are helpful for providing context to the stream temperatures observed. There was a fairly large flood event in early February 2015, which exceeded 15,000 cfs, but from July through November of 2015, low flows were consistently below 10 cfs.

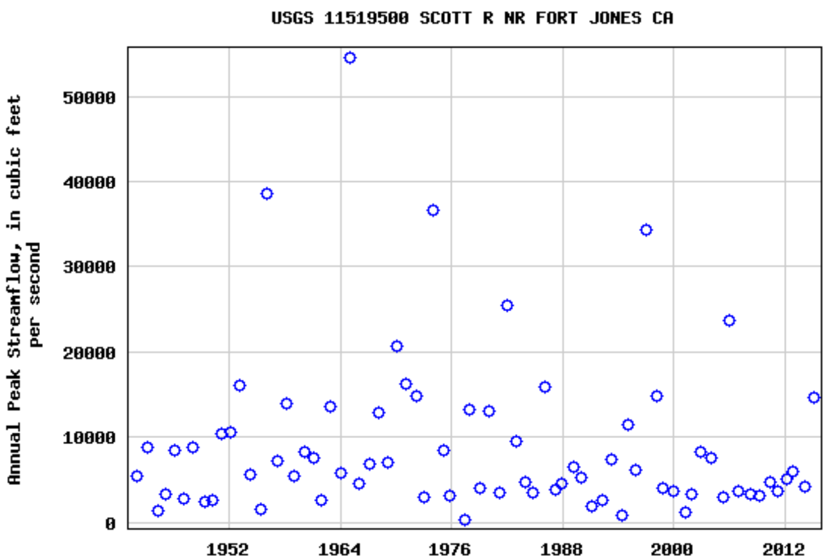


Figure 45. Annual peak flows in the Scott River, near Fort Jones.

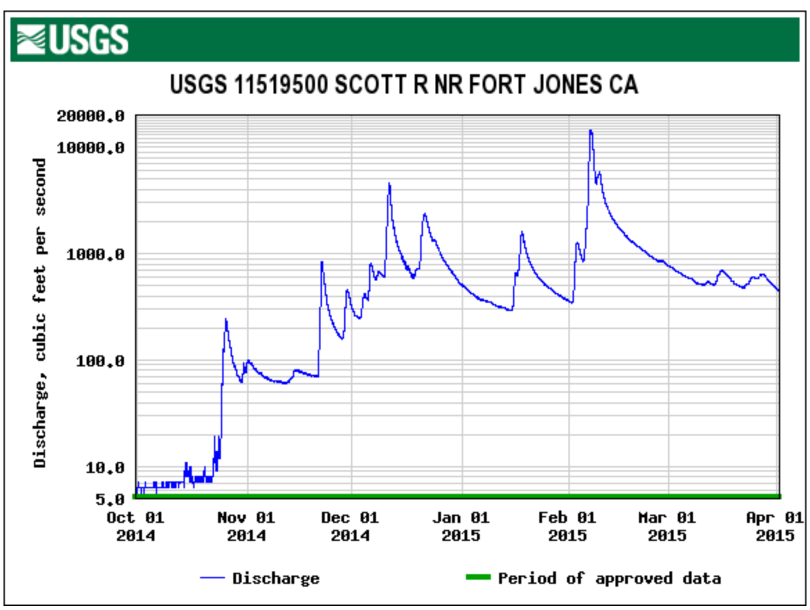


Figure 46. Stream discharge, water year 2015, Oct. 1, 2014 – April 1, 2015. Scott River below Fort Jones (river mile 21) – USGS gage 11519500.

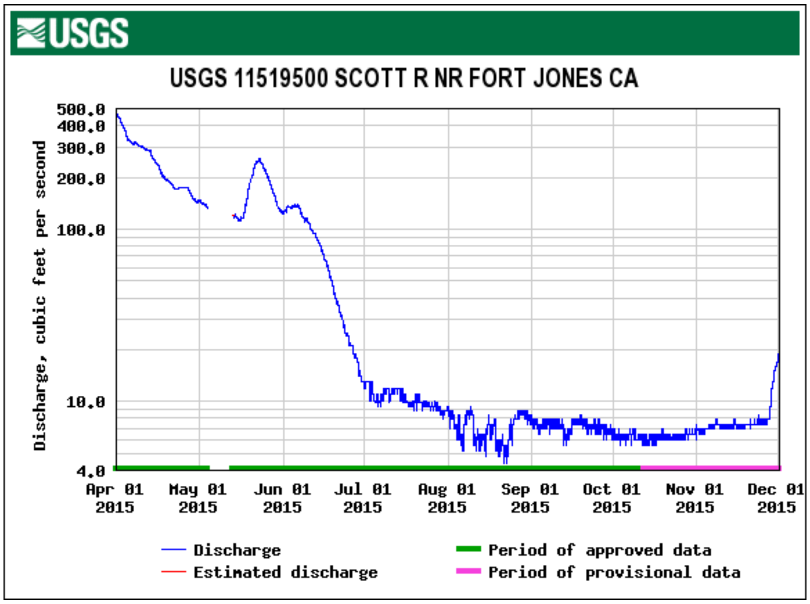


Figure 47. Stream discharge, water year 2015, April 1, 2015 – December 1, 2015. Scott River below Fort Jones (river mile 21) – USGS gage 11519500.

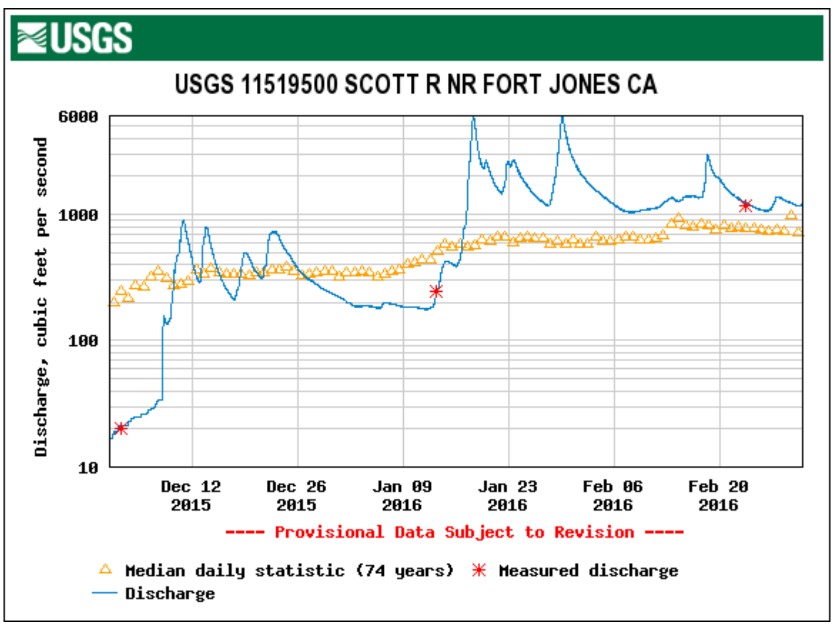


Figure 48. Stream discharge, water year 2016, December 1, 2015 – February 28, 2016. Scott River below Fort Jones (river mile 21) – USGS gage 11519500.

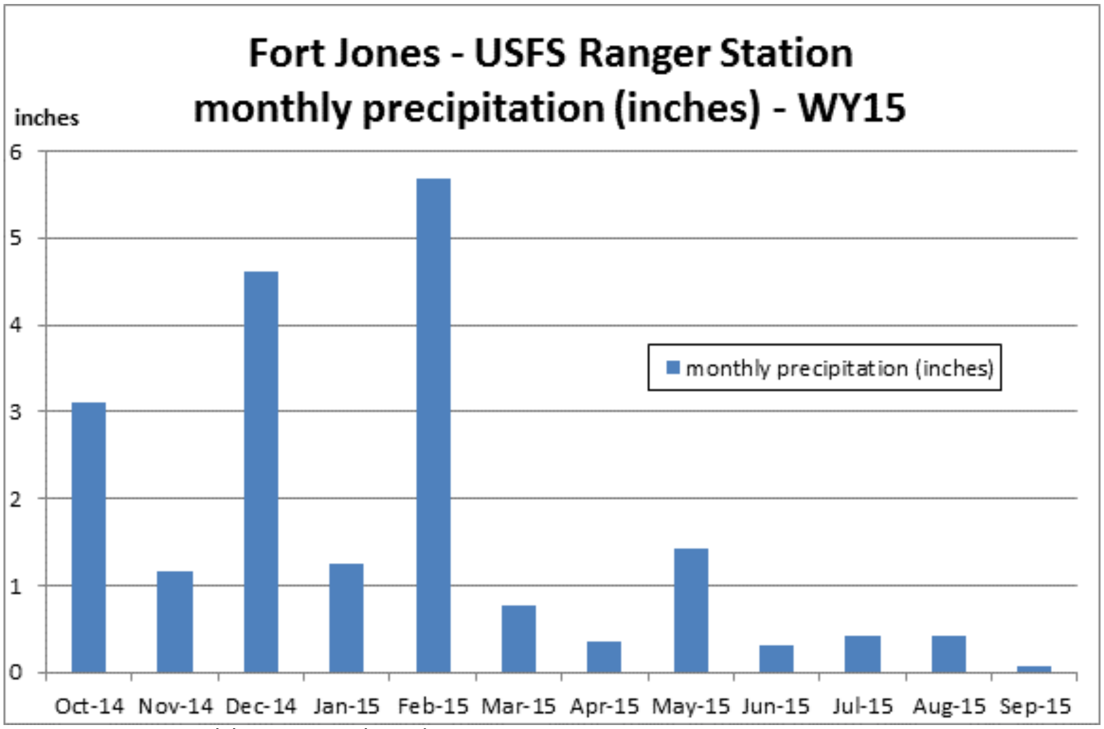


Figure 49. Monthly accumulated precipitation WY15 – Fort Jones US Forest Service Ranger Station – retrieved from CDEC.

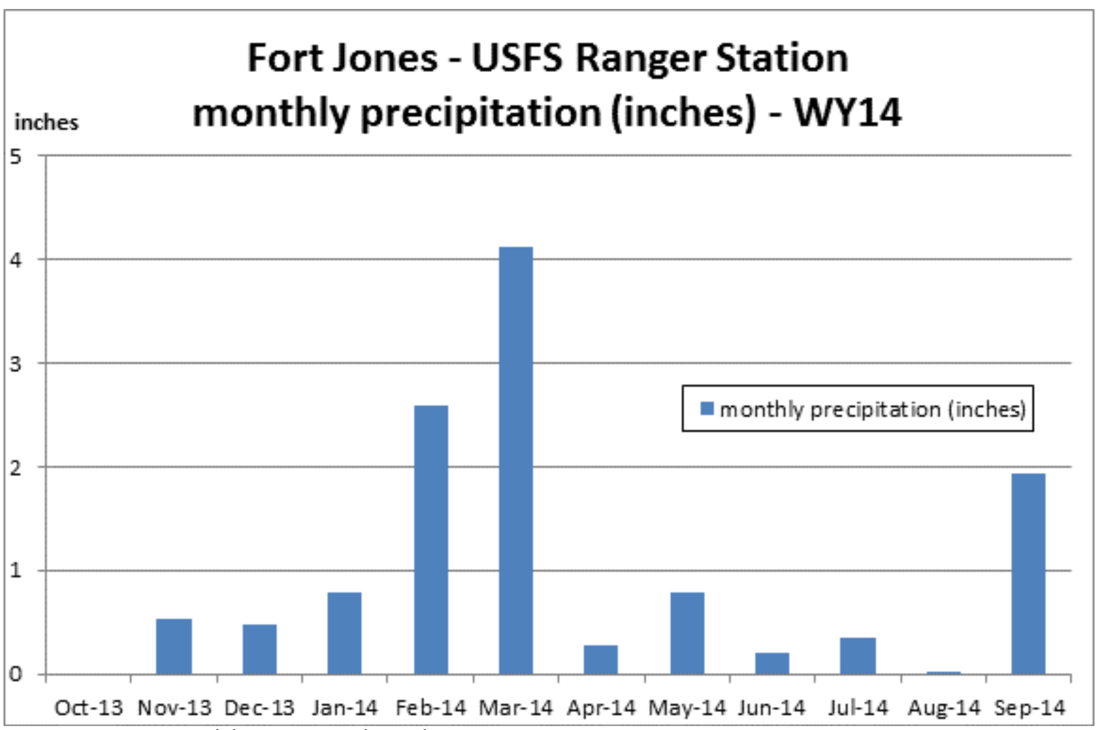


Figure 50. Monthly accumulated precipitation WY14 – Fort Jones US Forest Service Ranger Station – retrieved from CDEC.

Hydrographs- Sugar Creek

Stream discharge graphs for the California Department of Water Resources gage on Sugar Creek about 2.6 km up from the mouth are provided in Figures 49-51, while precipitation patterns in Callahan is shown in Figures 54-56. Total rainfall for Callahan for water year 2015 was 25.4 inches. The discharge in Sugar Creek at Rkm was monitored at DWR gage F25890. The stage data was downloaded from CDEC and converted to discharge (cfs) utilizing a rating table developed by DWR on 7/7/2015 (Joe Scott – CDWR, personal communication).

The Sugar Creek hydrographs show average daily discharge exceeding 4 cfs until mid-June and then a rapid drop off in flow in late June, followed by a rapid rise back up to 3 cfs, suggestive of a temporary water diversion. The flow then generally and slowly drops down until mid-September, but then bumps up again due to precipitation. Then again there is a rapid drop in flow followed by a rapid rebound, again suggestive of a temporary diversion of water.

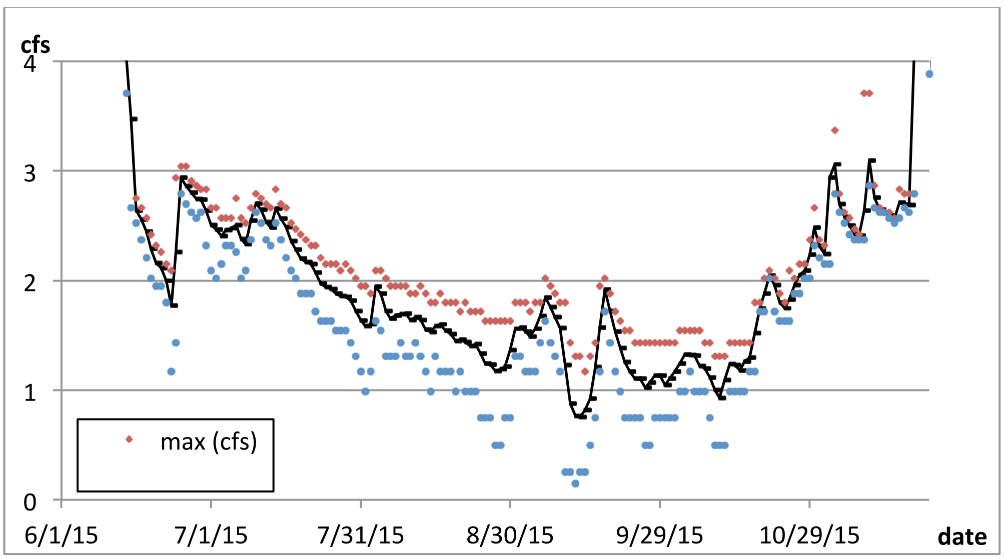


Figure 51. Calculated average, maximum and minimum daily discharge at Department of Water Resources Sugar Creek gage (F25890) at Rkm 1.0, from 6/1/15 to 11/30/15.

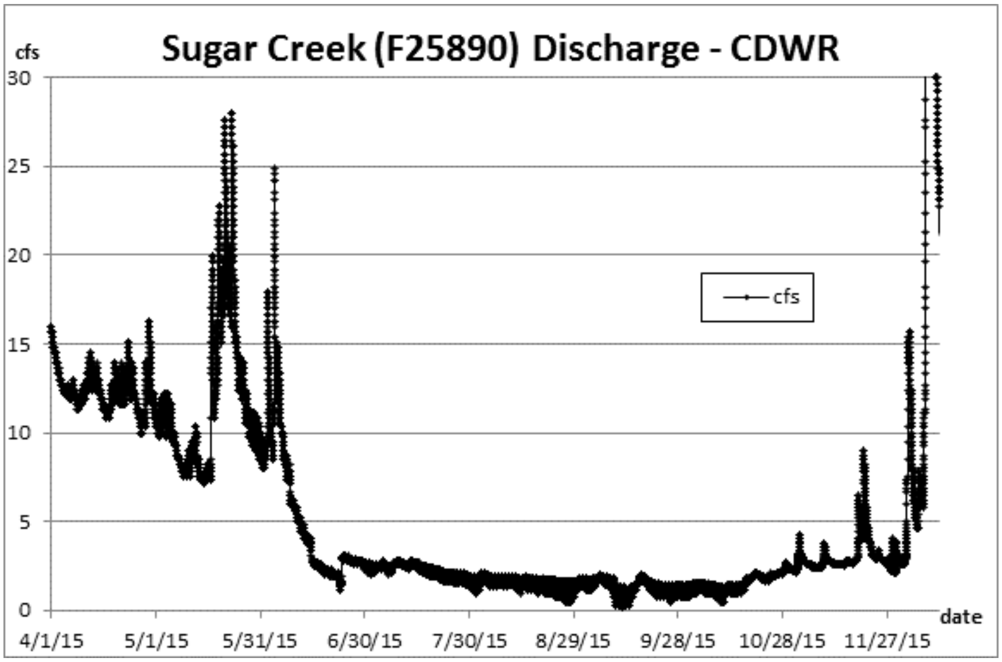


Figure 52. Calculated peak daily discharge at Department of Water Resources Sugar Creek gage (F25890) at Rkm 1.0, from 4/1/15 to 11/30/15.

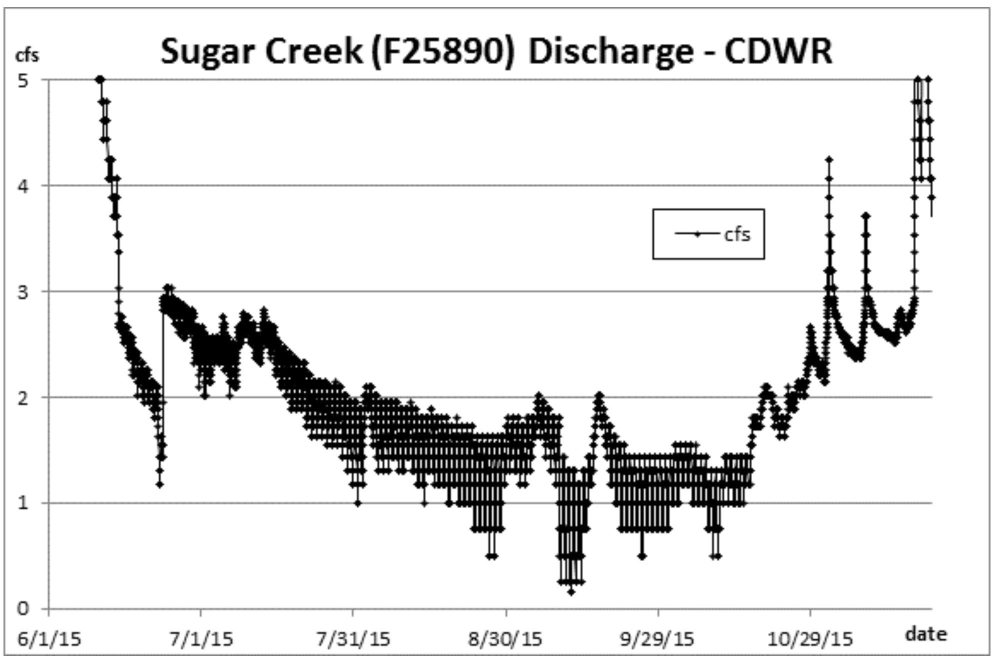


Figure 53. Calculated hourly discharge at Department of Water Resources Sugar Creek gage (F25890) at Rkm 1.0, from 6/1/15 to 11/30/15.

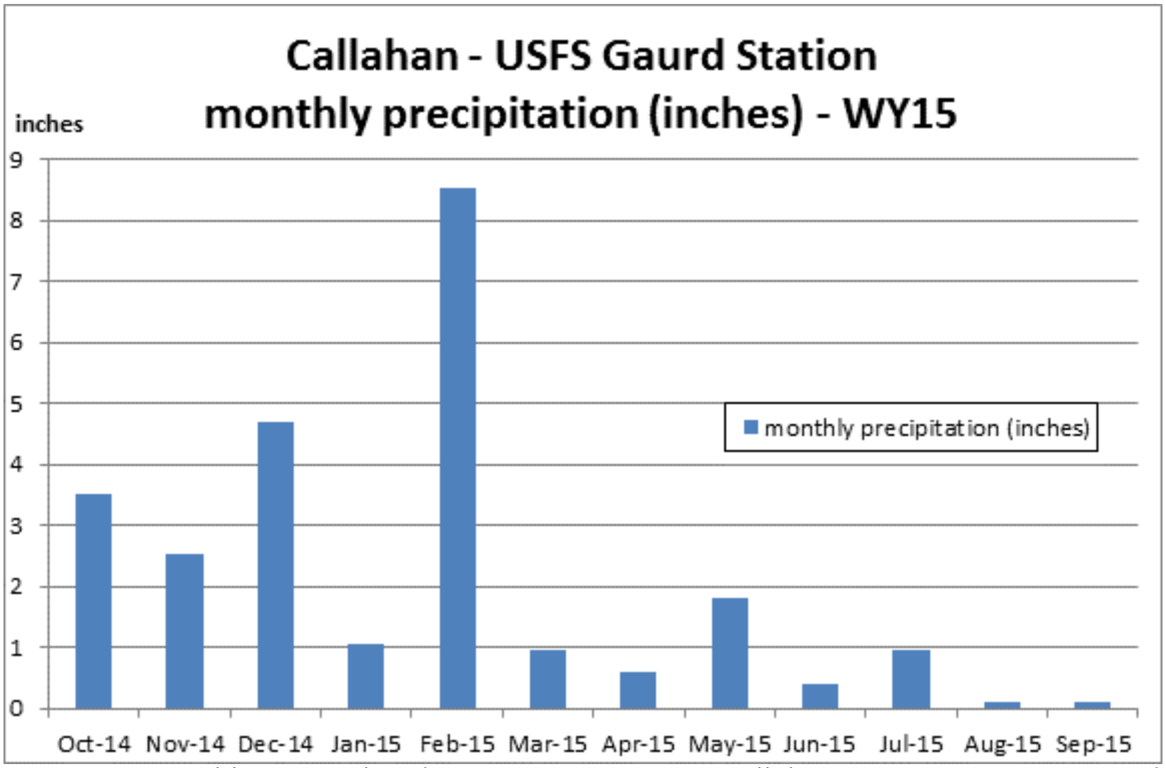


Figure 54. Monthly accumulated precipitation WY15 – Callahan US Forest Service Guard Station – retrieved from California Data Exchange Center.

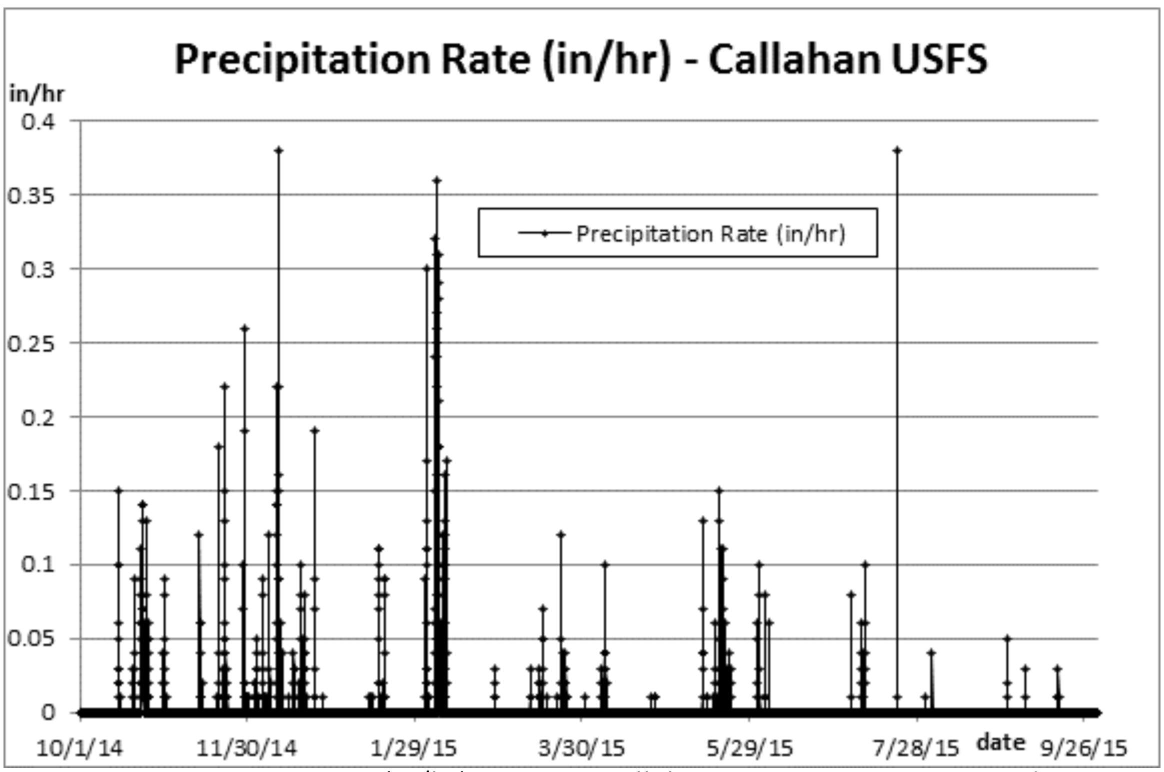


Figure 55. Precipitation rate (in/hr) - WY15 – Callahan US Forest Service Guard Station – retrieved from California Data Exchange Center.

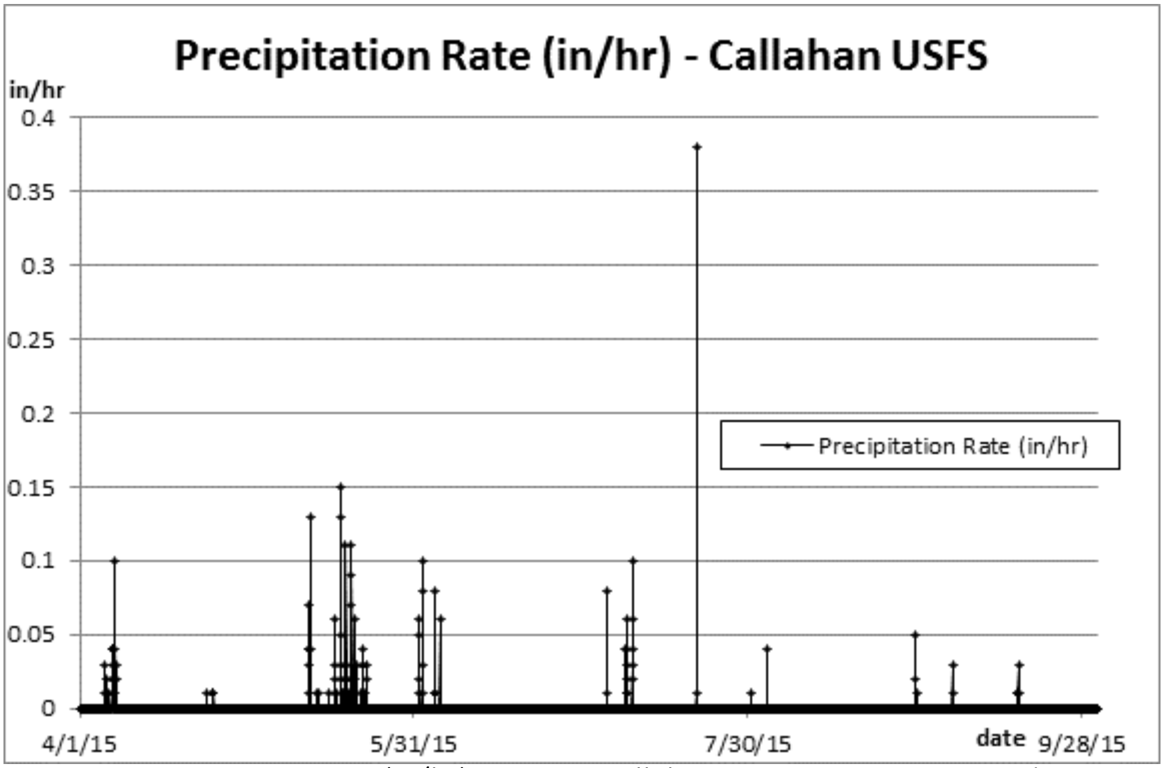


Figure 56. Precipitation rate (in/hr) - WY15 – Callahan US Forest Service Guard Station – retrieved from California Data Exchange Center.

Groundwater and Surface Water Elevations

Sugar Creek at Confluence with the Scott River—

The late summer water surface elevation around the confluence of Sugar Creek with the Scott River was measured to better understand the hydrological effects of the BDAs. Elevations were measured on Sugar Creek, on a small section of wetted Scott River side channel where Sugar Creek enters the Scott River, and on the Scott River main channel, upstream and downstream of the confluence with Sugar Creek (Figure 57). The location of the Scott River has significantly shifted since the time of the aerial photograph, abandoning the channel on the left side of the valley where it is present in the photograph, and moving over to the right side of the valley, along the intermittent line of dots where the surveys were taken (Figure 57). Most of the mainstem had dried up in the area, and the intermittent dots were locations where surface flow could be seen usually in scour holes. The line of dots along the abandoned channel on the left side of the valley indicate the extent of flow within that channel. Within the side channel, surface flow was limited to a short distance around the confluence with Sugar Creek, approximately 700 feet long (Figure 57). Thus within the Scott River floodplain in the area upstream and downstream of Sugar Creek, the only place with continuous, flowing water was near the confluence with Sugar Creek. The elevation of Sugar Creek from below the Highway 3 crossing to the lower BDA was nearly level, at approximately 3000.7-3000.9 feet, also the same approximate elevation (3000.9 feet) of two off-channel, groundwater fed ponds on the right side of Sugar Creek. The water surface elevation of the MW3, which is just above and to the right of the lower BDA, was at 2999.8 feet. The water surface elevation of the isolated flow in the abandoned mainstem channel was 2999.7 feet at the upper end and 2992.7 feet at the lower end, or between 1-6 feet below the surface elevation of Sugar Creek above the lower BDA. In contrast, the surface elevation of the isolated pools in the Scott River were 2999.7 feet at the most upstream end, approximately parallel with the upstream BDA, dropping to 2995.3 feet approximately parallel to the mouth of Sugar Creek and the beginning of the side channel flow, continuing to drop to 2990.9 feet approximately parallel to the lower end of the side channel flow, and then dropping to further to 2983.1 feet at the point where the side channel reconnects to the main channel (Figure 57). Thus the side channel flow maintained an elevation approximately 2 feet above the mainstem of the Scott River.

We interpret these data to mean that Sugar Creek has created an alluvial aquifer that is elevated above the main aquifer of the Scott River, and that the source of water in the 700 feet of side channel below Sugar Creek is almost certainly from this elevated aquifer. Because in the summer prior to the installation of the BDAs, lower Sugar Creek dried up and there was also no flow in the Scott River channel below Sugar Creek, we hypothesize that the likely cause of the isolated flow observed is a result of the BDAs and the approximate 3 foot elevation of groundwater recharge and storage that occurred for most of the year when the BDAs were intact. This created a hydraulic head above the side channel that supplied flow throughout the summer. This hypothesis is also supported by observations that water levels in MW1 (the off channel pond) and MW3 (the groundwater well near the lower BDA) both elevated in response to repairs of the BDA at the end of June that elevated the surface of lower Sugar Creek (Figures 58-59). While we can't be certain that the flow observed would not have occurred without the presence of the BDAs, the lack of flow in the year prior to the installation of the BDAs, suggests otherwise. This effect is also consistent with other observations and theory of expected flow paths below natural beaver dams and BDAs (see Woo and Waddington 1991, Pollock et al. 2014). Alternatively, the water level data loggers could have been collecting inaccurate data, but comparison of measured water surface elevations with estimated elevations from the water level loggers indicated a high degree of correlation (Figure 60).

Figure 57. Sugar Creek water surface elevation survey – September 9, 2015. The imagery is from 2014 and does not reflect the location of surface water at the time of the survey. Flow is towards the north. At the time of the survey, the mainstem of the Scott River had shifted over to the right side of the alluvial valley, and the channel on the left side, which is occupied in this aerial photograph, was abandoned.

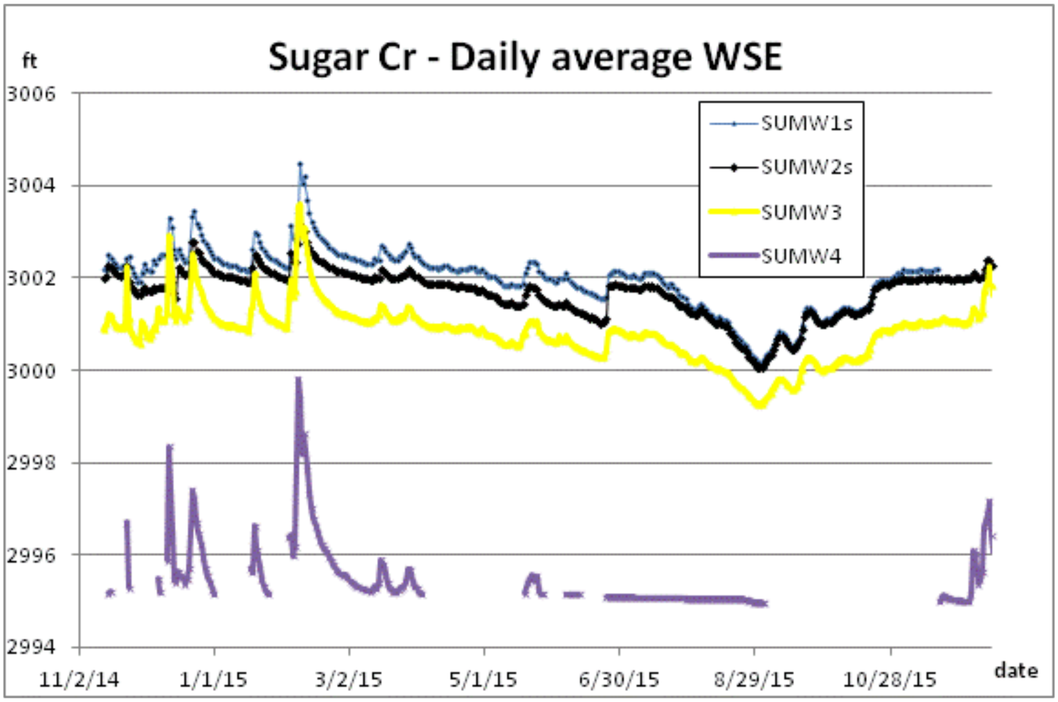


Figure 58. Daily average water surface elevation – SUMW1s (off channel pond), SUMW2s (BDA Rkm 0.1 pond), SUMW3 (groundwater) and SUMW4 (groundwater). The first three sites show clear indications of extensive hydraulic connectivity, while SUMW4 was frequently dry and did not appear to be hydraulically connected to the other sites, suggestive of complex subsurface geology and groundwater flow paths in the area.

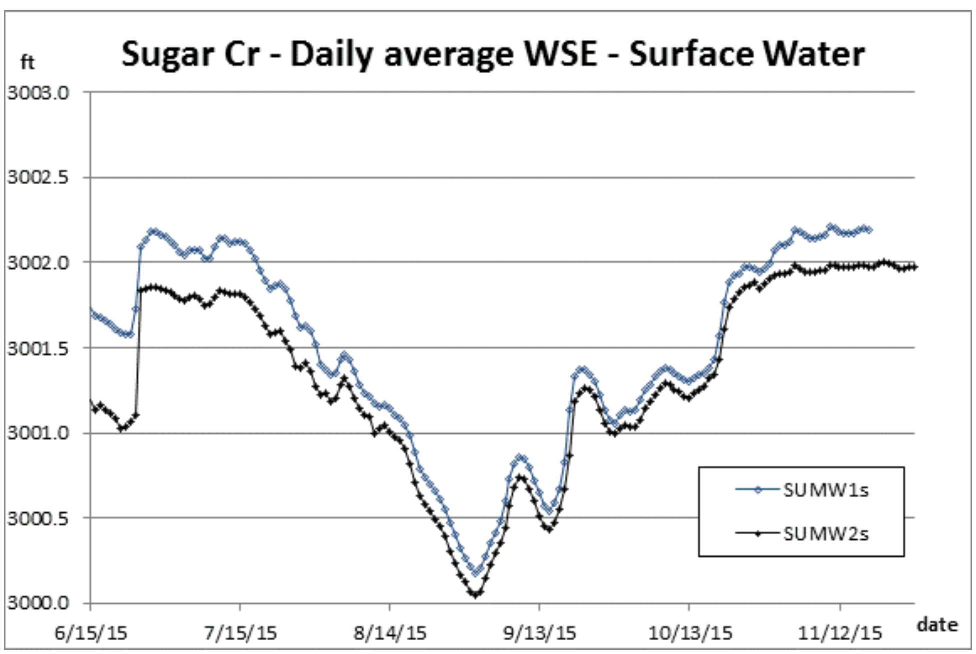


Figure 59. Detail of daily average water surface elevation for SUMW1s (off channel pond) & SUMW2s (BDA Rkm 0.1 pond), in the summer and fall, showing the high degree of correlation. The rapid rise in late June is the result of repairs to the BDAs, which raised both the level of lower Sugar Creek and the nearby off-channel pond (there was no precipitation at the time), showing a high degree of hydraulic connectivity.

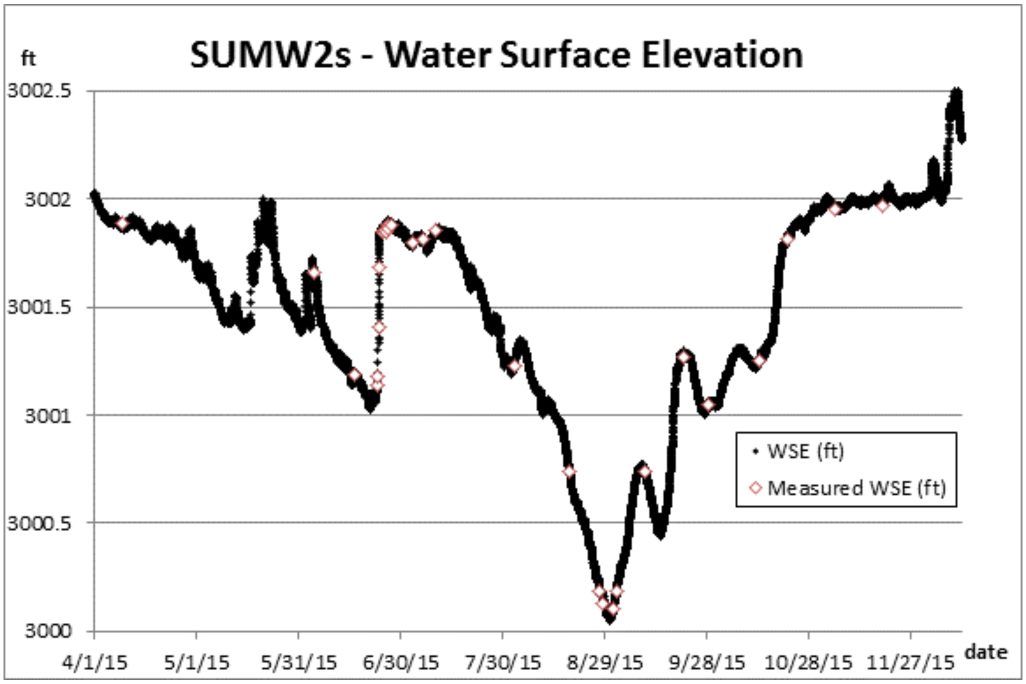


Figure 60. Calculated (wse) and measured water surface elevation at SUMW2s (Sugar Creek BDA, Rkm0.1 Pond), showing that the water level loggers accurately measured water levels across a range of water surface elevations.

Scott River at confluence with French Creek—

The data from this surface and groundwater monitoring network shows a subsurface gradient from river right, sloping down to river left. The groundwater surface elevations of MW10, which is on the left side of the Scott River floodplain, and upstream of French Creek, except at high flows, tended to be at an elevation about 0.5-1 foot below the groundwater surface elevations of MW11, which is on the right side of the Scott River and on approximately the same cross section (Figures 15 and 62). As expected, surface flow elevations showed much greater fluctuations than groundwater elevations, and French Creek side channels fluctuated much more frequently than side channels of the Scott River (Figure 63). On French Creek, MW2s is located on a back slough on river right, fluctuated the most, and went dry for extensive periods during the summer, while MW4s, which is located on a Scott River side channel just above the upper BDA, showed much lesser fluctuations and contained water throughout the year. Surprisingly, MW3, which is a groundwater well located on river left of the Scott River and is approximately at the same latitude and approximately equidistant between MW2s and MW4s, showed greater fluctuation than MW4s. Because it is closer to French Creek, this may be the result of receiving groundwater inputs from the French Creek systems, which would reflect the high degree of wse fluctuation seen in MW2s. Figure 64 compares the water level fluctuation in the upper BDA pond (MW12) with the groundwater fluctuations of MW6 and MW7. Both the groundwater wells fluctuated more on both a daily and seasonal basis, suggesting that the BDA may have helped to stabilized surface water elevations, but had less of an effect on groundwater elevations. There is a significant amount of groundwater pumping in the area, just downstream on river right, which would explain the groundwater fluctuations and the apparently lower groundwater elevations relative to the surface flow. This suggests that this area is a losing reach, and that there is a certain amount of hydraulic disconnectivity between the river and the groundwater. Otherwise, the river would be expected to dry up, given the relatively higher water levels in the river, especially later in the season (Figure 64). Finally, Figure 65 shows the elevation of the water level of the pond just upstream of the upper BDA, demonstrating that water was retained throughout the year with depths ranging from about 1-2 feet above the ground elevation.

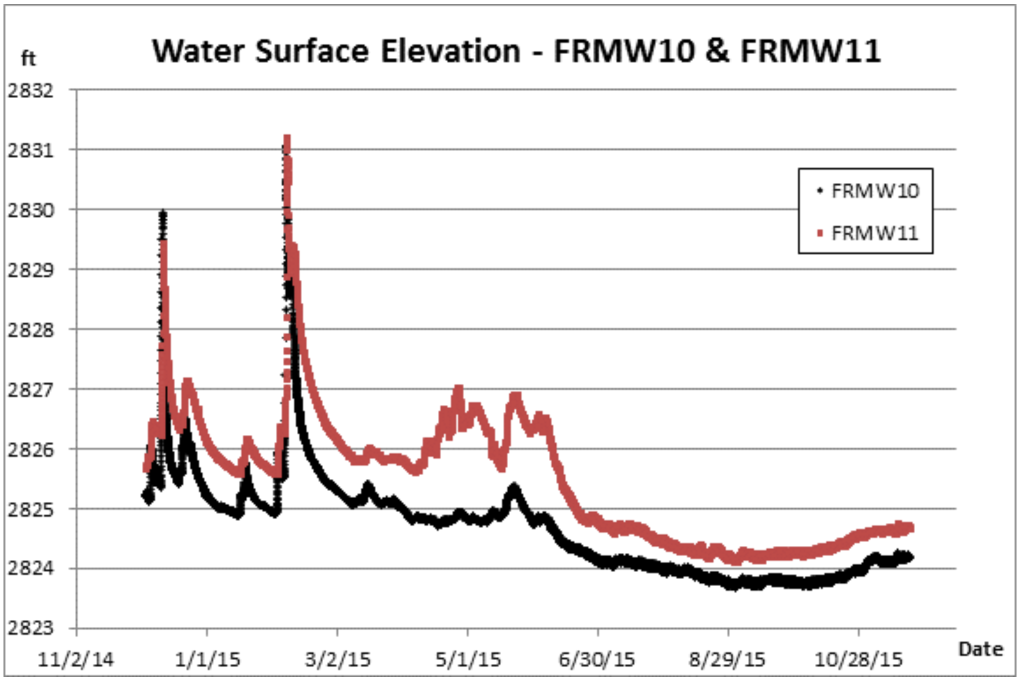


Figure 62. Water surface elevation (WSE)at French Creek confluence monitoring wells FRMW10 and FRMW11. MW10 is on the left side of the Scott River and MW11 is on the right side. Both stations are above the confluence with French Creek.

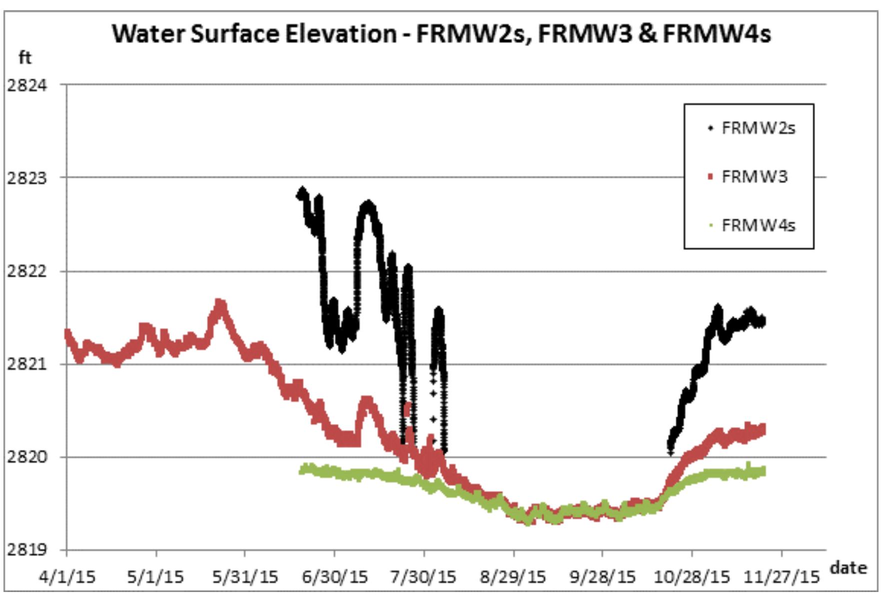


Figure 63. Water surface elevation (WSE) – FRMW2s, FRMW3 & FRMW4s.

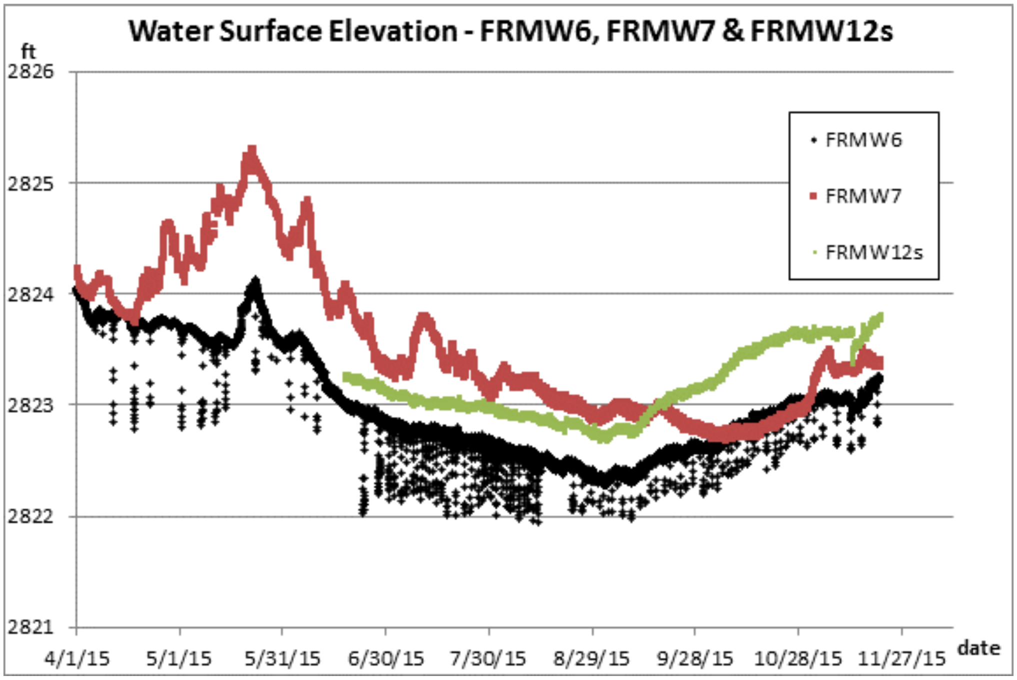


Figure 64. Water surface elevation (WSE) – FRMW6, FRMW7 & FRMW12s.

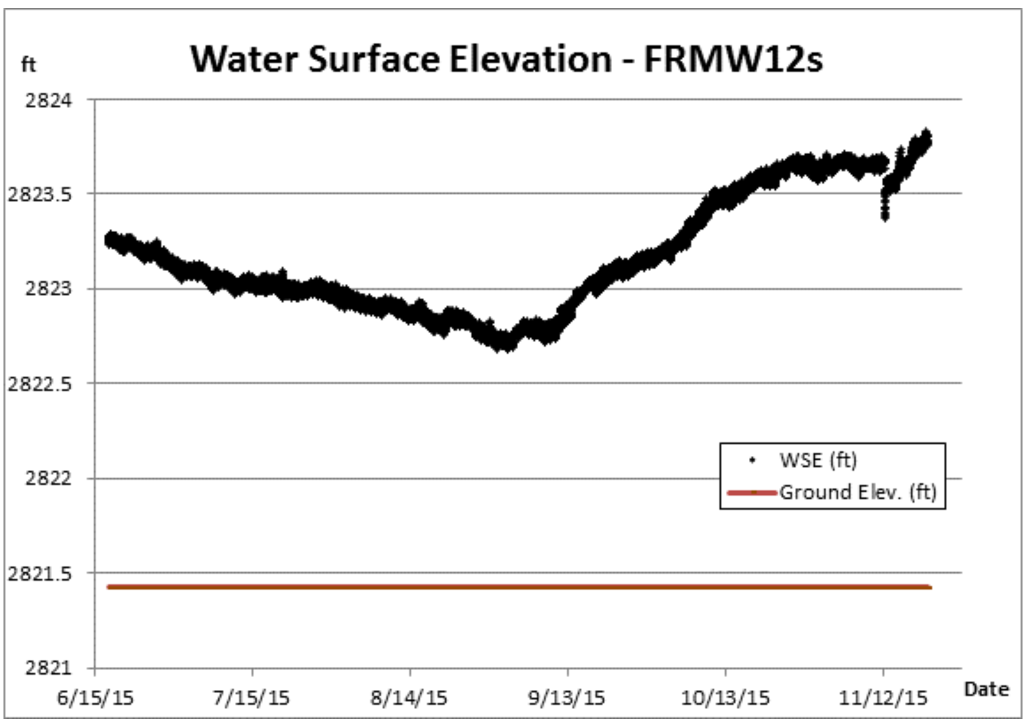


Figure 65. Water surface elevation (WSE) – BDA Rkm 78.2 pond – FRMW12s

Scott River at Confluence with Etna Creek—

The water level monitoring network installed at the Scott River at Etna Creek (Rkm 68.9 – 69.3) was installed above the BDA Rkm 68.9. The BDA Rkm 68.9 structure was obliterated during the winter of WY15 and no effort to restore the structure was made in 2015. The monitoring well at the confluence of Etna Creek and the Scott River (WHMW2) was destroyed during the winter of WY15 and the logger was lost in the well. We present the data here as part of the report, because it may be useful as background data if the BDA is repaired, but do not discuss it further at this time

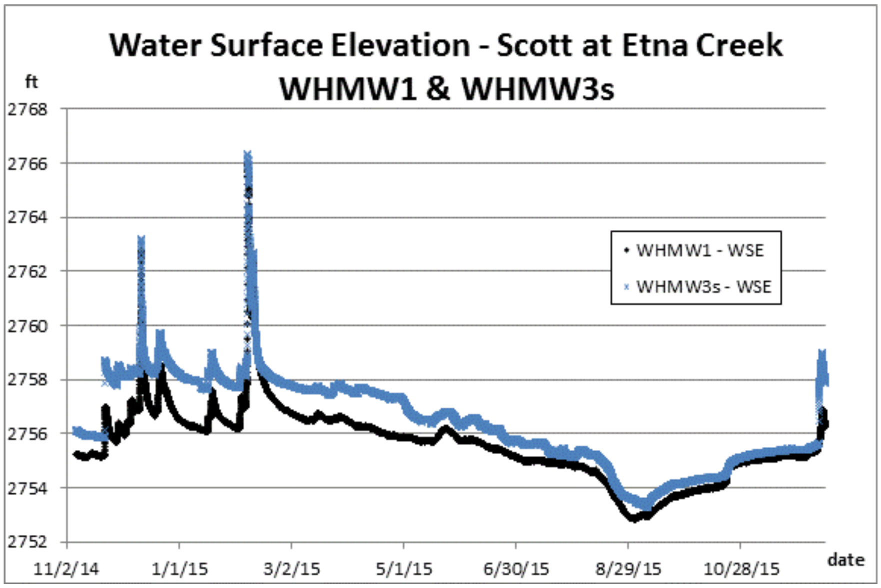


Figure 66. Water surface elevation (WSE) – WHMW1 & WHMW3s

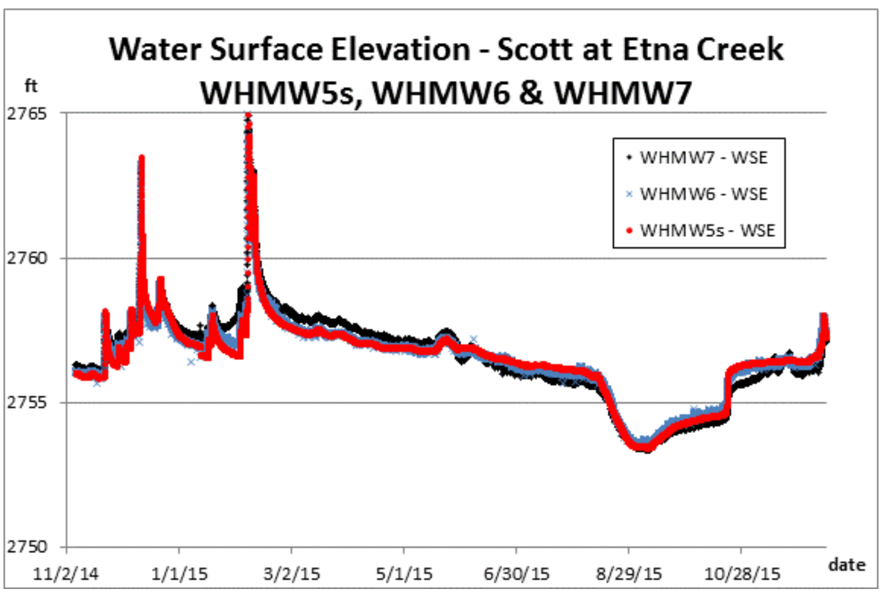


Figure 67. Water surface elevation (WSE) – WHMW5s, WHMW6 & WHMW7

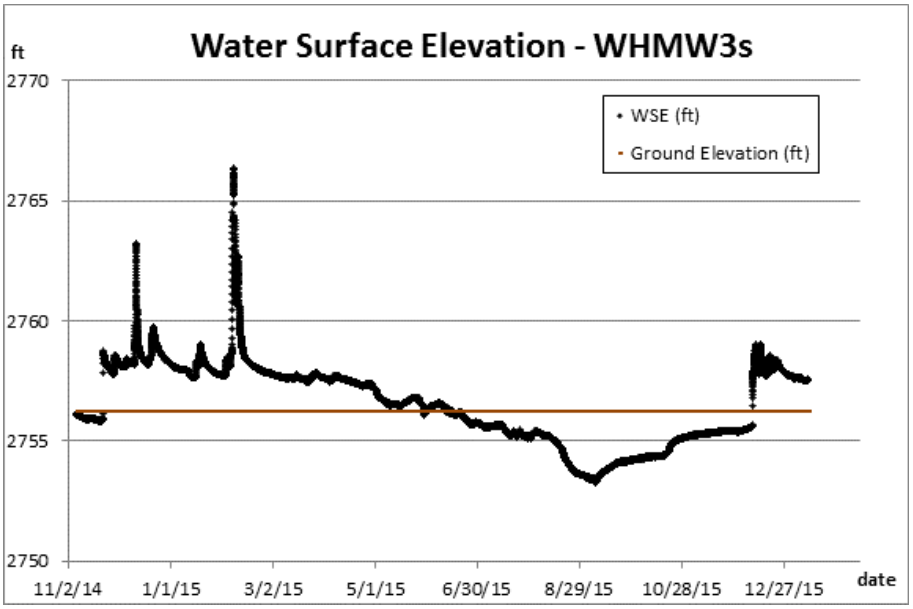


Figure 68. Water surface elevation (WSE) - Etna Creek – WHMW3s

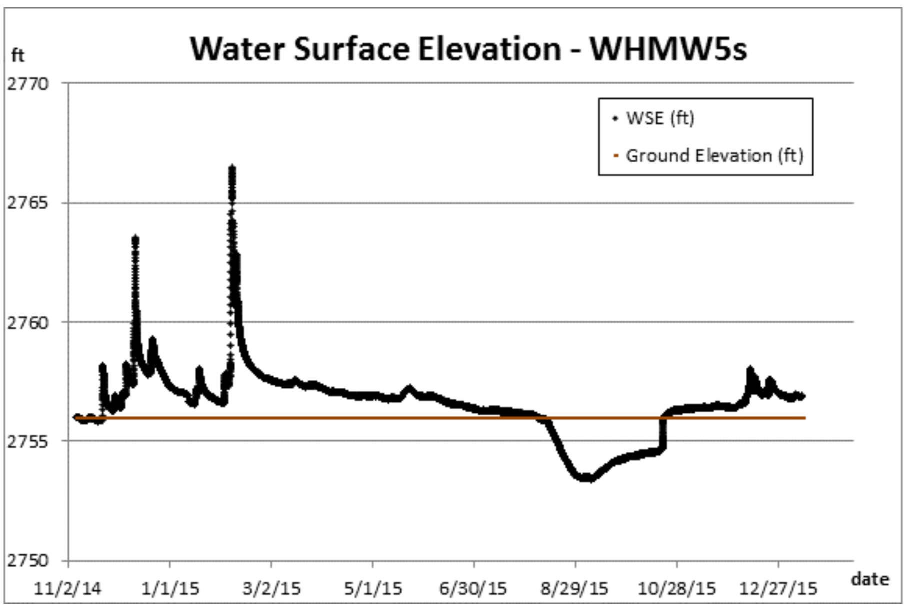


Figure 69. Water surface elevation (WSE) - Scott River – WHMW5s

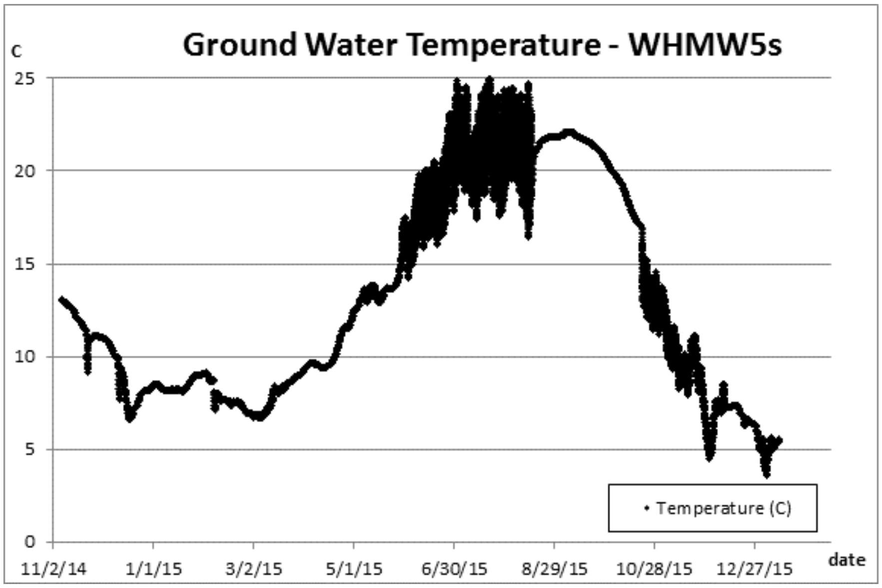


Figure 70. Water Temperature (°C) – WHMW5s

DISCUSSION

Fish Monitoring

Available data from the aquatic habitat surveys suggests that thousands of salmonids used the Sugar Creek BDA ponds over the summer. The RCD May 28th survey documented 772 juvenile coho salmon, 48 juvenile Chinook salmon and 134 trout (O. mykiss), which may or may not be the anadromous form. The RCD June 19th survey documented 925 juvenile coho salmon, 115 juvenile Chinook salmon and 2025 juvenile trout, suggesting movement of juvenile salmonids into the BDA pools as other habitat in the area dried up. There were no additional quantitative surveys after June 19th, and the PIT tagging effort was not sufficient for making populations estimates, but repeat observations throughout the summer suggest that hundreds of juvenile salmonids continued to use lower Sugar Creek BDA habitat at least until the fall flows raised the water tables and reconnected the habitat to the Scott River, and probably beyond. Unfortunately, during the summer, as flows dropped, the CDFW required the BDAs to be breached to ensure "visible (to humans) fish passage, and this resulted in the pools draining, which reduced the quality and quantity of aquatic habitat and may have contributed to high temperatures in some areas. Despite the pond draining, there were still sufficient pockets of deep cool water pools with cover to support juvenile fishes over the summer. We do not know if more fishes would have survived had the BDAs been allowed to remain intact and the water levels behind them kept high. However, we do know that draining the ponds eliminated much of the habitat that was classified as high quality juvenile coho salmon habitat in terms of velocity, depth and cover.

Fish Passage across BDAs

Available data from the juvenile PIT tagging effort in Sugar Creek suggests that juvenile salmonids were able to pass over the BDAs. The amount of data are limited, but what is available indicates that juveniles were able to out-migrate downstream (Figures 22-23). Juvenile salmon < 60 mm fork length cannot be PIT tagged. Therefore there are not PIT tag data available for assessing whether 0+ juveniles were able to successfully navigate upstream past the BDAs in the early summer as the Scott River began to dry up.

However, the juvenile survey data indicate that there were numerous mixed species schools of juvenile salmonids in the BDA ponds in late spring and early summer. The presence of juvenile 0+ Chinook salmon is particularly suggestive that the BDAs were passable, at least in late spring and early summer since there were no observations of Chinook salmon spawning on Sugar Creek above the BDAs. It is possible that all of the 0+ juvenile coho salmon and trout observed that were observed over the summer were produced from redds upstream of the BDAs, but the high densities observed make this seem less likely.

There were consistent observations of juveniles both above and below the BDAs and observation of the flow paths around and through the BDA appeared to be passable to fish much of the time. Because the BDAs helped to create habitat downstream of the structures, there is also a question as to whether the structures need to be passable to fish at all times. If quality habitat can be maintained below the structures, then it makes little sense to drain the ponds and degrade habitat so that passage is assured.

Since arguably all of the habitat would not only be impassible, but non-existent if the BDAs were not present, as the reach dried up in the year prior to BDA installation, then breaching the BDAs makes little sense from a fish conservation perspective. It makes far more sense to create high quality habitat that can sustain juvenile coho salmon throughout the summer, even if portions of it are not passable at all times, rather than creating habitat that is low-quality of non-existent during the summer dry season, but that would be passable, if any water was present.

We interpret the data to mean that from a fish conservation perspective, if given the choice, it is better to create high quality summer habitat that can sustain juvenile salmonids, but may not be passable at all times, than it is to ensure fish passage at all time even if the habitat quality is low or non-existent.

At the same time, it is important to note that we have no evidence that the BDAs ever presented a barrier to fish movement. All the available evidence suggests that juvenile salmonids were able to cross the BDAs, and juvenile salmonids were well distributed throughout the available habitat throughout the summer.

Our preliminary passage analysis suggests that for a typical BDA, orifice flow paths will only provide juvenile fish passage during low head or with unrealistic orifice hydraulics. Whereas, juvenile salmonids are more likely to pass a BDA via small side channels configured with reasonable channel roughness and slope. This is consistent with how natural beaver dams are constructed and maintained That is, beaver tend to seal their structures to retain flow sufficient to ensure that water flows over or around their dams and that the water surface elevation remains close to the dam top elevation. This is particularly true during low flow conditions or on small streams where flow is minimal. Dams on larger streams and dams during winter tend to be more porous because it is not necessary to seal a dam to keep water levels high under such conditions. In fact, beaver often cut notches in their dams during high flow conditions, which helps to keep the water level close to the dam elevation, rather than above it. Beaver need to maintain relatively constant water levels because their lodges are typically constructed to operate under a narrow range of water levels. High water will flood the lodge floor, and low water will expose the underwater entrances. Beaver and coho salmon (and other salmonids) have co-evolved in North America for millions of years such that juvenile coho have adapted to take advantage of how beaver construct, operate and manage their dams. We suggest that the closer that BDAs can be constructed, managed and operated in a manner similar to natural beaver dams, the more likely they are benefit coho salmon.

Adult Chinook salmon were observed on numerous occasions passing the BDAs on the mainstem of the Scott River, and the distribution of redds indicates throughout the mainstem in their typical spawning areas suggests that the BDAs, as constructed and maintained, did not present an obstacle to adult Chinook salmon.

Live adult coho salmon, carcasses or redds were observed above the tributary BDAs on Sugar Creek and Miners Creek in 2015. Because of low flow conditions, very few coho made it to these upper mainstem tributaries. The bulk of the run spawned in the Shackleford-Mill Creek system in the lower part of the watershed. Most of the observations of live coho, carcasses or redds in the upper watershed were above the BDAs, suggesting perhaps that the BDAs have created habitat attractive to adult coho salmon. This is similar to what was observed in Bridge Creek Oregon, where adult steelhead have begun to preferentially spawn throughout a reach where dozens of BDAs have been installed (M.M. Pollock, unpublished data).

Although extensive quantitative data are lacking, the available data and the numerous field observations over the course of the year suggest that the BDAs are used extensively by multiple life stages of multiple species of salmonids. Additional qualitative examples include observations of adult steelhead use of the deep pools created by the BDAs above French Creek during the summer, regular observations of juvenile salmonids feeding in the plunge pools below most of the BDAs except during the late summer months, and regular observations of large mixed species schools of juvenile salmonids in lower Sugar Creek in the BDA habitat throughout the summer.

Juvenile Salmon Habitat Capacity Estimates

The estimated habitat capacity of coho salmon production potential for the Sugar Creek BDA ponds (when completely full) and downstream side channel habitat are provided in Table 14. These data provide a rough estimate for capacity, but the similarity of the two capacity estimates is encouraging and suggests that over 7,000 juvenile coho salmon or other juvenile salmonids could be produced from these ponds, assuming that they were fully seeded and that the ponds remained full throughout the summer.

The downstream side channel provides some additional production, but adds only about a 5% increase in capacity relative to the full ponds. These estimates are within the ballpark of our maximum juvenile salmonid population estimates in early summer of over 3000 salmonids, a period when the BDAs were not at full storage capacity.

Lowering of pond levels and the subsequent reduction in habitat area and habitat quality will decrease the production potential. Because cover (along with depth and velocity) is one of the main drivers of juvenile coho salmon production capacity, the complex habitat on the river right side of the upper BDA, which has good riparian cover and extensive beds of emergent and aquatic vegetation, is especially important to maintain.

Maintenance of this habitat during the critical summer months requires maintaining water levels at or near the elevation of the top of the BDAs to ensure adequate depth and to maintain cool temperatures. Further, if the BDAs are properly maintained, habitat complexity and cover should continue to increase in the coming years as emergent and riparian vegetation continues to recolonize the site.

Surface Water And Groundwater

The surface water temperature regime in lower Sugar Creek is complex and appears to be controlled largely by groundwater temperatures. Within the tailings section of lower Sugar Creek, the temperature patterns of the lower BDA pool, a nearby, deep, artificial groundwater fed pond and the groundwater itself are nearly identical (Figure 40).

Both the pond and the BDA pool had very little canopy cover and are surrounded by piles of tailings cobble. The pond temperatures are slightly warmer than the groundwater and pool water in the winter and slightly cooler in the summer. This temperature modulation is likely due to the large thermal mass of the pond, which is often > 15 feet deep. In contrast, the BDA pool was much shallower, and lacking substantial riparian vegetation, it would be expected to experience substantial swings in temperature, correlated to air temperature changes, which often exceeded 100 ^{0}F during the summer (Figure 41).

The source of the groundwater was not determined, which would require tracer studies, but given that lower Sugar Creek below Highway 3 is within the floodplain of the Scott River, it is quite likely that the groundwater is part of the Scott River alluvial aquifer, and that lower Sugar Creek bisects and helps to drain the aquifer. If so, then the BDAs are helping to create cool water pools simply by raising the elevation of lower Sugar Creek and by both slowing the drainage of the alluvial aquifer as well as providing flow resistance which slows the rate at which Sugar Creek drain into the larger Scott River alluvial aquifer.

This interpretation is supported by examination of the temperature patterns of the upstream sites at Rkm 1.0 and Rkm 0.4, which are within or just below a reach shaded by an extensive dense closed canopy. If shade were the primary driver of stream temperatures, then the shaded sites should be much cooler than the exposed sites in the summer and warmer in the winter. However, this is not the case. The shaded sites are cooler in both the summer and winter, and approximately equal to the exposed sites in the spring.

The temperature signatures of the two shaded sites follow a similar pattern, while the downstream unshaded sites follow a similar pattern. We interpret these data to mean that the thermal regime in the upper sites, which are closer to bedrock and not able to interact with an extensive alluvial aquifer, is controlled largely by stream shading, and the temperature of the upstream surface water, which flows into this reach.

In contrast, when Sugar Creek crosses beneath Highway 3, it transitions from a bedrock dominated reach to an alluvially dominated reach as it enters the alluvial deposits of the Scott River. Because of the dredge mining that occurred in the alluvium and the large piles of cobble that were left behind, this area supports little in the way of riparian vegetation and the stream flows through a wide, shallow channel between piles of tailing cobble.

In the summer, such conditions should lead to rapid stream warming in response to rising air temperatures and severe diurnal temperature fluctuations would be expected. Because the observed temperature changes were only a few degrees above the shaded upstream reaches, and because the temperature regimes remained relatively stable as compare to the upstream reaches, we conclude that flow in lower Sugar Creek is a dominated by groundwater from the Scott River alluvial aquifer and that the BDAs, if structurally intact, will intercept and retain that groundwater, creating deep, coolwater pools.

Below the Sugar Creek pools, where Sugar Creek enters a side channel to the Scott River, there was approximately 700 feet of side channel habitat that flowed all summer long. This contrasts with the rest of the side channel and the mainstem of the Scott River, which were generally dry for most of the summer, except for a few isolated pools (Figure 57).

Extensive measurement of water surface elevations in the Scott River, the off channel ponds and in Sugar Creek indicated that the source of water sustaining flow in this side channel was likely from the Sugar Creek BDAs, and that the BDAs have raised both surface and groundwater levels and helped to create an elevated alluvial aquifer higher than the alluvial aquifer of the mainstem Scott River. The water surface elevations of the BDAs and the surrounding off channel ponds are 1-5 feet higher than the Scott River water surface elevations (figure 57).

The data from the groundwater and surface water elevations and the groundwater and surface water thermal signatures is most readily interpreted as a localized raised alluvial aquifer that was created by the construction of the BDAs and the subsequent capture and storage of Scott River alluvial groundwater during high flows and the slow release of those water into Sugar Creek and the downstream side channel reach during periods of low flow.

In effect, the BDAs appear to have perennialized both lower Sugar Creek and a side channel reach of the Scott River, both of which dried up during the previous year. We can’t think of another reasonable interpretation that explains the temperature and water surface elevation data observed, but additional monitoring in subsequent years should be undertaken to verify this interpretation, inclusive of tracer studies.

One possible alternative is that most of the groundwater is coming from a Sugar Creek aquifer that is isolated from the surface waters of Sugar Creek and therefore not affecting the upstream thermal signature of Sugar Creek. However this seems unlikely, since the aquifer would have to be near the surface to provide flow into lower Sugar Creek, and since Sugar Creek upstream of the highway is a bedrock system and there is not likely to be a substantive aquifer.

Nonetheless, it is possible that there is a deep, bedrock aquifer in the Sugar Creek aquifer that happens to emerge as a spring somewhere below the Highway 3 bridge, in the vicinity of the

BDAs. If this were the source of the cool water, the basic effect of the BDAs is still the same; they are retaining water and forming cool deep pools that can be used by juvenile salmonids.

The dissolved oxygen measurements in lower Sugar Creek indicated that for the most part, DO levels were above the threshold of 4 ppm, below which it is thought to be unsuitable for salmon. There were 10 observed occurrences of DO dropping below 4 ppm at a specific site, mostly at Station 0+50 (upstream of the lower BDA), with the duration ranging from 0.1-2.7 hr, with only 1 episode > 1 hr. (Table 19).

The low DO levels always occurred in late night or early morning, suggesting the low DO was likely a result of respiration from the abundant aquatic flora growing in the BDA pool, and not due to high stream temperatures (cold water can hold more DO than warm water). There was a certain amount of spatial and temporal variability in DO levels such that when DO levels were low in one location, there were other areas where DO levels were more suitable.

This variability helped to ensure that the habitat as a whole remained suitable for juvenile rearing throughout the summer time diurnal cycle, a conclusion supported empirically by the abundant juvenile coho salmon, steelhead and even Chinook salmon that remained and thrived in the pools upstream of the BDAs over the summer. There were no low DO occurrences after mid-September, coincident with the period of rapid decline in photosynthesis as deciduous vegetation begins to senesce.

Summary

The monitoring data collected to date suggests that BDAs in California can create complex, slow water habitat that is utilized by multiple life stages of multiple salmonid species. Juvenile coho salmon and juvenile steelhead/rainbow trout extensively utilized the ponds and pools created by the Sugar Creek BDAs during the summer, while juvenile Chinook salmon were observed in lesser abundance. However, the presence of any 0+ juvenile Chinook salmon oversummering is notable, because that life history strategy, which is commonly associated with spring Chinook, is not thought to be common in the Scott River. Consistent with the presence of fishes, the physical monitoring data indicates that water quality was adequate for supporting salmonids. A more concentrated effort to better seal the BDAs so that more flow passed over or around that structures would help to increase juvenile fish passability, retain more water and ensure that more cool, deep water habitat persisted for longer into the summer. Because beaver and coho salmon have co-evolved, we conclude that managing and operating BDAs in a manner analogous to how beaver manage and operate natural dams is most likely to create conditions that will be beneficial to coho salmon.

ACKNOWLEDGMENTS

We acknowledge the many people and agencies that have made this project possible. The amount of support, time and effort that people have contributed is humbling. First amongst those to be mentioned are the Scott Valley landowners who have participated: The Whipple Ranch, Mike Kalpine, The Farmer's Ditch Company, The Tobias Ranch and Rebecca Schenone. All of the Beaver Dam Analogues in the Scott River watershed are located on private property, where all the low gradient, high quality salmonid rearing habitat lies. Without these landowners' understanding of the geofluvial processes needed to restore the Valley, and their willingness to take a risk with this new-to-California restoration type, we would not have been able to proceed. Their almost endless tolerance for tours of interested parties on their property has been beyond generous. The SRWC is proud to be part of the Scott Valley community where such civic-minded people share their hard earned properties for the sake of restoration.

We can never express enough appreciation to the United States Fish and Wildlife Service. Mark Cookson, of the Yreka Field office, was an early and steady supporter of beaver based restoration, whether in the form of BDAs or mitigating beaver nuisance activity. His personal participation supplemented his agency's commitment and their financial support. Without his leadership the project would not have ever gotten off the ground, and his constant and enduring support is inspirational. Since Mark's departure for a position elsewhere, the US Fish and Wildlife Service remains a valued partner, and Dave Johnson has stepped into his shoes with thoughtful insight.

No work could be done without funds, and we must acknowledge, with deep appreciation, the funders who have taken a chance on this innovative project. In addition to the US Fish and Wildlife Service, the National Fish and Wildlife Foundation, while administering PacifiCorp's Klamath Coho Salmon Enhancement Fund, was willing to support us initially and then again when additional funds to carry out monitoring were needed. Their investment in pioneering BDA restoration in California was essential and cannot be acknowledged enough.

Support from NOAA has been greatly appreciated. Donald Flickinger has shared his knowledge, mentored our intellectual growth and been out on the field on many occasions. Shari Witmore has provided hands on assistance with fish tagging and sought ways to allow us to share project results with multiple people and at different venues. Bob Pagliuco has offered his advice and steered us at critical moments. Their combined efforts have been critical for project success and is appreciated.

The California Department of Fish and Wildlife (CDFW) has dedicated a tremendous amount of resources to the project. The list of the personnel who have been involved, and taken time from their many demands to consider project needs, is lengthy: Donna Cobb, Jennifer Bull, Mary Olswang, Mark Smelser, Curt Babcock, Gordon Leppig, Cailtlin Bean, Bill Chesney and many more in the background. There needs to be specific mention of the CDFW crew that led the PIT tagging effort - Steel Sims (CDFW), Barbara O'Steen (CDFW) and Molly Gorman (HSU).

Another of our regulatory partners is the North Coast Regional Water Control Board. They have shown a willingness to consider complexities with an eye toward the goal of restoration. Like their sister agency, CDFW, they have invested considerable resources in considering the questions that the project has raised. Gil Falcone, Jacob Shannon, Jonathan Warmerdam and

Michael Lennox have extended themselves for the project and their professionalism is noticed and appreciated.

For engineering support and analysis, there are several who must be mentioned. Lorrie Bundy, of the Yreka National Resource Conservation Service, with the support of her agency, has brought her knowledge of the Scott River system together with her love of learning has and been an important contributor. Joey Howard, of Cascade Stream Solutions, was willing to step in at a critical moment and his contribution was vital.

Dr. Thomas Harter, of University of California Davis, Department of Land Air and Water Resources, has offered guidance for considering BDA groundwater recharge issues. We look forward to continued collaboration as his Groundwater Model considers BDA recharge effects.

Our local restoration partners- Siskiyou Resource Conservation District, the Scott River Water Trust, and Northern California Resource Center have all contributed their expertise at various times. Their shared love for and commitment to the natural resources of the Scott Valley basin is an enduring bond and our respect for their efforts is deep. We also appreciate the other Klamath Basin restoration practitioners who offered advice, shared their hard earned knowledge and participated in various field days and exchanges.

There are community volunteers and many others who have participated, and to all, named and not named, Scott River Watershed Council expresses our profound appreciation for their willingness to join us in this effort to restore and enhance the vital ecosystem of the Scott River Watershed. Lastly, we cannot conclude without acknowledging the critical role our busy rodent partners, the beavers, have provided- they model for us how to be effective ecosystem engineers.

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