FINAL REPORT ◦ JANUARY 2015

Fish Passage in Lower Antelope Creek

PREPARED FOR

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National Fish Passage Program
Red Bluff, California

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Cover photo: The Antelope Creek–Craig Creek distributary junction located downstream of Edwards Diversion dam.

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1 INTRODUCTION

Anadromous salmonids in tributaries to California's Sacramento River have experienced substantial declines, in part due to the effects of streamflow diversion on impaired migration, excessively high stream temperatures, and entrainment (Yoshiyama et al. 1998, 61 FR 41541, NMFS 2014). Central Valley spring-run Chinook salmon (*Oncorhynchus tshawytscha*) and Central Valley steelhead (*Oncorhynchus mykiss*) are federally listed as threatened due to these declines, and critical habitat has been designated to assist recovery of their populations (NMFS 2014). The National Marine Fisheries Service (NMFS) Recovery Plan for spring-run Chinook salmon and steelhead identifies Butte, Big Chico, Deer, Mill, and Antelope creeks as the Sacramento River tributaries that provide critical migration, spawning, and rearing habitat for the last remaining naturally-produced spring-run Chinook salmon populations in the Northern Sierra Nevada Diversity Group (NMFS 2014). Antelope, Deer, and Mill creeks also provide critical habitat for wild steelhead populations.

Antelope Creek, the northern-most watershed in the Northern Sierra Nevada Diversity Group, originates in the southwestern Cascade Range and flows to the Sacramento River near Red Bluff (Figure 1-1). The Recovery Plan identifies Antelope Creek as having a Core 1 steelhead population and a Core 2 spring-run Chinook salmon population. Core 1 populations are a priority for recovery efforts, while Core 2 populations are assumed to have the potential to meet a moderate risk of extinction and are of secondary importance for recovery efforts (NMFS 2014).

The Edwards Diversion Dam, initially constructed in 1912 by Coneland Water Company, is located on Antelope Creek approximately 1 mile downstream of the canyon mouth (Figure 1-2). Two claims to pre-1914 appropriative water rights are diverted at the Edwards Diversion Dam; the Los Molinos Mutual Water Company (LMMWC) and the Edwards Ranch. These water diversions reduce flow in downstream channel reaches traversing the Sacramento Valley during adult and juvenile spring-run Chinook salmon and juvenile steelhead migrations.

The Recovery Plan identifies a comprehensive list of potential actions to restore spring-run Chinook salmon and steelhead populations in Antelope Creek (NMFS 2014). Priority actions include: (1) restoring instream flows during upstream and downstream migration periods through water exchange agreements and by providing alternative water supplies to Edwards Ranch and LMMWC in exchange for instream flows; and (2) restoring connectivity of the migration corridor during upstream and downstream migration periods by implementing Edwards and Penryn fish passage and entrainment improvement projects and identifying and constructing a defined stream channel for upstream and downstream fish migration (NMFS 2014). A new fish ladder was constructed at the Edwards Diversion Dam in 2007 to improve fish passage, and additional measures are being considered at the dam to prevent entrainment of emigrating salmonids in the Edwards Ranch and LMMWC diversion canals.

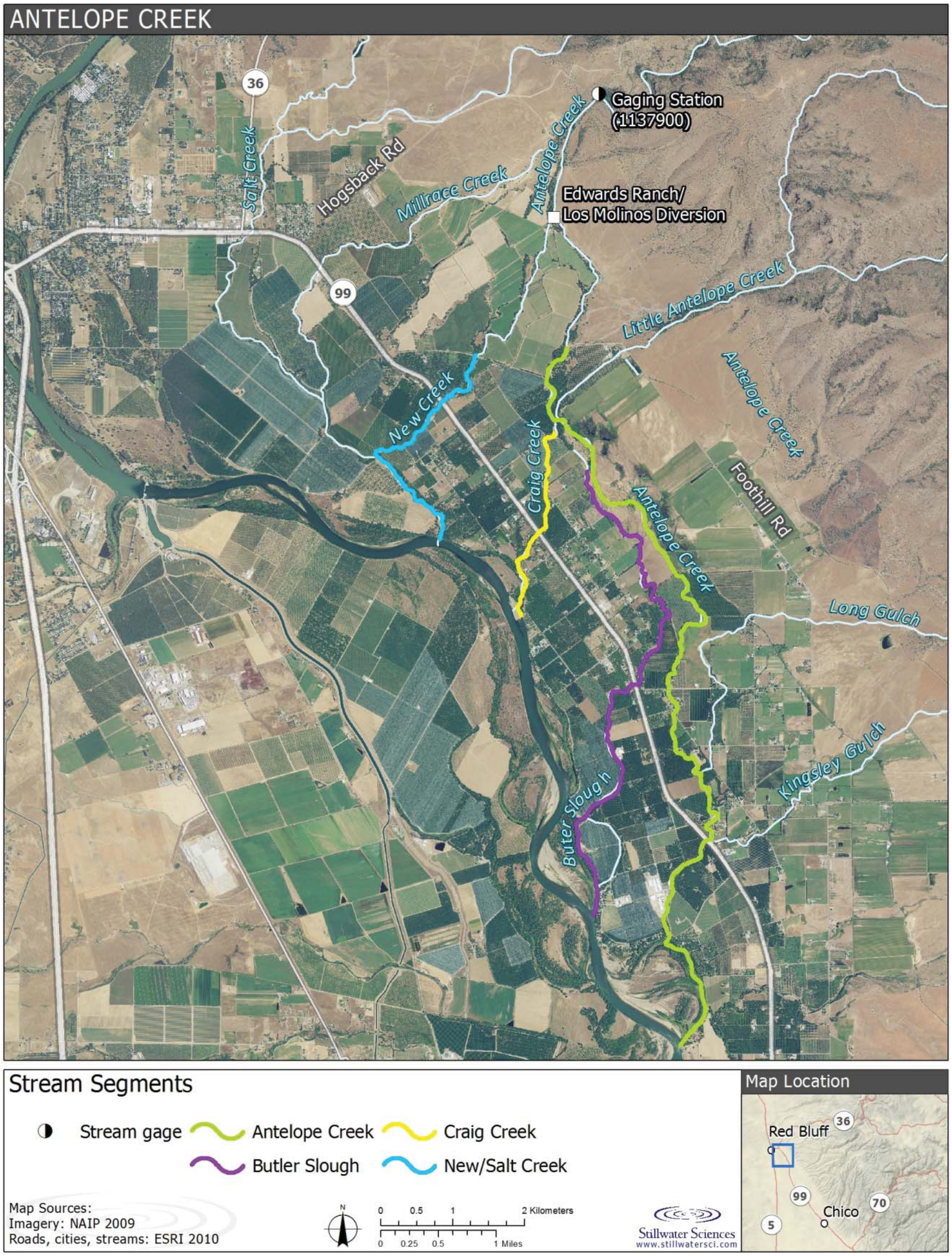


Figure 1-1. Lower Antelope Creek.

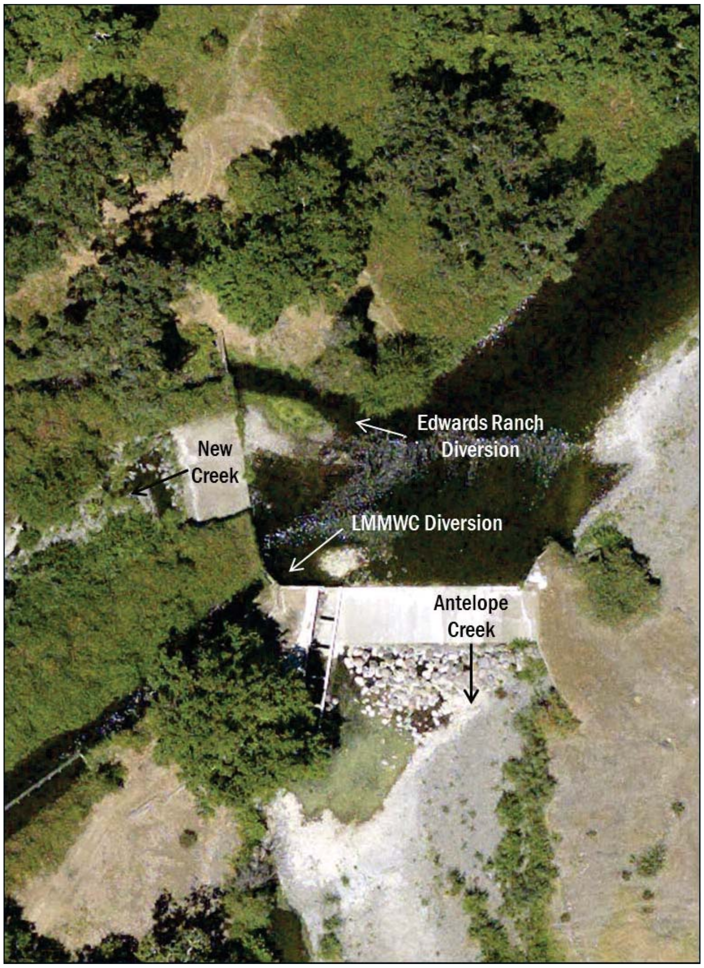


Figure 1-2. Edwards Diversion Dam.

Through grants from the United States Fish and Wildlife Service's National Fish Passage Program (NFPP) and Anadromous Fish Restoration Program (AFRP), the Tehama County Resource Conservation District (TCRCD) and Stillwater Sciences evaluated streamflow, stream temperature and quality, and existing channel conditions related to fish passage in lower Antelope Creek downstream of Edwards Diversion Dam and developed a strategy for improving fish passage between the Sacramento River and Edwards Diversion Dam. Specific objectives of this cooperative project in lower Antelope Creek included the following:

- Summarize available information on hydrology and geomorphology in the project area (Section 2);
- Summarize the occurrence, distribution, and life histories of anadromous salmonids in the Antelope Creek watershed (Section 2)
- Identify any potential barriers to adult and juvenile spring-run Chinook salmon and steelhead migration in lower Antelope Creek (Section 3);
- Characterize streamflow, stream temperatures, and water quality in lower Antelope Creek (Section 4); and
- Develop a strategy for improving spring-run Chinook salmon and steelhead migration between the Sacramento River and Edwards Diversion Dam (Section 5).

The approach involved compiling existing physical and biological information; developing advisory groups to facilitate technical input and community participation; strategically collecting streamflow, water quality, channel condition, and habitat information; and identifying opportunities and constraints to improving fish migration in lower Antelope Creek. The TCRCD convened a stakeholder group, comprised of lower Antelope Creek property owners and others with interest in the watershed. The stakeholder group provided information about the project area, helped disseminate information about the project, assisted with coordinating access for field data collection, and discussed the feasibility of various potential measures for improving fish passage. Stakeholder meetings were held to coincide with key project decision-points and were augmented by individual outreach by the TCRCD. The TRCD also convened a Technical Advisory Committee (TAC) comprised of representatives from local, state, and federal agencies; conservation groups; and representative landowners in the project area to review project plans and outcomes and to provide relevant technical input. The approach is consistent with NFPP goals of developing cooperative and environmentally-sound solutions to fish passage issues through local stewardship and increased public understanding.

2 SETTING

2.1 Hydrology

The only long-term streamflow record in Antelope Creek is from U.S. Geological Survey (USGS) gage no. 11379000, located approximately 1.2 miles (2.0 km) upstream of the Edwards Diversion Dam near where the bedrock canyon that confines mainstem Antelope Creek opens onto the relatively unconfined Sacramento Valley floor (Figure 1-1). The USGS operated gage no. 11379000 from 1941 to 1982. Downstream of USGS gage no. 11379000, lower Antelope Creek receives flow inputs from Little Antelope Creek, Long Gulch, Kingsley Gulch, Salt Creek, and other small unnamed tributaries. No flow records exist for these channels. Lower Antelope Creek also receives flow inputs via the HiLine Canal (approximately 20 cfs capacity) and Main Canal (approximately 50 cfs capacity), which bring irrigation water from Mill Creek (D. Mullins, District Manager, LMMWC, pers. comm., 27 January 2011). Rates and volumes of water returned to lower Antelope Creek from the HiLine Canal and Main Canal are unknown.

The State Water Resources Control Board recognizes two claims to Riparian and pre-1914 water rights from Antelope Creek, both located at Edwards Diversion Dam. The LMMWC claim allows a maximum diversion of 80 cfs, while the Edwards Ranch claim allows a maximum diversion of another 50 cfs. Flows are diverted primarily for agricultural purposes. If inflows are less than the combined 130 cfs allocation, available flow is split 50/50 between diverters. Flow diversions by LMMWC and the Edwards Ranch are measured by Parshall flumes installed in each diversion canal. In 2010, LMMWC and Edwards Ranch reported diverting 7,144 and 12,237 ac-ft, respectively, representing approximately 95% of the total riparian and pre-1914 water use within the Antelope Creek watershed (SWRCB 2014). Long-term records of diversion rates by LMMWC and Edwards Ranch were not available at the time this report was prepared.

Lower Antelope Creek is part of the Antelope Creek groundwater inventory unit, which is part of the larger Sacramento Valley groundwater basin (DWR 2003). Average and maximum water well yields within the Antelope Creek inventory unit were 575 gpm and 800 gpm, respectively (CDM. 2003). The only well in the Antelope Creek subbasin with specific current delivery data is operated by the Los Molinos Mutual Irrigation Company (CDM. 2003). That well was reported to have a delivery rate of 4 cfs. Water demand within the Antelope Creek inventory unit during an average year is 31,300 ac-ft, of which 24,000 ac-ft is used for agriculture, 2,200 ac-ft is consumed by municipal and industrial uses, and 5,100 ac-ft is lost during conveyance (CDM. 2003). During an average year, 13,300 ac-ft is supplied through local stream diversions and another 18,000 ac-ft is developed from ground water. Water demand during a dry year is roughly 34,900 ac-ft, of which 27,700 ac-ft is used for agriculture, 2,500 ac-ft is consumed by municipal and industrial uses, and 4,700 ac-ft is lost during conveyance (CDM. 2003). During a dry year, 10,400 ac-ft is supplied through local stream diversions and 24,600 ac-ft is developed from ground water.

2.1.1 USGS gaging station #11379000, 1941–1982

USGS gage no. 11379000 has a drainage area of 123 mi^2 (318 km^2). The mean annual flow over the period of record (1941–1982) was 151 cfs, resulting in an average annual yield of approximately 109,000 ac-ft (Figure 2-1). The average annual hydrograph includes high flows driven by rainfall events from mid-November into April, a spring snowmelt runoff period from April into early June, and prolonged summer low flow from July through early October (Figure 2-2, Table 2-1). The 1.5 to 2.0 year flood recurrence is 4,000 to 5,500 cfs (Figure 2-3), and the summer baseflow from July through September during the period of record ranged from about

25 cfs (100 percent exceedance) to 40 cfs (80 percent exceedance and mean discharge for July through September) (Figure 2-4, Table 2-1).

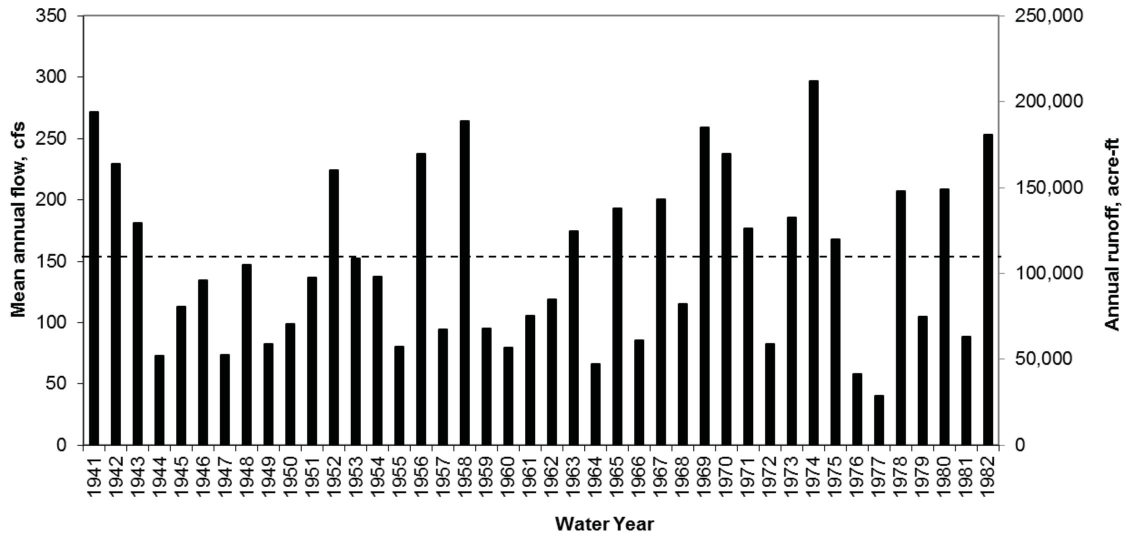


Figure 2-1. Annual mean flow and mean annual runoff in Antelope Creek at USGS gage no. 11379000, 1941–1982. The dotted line indicates the mean over the period of record (151 cfs, 109,000 ac-ft).

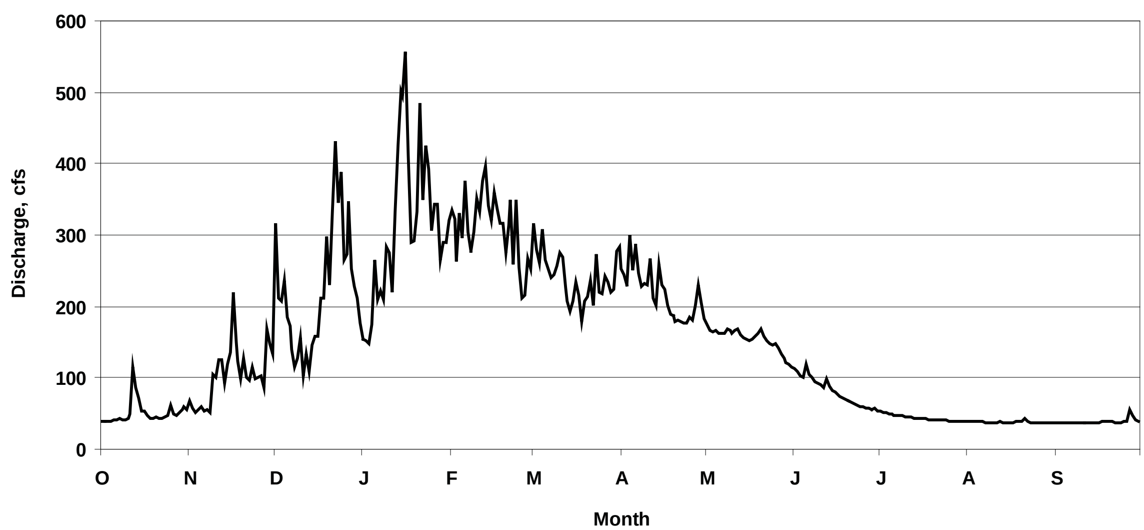


Figure 2-2. Average annual hydrograph in Antelope Creek at USGS gage no.11379000, 1941–1982.

Table 2-1. Mean monthly discharge in Antelope Creek at USGS gage no.11379000, 1941–1982.

Month	Mean	Min	Max
January	315	42	1,191
February	312	44	953
March	242	47	662
April	218	43	567
May	154	45	315
June	81	33	219
July	44	29	72
August	38	27	55
September	39	27	72
October	51	31	233
November	104	36	523
December	222	39	678

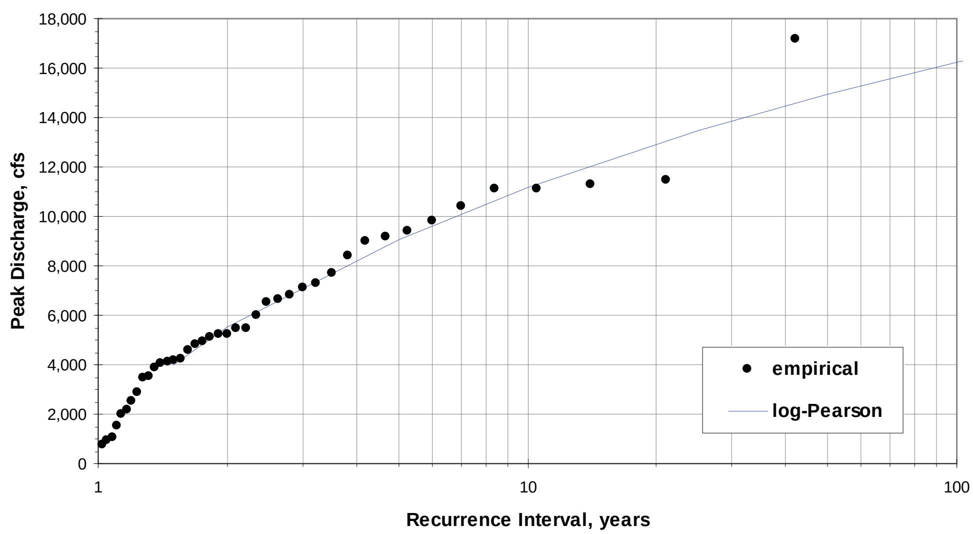


Figure 2-3. Flood frequency in Antelope Creek at USGS gage no. 11379000, 1940–1982.

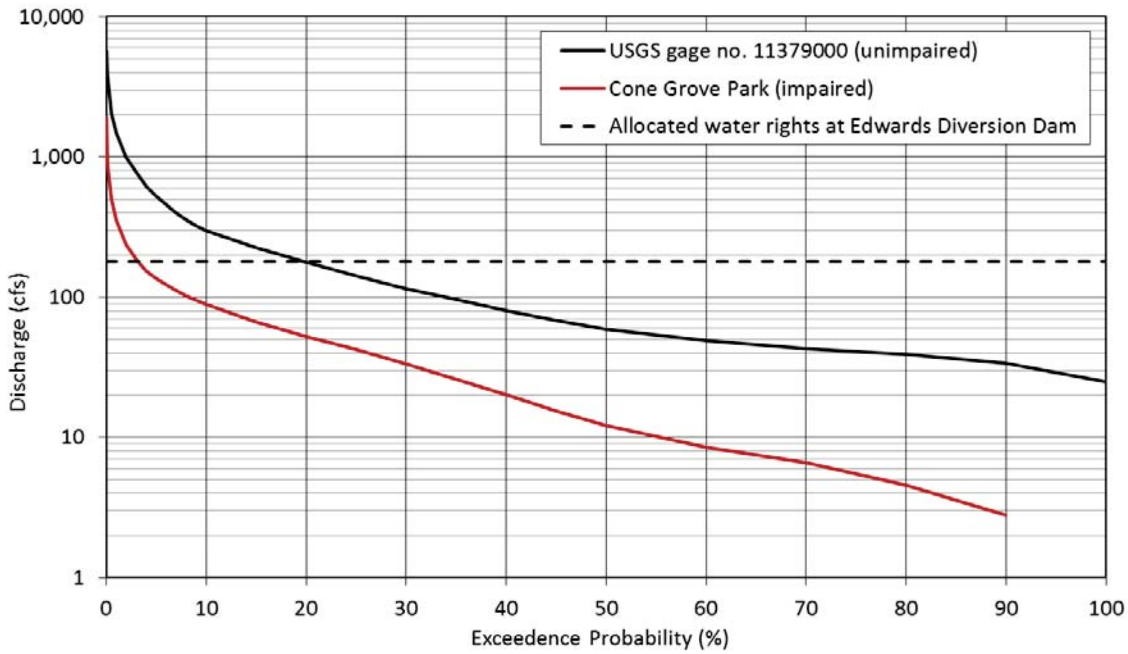


Figure 2-4. Exceedance probability of average daily discharge in Antelope Creek measured at USGS gage no.11379000 and estimated at Cone Grove Park, 1941–1982.

Antelope Creek annual hydrographs from representative water years, shown in Figure 2-5 with typical spring-run Chinook salmon and steelhead adult migration periods, illustrates the unique life history strategies of the two species. Adult steelhead opportunistically immigrate during winter peak flows, while adult spring-run Chinook salmon rely on relatively high and more stable baseflow during the spring snowmelt period. Adult steelhead therefore potentially utilize more of the distributary channel network in lower Antelope Creek that conveys high flows but little baseflow. Figure 2-5 also illustrates the potential for dewatering of mainstem Antelope Creek and its distributaries during the spring-run Chinook salmon migration period and juvenile steelhead in Below Normal and Dry Water Years when unimpaired inflow to the diversion remains below 130 cfs (maximum allowable diversion capacity at Edwards Diversion Dam).

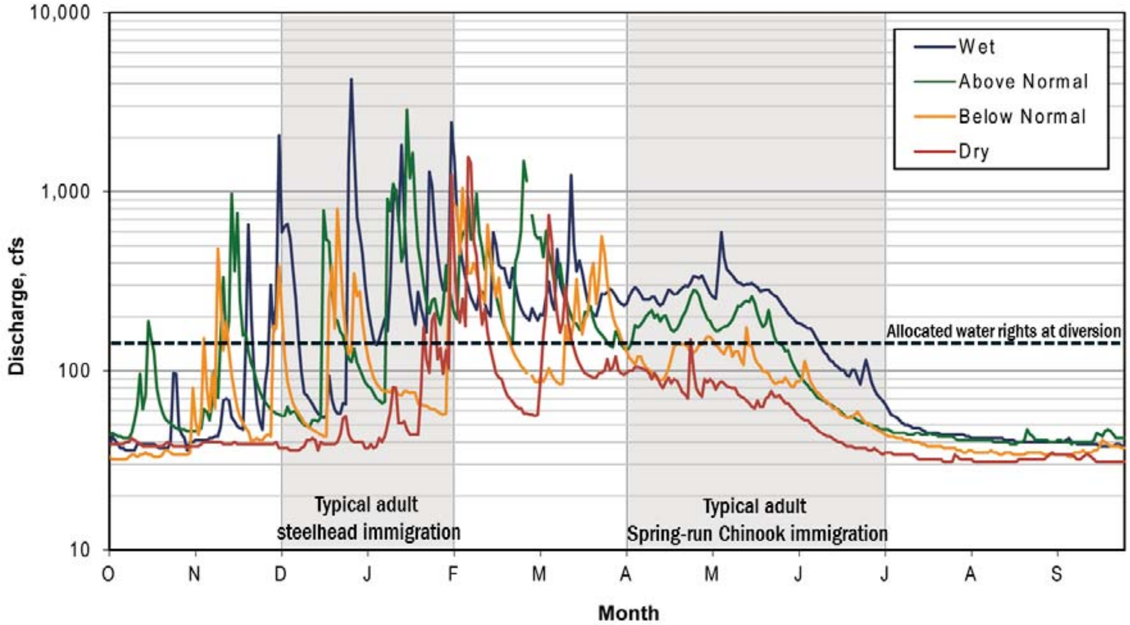


Figure 2-5. Annual hydrographs at USGS gage no. 11379000 for typical wet (1952), above normal (1973), below normal (1945), and dry (1960) Water Years.

2.1.2 Water Years 2010-2014

Because streamflow has not been monitored in Antelope Creek since the USGS discontinued operation of gage no. 11379000, average daily discharge at the former gage site during Water Years 2010–2014 was synthesized by prorating discharge measured at USGS gage no. 11381500 on Mill Creek. USGS has continuously operated gage no. 11381500 since 1928, which overlaps the entire period of record at USGS gage no. 11379000 on Antelope Creek. The two adjacent basins have similar geology, and the two gages are located at similar positions within their respective basins. The Mill Creek watershed is larger, has more relief, and higher spring and summer baseflow. Of the various proration techniques investigated, the ratio of average daily discharge at the two gages produced the best fit over the common period of record (1941–1982). Average daily streamflows estimated by proration and monitored at the former USGS gage site during WY2013 (Section 4.1.2) generally agree during the rainfall runoff season (December–March) but diverge beginning in April due to the larger baseflow in Mill Creek relative to Antelope Creek.

Average daily discharges were also estimated in Antelope Creek at Cone Grove Park during Water Years 2010–2014 using a flow regression equation developed by the USFWS (USFWS 2009). Comparison of flow estimates at USGS gage no. 11379000 and Cone Grove Park illustrates the critical spring and summer period when flows in lower Antelope Creek are most affected by water diversion at the Edwards Diversion Dam (Figure 2-6).

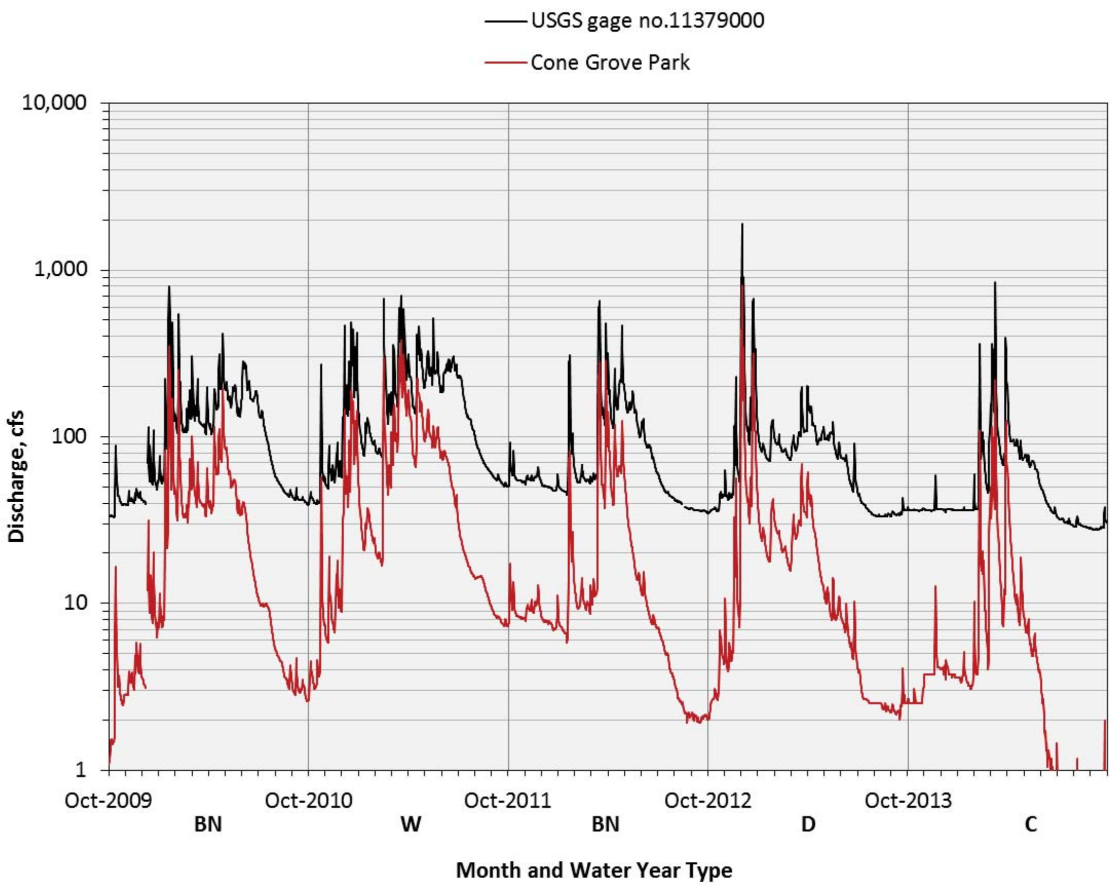


Figure 2-6. Synthetic hydrographs for Antelope Creek during Water Years 2010–2014 at USGS gage no. 1137900 and at Cone Grove Park (Water Year type: W=wet, BN=Below Normal, D=Dry, C=Critical).

2.2 Geomorphology

2.2.1 Geologic terranes

The Antelope Creek watershed is divided into two distinct geologic terranes: the mountainous southwestern Cascade Range comprised of Tertiary volcanic rocks and the northeastern Sacramento Valley comprised of Quaternary sediments. The two terranes are separated by the Chico Monocline, a prominent northwest-trending tectonic flexure of Late Cenozoic age that bounds the eastern margin of the Sacramento valley from Red Bluff to Chico (Harwood and Helley 1987). The Chico Monocline creates an abrupt topographic change from the steep, bedrock confined channel reaches draining the Cascade Range to the lower gradient, less unconfined channel reaches traversing the Sacramento Valley. This abrupt topographic break forces development of large coalescing alluvial fans along the mountain front where these river systems deposit their coarse load. Distributary channel networks are developed across these fan surfaces in Antelope, Little Antelope, Mill, and Deer creeks.

The dominant geologic unit in the upper watershed is the Tuscan Formation comprised of interbedded lahars (volcanic mudflow), fluvial deposits, ash-flow and air-fall tuffs, and basalt flows of late Pliocene age (~3.3 Ma) (Lydon 1968, Helley and Harwood 1985). The Tuscan Formation extends beneath Quaternary sediments in the northeastern Sacramento Valley. The Antelope Creek, Craig Creek, and Butler Slough channels are relatively fixed by resistant outcrops of this geologic unit upstream of approximately State Route 99.

The oldest Quaternary geologic unit in the Sacramento Valley is the Red Bluff Formation, a thin (3-33 ft), coarse-grained and highly weathered fanglomerate derived from erosion of the Tuscan Formation and associated volcanic rocks (Diller 1894, Helley and Harwood 1985). The Red Bluff Formation occurs in lower Antelope Creek as a broadly dissected surface along the mountain front from north of Mill Race Creek to south of Little Antelope Creek (Blake et al. 1995). Antelope Creek impinges on the Red Bluff Formation at the head of the alluvial fan and intermittently in downstream reaches.

A series of fan and river terrace deposits are inset within and/or overly the Red Bluff Formation: the Lower Riverbank, Upper Riverbank, Lower Modesto, and Upper Modesto formations (Helley and Harwood 1985). These formations step up in elevation and increase in age with distance from the present-day stream channels. They average about 6–13 ft thick and are composed of weathered alluvial sediment similar to modern stream channel deposits. Where present-day channels impinge on the Riverbank Formation, the consolidated deposits and well developed soils are moderately resistant to erosion. The less consolidated and less weathered deposits of the upper and lower Modesto formations are extensive along the Sacramento River and its tributaries and are typically more erosive. Much of the lower Antelope Creek channel network is bordered by deposits of Modesto age.

2.2.2 Channel network

Over recent geologic history (e.g., late Holocene ~10 ky), lower Antelope Creek has occupied at least four channels (from north to south): New Creek, Antelope Creek, Craig Creek, and Butler Slough (Table 2-2, Figure 2-7).

Table 2-2. Length and average slope of channels in lower Antelope Creek.

Channel	Length[1], mi	Slope[2]
New Creek	4.29	0.0038
Antelope Creek upstream of Antelope Creek–Craig Creek distributary junction	2.21	0.0033
Antelope Creek downstream of Antelope Creek–Craig Creek distributary junction	6.30	0.0017
Craig Creek	2.05	0.0043
Butler Slough	5.00	0.0015

[1] Length of Antelope Creek and New Creek from Edwards Diversion Dam to the Sacramento River; Length of Craig Creek and Butler slough from the channel head at the distributary junctions to the Sacramento River.
[2] Average slope derived from 10 m DEM data.

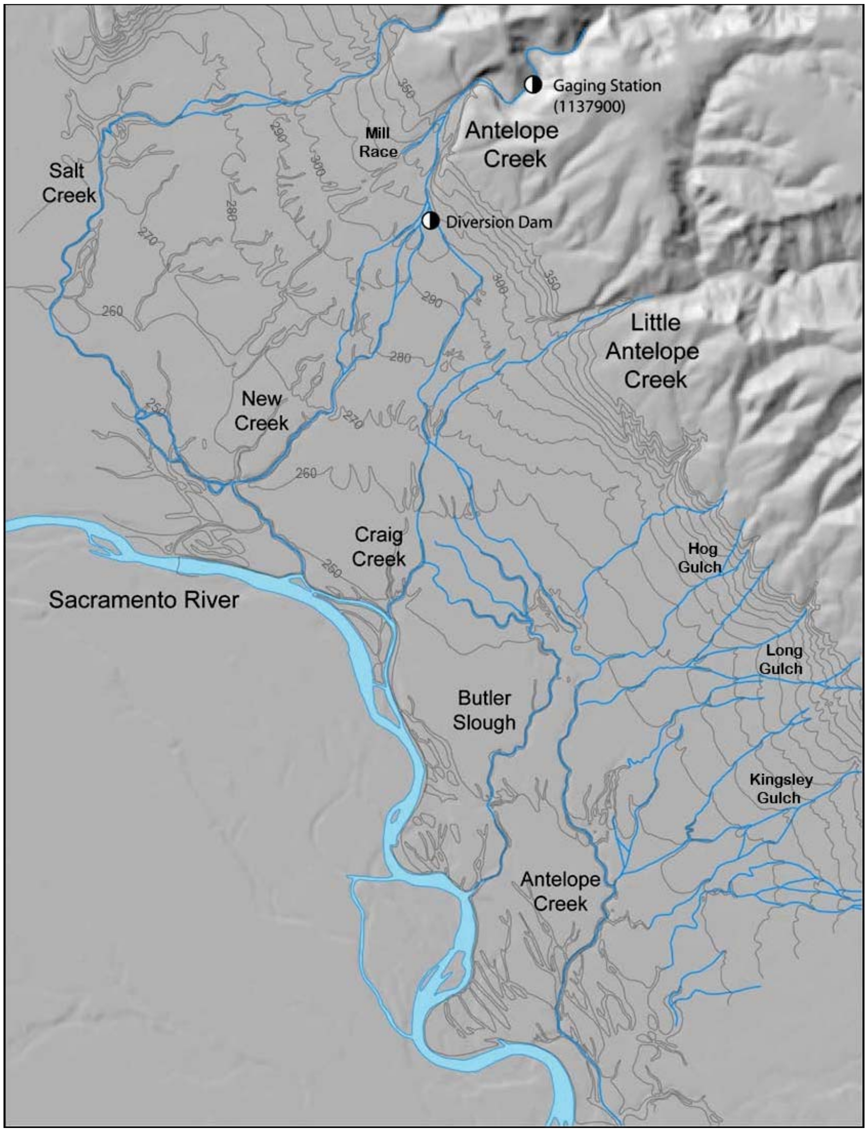


Figure 2-7. Topography (10-ft contours) and drainage network in lower Antelope Creek derived from the 1905 Tehama 15' quadrangle map.

Available historical maps compiled for lower Antelope Creek included the 1905 USGS Tehama 15' quadrangle and maps from 1903, 1908, 1913, 1927, 1943, and 1952 prepared by Tehama County. A time series of historical aerial photography compiled for the area included photo sets from 1938, 1958, 1972, 1994, 1998, and 2009. Historical maps and aerial imagery were used to assess changes in the lower Antelope Creek channel network since 1905. The 1905 USGS quadrangle map and the 1938 and 1958 aerial photography were scanned and georeferenced to California State Plane Zone 1 (NAD 1983 in feet). The channel centerlines for New Creek, Antelope Creek, Craig Creek, and Butler Slough were then digitized from these data and from 2009 color aerial photography obtained from the National Agricultural Imagery Program (NAIP). Observable geomorphic changes between photo years were recorded in a point file with attributes. Additional historical information was obtained from documents archived by the Tehama County Historical Society and Special Collections facility at California State University's Merriam Library and from interviews with long-term residents of lower Antelope Creek.

Topographic contours on the Tehama 15’ quadrangle map from 1905 illustrate a conical-shaped alluvial fan built out from the 350-ft contour (near the opening of the Antelope Creek canyon) to about the 270-ft contour (Figure 2-7). Below the 270-ft contour, erosion and deposition within the Sacramento River floodplain have modified the distal fan margin. Several named channels and many smaller, unnamed ephemeral channels bifurcated from mainstem Antelope Creek and/or drained the fan surface between the 350-ft and 270-ft contours. Mill Race Creek, the smallest of the named channels, branched from mainstem Antelope Creek at an elevation of about 325 ft and drained west-southwest off the central portion of the fan. Multiple small channels branched from mainstem Antelope Creek between the 310-ft and 300-ft contours, eventually coalescing into New Creek. Mainstem Antelope Creek drained the southern edge of the fan. At about the 290-ft contour, mainstem Antelope Creek encounters the northern margin of the Little Antelope Creek fan and is deflected sharply southwest along the line of intersection between the two fans. Fan morphology below the 300-ft contour between New Creek and Little Antelope Creek is more planar and lacks drainage crenulations characteristic of other fan surfaces, suggesting geologically recent channel migration, more widespread flood inundation, and/or higher sedimentation rates in this area.

The 1905 Tehama 15’ quadrangle shows mainstem Antelope Creek bifurcating into Craig Creek and Antelope Creek at about the 270-ft contour (Figure 2-7). Downstream of this distributary junction, the larger channel (labeled Craig Creek) appears to be a continuation of mainstem Antelope Creek, while the smaller channel (labeled Antelope Creek) followed a more south-southwesterly course, joining one of several Little Antelope Creek distributaries before entering a low gradient area with several southeast-trending subparallel drainages. Topography and drainage patterns in this vicinity (between the 260-ft and 250-ft contours) suggest the area received considerable overbank flow from Craig Creek and other sources. Downslope of the 250-ft contour, three of the four distributary channels coalesced into Butler Slough while the fourth became Antelope Creek. Each of these named distributaries maintained separate, single-thread courses to the Sacramento River. Several small tributaries (Hog Gulch, Long Gulch, and Kingsley Gulch) drain from the foothills to the lower Antelope Creek distributary upstream of the present-day State Route 99 crossing (Figure 1-1 and Figure 2-7). Downstream of the 240-ft contour, Antelope Creek and its distributaries are highly influenced by the topography and the dynamic erosion and deposition processes occurring within the Sacramento River meander zone.

Analysis of historical maps and aerial photographs indicates few changes in the position of the Antelope Creek mainstem and distributary channel network relative to that shown on the 1905 Tehama 15’ quadrangle. Site-specific geomorphic changes have occurred in the vicinity of Edwards Diversion Dam, the Antelope Creek-Craig Creek distributary junction, and the lower reaches influenced by the Sacramento River. Construction of Edwards Diversion Dam and related diversion infrastructure changed New Creek from a multi-thread distributary network to a single thread channel (Figure 2-7). Where high flows once topped the left channel bank in the vicinity of the Antelope Creek-Craig Creek distributary junction and downstream in Craig Creek (Figure 2-7), levees and channel armoring have concentrated out-of-bank flow over a much shorter length. Out-of-bank flows now route through a more narrowly confined floodway extending to approximately Electric Avenue, downstream of which surface flow concentrates into Antelope Creek and Butler Slough (Figure 2-8). Small channels that once drained the floodplain area between the 260-ft and 250-ft contours are no longer apparent due to agricultural development. The effect of these changes have likely increased peak flow stage heights in the floodprone area immediately downstream of the distributary junction and focused baseflows within Craig Creek. These changes also focus coarse sediment deposition in the vicinity of the distributary junction during high flow events, as indicated by the gravel-cobble bars at the entrances to the two high flow channels and immediately downstream in Craig Creek. Sediment dynamics in the vicinity of the distributary junction have the potential to significantly change flow splits between the mainstem and distributary channels, as well as create low flow migration barriers.

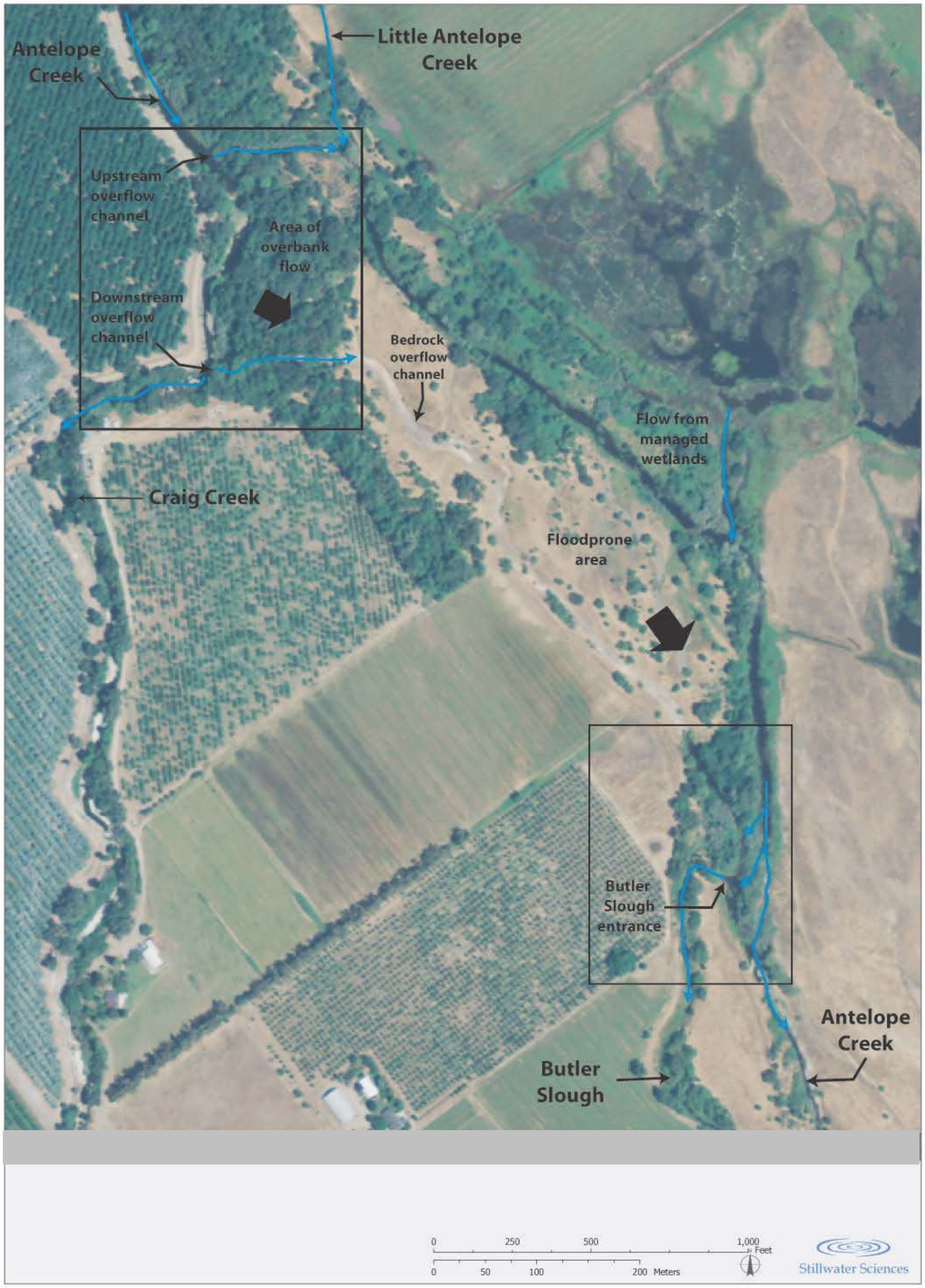


Figure 2-8. Distributary junctions and intervening floodprone area.

The lower reaches of New Creek, Antelope Creek, Craig Creek, and Butler Slough occupy former meanders and high flow channels within the Sacramento River meanderbelt that lack confinement and reflect a pre-existing gradient, grain size, and riparian vegetation community. Major adjustments by the Sacramento River (e.g., meander cutoff, rapid channel migration, episodic erosion and sedimentation) have profound effects on tributary base level and bed elevation, channel length and width, bed surface texture, and morphology. The lowest reach of Craig Creek, for example, flows within an abandoned side channel of the Sacramento River that once formed the eastern edge of Blackberry Island. The Sacramento River deposited a large cobble-gravel bar at the present mouth of Craig Creek, forcing Craig Creek to lengthen around the bar. Since 1905, Butler Slough has also lengthened within old channels of the Sacramento River as the river has migrated west and downstream into Mooney Island. Antelope Creek has also dramatically lengthened since 1905, as the large meander of the Sacramento River in the vicinity of the confluence has migrated downstream. These changes have the potential to create migration barriers related to channel morphology and shallow and/or intermittent surface flow.

2.3 Occurrence, Distribution, and Life Histories of Anadromous Salmonids

Spring-run Chinook salmon (*Oncorhynchus tshawytscha*), steelhead (*O. mykiss*), and fall-run and late fall-run Chinook salmon (*O. tshawytscha*) are all known to occur Antelope Creek (Rectenwald 1998; Hayes and Lindquist 1967). Antelope Creek provides 35 miles of anadromous habitat from the Sacramento River confluence to four miles up the north fork and seven miles up the south fork (C. Harvey-Arrison, CDFG, pers. comm., 2009). Spring-run Chinook salmon and steelhead must immigrate through one of four potential migration corridors (Antelope Creek, Craig Creek, Butler Slough, and New Creek) connecting the Sacramento River to holding, spawning, and rearing habitat upstream of the canyon mouth (about 1 mile upstream of Edwards Diversion Dam). The distributions of anadromous salmonids upstream of Edwards Diversion Dam are not described in detail here (refer to Rectenwald 1998; CDFG 2001; Armentrout et al. 1998). Some life history information described below is derived from studies in nearby east side Sacramento River tributaries with more information about salmon and steelhead populations (e.g., Mill, Deer, and Butte creeks).

The California Department of Fish and Wildlife (CDFW) has estimated annual adult Chinook salmon escapement in Antelope Creek based on snorkel surveys, redd counts, and carcass surveys since about 1992. CDFW has intermittently operated video monitoring equipment at Edwards Diversion Dam since 2007 to count adult salmon and steelhead escapement, better understand run timing, and ultimately improve water management for anadromous fish passage (M. Johnson, CDFW, pers. comm., 2014). Video monitoring was first conducted at the dam from winter 2007 to spring 2008, but was discontinued thereafter. A Section 1602 Streambed Alteration Agreement issued to Edwards Ranch in 2013 required reinstatement of video monitoring at the dam over a five year period from 2013 to 2018. Video monitoring equipment was reinstalled on 15 October 2013 and operated through 30 June 2014. Monitoring was reinstated on 14 October 2014, but was destroyed by high flows on 6 December 2014 (M. Johnson, CDFW, pers. comm., 2014). Since 1981, CDFW has also rescued out-migrating juvenile Chinook salmon, juvenile steelhead, and adult steelhead kelts trapped between the canal head-gates and fish screens at Edwards Diversion Dam (M. Johnson, CDFW, pers. comm., 2014). Once entrained, these fish must be manually captured and released downstream of the diversion or they will die from predation or lethal summer water temperatures.

2.3.1 Spring-run Chinook salmon

The Central Valley spring-run Chinook salmon ESU was federally listed as threatened on 16 September 1999 (NMFS 1999), threatened status was reaffirmed in NMFS's final listing determination issued on 28 June 2005 (70 FR 37160), and critical habitat was designated by NMFS on September 2, 2005 (70 FR 37160). Adults immigrate from the Sacramento River into Antelope Creek from late-March through June, holding in pools upstream of the diversion dam (Table 2-3) (C. Harvey-Arrison, CDFG, pers. comm., 2009; CDFG 1998). Fish migrate from holding pools to upstream spawning grounds when stream temperatures cool, typically during late August through October (C. Harvey-Arrison, CDFG, pers. comm., 2009; P. Moyle, personal observation, as cited in Moyle et al. 1995; 69 FR 33102). Suitable holding and spawning habitat occurs from about 2 miles downstream of Paynes Place upstream into the north and south forks of Antelope Creek (C. Harvey-Arrison, CDFG, pers. comm., 2009; Rectenwald 1998; Airola 1983). Egg incubation generally lasts 40 to 90 days during late August to March (Fisher 1994, Ward and McReynolds 2001) when stream temperatures are 42.8 to 53.6°F (6 to 12°C) (Vernier 1969, Bams 1970, Heming 1982, all as cited in Bjornn and Reiser 1991). Fry emergence occurs two to three weeks after hatching, typically November to March (Fisher 1994, Ward and McReynolds 2001). Rearing and outmigration is highly variable, with some fry dispersing downstream soon after emergence during December through February while others smolt and outmigrate as subyearlings from March to mid-June or oversummer and emigrate as yearlings from September through March (USFWS 1995, as cited in Yoshiyama et al. 1998; Hill and Webber 1999; Ward and McReynolds 2001; Ward et al. 2004). Scale analysis indicates most returning adults emigrated as subyearlings (Myers et al. 1998; Calkins et al. 1940, as cited in Myers et al. 1998). Rearing habitat distribution generally overlaps with spawning areas and downstream reaches with suitable summer stream temperatures.

Table 2-3. Life history timing of spring-run Chinook salmon in Antelope Creek.

Life stage	Month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Adult immigration[1,2,3]												
Adult holding												
Spawning[2]												
Incubation												
Emergence[2]												
Rearing[2]												
Juvenile emigration[2]												

[1] C. Harvey-Arrison, CDFG, pers. comm., 2009
[2] Yoshiyama et al. 1998
[3] NMFS 2014

= Span of life history activity
= Peak of life history activity

Historical spring-run Chinook salmon population levels in Antelope Creek are estimated to have been around 500 adult fish (Hayes and Lindquist 1967). Maximum run size reported in 1954 was 253 fish (CDFG 2001, Rectenwald 1998). Adult counts in Antelope Creek from 1992 to 2013 ranged from 0 to 154 fish (Figure 2-9) (CDFG 2001, Armentrout et al. 1998).

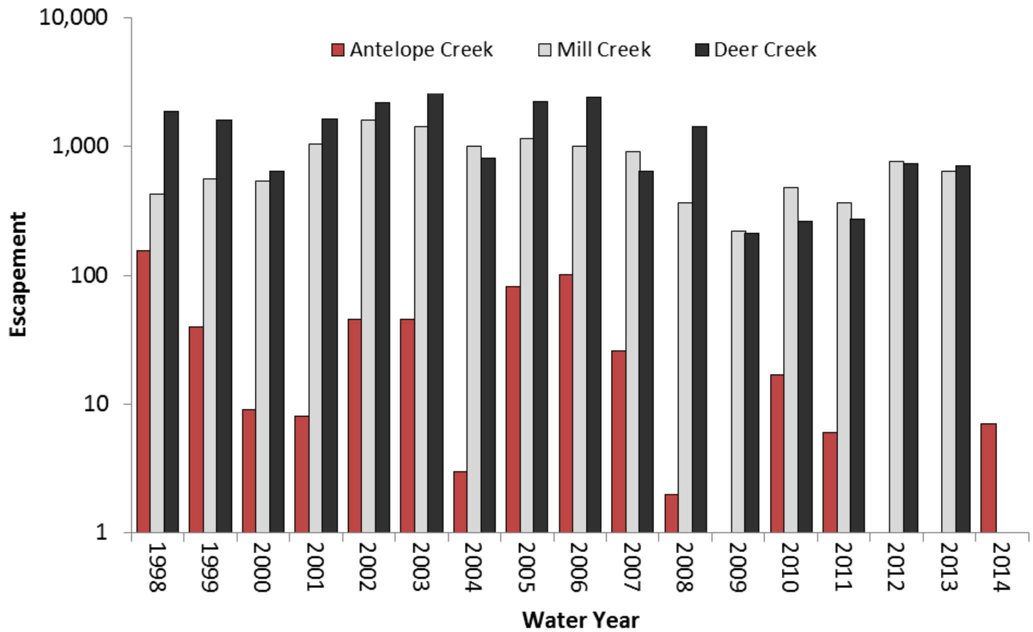


Figure 2-9. Spring-run Chinook salmon escapement in Antelope, Mill, and Deer creeks, 1998–2014 (1998-2013 data from the Fisheries Branch Anadromous Resource Assessment Unit of CDFW. 2014 data for Antelope Creek is preliminary, 2014 data for Mill and Deer creeks were not available).

2.3.2 Fall-run Chinook salmon

NMFS designated the Central Valley Fall (and Late-fall) Chinook salmon ESUs as a species of concern in 2004 (NMFS 2004). Fall-run Chinook salmon enter Antelope Creek in late-September and October when fall rains allow access (Table 2-4). Adults spawn from October through December. Fall-run Chinook salmon historically spawned in distributary channels in lower Antelope Creek downstream of Edwards Diversion Dam (NMFS 2008). Eggs incubate for 2 to 4 months, depending on stream temperature, with fry emergence occurring during winter and early spring. Fry disperse downstream from early January through March, whereas smolts typically migrate between April and mid-June. Hayes and Lindquist (1967) indicate that the Antelope Creek, New Creek, and Butler Slough distributaries stranded fish following high flows, whereas Craig Creek provided more consistent passage during winter baseflow. Recent observations of spawning activity extend from about 0.5 miles from the Sacramento River upstream to about Paynes Crossing (NMFS 2014; C. Harvey-Arrison, CDFG, pers. comm., 2009). CDFW observed 28 fall-run Chinook salmon redds between the Sacramento River and Edwards Diversion Dam on 7 November 2014, most of which were located in Craig Creek (M. Johnson, CDFW, pers. Comm., 2014). Juveniles below a critical size threshold may oversummer in Antelope Creek (Bradford et al. 2001). Rearing habitat distributions in Antelope Creek generally overlap with spawning distribution and downstream reaches with suitable temperatures. Historical fall-run Chinook salmon population estimates in Antelope Creek (1947–1998) ranged from 60 to 4,150

(Rectenwald 1998, Hayes and Lindquist 1967). The AFRP restoration goal for Fall-run Chinook in Antelope Creek is 720 fish annually (USFWS and AFRP 2001)

Table 2-4. Life history timing of fall Chinook salmon in the Antelope Creek basin.

Life stage	Month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Adult immigration[1]												
Spawning[2]												
Incubation												
Emergence[2]												
Rearing[2]												
Juvenile emigration												

[1] C. Harvey-Arrison, CDFG, pers. comm., 2009
[2] Yoshiyama et al. 1998
= Span of life history activity
= Peak of life history activity

Late-fall run Chinook salmon historically used Antelope Creek (Yoshiyama et al. 1998), although past and present populations are unknown. Adults enter Antelope Creek during January through March, with spawning extending from January through April and emergence occurring April through June. (C. Harvey-Arrison, CDFG, pers. comm., 2009) (Table 2-5). Juveniles emigrate to the Sacramento River soon after emergence. Late-fall run juveniles generally reside longer (7–13 months) in fresh water compared with fall-run juveniles (1–7 months) (Moyle 2002).

Table 2-5. Life history timing of late-fall Chinook salmon in the Antelope Creek basin.

Life stage	Month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Adult immigration[1,2]												
Spawning[1]												
Incubation												
Emergence[1]												
Rearing[1]												
Juvenile emigration												

[1] Yoshiyama et al. 1998
[2] C. Harvey-Arrison, CDFG, pers. comm., 2009
= Span of life history activity
= Peak of life history activity

2.3.3 Steelhead

NMFS listed the Central Valley California DPS as threatened in 1998 [63 FR 13347]), reaffirmed the listing in 2006 (71 FR 834), and designated critical habitat on September 2, 2005 (70 FR 52488). Adults opportunistically migrate through lower Antelope Creek distributaries to canyon reaches upstream of the diversion dam during the late fall and winter when stream temperatures drop and flow increases. Migration often exhibits a bimodal distribution, with a pulse in late fall (e.g., November) and another during winter (e.g., January) (Table 2-6) (C. Harvey-Arrison, CDFG, pers. comm., 2009). Since steelhead migrate during high flows, they are more likely to use lower Antelope Creek distributary channels than other anadromous salmonids. Spawning occurs soon after reaching spawning grounds. Spawning has been observed as far downstream as Grapevine Creek (C. Harvey-Arrison, CDFG, pers. comm., 2009), and extends upstream to four and seven miles on the north and south forks of Antelope Creek, respectively (C. Harvey-Arrison, CDFG, pers. comm., 2009). Incubation typically requires one to three months to fry emergence, depending on temperatures. Juveniles generally rear for two years in reaches of upper Antelope Creek with suitable summer stream temperatures (C. Harvey-Arrison, CDFG, pers. comm., 2009). Post-spawn adults and smolts emigrate during April and May (C. Harvey-Arrison, CDFG, pers. comm., 2009). In 2007/2008, 140 steelhead were observed moving through the ladder at Edwards Diversion Dam (C. Harvey-Arrison, CDFG, pers. comm., 2009). Historical population levels are estimated to be around 300 adult fish (Hayes and Lindquist 1967).

Table 2-6. Life history timing of steelhead in the lower Antelope Creek basin.

Life stage	Month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Adult immigration[1]	Peak	Peak	Peak	Span						Span	Span	Peak
Spawning[2]	Peak	Peak	Peak	Span								Span
Adult emigration		Span	Span	Span	Span							
Emergence[2]		Span	Span	Span	Span	Span (partial)						
Rearing	Span	Span	Span	Span	Span	Span	Span	Span	Span	Span	Span	Span
Juvenile emigration[1]	Span				Peak	Peak	Span				Span	Span

1 C. Harvey-Arrison, CDFG, pers. comm., 2009
2 NMFS 2014
= Span of life history activity
= Peak of life history activity

3 CHANNEL CONDITIONS AND POTENTIAL MIGRATION BARRIERS

Adult spring-run Chinook salmon and steelhead in Antelope Creek must immigrate from the Sacramento River through valley floor distributary channels to summer holding, spawning, and rearing habitats located in the canyon upstream of Edwards Diversion Dam. Juvenile fish must then emigrate from these habitats past the diversion dam and through the valley floor distributary channels to the Sacramento River. The following sections describe fish passage conditions in lower Antelope Creek downstream of Edward Diversion Dam, including channel morphology and condition, streamflow, water quality and temperature, and potential barriers. Descriptions are drawn from literature review and analysis of historical information; field mapping and monitoring; experience of CDFW and USFWS field staff, and input from stakeholders.

Field surveys were conducted in lower Antelope Creek during fall 2009 (28 October 28–1 November) and spring 2010 (13–14 May) (Figure 3-1). The fall 2009 survey documented channel reach morphology and condition, spawning and rearing habitat conditions, and potential barriers to migration when water diversions most affect adult fall-run Chinook salmon immigration and juvenile Steelhead and spring-run Chinook salmon emigration. Potential sites for monitoring streamflow, stream temperature, and water quality were identified during the fall field effort. The spring 2010 survey documented spawning and rearing habitat conditions and potential barriers when water diversions most affect adult spring-run Chinook salmon and steelhead immigration. Water Year 2010 (mean annual runoff =115 cfs) ranks in the 55th percentile for the gaging period of record and was a Below Normal Water Year according to the Sacramento River Index. The spring runoff period was wet, with relatively high baseflow into June. Table 3-1 summarizes estimated streamflows in lower Antelope Creek during the fall 2009 and spring 2010 surveys.

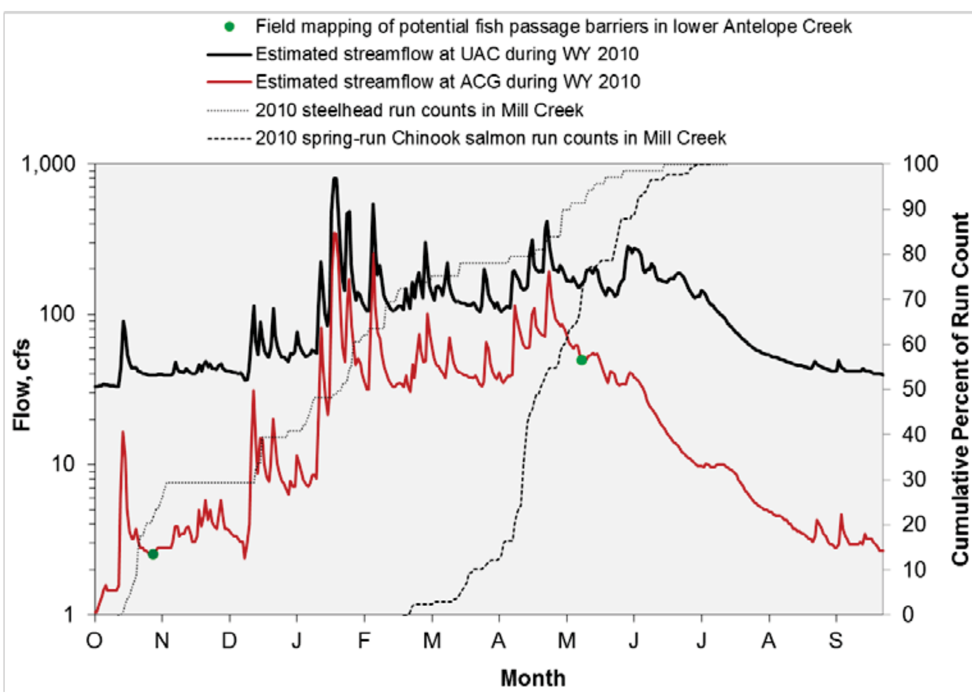


Figure 3-1. Estimated streamflow and field survey dates during WY2010. Spring-run Chinook salmon and steelhead run counts in Mill Creek during WY2010 illustrate probable run timing in Antelope Creek.

Table 3-1. Estimated flow observed during fall 2009 and spring 2010 surveys.

Channel	Reach	Fall 2009	Spring 2010
Antelope Creek	Reach 1	20	50
	Reach 2	2	<1
	Reach 3	2	2
	Reach 4	2	2
	Reach 5	2	10
	Reach 6	2	10
Little Antelope Creek	confluence	<1	<1
Craig Creek	Reach 1	18	50
	Reach 2	18	50
	Reach 3	18	50
Butler Slough	Reach 1	<1	2
	Reach 2	0	2
	Reach 3	0	2
New Creek	Reach 1	0	8
	Reach 2	0	8

Surveys were conducted by walking the four main channels in lower Antelope Creek (Antelope Creek, Craig Creek, Butler Slough, and New Creek) from approximately Cone Grove Road to their confluence with the Sacramento River. Antelope Creek between Cone Grove Park and Edwards Diversion Dam, and New Creek between Cone Grove Road and Edwards Diversion Dam were not accessible at the time surveys were conducted. Field data were logged on standardized data sheets (Appendix A) and mapping tiles at a scale of 1:3,000 (Appendix B). Longitudinal stationing was established relative to Edwards Diversion Dam (Station 0) for Antelope Creek and New Creek, and the channel head distributary junctions (Station 0) of Craig Creek and Butler Slough (Appendix B). Locations throughout lower Antelope Creek are identified in this document using these station numbers. A global positioning system (gps) was used to document locations along the channel (e.g., reach breaks, significant geomorphic features, spawning and rearing habitat for anadromous salmonids, potential barriers, and potential sites for monitoring temperature and stage). Ground-level photographs documented each survey reach and site (Appendix C).

To better understand the locations and mechanisms limiting fish passage, channels reaches with similar channel morphology and hydraulic conditions were delineated during fall 2009 based on observations of bedrock and stratigraphic controls, channel geometry, bedforms, and bed surface textures (Figure 3-2). Wetted channel width, bankfull width, and valley bottom width were measured or estimated at typical cross sections in each reach (Table 3-2). Observations of local sediment sources and active sediment storage, anthropogenic influences on the channel (e.g., water diversion, irrigation return flow, levees and bank protection, impoundments, and crossings), and riparian vegetation encroachment in the bankfull channel were also made in each reach. Limited mapping and survey work was conducted at distributary junctions to develop an understanding of local hydraulics and sediment dynamics controlling flow splits.

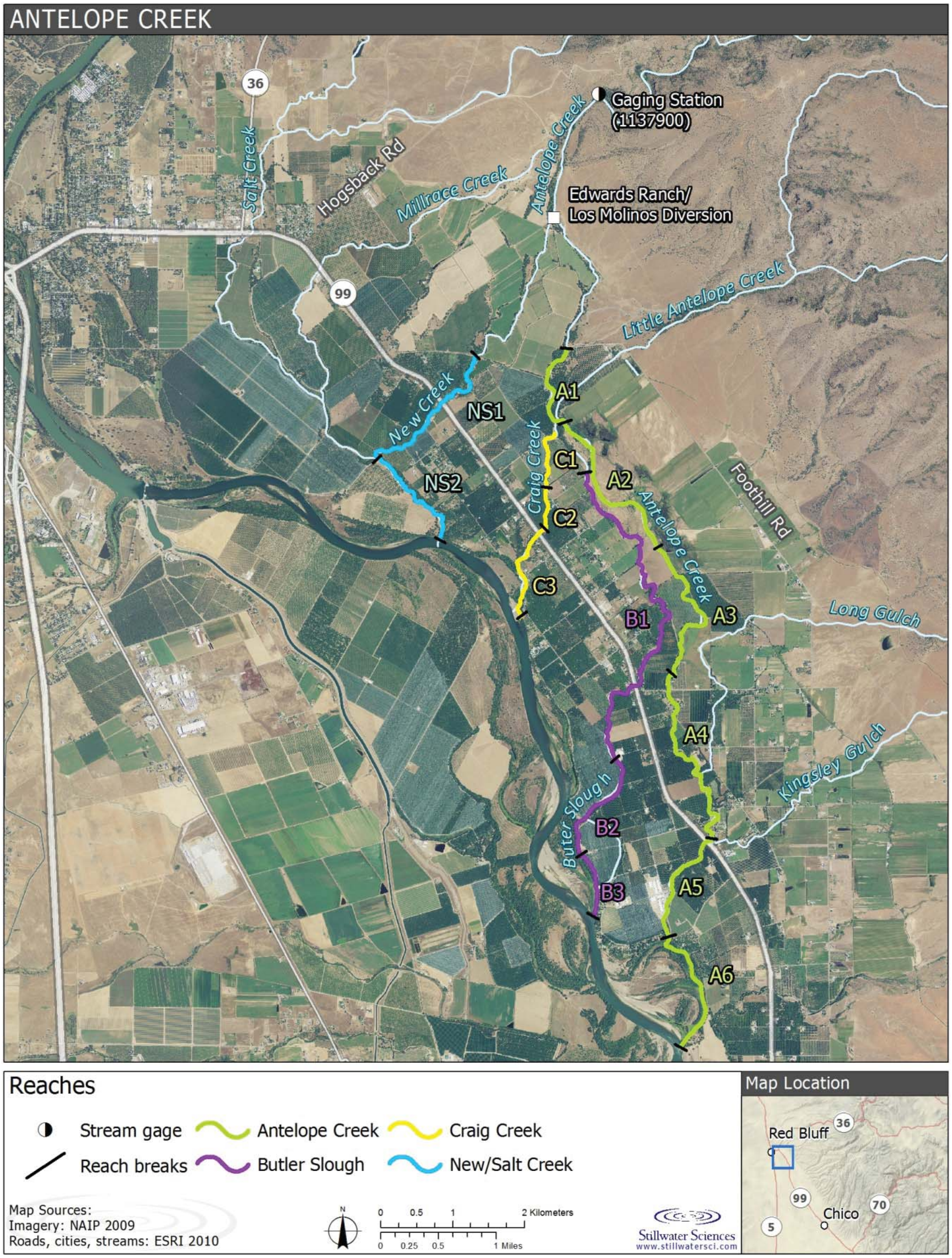


Figure 3-2. Channel reaches delineated in lower Antelope Creek.

Table 3-2. Reach-average channel characteristics in lower Antelope Creek.

Channel[1]	Reach	Endpoints (Station, m)		Reach morphology	Wetted channel dimensions[1]		Bankfull channel dimensions[1]		Bed surface texture[2]
		us	ds		W, m	D, m	W, m	D, m	
Antelope	1	2,300	3,545	Pool riffle	12	0.2	18	1.5	CbGr, GrCb
	2	3,700	6,700	Plane bed	11	<0.1–0.9	16	1.4	Br
	3	6,700	8,700	Pool riffle, plane-bed	8	<0.1–0.9	21	1.5	Gr, Br
	4	8,700	11,850	Pool riffle, plane bed	6	0.6	12	1.5	Gr, GrSa
	5	11,850	13,600	Pool riffle, plane bed	12	1	14	3	Gr, GrCb
	6	13,600	mouth	Plane bed	22	0.6	na	na	GrSa, Sa
Craig	1	200	1,100	Plane bed	9	0.6	13	1.7	GrCb
	2	1,100	1,700	Plane bed	2	0.5	8	2.4	Br
	3	1,700	3,200	Pool riffle	12	0.5	20	1.7	Gr, GrCb
Butler	1	0	5,500	Plane bed	6	0–0.2	12	1..2	Br, Gr
	2	5,500	8,040	Plane bed, pool riffle	dry	dry	incised	incised	Sa
	3	8,040	mouth	Plane bed, pool riffle	dry	dry	na	na	SaSi
New	1	2,700	5,200	Pool riffle	7	0–0.3	incised	incised	GrCb, GrCbSa, SaSi
	2	5,200	6,900	Plane bed	12	0.6	incised	incised	GrSa, SaSi

[1] Average width (W), average depth (D).
[2] Bed surface textures, reported as dominant followed by subdominant. Textures are cobble (Cb), gravel (Gr), sand (Sa), silt (Si), and bedrock (Br).

The relative abundance and quality of suitable spawning and rearing habitat for salmon and steelhead was surveyed during fall 2009. A second survey during spring 2010 focused on reassessing conditions at potential barriers and other points of interest during higher flow. The surveys focused on substrate and flow conditions required for fall-run Chinook salmon, the species most likely to spawn in lower Antelope Creek. Suitable spawning substrate included rounded particles (d_{50}=10–78 mm) in riffle and pool tail locations with favorable hydraulics (>0.33 ft depth and 0.5–3.2 ft/s velocity) and sufficient depth for redd construction (≥0.75 ft) (Appendix A). Substrate embeddedness at pool tails was also evaluated as an indicator of subsurface incubation conditions. The fall survey also documented rearing habitat conditions for juvenile Chinook salmon and steelhead, focusing on available cover and complexity within pool and run habitats. Habitat characteristics recorded during the fall 2009 survey included habitat type (e.g., pool, riffle, run, dry), wetted width, mean and maximum depth, and hydraulic control depth (where appropriate). The survey documented total amount (percent) of available cover, contribution of various cover components, and cover complexity (low, medium, high relative ranking) (Table 3-3, Appendix A). The rapid assessment provided the means to compare habitat conditions in different migration routes over a range of flow conditions.

Table 3-3. Spawning habitat areas for fall-run Chinook salmon observed in lower Antelope Creek during fall 2009.

Channel[1]	Reach	Area observed (ft^2)		Percent of total[2]	
		Potential	Suitable	Potential	Suitable
Antelope Creek	Reach 1	1,070	470	27	82
	Reach 2	0	0	0	0
	Reach 3	180	0	5	0
	Reach 4	2,230	0	56	0
	Reach 5	480	100	12	18
	Reach 6	0	0	0	0
	Antelope Creek total	3,960	570	35	19
Craig Creek	Reach 1	4,100	1,000	57	40
	Reach 2	100	100	1	4
	Reach 3	3,020	1,410	42	56
	Craig Creek total	7,220	2,510	65	81
Total in lower Antelope Creek		**11,180**	**3,080**		

1 Spawning gravel area was not quantified in New Creek. No spawning habitat was observed in Butler Slough.
2 Observed area in each reach is expressed as percent of total area for that channel. Total area in each channel is expressed as percent of total area in lower Antelope Creek.

The location and characteristics of potential fish migration barriers (e.g., dams or diversions, pumps, culverts and other structures with limiting flow velocities and/or jump heights, and reaches with limiting flow depths) were documented during the fall 2009 and spring 2010 field surveys (Figure 3-3). Potential barriers were characterized by type (e.g., anthropogenic versus natural) and their status (e.g., barrier, obstacle, passable) qualitatively assessed based on minimum flow depths for upstream adult passage (0.6 ft) and downstream juvenile passage (0.4 ft) (Table 3-4) (Thompson 1972). Wetted width, mean and maximum depth, and length of channel segments where passage may be limited by low flow depths were also measured (Table 3-5). Features posing a potential vertical barrier to fish were also described, including the height and length of the barrier, horizontal and vertical jump distance, mean and maximum jump pool depth, and depth of the hydraulic control.

Figure 3-3. Potential fish barriers observed in lower Antelope Creek during fall 2009 and spring 2010.

Table 3-4. Potential fish passage barriers observed during fall 2009 and spring 2010 and estimated status.

Stream	Reach	ID	Description	Passage status[1]			
				Fall 2009		Spring 2010	
				Adult	Juvenile	Adult	Juvenile
Antelope	1	A1	Beaver dam	—	—	Barrier	Barrier
	2	A1.1	Shallow flow over bedrock	Barrier	Barrier	Barrier	Barrier
		A2	Beaver dam	Barrier	Barrier	Barrier	Barrier
		A3	Beaver dam, bedrock step	Barrier	Barrier	--	--
		A4	Shallow flow over bedrock	Barrier	Barrier	Barrier	Barrier
		A5	Beaver dam	Barrier	Barrier	Barrier	Barrier
		A6	Shallow flow over bedrock	Barrier	Barrier	Barrier	Barrier
		A7	Beaver dam	Barrier	Barrier	—	—
	3	A8	Dense aquatic vegetation	Obstacle	Obstacle	—	—
		A9	Shallow flow over bedrock	Barrier	Barrier	—	—
		A10	Beaver dam	Barrier	Barrier	—	—
		A11	Shallow flow over bedrock	Barrier	Obstacle	—	—
		A12	Pipe crossing w/concrete	Obstacle	Obstacle	—	—
	4	A13	Beaver dam	Barrier	Obstacle	—	—
		A14	Beaver dam	Barrier	Obstacle	—	—
		A15	Beaver dam	Barrier	Obstacle	—	—
	5	A16	Beaver dam	Barrier	Barrier	Barrier	Barrier
	6	A17	Dense aquatic vegetation	Unknown	Unknown	Passable	Passable
Butler	1	B1	Beaver dam	Barrier	Barrier	—	—
		B2	Shallow flow over bedrock	Barrier	Barrier	—	—
		B3	Debris dam	Barrier	Barrier	—	—
		B4	Shallow flow over gravels	Barrier	Barrier	—	—
	2	B5	Intermittent/dry	Barrier	Barrier	—	—
		B6	Road crossing w/rack, dry	Obstacle[2]	Obstacle[2]	—	—
		B7	Road crossing w/culvert, dry	Barrier	Barrier	—	—
	3	B8	Beaver dam, dry	Barrier	Barrier	Obstacle	Obstacle
		B9	Beaver dam, intermittent	Barrier	Barrier	Obstacle	Obstacle
		B10	Beaver dam, intermittent	Barrier	Barrier	Obstacle	Obstacle
		B11	Dense aquatic vegetation	Obstacle	Obstacle	Obstacle	Obstacle
New	1	N1	Beaver dam	Barrier	Barrier	Passable	Passable
		N2	Beaver dam/intermittent	Obstacle	Obstacle	—	—
		N3	Intermittent/dry	Barrier	Barrier	Barrier	Passable

[1] Barrier = complete impediment to passage; Obstacle = obstruction present that can be negotiated with increased effort, may cause delay; Passable = non-obstructed passage. The term "—" indicates that the potential barrier was not present during fall 2009 or was not visited during spring 2010.

[2] Not considered a barrier during the fall survey but located within a dry channel.

Table 3-5. Characteristics of potential fish passage barriers observed during fall 2009 and spring 2010.

Stream	Reach	ID	Description	Characteristics of potential barrier				Low-flow characteristics	
				Height (ft)	Length (ft)	Water depth u/s (ft)	Water depth d/s (ft)	Limiting water depth (ft)	Length of channel with limiting depth (ft)
Antelope	1	A1	Beaver dam	1.75	5	0.5	0.8	—	—
	2	A1.1	Shallow flow over bedrock	—	—	—	—	0	2,000
		A2	Beaver dam	4.6	8	4.7	1.7	—	—
		A3	Beaver dam, bedrock step	1.5	30	1.5	0.4	0.3	3
		A4	Shallow flow over bedrock	—	—	—	—	0.1–0.2	500
		A5	Beaver dam	2.5	7	2	0.3	—	—
		A6	Shallow flow over bedrock	—	—	—	—	0.1–0.2	750
		A7	Beaver dam	3.5	18	1.5	0.3	—	—
	3	A8	Dense aquatic vegetation	--	100	0.8	0.6	—	—
		A9	Shallow flow over bedrock	—	—	—	—	0.1	8
		A10	Beaver dam	1.3	5	1.3	0.25	—	—
		A11	Shallow flow over bedrock step	1.5	10	—	—	0.2	4
		A12	Pipe crossing w/concrete	2	5	—	—	0.2	4
	4	A13	Beaver dam	1.3	5	0.5	0.4	—	—
		A14	Beaver dam	1.5	10	>1	0.4	—	—
		A15	Beaver dam	1	7	1	0.4	—	—
	5	A16	Beaver dam	3.5	10	1.3	1	—	—
	6	A17	Dense aquatic vegetation	—	—	—	—	>1	800

Stream	Reach	ID	Description	Characteristics of potential barrier				Low-flow characteristics	
				Height (ft)	Length (ft)	Water depth u/s (ft)	Water depth d/s (ft)	Limiting water depth (ft)	Length of channel with limiting depth (ft)
Butler	1	B1	Beaver dam	1.5	4	0.8	0.3		
		B2	Shallow flow over bedrock	—	—	—	—	0.1	40
		B3	Debris dam	1	4	0.4	0.3	—	
		B4	Shallow flow over gravels	—	—	—	—	0.1	30
	2	B5	Intermittent/dry	—	—	—	—	—	14,750
		B6	Road crossing w/trash rack, dry	—	20	—	—	—	—
		B7	Road crossing w/culvert, dry	3.2	16	—	—	—	—
	3	B8	Beaver dam, dry	1.7	9	0.1	0.3	—	—
		B9	Beaver dam, intermittent	2.7	16	0.4	0.2	—	—
		B10	Beaver dam, intermittent	2.2	4	0.4	0.2	—	—
		B11	Dense aquatic vegetation	—	—	—	—	>1	1,200
New	1	N1	Beaver dam/ intermittent	2.7	10	0.4	0	—	—
		N2	Beaver dam/intermittent	n/a	n/a	n/a	n/a	—	—
		N3	Intermittent/Dry	—	—	—	—	—	7,700

3.1 Antelope Creek

Mainstem Antelope Creek conveys runoff from the upper watershed across the proximal part of the alluvial fan past Edwards Diversion Dam and downstream to a distributary junction with Craig Creek, located approximately 2,100 ft (640 m) downstream of Cone Grove Road (Figure 1-1 and Figure 2-8). Antelope Creek provides high quality spawning and rearing habitat upstream of the Antelope Creek-Craig Creek distributary junction, but is a relatively small distributary with less and lower quality spawning and rearing habitat downstream of the junction (Table 3-4, Appendix D). Antelope Creek contained 35% of the potential spawning habitat and 19% of the suitable spawning habitat observed in all of the lower Antelope Creek channels (Table 3-4). There were no potential barriers to fish passage observed in Antelope Creek upstream of the Antelope Creek-Craig Creek distributary junction during fall 2009 and spring 2010, but numerous potential barriers to adult and juvenile migration were observed downstream of this point (Table 3-4 and Table 3-5, Figure 3-3). Flow and stage monitoring data suggest that flow depths are expected to be adequate for passage at these potential barriers during high flow events, but that fish migrating into these reaches may become stranded as high flows recede.

The fall 2009 survey of Antelope Creek began at the upstream end of Cone Grove Park (Station 2,300 m) (Figure 3-2, Appendix B). Upstream of this point, Antelope Creek passes through private property that was not accessible at the time of the survey. Downstream of this point, Antelope Creek was divided into six reaches (Figure 3-2, Table 3-1). Reach-specific channel morphology and condition, spawning and rearing habitat, and potential barriers in Antelope Creek are described below.

3.1.1 Reach 1

Reach 1 of Antelope Creek extends from the upstream end of Cone Grove Park to the Antelope Creek–Craig Creek distributary junction (Figure 3-2). The reach is relatively steep (0.33 % slope) and predominantly a cobble-gravel bed with intermittent bedrock control (i.e., outcrops of coarse-grained volcaniclastic mudflow deposits). The slightly entrenched and relatively straight channel has pool-riffle morphology and alternating, semi-active cobble-gravel bars (Appendix C, Figure C-1). Young woody riparian vegetation (e.g., 2–5 year old willow and alder) commonly occupies bar surfaces, and mature riparian vegetation occupies both banks. The distribution and age of riparian vegetation, combined with the large embedded grain sizes in this reach suggest a stable channel with relatively infrequent bed mobilization.

The Antelope Creek–Craig Creek distributary junction, located approximately 2,130 ft (650 m) downstream of Cone Grove Road, is a significant flow separation point downstream of Edwards Diversion Dam (Figure 2-8). When mainstem flow exceeds approximately 60 cfs, a portion of the flow moves out the left bank into two high flow channels, while the majority of flow continues down Craig Creek. Little Antelope Creek meets the upstream-most and smaller of the two high flow channels a short distance downstream of the distributary junction. The combined flow is conveyed through a floodprone area, eventually coalescing in a distributary channel referred to as Antelope Creek. The downstream-most and larger of the two high flow channels at the distributary junction conveys flow through the floodprone area to the head of the Butler Slough distributary channel (Figure 2-8). The dispersed flow and associated decreases in flow depth and shear stress in the vicinity of the Antelope Creek–Craig Creek distributary junction reduces sediment transport capacity and promotes bedload deposition during the receding limb of large flow events, as evidenced by the extensive gravel deposits in the vicinity of the two high flow channel entrances and in the reach of Craig Creek immediately downstream. During Water Year 2010, significant changes occurred to the size and elevation of the deposit in the vicinity of the entrance to the downstream-most and larger of the two high flow channels (Appendix C, Figure C-2). High flows scoured woody riparian vegetation from the bar surface, reduced bar elevations, and increased bar area (Appendix C, Figure C-2). Relatively small changes in the height and form of this bar and the riparian vegetation established in the vicinity have the potential to significantly affect the flow volume split between Craig Creek and the downstream distributaries. Hydraulic modeling and field observations indicate that when mainstem flow drops below about 60 cfs, the high flow channels cease flowing and the Antelope Creek and Butler Slough distributaries become disconnected (Refer to Section 4.1.3). The precise flow at which distributaries become disconnected is uncertain and changes over time in response to changes in channel morphology and vegetation.

Potential spawning and rearing habitat was relatively abundant in Reach 1, although no evidence of recent spawning was observed. Reach 1 contained approximately 27% of the potentially suitable spawning habitat, and 80% of the suitable spawning habitat observed in this particular lower Antelope Creek channel during the fall 2009 survey. Gravel in potential spawning patches was generally well-rounded and of suitable size for both Chinook salmon and steelhead spawning (Appendix C, Figure C-12). Gravel and cobble substrate in pool tails was moderately embedded (range 35–50%). During spring 2010, higher baseflows increased suitable spawning gravel area. Additional potential spawning gravels were observed where some mid-channel riparian vegetation was scoured and removed by high flows near the downstream-most and larger high flow channel at the Antelope Creek-Craig Creek distributary junction (Appendix C, Figure C-2). Large deep pools provide summer rearing habitat, given suitable temperatures. Low to moderate habitat complexity was provided by riparian vegetation. Natural banks provided more habitat complexity and better rearing habitat than leveed and riprapped banks.

No potential barriers to fish passage were observed in Reach 1 during fall 2009. A beaver dam located at the head of the upstream-most high flow channel at the Antelope Creek-Craig Creek distributary junction was considered a barrier to upstream adult and downstream juvenile fish passage during spring 2010 (Appendix C, Figure C-15). The barrier prohibited fish from migrating between Reaches 1 and 2 of Antelope Creek, but did not inhibit migration from Craig Creek into upper Antelope Creek.

3.1.2 Reach 2

Reach 2 of Antelope Creek extends downstream from the Antelope Creek-Craig Creek distributary junction to approximately the southern extent of the managed wetlands located to the east (Figure 3-2, Appendix B). Reach 2 is predominantly a wide and shallow bedrock channel with plane bed morphology and little sediment storage (Appendix C, Figure C-3). Beaver dams of various heights and degrees of structural integrity span the channel in the reach, resulting in ponded steps of up to a meter. Channels upstream of the steps typically contained more alluvial sediment deposits (gravel, sand, and silt) (Appendix C, Figure C-4). Most of the land bordering the channel in Reach 2 is in some form of conservation management by the California Department of Fish and Wildlife, The Nature Conservancy, and other private landowners. Concentrated surface runoff draining the managed wetlands to the east enters the reach at several locations, the largest of which occurs through a sill in a concrete structure impounding wetlands at Station 6,350 m. Levees constructed of native material (e.g., alluvial gravel, sand and, silt) occur intermittently and at various elevations along both channel banks.

No suitable spawning habitat was observed in Reach 2 during the fall 2009 and spring 2010 surveys. Many of the beaver ponds, pools, and deeper runs provided high-quality rearing habitat with moderate to high complexity and substantial terrestrial and aquatic vegetation cover (>30%) (Appendix C, Figure C-13). Conversely, shallow flow over bedrock riffles and runs provided poor rearing habitat with little cover or habitat complexity (Appendix C, Figure C-14). These shallow reaches also had excessively high stream temperatures.

Seven potential barriers to fish passage were identified in Reach 2 during fall 2009, including three geomorphic (low flow) features and four beaver dams. The three geomorphic features were channel segments with no or very shallow flow over bedrock. The upstream feature encompassed most of the bedrock high flow channel located immediately downstream of the Antelope Creek-Craig Creek junction. This segment was dry during fall 2009 and considered a barrier to passage (Appendix C, Figure C-16). During spring 2010, this segment had shallow flow (<0.2 ft) over long extents and was considered a barrier to both adult and juvenile passage (Appendix C, Figure C-17). The middle and downstream geomorphic features were both long segments (several hundred feet) with shallow flow (<0.2 ft) over a relatively wide and low-gradient bedrock channel (Appendix C, Figure C-18, Figure C-19). Both were considered barriers to adult and juvenile fish passage. The four beaver dams in Reach 2 were all considered barriers to adult and juvenile fish passage during fall 2009 and spring 2010. During the fall 2009 survey, the most upstream dam was 4.6 ft high (Appendix C, Figure C-20), the second dam was 1.5 ft high (Appendix C, Figure C-21), the third was 2.5 ft high (Appendix C, Figure-C22), and the most downstream dam was 3.5 ft high (Appendix C, Figure C-23). High winter flows during spring 2010 modified the dams and scoured surrounding vegetation, but the three tallest dams remained barriers to adult upstream and juvenile downstream passage.

3.1.3 Reach 3

Reach 3 extends from the southern extent of the managed wetlands (Station 6, 700 m) to Kauffman Avenue (Figure 3-2). Reach 3 becomes increasingly entrenched, with as much as 18 ft of incision occurring by Kauffman Avenue (Appendix C, Figure C-5). The channel is intermittently bedrock controlled, occasionally forming bedrock knickpoints and associated step pools. Steep banks are prone to failure during high flow events, recruiting large quantities of gravel, sand, and silt. Bank erosion has exposed the roots of mature riparian trees growing in or at the top of the bank. Dense herbaceous and woody riparian vegetation typically occupies bar surfaces in the reach.

Spawning habitat conditions in Reach 3 were relatively poor. Two potentially suitable spawning patches in Reach 3 represented 5% of the potential spawning habitat observed in this particular lower Antelope Creek channel during fall 2009. Water depth during the fall 2009 survey was too shallow for these patches to be considered suitable spawning habitat. Substrate embeddedness was high (50%) at the one pool tail it was measured. Rearing habitat conditions in Reach 3 were generally poor where there was shallow flow over bedrock, and fair in deeper pools and runs. Habitat complexity and total cover were generally low, and cover elements were primarily composed of terrestrial (grasses and woody riparian shrubs) and aquatic vegetation.

Five potential barriers to fish passage were identified in Reach 3 during the fall 2009 survey; including two natural, two geomorphic (low flow) features, and one anthropogenic. The most upstream natural potential barrier was a dense matt of aquatic vegetation in a backwater pond formed upstream of a bedrock step (Appendix C, Figure C-24). This feature was considered an obstacle to adult and juvenile passage during fall 2009. The more downstream natural feature was a 1.3 foot high beaver dam that was considered a barrier to adult and juvenile passage during fall 2009 (Appendix C, Figure C-25). The two geomorphic features were 25 to100 foot segments with shallow flow (<0.2 ft) over bedrock (Appendix C, Figure C-26, Figure C-27). A two-foot-high channel-spanning concrete apron embedded with a water pipe crossing the channel upstream of Kauffman Avenue was considered an obstacle to fish passage (Appendix C, Figure C-6).

3.1.4 Reach 4

Reach 4 extends from Kauffman Avenue to State Route 99 (Figure 3-2). The reach is entrenched 15 to 18 ft within vertical banks. The grain size of the channel bed is locally controlled by sediment recruited by bank erosion, which is severe in places (e.g., Station 11,400 m) (Appendix C, Figure C-7). Short lengths of rip rap bank protection are common. The channel becomes increasingly alluvial, with alternating gravel point bars and large, deep pools between Kansas Avenue and State Route 99. Gravel bars are densely vegetated with woody and herbaceous riparian vegetation. Large stands of *Arundo Donax* and other invasive vegetation occupying bars within the bankfull channel significantly increase flow resistance, reduce conveyance capacity, and force gravel and sand deposition that progressively increases bar heights (Appendix C, Figure C-8). During fall 2009, it did not appear that flood flows during the last five years have been sufficiently large to scour vegetation from bar surfaces in the reach. Long Gulch and Kingsley Gulch enter from the left bank in this reach.

Potential spawning and rearing habitat in Reach 4 was relatively abundant, representing approximately 56% of the potentially suitable spawning habitat observed in this particular lower

Antelope Creek channel. Eleven potentially suitable spawning patches were observed in the reach, although none had suitable hydraulics for spawning during fall 2009. Substrate embeddedness in pool tails was high (>50%), indicating potentially poor incubation conditions. Large deep pools and runs provided favorable rearing habitat conditions (assuming stream temperatures and water quality are suitable). Habitat complexity was low to moderate, and cover elements were comprised mostly of terrestrial and aquatic vegetation. Large and small wood provided habitat complexity and was relatively abundant in Reach 4 compared with other reaches. Water quality conditions in Reach 4 appeared poor compared with upstream reaches. Field observations of poor water quality are supported by water quality monitoring results indicating low dissolved oxygen concentrations, high pH levels, and relatively high hydrogen sulfide concentrations associated with intense algae or periphyton productivity and photosynthesis (refer to Section 4.2).

Three relatively small beaver dams were considered obstacles to adult and juvenile fish passage in Reach 4 (Appendix C, Figure C-29, Figure C-30).

3.1.5 Reach 5

Reach 5 extends from State Route 99 to the point where Antelope Creek enters the Sacramento River meander belt just downstream of the Crane Orchards processing plant (approximately Station 13,600 m) (Figure 3-2). Downstream of State Route 99, the channel widens and the banks become less steep and less erosive. Mature riparian forest occupies both banks. Predominantly meandering pool-riffle channel morphology transitions to predominantly plane-bed morphology with lower sinuosity downstream of the Crane Orchards processing plant (Appendix C, Figure C-9). Extensive mattes of emergent aquatic vegetation first occur in the channel immediately downstream of the Crane Orchards plant.

Potential spawning habitat was rare in Reach 5, although rearing habitat was abundant. One large (480 ft^2) potential spawning gravel patch contained 12% of the potentially suitable spawning habitat observed in Antelope Creek during fall 2009. No recent spawning was observed. Runs with abundant cover and complexity from aquatic and terrestrial vegetation provided the majority of the rearing habitat in the reach. One large beaver pond created rearing habitat with abundant cover and good complexity.

One large, channel-spanning beaver dam was considered a barrier to adult and juvenile passage in Reach 5 during fall 2009 and spring 2010 (Appendix C, Figure C-30). This feature was approximately 3.5 feet high and 10 feet long at its least restrictive point. The beaver dam remained intact following high flows in WY 2010, but was smaller and scoured of aquatic vegetation (Appendix C, Figure C-31). This feature likely prohibited adult salmon from entering the Antelope Creek distributary during the migration period.

3.1.6 Reach 6

3.1.6.1 Channel morphology and condition

Reach 6 extends from the point where Antelope Creek enters the Sacramento River meander belt (Station 13,600 m) to the confluence with the Sacramento River (Figure 3-2). The reach is strongly influenced by the morphology, sediment dynamics, and hydrology of the Sacramento River. The unconfined channel in this reach is formed within abandoned meanders of the Sacramento River, where the substrate is dominantly medium to fine gravel and sand and the streamside riparian forest is dense. Several large beaver dams create ponds followed immediately downstream for a short distance by meandering gravel bed channel morphology (Appendix C, Figure C-10). Emergent aquatic vegetation becomes increasingly dense through the reach until forming a closed canopy over the water surface near the confluence with the Sacramento River (Appendix C, Figure C-11).

No potentially suitable spawning habitat was observed in Reach 6, primarily due to the fine substrate. Rearing habitat in runs and glides was abundant.

Although there was a continuous open channel with sufficient depth for salmon and steelhead passage between the beaver dam in Reach 5 and the confluence with the Sacramento River, dense mattes of invasive aquatic vegetation (*Ludwigia* sp.) created a closed canopy over the water surface (Appendix C, Figure C-33). These aquatic plants and their effects on water quality may present potential obstacles to adult fish passage.

3.2 Craig Creek

Craig Creek is functionally a continuation of mainstem Antelope Creek downstream of the Antelope Creek-Craig Creek junction (i.e., the channel conveys most of the water and sediment from the upper basin to the Sacramento River). Craig Creek is the shortest and steepest (0.43%) distributary channel connecting upper Antelope Creek to the Sacramento River. Unlike Antelope Creek and Butler Slough, which both have long reaches of low-gradient, sand-bed channels occupying abandoned oxbows within the Sacramento River floodplain, Craig Creek maintains relatively steep, gravel bed channel morphology all the way to the Sacramento River. Craig Creek contains the majority of the potential spawning habitat (65%) and suitable spawning habitat (81%) observed in all of the lower Antelope Creek channels (Table 3-4), and had the only evidence of spawning activity (1 redd). Pools and deep runs provide good potential rearing habitat, while levees and deep channel entrenchment limit cover and complexity. Craig Creek was the only channel with unobstructed upstream and downstream adult and juvenile fish passage during fall 2009 and spring 2010. The steeper channel slope, higher flow, and higher bedload transport rates limits construction and persistence of large, competent beavers dams and minimizes growth of emergent aquatic vegetation. Based on analysis of historical maps and photos and field observations of flow and channel morphology, Craig Creek was divided into three reaches (Figure 3-2, Table 3-3). Reach-specific channel morphology and condition, spawning and rearing habitat, and potential barriers in Craig Creek are described below.

3.2.1 Reach 1

Reach 1 of Craig Creek extends from the Antelope Creek–Craig Creek distributary junction to Craig Avenue (Figure 3-2). The reach has predominately gravel-cobble plane bed channel morphology. The reach is confined by a levee on the right bank, and segments of both channel banks are protected by riprap or by gravelly alluvium excavated from the channel. Streamside riparian vegetation was removed from these segments (Appendix C, Figure C-34).

Potential spawning habitat in Reach 1 was abundant. Four potentially suitable patches with a total area of 4,100 ft^2 were identified during fall 2009, of which approximately 1,000 ft^2 was considered suitable for spawning. One redd was observed within the suitable portion of this large patch during fall 2009 (Appendix C, Figure C-38). Rearing habitats provided by riffles and runs had relatively low habitat complexity and cover due to levees and riprap (Appendix C, Figure C-39). The reach lacked pools.

There were not potential barriers to salmon and steelhead passage identified in Reach 1 of Craig Creek.

3.2.2 Reach 2

Reach 2 extends from Craig Avenue to approximately State Route 99 (Station 1,700 m) (Figure 3-2). The reach is formed entirely in volcaniclastic bedrock (volcanic mudflow and related fluvial deposits) with few alluvial deposits. The bedrock channel with plane-bed morphology abruptly changes to a deeply incised slot channel downstream of Craig Avenue. At approximately Station 1,500 m, the channel excavates a large bedrock pool bound by 20-foot-high vertical banks of soil-mantled alluvium (Appendix C, Figure C-35). The deeply incised channel remains confined within vertical banks for about another 330 ft to the downstream end of the reach (approximately Station 1,700 m) where the channel widens, bank angles decrease, and large gravel point bars develop.

One potentially suitable 100 ft^2 spawning patch was identified in Reach 2 during fall 2009. Water depth, bedrock ledges, and bubble curtain provided relatively abundant rearing habitat within the deeply incised segment. The large, deep pool provided adult holding habitat and juvenile rearing habitat with low complexity.

There were no potential barriers to salmon and steelhead passage identified in Reach 2.

3.2.3 Reach 3

Reach 3 of Craig Creek extends from approximately State Route 99 to the Sacramento River confluence (Figure 3-2). A reduction in slope at the break between Reach 2 and Reach 3, combined with the large quantities of mobile coarse sediment recruited by channel incision and bank erosion in Reach 2, forces a transition from a bedrock channel to a meandering gravel bed channel with pool-riffle morphology. Clean, bright, and mobile gravel deposits forming lateral and point bars indicate dynamic sediment transport and channel morphology in Reach 3. Medium and fine gravel patches near the low flow channel margin indicate a large supply of mobile coarse sediment. Gravel bars had notably less vegetation encroachment compared to other distributary channels in lower Antelope Creek. Accumulations of large woody debris with associated scour pools occurred at numerous locations along the low flow channel and on bar surfaces. The bed texture, channel morphology, riparian vegetation, and large woody debris accumulation indicate that the channel frequently conveys large flows that mobilize coarse sediment, scour vegetation from the bed and banks, and reshape bar morphology (Appendix C, Figure C-36). The channel in the vicinity of the confluence with Craig Creek and the Sacramento River was free of aquatic vegetation during fall 2009 and spring 2010 (Appendix C, Figure C-36 and Figure C-37).

Spawning habitat was the most abundant of any reach. Ten patches of potentially suitable spawning substrate were identified during fall 2009, including 8,610 ft^2 of potentially suitable spawning habitat. No redds were observed during fall 2009. Rearing habitat comprised of pools and runs was abundant, with moderate levels of instream cover (5–40%) and habitat complexity. Riparian vegetation and woody debris provided substantial habitat complexity and cover (Appendix C, Figure C-41). Pools and runs provided favorable rearing habitat, given suitable stream temperatures. Water quality appeared better than in other lower Antelope Creek distributaries.

There were no potential barriers to salmon and steelhead passage identified in Reach 3.

3.3 Butler Slough

Butler Slough is one of longest and lowest average gradient (0.15%) distributary channels in lower Antelope Creek. Much of the flow from the downstream-most and larger of the two high flow channels at the Antelope Creek-Craig Creek junction is conveyed directly to the Butler Slough channel head during high flows. Spawning and rearing habitat conditions in Butler slough are generally poor (Table 3-4). No potentially suitable spawning habitat was identified in Butler Slough, and rearing habitat quality and quantity was limited by low stream flow and shallow water depths. Ten potential barriers to fish passage were observed in Butler Slough during fall 2009 and spring 2010 (Figure 3-3, Table 3-5). Based on analysis of historical maps and photos and field observations of flow and channel morphology, Butler Slough was divided into three reaches (Figure 3-2, Table 3-3). Reach-specific channel morphology and condition, spawning and rearing habitat, and potential barriers in Butler Slough are described below.

3.3.1 Reach 1

Reach 1 of Butler Slough extends from the channel head (Station 4, 450 m) to approximately Station 5,500 m, where surface flow ceased during fall 2009 (Figure 3-2). Reach 1 is predominantly a bedrock-controlled, plane-bed channel bound intermittently by rip rap and levees on both banks (Appendix C, Figure C-42). The channel becomes progressively entrenched, reaching up to 15 ft of incision at the downstream end of the reach. Although herbaceous and young riparian vegetation occupy much of the active channel bottom, long segments of the channel have little streamside riparian vegetation. Water quality was noticeably poor in Butler Slough compared with other distributaries, likely due to the low slope with little surface flow, the length of channel receiving direct sunlight, and influence of irrigation return flows.

No potentially suitable spawning habitat was observed in Reach 1, and rearing habitat was limited by low stream flow. The majority of the plane-bed channel was characterized as run habitat, with only one pool in the reach. Rearing habitat conditions were generally poor, with low complexity and cover in segments with shallow flow over bedrock. Complexity and cover were fair where narrower and deeper channel morphology concentrated flow and provided more terrestrial vegetation cover.

Four potential barriers to fish passage were identified in Reach 1 during fall 2009 and revisited in spring 2010. Three were natural barriers consisting of a beaver dam, a debris dam, and a geomorphic (low-water) feature. The debris dam was relatively small (1 ft high by 4 ft long) but considered a barrier to adult and juvenile passage (Appendix C, Figure C-46). The beaver dam (Appendix C, Figure C-47) and geomorphic feature (a shallow channel segment recently disturbed by excavation) were considered barriers to adult passage and obstacles to juvenile downstream passage.

3.3.2 Reach 2

3.3.2.1 Channel morphology and condition

Reach 2 of Butler Slough extends from Station 5,500 m to where Butler Slough enters the meanderbelt of the Sacramento River (Station 8,039 m) (Figure 3-2). The reach has plane bed and pool riffle morphology with predominantly sand and fine gravel bed surface texture. The reach was dry during the fall 2009 survey.

No potentially suitable spawning habitat was observed in Reach 2. Bed substrate in the reach was too fine to be considered suitable. Rearing habitat quantity and quality was poor and limited by low streamflow. Rearing habitat in isolated pools and depressions was generally poor with low cover and complexity.

Fish passage in Reach 2 was entirely blocked by dry channel conditions during fall 2009 (Appendix C, Figure C-50). Two road-stream crossings were identified as potential barriers. The more upstream of the two consisted of four corrugated metal culverts with a steel trash rack across their inlets (Appendix C, Figure C-52). This crossing was not considered a barrier at the time of the survey because the culverts were at or below grade and the bar spacing on the trash rack is wide enough for adult Chinook salmon and steelhead passage. However, debris on the trash rack would influence passage. The more downstream of the two consisted of two culverts with angular cobble at the outfall (Appendix C, Figure C-51).

3.3.3 Reach 3

Reach 3 of Butler Slough extends from Station 8,039 m to the confluence with the Sacramento River. The reach is strongly influenced by the morphology, sediment dynamics, and hydrology of the Sacramento River. The Butler Slough channel in this reach is similar to but smaller than the Antelope Creek distributary channel where it occurs within the Sacramento River meanderbelt (Appendix C, Figure C-43). The channel substrate is dominantly medium to fine gravel and sand and the channel slope is very low. Dense stands of riparian forest occur on both banks. There was no flow in the reach at the time of the fall 2009 survey, but water was ponded behind beaver dams. Invasive emergent aquatic vegetation formed a closed canopy on the water surface near the confluence with the Sacramento River (Appendix C, Figure C-44).

No potentially suitable spawning habitat was observed in Reach 3 of Butler Slough. Bed substrate was too fine to be suitable. Rearing habitat quantity and quality in Reach 2 was poor and limited by low streamflow during fall 2009. Rearing habitat in isolated pools and depressions was poor with low cover and complexity.

Fish passage in Reach 3 of Butler Slough was entirely blocked by dry channel conditions during fall 2009 (Appendix C, Figure C-50). Four potential barriers were identified in Reach 3, including three beaver dams and one densely vegetated wetland. The three beaver dams formed a series of pools in the portion of the reach within the Sacramento River floodplain (Appendix C, Figure C-53, Figure C-54, and Figure C-55). The beaver dams were considered potential barriers to adult and juvenile passage in fall 2009 and obstacles during spring 2010. A dense matte of invasive aquatic vegetation (Ludwigia sp.) created a closed canopy over the water surface at the mouth of Butler Slough. These aquatic plants and their effects on water quality may present potential obstacles to adult fish passage.

3.4 New Creek

Flow into New Creek is controlled by a concrete headgate at the Edwards Diversion Dam. New Creek flows southwest from the diversion dam to meet Salt Creek, then continues another 1.1 mi to the Sacramento River (Figure 1-1). New Creek is the second steepest (0.38%) and second shortest (4.3 mi [6.9 km]) distributary channel in lower Antelope Creek. Surveys of New Creek began at Cone Grove Road and extended to the Sacramento River. The reach of New Creek between Cone Grove Road and Edwards Diversion Dam passes through private property that was not accessible at the time of the survey. During the fall 2009 survey, nearly the entire surveyed channel length was dry or intermittent and formed a total barrier to fish passage. During the 2010 survey, New Creek downstream of Cone Grove Road conveyed adequate flow for unimpeded juvenile passage and provided some suitable spawning and rearing habitat, but flow depths were too shallow for adult passage. Three potential barriers to fish passage were observed in New Creek (Figure 14). Based on analysis of historical maps and photos and field observations of flow and channel morphology, New Creek downstream of Cone Grove Road was divided into two reaches (Figure 3-2, Table 3-3). Reach-specific channel morphology and condition, spawning and rearing habitat, and potential barriers in New Creek are described below.

3.4.1 Reach 1

Reach 1 of New Creek extends from Cone Grove Road to the confluence with Salt Creek (Figure 3-2). The channel in Reach 1 has meandering pool-riffle morphology with predominantly gravel-cobble substrate, although thin and patchy veneer of sand and silt commonly blanketed the channel bed (Appendix C, Figure C-57). During fall 2009, the channel was wet and had disconnected pools to approximately State Route 99, downstream of which the channel was continuously dry. The channel becomes progressively entrenched, reaching 10 to12 ft of incision in the vicinity of State Route 99 and as much as 20 ft of incision just upstream of the Salt Creek confluence. Vertical stream banks exposing bare soil and the roots of large woody riparian trees indicate ongoing bank erosion, particularly between Cone Grove Road and State Route 99. Bank erosion in this reach is likely a source of fine sediment to the channel and may account for the veneer of fine sediment covering the bed in places. Downstream of State Route 99, the channel banks are more densely vegetated with native riparian trees and shrubs and are typically not as erosive.

Dry channel conditions provided no suitable spawning habitat in fall 2009. Suitable spawning habitat was observed at a number of locations during spring 2010. Rearing habitat quantity in Reach 1 was limited by low, intermittent streamflow during fall 2009. Habitat quality in wetted segments was generally poor due to shallow depths, little cover, and low complexity. Rearing habitat conditions improved during spring 2010 due to more wetted area, increased flow depths, and greater cover and complexity afforded by terrestrial vegetation and roots.

Dry conditions in Reach 1 of New Creek during fall 2009 were a barrier to juvenile and adult fish passage (Appendix C, Figure C-60). In addition, a beaver dam immediately upstream of Cone Grove Road was considered a passage barrier (Appendix C, Figure C-61). Two other beaver dams observed in the reach were not considered barriers (Appendix C, Figure C-62). The higher flow observed during spring 2010 continuously wetted the reach, although flow depths over riffles were shallow (0.2 ft in some cases). Under these flow conditions, the reach was passable to emigrating juvenile salmon and steelhead but was considered a barrier to immigrating adults. The beaver dam upstream of Cone Grove Road was not considered a barrier during spring 2010 (Appendix C, Figure C-63).

3.4.2 Reach 2

3.4.2.1 Channel morphology and condition

Reach 2 of New Creek extends from the confluence with Salt Creek to the Sacramento River (Figure 3-2). The plane bed channel in Reach 2 is typically deep and wide with gravel, sand, and silt substrate (Appendix C, Figure C-58). During fall 2009, the New Creek channel had deep standing water from the vicinity of the Salt Creek confluence downstream to the Sacramento River, but no flow was observed. Gravel and sand deposits were observed in the lee of large woody debris. Dense riparian vegetation occurs along either bank except where banks have been recently stabilized with rock rip rap (e.g., on the right bank immediately downstream of the confluence between New Creek and Salt Creek). No emergent aquatic vegetation was observed in the vicinity of the Sacramento River confluence.

No suitable spawning habitat was observed in Reach 2 of New Creek during fall 2009. Suitable spawning habitat was observed in the reach during spring 2010 (e.g., large area immediately downstream of the Salt Creek confluence). Abundant rearing habitat was observed in large deep pools with moderate cover and complexity during fall 2009 (Appendix C, Figure C-59). The channel segment backwatered by the Sacramento River provides good rearing habitat, but likely supports more predators than other reaches.

4 STREAMFLOW, TEMPERATURE, AND WATER QUALITY

Stage height, streamflow, stream temperature, and water quality were monitored at nine sites in lower Antelope Creek during WY2010 and WY2013 (Table 4-1, Figure 4-1). Monitoring sites were selected to characterize relative differences upstream and downstream of the diversion dam and distributary junctions.

Table 4-1. Monitoring sites in lower Antelope Creek.

Site ID	Description	Distance from dam, mi	Type[1]		Latitude[2]	Longitude[2]
			2010	2013		
UAC	Upper Antelope Creek	-1.92	N/A	Q, T, W	40°12'10.36"N	122° 7'7.25"W
ACG	Antelope Creek at Cone Grove Park	1.58	S, T	Q, T, W	40°10'9.25"N	122° 8'3.98"W
ACK	Antelope Creek at Kaufmann Av	5.59	S, T	Q, T, W	40° 7'38.29"N	122° 7'1.14"W
ACR	Antelope Creek at SR 99	7.48	T	N/A	40° 6'31.00"N	122° 6'39.58"W
CRC[3]	Craig Creek at SR 99	3.34	S, T	Q, T, W	40° 8'51.53"N	122° 8'16.19"W
BTS	Butler Slough at Electric Av	3.37	S, T	Q, T	40° 8'58.94"N	122° 7'35.87"W
BTR	Butler Slough at SR 99	5.59	T	N/A	40° 7'42.35"N	122° 7'20.76"W
NEW[3]	New Creek at SR 99	2.40	S, T	Q, T, W	40° 9'50.49"N	122° 9'13.34"W
LAC	Little Antelope Creek at Foothill Blvd	N/A	N/A	Q	40°10'14.33"N	122° 7'21.87"W

1 Monitoring types: S=stage, Q=discharge, T=stream temperature, W=water quality, N/A=not applicable. Continuous sampling for water quality occurred at UAC and CRC. Grab sampling for water quality occurred at UAC, ACG, NEW, CRC, and ACK.
2 All latitude and longitude are reported in WGS84.
3 The NEW and CRC sites were located upstream of irrigation returns that may influence stream temperature and water quality during periods when the volume of irrigation return flow is large relative to streamflow.

Figure 4-1. Monitoring sites in lower Antelope Creek.

4.1 Streamflow and Temperature

The general monitoring objective was to obtain a continuous record of stage height, discharge, and stream temperature at a sufficient number of suitable and accessible locations to characterize flow conditions in lower mainstem Antelope Creek and distributary channels. Edwards Diversion Dam has little effect on downstream winter peak flows. Monitoring therefore focused on characterizing baseflow conditions when water diversions have the greatest potential effect on salmon and steelhead migration through lower Antelope Creek. Monitoring techniques were adapted from standard USGS methods and protocols (refer to Techniques of Water Resource Investigations and USGS Water Resources Techniques, Methods, and Modeling publications).

Submersible pressure transducers (Global Water WL-16 and WL-15x Water Level Loggers) and reference stage gages were installed at five locations during November 2009 for the purpose of monitoring stream stage. Temperature loggers (StowAway TidbiT) were also installed at these five sites, as well as at BSR and ACR. Pressure transducers were located upstream of a stable hydraulic control at each site. An arbitrary datum was established at each location and level-loop surveys were conducted to measure elevations of the pressure transducer, reference stage gage, and height of zero flow. During fall 2012, pressure transducers at the five existing sites were upgraded to Solinst level loggers that record stage and temperature. Additional monitoring sites were added at UAC and LAC, and a barometer (Solinst® Barrologger) was installed at BTS for stage data compensation. Stream stage, stream temperature, and barometric pressure were continuously recorded at a 15-minute interval. Stage and temperature data were downloaded and inspected periodically during WY2013. A reference stage measurement was recorded during each download. Rapid spikes or drops in stage outside the range of natural variation were corrected by linear interpolation. Anomalous readings of longer duration that occurred when a stage recorder was dewatered or malfunctioning due to sedimentation or biological buildup were removed.

During WY 2013, discharge measurements were collected at the seven monitoring locations over a range of streamflows using accepted field data collection and quality assurance protocols (Buchanan and Somers 1969, Mueller et al. 2013, USGS 1982). When conditions allowed safe wading, standard current meter discharge methods were used with Price AA or Price Pygmy current meters attached to a wading rod and connected to a discharge field computer (JBS Energy Inc., AquaCalc Pro Plus). A broadband Acoustic Doppler Current Profiler (1,200 kHz Teledyne RD Instruments Rio Grande) was used for a limited number of high flow measurements. Each discharge record included a description of general flow conditions; measurements of reference stage, water edge, and section hydraulic control; current meter spin tests (where applicable), and begin and end times. All discharge measurements were inspected by a senior hydrographer and compiled in a discharge measurement database.

Composite stage-discharge ratings were developed for six of the seven monitoring sites by fitting power functions to a range of stage and corresponding discharge points collected during 2013 (Kennedy 1984). The complex flow patterns and flashy nature of runoff in Little Antelope Creek prohibited rating the LAC site.

4.1.1 Water Year 2010

Water Year 2010 was a Below Normal Water Year according to the Sacramento River Index. Because discharge was not measured, nor were ratings developed or discharge records calculated at monitoring stations in Antelope Creek during Water Year 2010, average daily discharge records were synthesized at UAC and ACG (Figure 3-1) (refer to Section 2.1.2 for a discussion of methods used to synthesize discharge at these locations). Despite the Below Normal Water Year, numerous small peak flow events occurred between early December and mid-June, the largest of which was approximately 800 cfs on 19 January. The spring months (April–June) were relatively wet, with peak flows exceeding 280 cfs on several occasions into early June, after which time baseflow at UAC gradually receded to a steady summer low of about 40 cfs.

4.1.1.1 WY 2010 stream stage

Stage measurements during WY 2010 indicated that all of the mainstem and distributary channels in lower Antelope Creek conveyed significant winter flood discharges (Appendix E). Antelope Creek (from Edwards Diversion Dam to the head of Craig Creek) and Craig Creek conveyed the largest flood volumes and sustain the highest winter and spring baseflows. During WY 2010, mainstem Antelope Creek and Craig Creek reached summer baseflow levels in July and sustained flow throughout the summer months, while other distributaries dropped to little or no summer baseflow by mid-June. Summer water levels fluctuated by as much as 1.5 ft in some channel reaches due to changes in water diversion and/or pulses of return flow from pastures and other irrigated agricultural lands.

4.1.1.2 WY 2010 stream temperature

Stream temperatures were measured at seven sites downstream of Edward Diversion Dam (Table 4-1, Figure 4-1) from late April through October 2010. Stream temperatures upstream of Edwards Diversion Dam were not measured during 2010 due to access limitations on private property. Mean daily temperatures at all monitoring sites generally increased steadily from a low of 11–14°C in mid-May to a high exceeding 25°C in mid-July (Figure 4-2, Figure 4-3, Table 4-2). ACK had the highest temperatures early in the monitoring period (e.g., prior to July), but cooled relative to other monitoring sites during July and August, likely due to the influence of relatively cool tailwater supplied by the HiLine Canal and Main Canal carrying water from Mill Creek. Stream temperatures at ACG, CRC, and NEW were very similar until June 23, after which temperatures at these sites began to diverge. ACG was typically warmer than CRC and NEW during much of the remaining monitoring period, likely due to greater solar insolation and influence of relatively warm return flows from flood-irrigated pastures in the reach from Edwards Diversion Dam to Cone Grove Park. By the beginning of October, temperatures at ACG, CRC, and NEW were again very similar and slightly higher than ACK. ACG and CRC maintained similar MWAT each month during the monitoring period (Table 4-2).

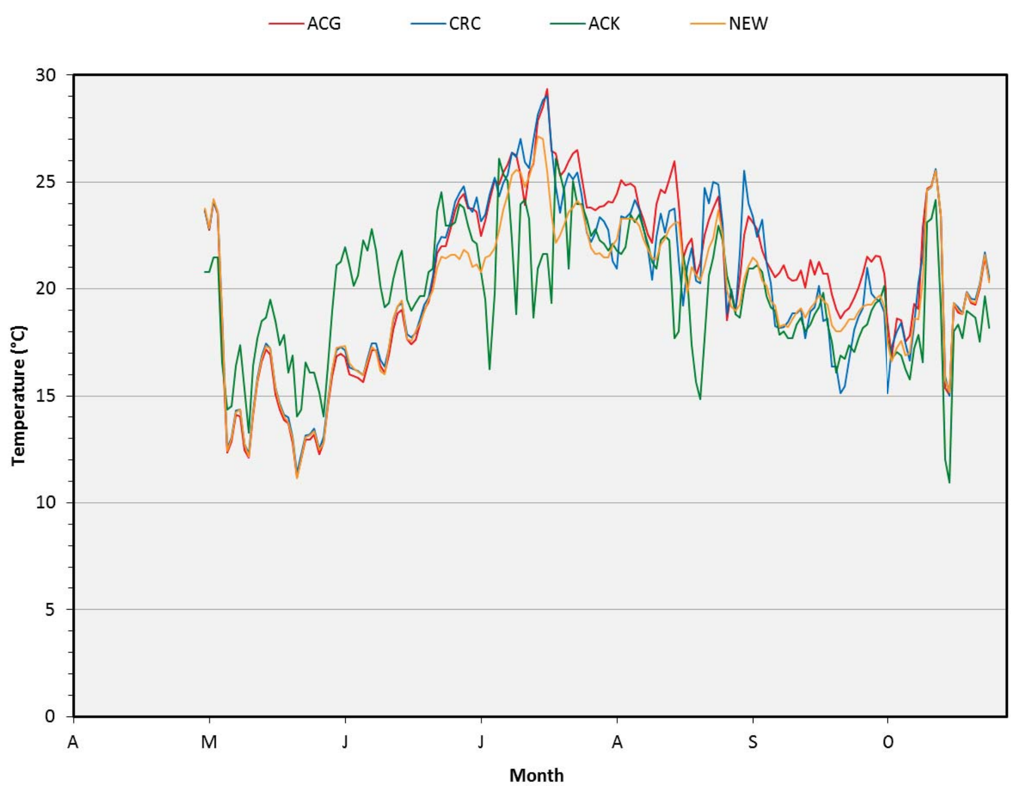


Figure 4-2. Mean daily stream temperatures during May through October, WY2010.

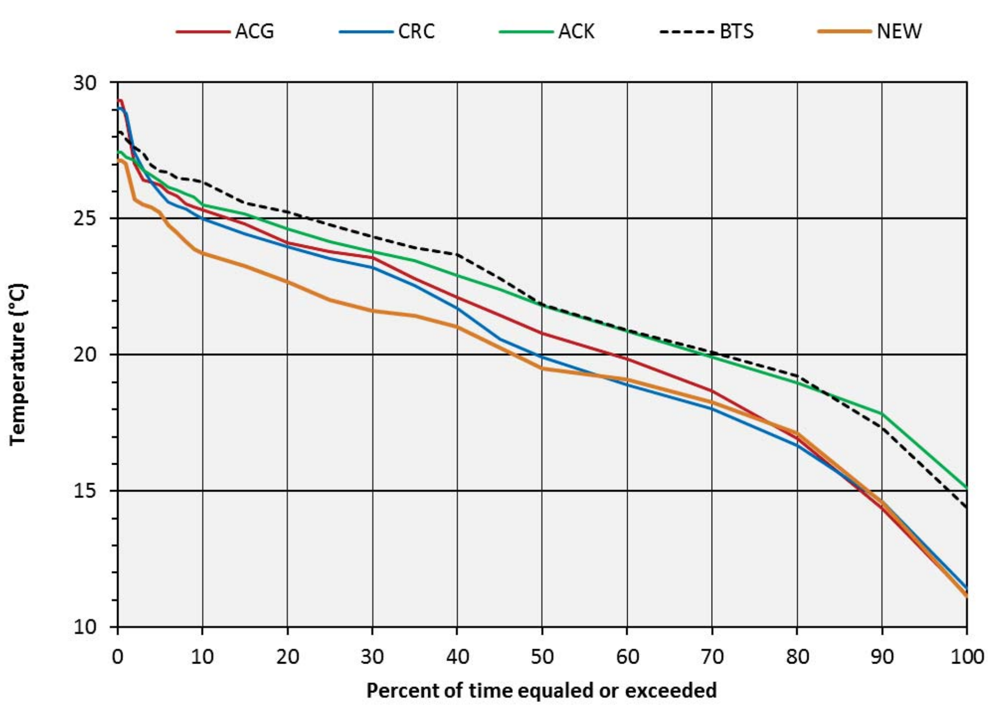


Figure 4-3. Stream temperature exceedance during May through October WY2010.

Table 4-2. Summary of WY 2010 stream temperatures (°C).

Metric	Site	May	June	July	Aug	Sept	Oct
MWAT[1]	ACG	19.6	23.8	27.1	24.6	22.3	22.8
	ACK	21.1	25.8	26.6	24.6	22.1	22.6
	ACR	20.8	24.0	27.5	24.5	22.0	22.4
	CRC	19.8	24.0	27.4	23.3	23.1	22.7
	BTS	21.2	25.8	26.8	25.1	25.0	22.7
	BTR	20.5	24.6	27.1	24.2	21.6	22.4
	NEW	19.8	21.6	25.9	23.0	20.6	22.3
Maximum daily average	ACG	24.1	24.5	29.3	26.0	23.4	25.6
	ACK	24.1	26.5	27.4	25.4	23.1	25.6
	ACR	24.2	25.4	29.0	25.1	23.1	25.6
	CRC	24.1	24.8	29.0	25.0	25.5	25.6
	BTS	24.3	26.8	27.9	27.5	28.2	25.7
	BTR	24.3	26.3	29.0	25.8	23.5	25.6
	NEW	24.2	21.8	27.1	23.7	21.5	25.5
Maximum daily maximum[2]	ACG	26.4	28.9	38	38	38	36.4
	ACK	27.9	29.9	30.1	28.0	25.4	36.4
	ACR	28.2	27.6	30.9	26.7	25.0	35.3
	CRC	28.1	27.9	38	38	38	36.3
	BTS	27.8	38	38	38	38	38.2
	BTR	28.6	38	38	38	38	38.2
	NEW	28.0	24.3	29.5	26.0	23.3	33.5

[1] Maximum Weekly Average Temperature (MWAT) is the maximum seven-day moving average of the mean daily temperature.

[2] Maximum temperature range for the StowAway TidbiT logger is approximately 38°C. Reported maximum daily temperatures of 38 indicate the logger was dewatered.

4.1.2 Water Year 2013

Water Year 2013 was a Dry Water Year according to the Sacramento River Index. Two significant flow events occurred during the winter period; the first peak occurred on 2 December 2013 (1,905 cfs at UAC) and the second peak occurred on 31 December 2013 (1,226 cfs at UAC). Several smaller flow events occurred between mid-January and mid-April, after which baseflow at UAC gradually receded to a steady low of about 18 cfs by mid-July.

4.1.2.1 WY 2013 streamflow

WY2013 was the first year ratings were developed for monitoring stations. Ratings were developed from a limited number of discharge measurements over a relatively narrow range of streamflows and are considered provisional. Although provisional and subject to revision as more discharge measurements over a broader range of streamflows become available, these ratings provide reliable discharge values within the approximate range of discharges measured in WY2013 (Appendix F). Factors influencing the quality of a site rating include the number and distribution of measurements, measurement uncertainty, channel hydraulics, and agricultural return flows. Calculated discharges outside the range of the measured discharges (i.e., peak flows) may lead to misleading streamflow statistics and should be interpreted with caution.

Appendix G includes plots of provisional annual hydrographs and flow exceedance curves compiled for daily mean discharge and temperature during WY 2013, and Table 4-3 summarizes streamflow statistics. The 10% and 90% exceedance flows at UAC (unimpaired mainstem flow upstream of Edwards diversion dam) during WY2013 were 165 cfs and 17 cfs, respectively (Figure 4-5, Table 4-3). In comparison, the 10% and 90% exceedance flows at USGS gage #11379000 (located in the vicinity of UAC) during the 41-year period of record from 1941 to 1982 were 299 cfs and 34 cfs, respectively. The differences highlight the drought conditions during WY 2013. The timing and relative magnitude of peak flows and early spring baseflows at both ACG and CRC (impaired mainstem flow downstream of Edward diversion dam), closely resembled those at UAC through mid-April (Figure 4-4). Streamflow monitoring results indicated year round continuity in baseflow conveyance between ACG and CRC. The 10% and 90% exceedance flows at CRC and ACG were 100–109 cfs and 0.2–1.2 cfs, respectively. After mid-April, all monitoring stations downstream of the diversion dam experienced lower and more variability streamflow than UAC due to diversions, distributary flow splits, and agricultural return flows. Flow at NEW and ACK (distributaries) was far less than in mainstem reaches (10% and 90% exceedance flows 17–18 cfs and 0.1–1.0 cfs, respectively).

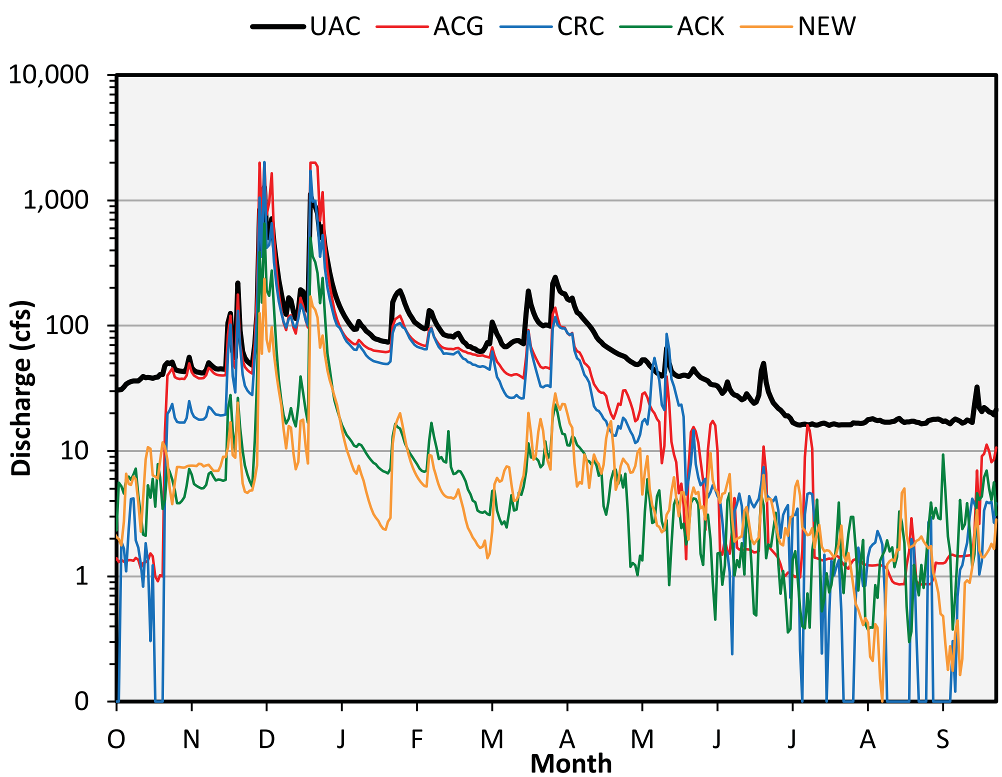


Figure 4-4. WY2013 hydrographs at monitoring sites.

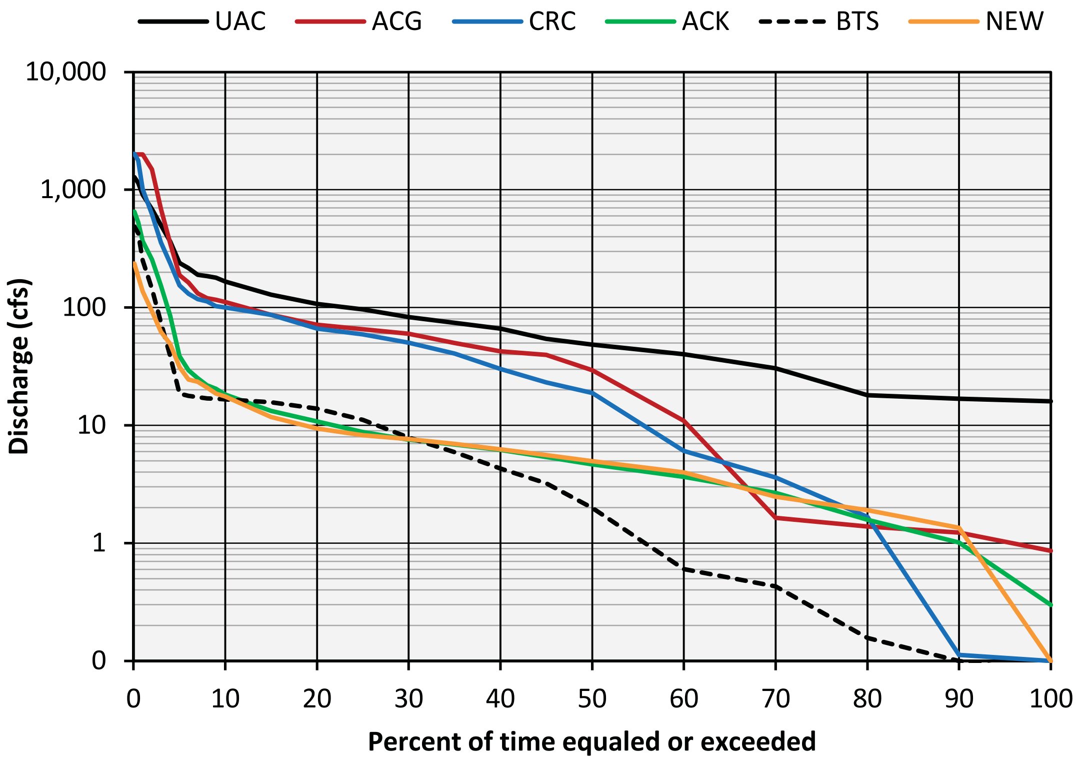


Figure 4-5. WY2013 streamflow exceedence.

Table 4-3. WY 2013 streamflow statistics for lower Antelope Creek monitoring stations.

Streamflow statistic[1]	Site					
	UAC	CGP	CRC	ACK	NEW	BTS
Annual runoff (ac-ft)	65,285	na	na	na	na	na
Annual mean discharge (cfs)	90	na	na	na	na	na
Highest daily mean discharge (cfs)	1,280	na	2,017	1,295	236	489
10 percent exceedance (cfs)	165	109	100	18	17	17
50 percent exceedance (cfs)	48	29	19	4.7	5.0	2.0
90 percent exceedance (cfs)	17	1.2	0.2	1.0	1.4	0.1
Lowest daily mean discharge (cfs)	16	0.9	0.1	0.6	0.1	0.1

[1] Streamflow statistics are derived from discharges calculated from provisional rating curves developed from a limited number of flow measurements during WY2013; "na" indicates statistical parameters that cannot be calculated with confidence using provisional rating curves.

4.1.2.2 WY 2013 stream temperature

Stream temperatures during WY2013 exhibited seasonal patterns at all sites, with the coldest values (0–5 ^{o}C) occurring December through February and the warmest values (25–28 ^{o}C) occurring June through August (Figure 4-6, Figure 4-7, Table 4-4). Spatial differences in mean daily temperatures were similar to those observed during 2011, with the highest temperatures typically measured at ACK (especially prior to June) and the lowest typically measured at NEW.

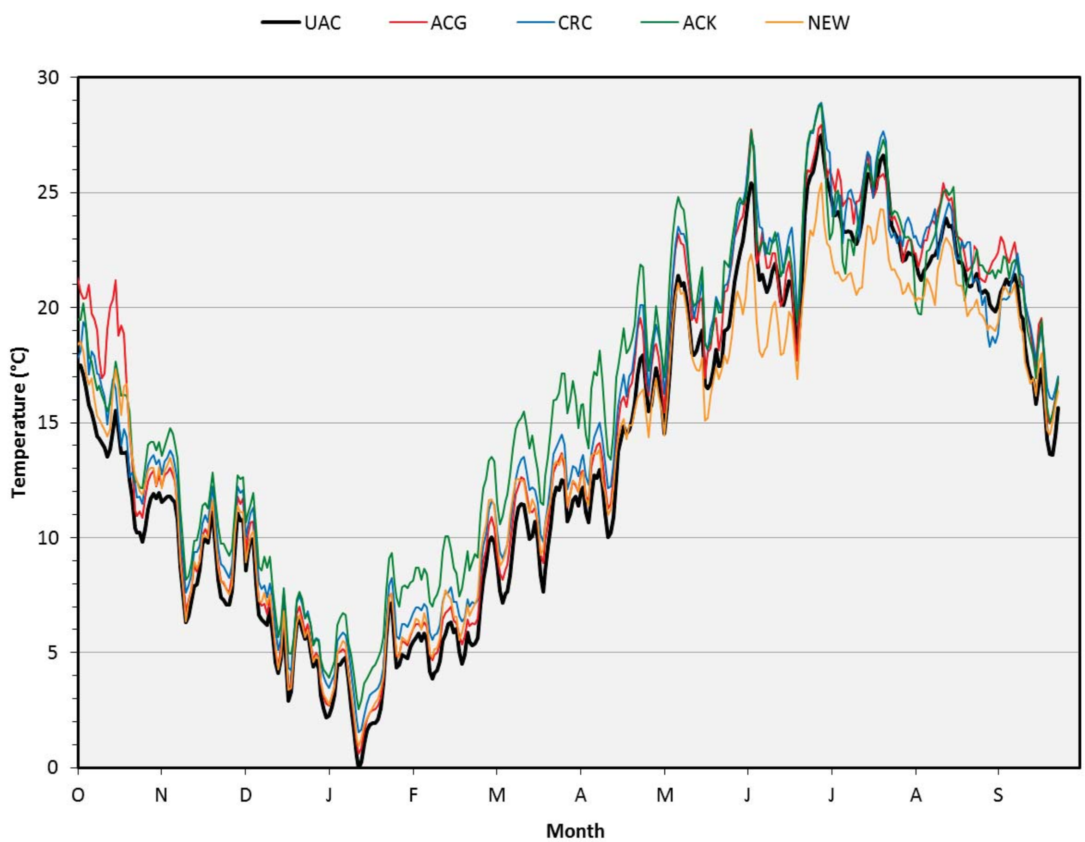


Figure 4-6. Mean daily stream temperatures during WY2013.

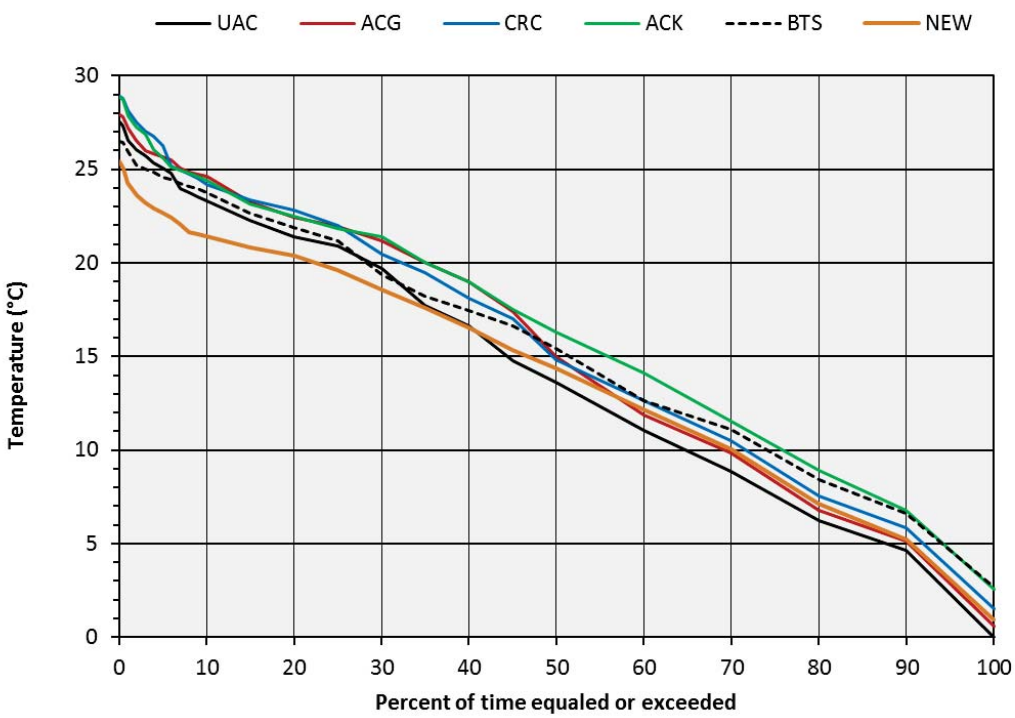


Figure 4-7. Stream temperature exceedance during WY2013.

Table 4-4. Summary of WY 2013 stream temperatures (°C).

Metric	Site	April	May	June	July	Aug	Sept
MWAT[1]	UAC	16.8	20.4	25.3	26.4	23.3	21.0
	ACG	18.0	22.1	26.0	26.8	24.7	22.5
	ACK	20.0	23.7	27.0	27.9	24.8	21.9
	CRC	18.6	22.6	26.9	28.0	23.7	21.3
	NEW	15.8	20.1	22.8	23.9	22.4	20.6
	BTS	17.3	21.1	22.1	23.9	24.8	25.9
Maximum daily average	UAC	17.9	21.4	25.7	27.5	23.9	21.4
	ACG	19.5	23.2	27.7	27.9	25.4	23.1
	ACK	21.9	24.8	27.7	28.8	25.3	22.3
	CRC	20.1	23.5	27.6	28.9	24.6	22.4
	NEW	16.5	21.1	23.4	25.4	23.1	21.0
	BTS	19.1	21.8	22.3	24.5	25.2	26.5
Maximum daily maximum	UAC	19.5	23.1	27.7	29.3	25.4	22.7
	ACG	23.6	27.4	32.4	33.2	30.6	27.5
	ACK	23.4	26.5	30.2	31.7	27.0	24.3
	CRC	21.2	24.1	28.6	35.7	30.0	24.5
	NEW	17.5	23.5	25.3	27.5	26.3	23.8
	BTS	20.3	22.7	24.5	26.6	29.1	31.9

[1] Maximum Weekly Average Temperature (MWAT) is the maximum seven-day moving average of the daily mean temperature.

Mean daily temperatures at sites downstream of Edwards Diversion Dam were about 0.5 to 5°C warmer than UAC from October through April (Figure 4-8). Stream temperatures at mainstem sites downstream of the diversion (ACG and CRC) had a similar and more stable pattern than sites in distributaries (ACK and NEW), each remaining about 0.5 to 2° C warmer than UAC through mid-June. Temperatures at ACK were the warmest, on average 2.8°C warmer than UAC between October 16 and May 22, with maximum departures up to 5.2°C during the first two weeks of April. Warmer temperatures at ACK relative to UAC during this period are likely due to low streamflow and greater solar insolation related to lack of vegetation cover in nearby upstream reaches. Temperatures at ACK significantly cooled relative to UAC and other sites from mid-May through September, likely due to the influence of tailwater returned to the channel after adjacent pastures to the east were flood irrigated with relatively cool water supplied from Mill Creek. Stream temperatures at NEW were variable but typically about 1 to 2°C warmer than UAC during March and early April. Temperatures thereafter at NEW were significantly cooler than UAC and other sites, likely due to relatively more vegetation cover and topographic shading and/or the influence of relatively cool water discharged to New Creek via an irrigation canal located immediately downstream of the monitoring site. The volume, quality, and timing of irrigation water discharged to the channel at this location is unknown. After late May, temperatures at sites downstream of the diversion were generally similar to but more variable than UAC.

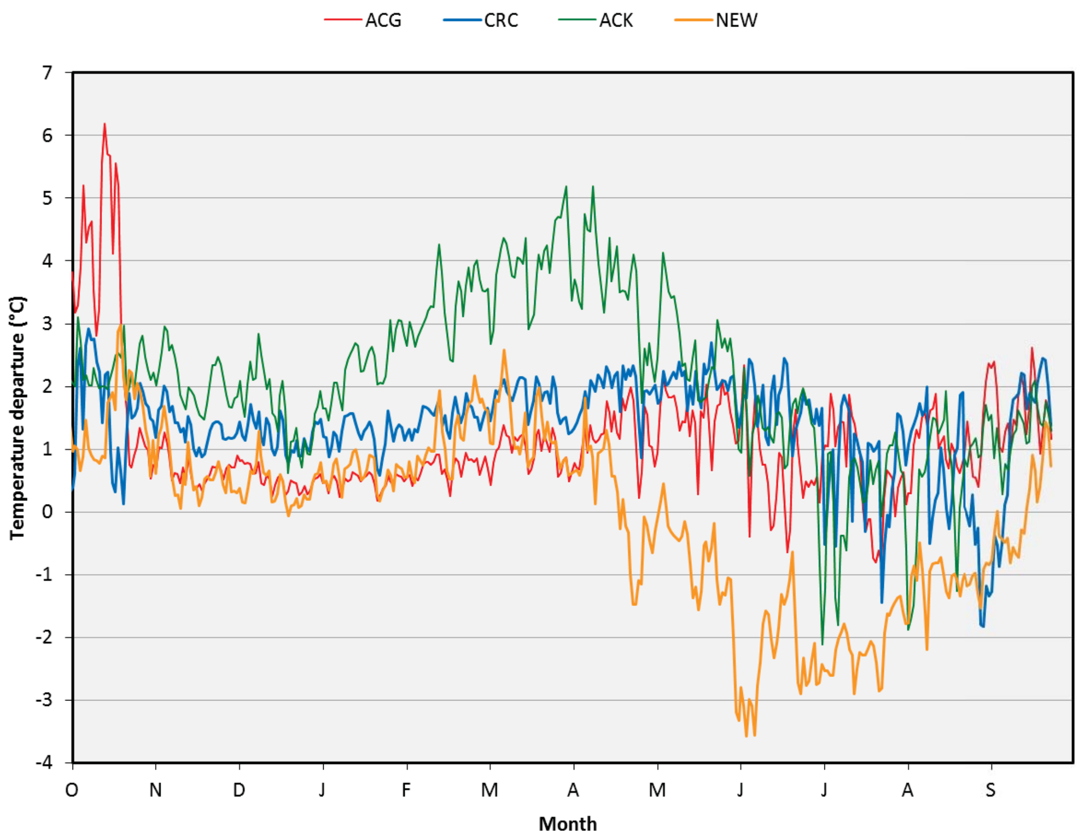


Figure 4-8. Departure in WY2013 mean daily stream temperatures from those measured at UAC.

Appendices

Appendix A

Samples of Data Sheets Used During the Fall 2009 and Spring 2010 Field Surveys

CHANNEL REACH MORPHOLOGY AND CONDITION (front) **Page ______ of _________**

Study Stream:____ **Crew Initials**: ___________________________
Reach Number : ______________________________________ **Date**: ______ /_______ /_______
Longitudinal station: Begins:___________Ends:__________ **Survey length** *(specify units)*: _______________

Channel reach morphology: PR PB FPR SP CAS BRX
PR=pool/riffle, PB=plain bed, FPR=forced pool/riffle, SP=step-pool, CAS=cascade, BRX=bedrock

Channel pattern: meandering sinuous straight braided

Dominant roughness elements: large grains bedforms steps banks planform curvature Bo BRX Veg
Dominant controls on gradient, morphology, and bedform: ____

____

____

	measurement 1	measurement 2	measurement 3	measurement 4	measurement 5
Channel Geometry					
Channel gradient					
Bankfull Width (W_{bf})					
Bankfull Depth (D_{bf})					
Wetted Width					
Wetted Depth					
Valley bottom width (W_{vb})					
Substrate					
Dom/Subdom Facies					
Estimated d_{16}					
Estimated d_{50}					
Estimated d_{84}					

Local sediment sources: streambank failure gully road-related (fill, cutbank, surface erosion, rilling, gullying)
Dominant sediment storage elements: bed bedforms step pools lee and stoss of obstruction overbank
Activity level of stored sediment ______________________

Estimated % area in active storage: ______________________

Estimated Q:_____________________________. **Sources of Q:**____.

Water diversion:

____

____

____

____

Irrigation return: ____

____

____

____

Vegetation cover and distribution in channel: ______________________________

____

____

CHANNEL REACH MORPHOLOGY AND CONDITION (back) **Page ______ of ________**

Study Stream:______________________________ **Crew Initials**: ______________________
Reach Number : ______________________________ **Date**: _____ / ______ / ______
Longitudinal station: Begins:__________Ends:__________ **Survey length** *(specify units)*: ______________

Anthropogenic influences on channel morphology (e.g., levees, impoundments, crossings, structural confinement):

____
____
____
____
____

Potential Study Sites for monitoring stage:
Location coordinates (SP ft): ____

Description: ____
____

Rationale for site selection: ____
____

Equipment and materials needed: ____
____

Potential Study Sites for monitoring temperature:
Location coordinates (SP ft): ____

Description: ____
____

Rationale for site selection: ____
____

Equipment and materials needed: ____
____

Potential Study Sites for monitoring barriers:
Location coordinates (SP ft): ____

Description: ____
____

Rationale for site selection: ____
____

Equipment and materials needed: ____
____

Habitat Inventory Data Form

PROJECT CODE ____________
Page _____ of _____

Stream Name: ______________________ **Reach:** ________________ **Crew Initials**: ____________________

Date: _____/______/______ (month day year) **Start Time**: _________ (24-hour clock) **Stop Time**: _________ (24-hour clock)

General Habitat Characteristics					
Habitat unit number [1]					
Habitat type [2]					
Mean wetted width (ft)					
Mean depth (ft)					
Max depth (ft)					
Hydraulic control depth (ft)					
Cover Characteristics of Pools and Runs					
Cover complexity (L, M, H)					
Total cover (%)					
Undercut bank					
Swd (<12”)					
LWD (>12”)					
Root mass					
Terr. vegetation					
Aquatic vegetation					
Bubble curtain					
Boulders					
Bedrock					
Substrate/Spawning Patch Characteristics					
Substrate composition (dom/sub) [3]					
Patch dimensions (LxW) (ft) [4]					
Suitable habitat area (LxW) (ft)					
Pool-tail embeddedness (%)					
Other					
Photo Number(s)					
GPS Point Number					

1 Natural Sequence Order, each unit numbered sequentially. Decimals denote side channels
2 Habitat type code
3 Bx (bedrock), Bo (boulder), Co (cobble), Gr (gravel), Sd (sand), Fi (fines – silt/clay), Or (organics).
4 Suitable spawning substrate characteristics = 10–78 mm d50, 10 to 200 cm, 15 to 100 cm/s

Comments ____

Obstacle / Barrier Inventory Form

PROJECT CODE ______________
Page ______ of ______

River/Stream Name ____ **Crew Initials**: ______________________________

Date: ______/_______/_______ (month / day / year) **Start Time**: __________ (24-hour clock) **Stop Time**: __________ (24-hour clock)

General Characteristics					
Habitat unit number [1]					
Barrier ID number [2]					
Barrier type [3]					
Passage status [4]					
Diversion Structure Characteristics					
Diversion type [5]					
Construction material(s)					
Obstacle height					
Obstacle length					
Water depth u/s					
Water depth d/s					
Geomorphic (Low-water) Obstacle Characteristics					
Riffle					
Water depth (ft)					
Length of low water depth (ft)					
Pool/Run (if hydraulic control is dry)					
Surveyed hydraulic control elev. (ft)					
Surveyed water surface elev. (ft)					
Surveyed maximum depth elev. (ft)					
Natural Obstacle Characteristics					
Obstacle type (e.g., LWD jam)					
Obstacle height (ft)					
Obstacle length (ft)					
Water depth u/s					
Water depth d/s					
Jump Pool Characteristics (if applicable)					
Mean depth (ft)					
Max depth (ft)					
Horizontal jump distance (ft)					
Vertical jump distance (ft)					
Hydraulic control depth (ft)					
Other					
Photo Number(s)					
GPS Point Number					

1 Natural Sequence Order, each unit numbered sequentially. Decimals denote side channels.
2 Sequential number.
3 Anthropogenic (culvert, diversion structure), geomorphic, natural
4 Assessment of whether structure forms a total, partial, or passable barrier under existing conditions at the time of survey
5 Description (e.g., weir & siphon pump)

Comments:____
____
____
____

Appendix B

Mapping Tiles


4449100
573948
4448850
574198
4448600
574448
573698
573448
4448860
4448100
Edward's Dam
0
500
1000
ANTELOPE CREEK - Field Tiles 1:3000
Survey Crew:
Notes:
Bridge
Culvert
Pipe
Slab crossing
River meters shown as white Xs; 100m interval.
Grid: NAD83 UTM Zone 10N; 250m spacing
0
50
100
200 Meters
Tile 01
Stillwater Sciences


4448003
4447753
4447503
574340
574340
4448253
574090
574090
573840
1000
1500
2000
ANTELOPE CREEK - Field Tiles 1:3000
Survey Crew:
Notes:
Bridge
Culvert
Pipe
Slab crossing
River meters shown as white Xs; 100m interval.
Grid: NAD83 UTM Zone 10N; 250m spacing
0
50
100
200 Meters
Tile 02
Stillwater Sciences


4447153
4446903
573962
4446653
4446403
4446153
4447153
573712
573462
573962
573712
573462
2500
3000
3500
ANTELOPE CREEK - Field Tiles 1:3000
Survey Crew:
Notes:
Bridge
Culvert
Pipe
Slab crossing
River meters shown as white Xs; 100m interval.
Grid: NAD83 UTM Zone 10N; 250m spacing
0
50
100
200 Meters
Tile 03
Stillwater Sciences


4446087
574156
4445837
574406
4445587
574656
4445337
573906
4446087
573656
4445837
574656
4445087
574406
4000
4500
ANTELOPE CREEK - Field Tiles 1:3000
Survey Crew:
Notes:
Bridge
Culvert
Pipe
Slab crossing
River meters shown as white Xs; 100m interval.
Grid: NAD83 UTM Zone 10N; 250m spacing
0
50
100
200 Meters
Tile 04
Stillwater Sciences


4445188
574929
4444938
575179
4444688
575429
4444438
574679
4445188
574429
4444938
575429
4444188
575179
5500
6000
5000
Well
ANTELOPE CREEK - Field Tiles 1:3000
Survey Crew:
Notes:
Bridge
Culvert
Pipe
Slab crossing
River meters shown as white Xs; 100m interval.
Grid: NAD83 UTM Zone 10N; 250m spacing
0
50
100
200 Meters
Tile 05
Stillwater Sciences

4444216
575680
4443966
4443716
4443466
575930
575430
575180
Siphon
8500
8000
7500
7000
ANTELOPE CREEK - Field Tiles 1:3000
Survey Crew:
Notes:
Bridge
Culvert
Pipe
Slab crossing
River meters shown as white Xs; 100m interval.
Grid: NAD83 UTM Zone 10N; 250m spacing
0
50
100
200 Meters
Tile 06
Stillwater Sciences


4442906
4442656
4442406
575630
575630
4443156
575380
575380
575130
8000
8500
9000
ANTELOPE CREEK - Field Tiles 1:3000
Survey Crew:
Notes:
Bridge
Culvert
Pipe
Slab crossing
River meters shown as white Xs; 100m interval.
0
50
100
200 Meters
Tile 07


4441938
4441688
4441438
4441188
575526
575276
10500
9900
9500
ANTELOPE CREEK - Field Tiles 1:3000
Survey Crew:
Notes:
Bridge
Culvert
Pipe
Slab crossing
River meters shown as white Xs; 100m interval.
Grid: NAD83 UTM Zone 10N; 250m spacing
0
50
100
200 Meters
Tile 08
Stillwater Sciences


4440747
576184
4440247
4439997
575934
575684
575434
4440997
12000
11500
11000
ANTELOPE CREEK - Field Tiles 1:3000
Survey Crew:
Notes:
Bridge
Culvert
Pipe
Slab crossing
River meters shown as white Xs; 100m interval.
Tile 09
Stillwater Sciences


4439628
575716
4439128
4438878 575466
575716
575216
4439878
575466
574966
4438878
12500
13000
13500
ANTELOPE CREEK - Field Tiles 1:3000
Survey Crew:
Notes:
Bridge
Pipe
Culvert
Slab crossing
River meters shown as white Xs; 100m interval.
Grid: NAD83 UTM Zone 10N; 250m spacing
0
50
100
200 Meters
Tile 10


4446161
4445911
4445661
573905
573655
4446411
573405
CRAIG CREEK - Field Tiles 1:3000
Survey Crew:
Notes:
Bridge
Culvert
Pipe
Slab crossing
River meters shown as white Xs; 100m interval.
Grid: NAD83 UTM Zone 10N; 250m spacing
0
50
100
200 Meters
Tile 1
Stillwater Sciences
0
200


574015
4445074
4444824
4444574
4444324 573765
574016
573765
4445324
573615
573515
573265
1000
1500
2000
CRAIG CREEK - Field Tiles 1:3000
Survey Crew:
Notes:
Bridge
Pipe
Culvert
Slab crossing
River meters shown as white Xs; 100m interval.
Grid: NAD83 UTM Zone 10N; 250m spacing
0
50
100
200 Meters
Tile 2
Stillwater Sciences


573579
4443825
4443575
4443325
4443076
573329
573079
2500
3000
CRAIG CREEK - Field Tiles 1:3000
Survey Crew:
Notes:
Bridge
Culvert
Pipe
Slab crossing
River meters shown as white Xs; 100m interval.
Grid: NAD83 UTM Zone 10N; 250m spacing
0
50
100
200 Meters
Tile 3
Stillwater Sciences


4445451
574513
4445201
4444951
574763
4444451
574263
574013
1000
500
0
BUTLER SLOUGH - Field Tiles 1:3000
Survey Crew:
Notes:
Bridge
Pipe
Culvert
Slab crossing
River meters shown as white Xs; 100m interval.
Grid: NAD83 UTM Zone 10N; 250m spacing
0
50
100
200 Meters
Tile 1
Stillwater Sciences

4444546
575058
4444296
4444046
575308
4443796
574808
574558
575308 4443546
575058
Well
1500
2000
2500
BUTLER SLOUGH - Field Tiles 1:3000
Survey Crew:
Notes:
Bridge
Culvert
Pipe
Slab crossing
River meters shown as white Xs; 100m interval.
Grid: NAD83 UTM Zone 10N; 250m spacing
0
50
100
200 Meters
Tile 2
Stillwater Sciences


4443344
4443094
4442844
4442594575350
575350
4443594
576100
576100
574850
3000
2500
2500
BUTLER SLOUGH - Field Tiles 1:3000
Survey Crew:
Notes:
Bridge
Pipe
Culvert
Slab crossing
River meters shown as white Xs; 100m interval.
Grid: NAD83 UTM Zone 10N; 250m spacing
0
50
100
200 Meters
Tile 3
Stillwater Sciences


4442500
4442250
4442000
574856
574606
574356
4000
4500
5000
BUTLER SLOUGH - Field Tiles 1:3000
Survey Crew:
Notes:
Bridge
Culvert
Pipe
Slab crossing
River meters shown as white Xs; 100m interval.
Grid: NAD83 UTM Zone 10N; 250m spacing
0
50
100
200 Meters
Tile 4
Stillwater Sciences


4441386
4441136
4440886
574726
574726
574476
574226
574476
574226
5500
6000
6500
BUTLER SLOUGH - Field Tiles 1:3000
Survey Crew:
Notes:
Bridge
Culvert
Pipe
Slab crossing
River meters shown as white Xs; 100m interval.
Grid: NAD83 UTM Zone 10N; 250m spacing
0
50
100
200 Meters
Tile 5
Stillwater Sciences


4440227
4439977
574805
4439727
574555
574305
574055
4439477
4440477
7000
7500
8000
BUTLER SLOUGH - Field Tiles 1:3000
Survey Crew:
Notes:
Bridge
Culvert
Pipe
Slab crossing
River meters shown as white Xs; 100m interval.
Grid: NAD83 UTM Zone 10N; 250m spacing
0
50
100
200 Meters
Tile 6


4448827
573931
4448577
4448327
4448077 573681
573931
573681 4449077
573431
573431
573181
4448077
Edward's Dam
500
1000
SALT/NEW CREEKS - Field Tiles 1:3000
Survey Crew:
Notes:
Bridge
Culvert
Pipe
Slab crossing
River meters shown as white Xs; 100m interval.
Grid: NAD83 UTM Zone 10N; 250m spacing
0
50
100
200 Meters
Tile 1


573674
4447590
573424
4447340
573174
572924
572674
4448090
2000
2500
3000
SALT/NEW CREEKS - Field Tiles 1:3000
Survey Crew:
Notes:
Bridge
Culvert
Pipe
Slab crossing
River meters shown as white Xs; 100m interval.
Grid: NAD83 UTM Zone 10N; 250m spacing
0
50
100
200 Meters
Tile 2
Stillwater Sciences


572983
4446654
572733
4446404
572483
572233
571983
4447154
2500
3000
3500
SALT/NEW CREEKS - Field Tiles 1:3000
Survey Crew:
Notes:
Bridge
Culvert
Pipe
Slab crossing
River meters shown as white Xs; 100m interval.
Grid: NAD83 UTM Zone 10N; 250m spacing
0
50
100
200 Meters
Tile 3
Stillwater Sciences


572134
4445707
571884
4445457571634
571384
4445957
572134
4446207
4446457
4445457 571134
4445707
4000
4500
5000
5500
SALT/NEW CREEKS - Field Tiles 1:3000
Survey Crew:
Notes:
Bridge
Pipe
Culvert
Slab crossing
River meters shown as white Xs; 100m interval.
0
50
100
200 Meters
Tile 4


4445415
571978
4445165
4444915
572228
4444665
571728
4444415
572228
4445415
571478
571978
6500
6000
SALT/NEW CREEKS - Field Tiles 1:3000
Survey Crew:
Notes:
Bridge
Culvert
Pipe
Slab crossing
River meters shown as white Xs; 100m interval.
Grid: NAD83 UTM Zone 10N; 250m spacing
0
50
100
200 Meters
Tile 5
Stillwater Sciences

Appendix C

Photographs of Channel Conditions in Project Reaches

Figure C-1. Antelope Creek in Reach 1 at the upstream end of Cone Grove Park.

Figure C-2. The distributary junction between Antelope Creek and Craig Creek. Flow in mainstem Antelope Creek (foreground left to right) moves out of bank into the larger of two side channels (background). The channel referred to as Craig Creek begins at the right edge of the photograph.

Figure C-3. Antelope Creek in Reach 2. Shallow and wide bedrock channel.

Figure C-4. Antelope Creek in Reach 2. Beaver dam and upstream pond formed in shallow, wide bedrock channel.

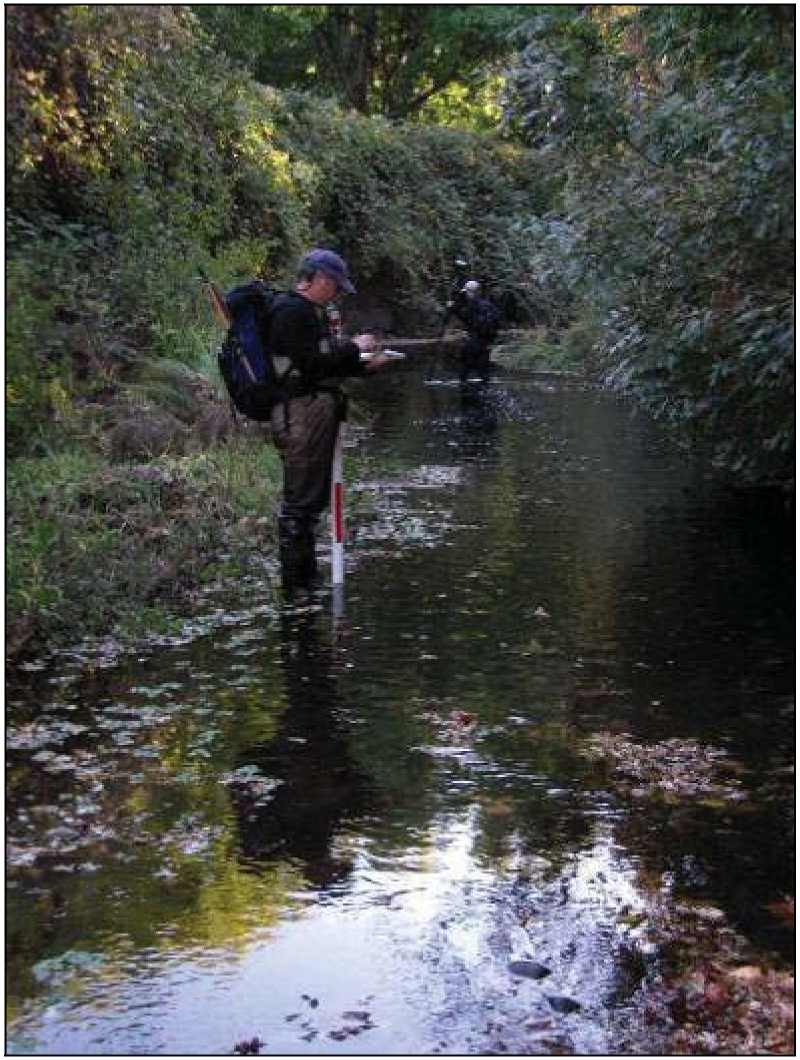


Figure C-5. Antelope Creek in Reach 3. Channel is entrenched within vertical banks of unconsolidated alluvium and soil material.

Figure C-6. Antelope Creek in Reach 3. Channel-spanning concrete apron that encases a water pipe.

Figure C-7. Eroding bankline in Reach 4 of Antelope Creek.

Figure C-8. Antelope Creek in Reach 4. Large stand of *Arundo Donax* in the active channel.

Figure C-9. Antelope Creek in Reach 5. Entrenched gravel-bed channel with pool-riffle morphology.

Figure C-10. Antelope Creek in Reach 6. Meandering gravel bed channel downstream of beaver dam.

Figure C-11. Antelope Creek in Reach 6. Invasive aquatic vegetation forms a closed canopy over the water surface near the confluence with the Sacramento River.

Figure C-12. Gravel particles in potential spawning patches in Reach 1 of Antelope Creek.

Figure C-13. A pool providing high-quality rearing habitat in Reach 2 of Antelope Creek.

Figure C-14. An example of poor rearing habitat conditions in Reach 2 of Antelope Creek.

Figure C-15. Potential barrier A1 (spring 2010). A beaver dam located at the head of the upper overflow channel at the Antelope Creek-Craig Creek junction.

Figure C-16. Potential barrier A1.1 (fall 2009). A dry channel segment in Reach 2 of Antelope Creek**.**

Figure C-17. Potential barrier A1.1 (spring 2010). A wide, shallow bedrock channel segment forming a potential barrier in Reach 2 of Antelope Creek**.**

Figure C-18. Potential barrier A4 (fall 2009). A wide and shallow bedrock channel segment creating a potential barrier in Reach 2 of Antelope Creek.

Figure C-19. Potential barrier A6 (fall 2009). A wide and shallow bedrock channel segment creating a potential barrier in Reach 2 of Antelope Creek.

Figure C-20. Potential barrier A2 (fall 2009). The most upstream beaver dam in Reach 2 of Antelope Creek.

Figure C-21. Potential barrier A3 (fall 2009). Beaver dam in Reach 2 of Antelope Creek.

Figure C-22. Potential barrier A5 (fall 2009). Beaver dam in Reach 2 of Antelope Creek.

Figure C-23. Potential barrier A7 (fall 2009 survey). Beaver dam in Reach 2 of Antelope Creek.

Figure C-24. Potential barrier A8 (fall 2009). A dense matt of aquatic vegetation in a backwater pond formed upstream of a bedrock step in Reach 3 of Antelope Creek.

Figure C-25. Potential barrier A10 (fall 2009). Beaver dam in Reach 3 of Antelope Creek.

Figure C-26. Potential barrier A9 (fall 2009). Shallow flow over a bedrock channel bed in Reach 3 of Antelope Creek.

Figure C-27. Potential barrier A11 (fall 2009). Shallow flow over a bedrock channel bed in Reach 3 of Antelope Creek.

Figure C-28. Potential barrier A12 (fall 209). Concrete apron embedded with a water pipe crossing the channel in Reach 3 of Antelope Creek upstream of Kauffman Avenue.

Figure C-29. Potential barrier A15 (fall 2009). A beaver dam in Reach 4 of Antelope Creek.

Figure C-30. Potential barrier A16 (fall 2009). A large beaver dam in Reach 5 of Antelope Creek.

Figure C-31. Potential barrier A16 (spring 2010). Beaver dam in Reach 5 of Antelope Creek.

Figure C-32. Potential barrier A16 (spring 2010). Upstream view of beaver dam in Reach 5 of Antelope Creek (backwater from the Sacramento River).

Figure C-33. Potential barrier A18. Lower segment of Reach 6 of Antelope Creek with dense emergent aquatic vegetation.

Figure C-34. Channel modified by heavy equipment excavation in Reach 1 of Craig Creek.

Figure C-35. Bedrock slot channel and large pool entrenched within vertical alluvial banks in Reach 2 of Craig Creek.

Figure C-36. Craig Creek in Reach 3. Gravel bed, pool-riffle channel with accumulations of large woody debris. Active gravel bars have less vegetation encroachment compared to other channels in the Project area.

Figure C-37. Confluence of Craig Creek and the Sacramento River. Confluence is free of emergent aquatic vegetation.

Figure C-38. Patch of potentially suitable spawning gravel in Reach 1 of Craig Creek.

Figure C-39. Levees and riprap along channel banks in Reach 1 of Craig Creek.

Figure C-40. Narrow and deeply incised bedrock channel in Reach 2 of Craig Creek.

Figure C-41. Gravel bed channel with woody debris in Reach 3 of Craig Creek.

Figure C-42. Butler Slough in Reach 1.

Figure C-43. Beaver dam in Reach 2 of Butler Slough.

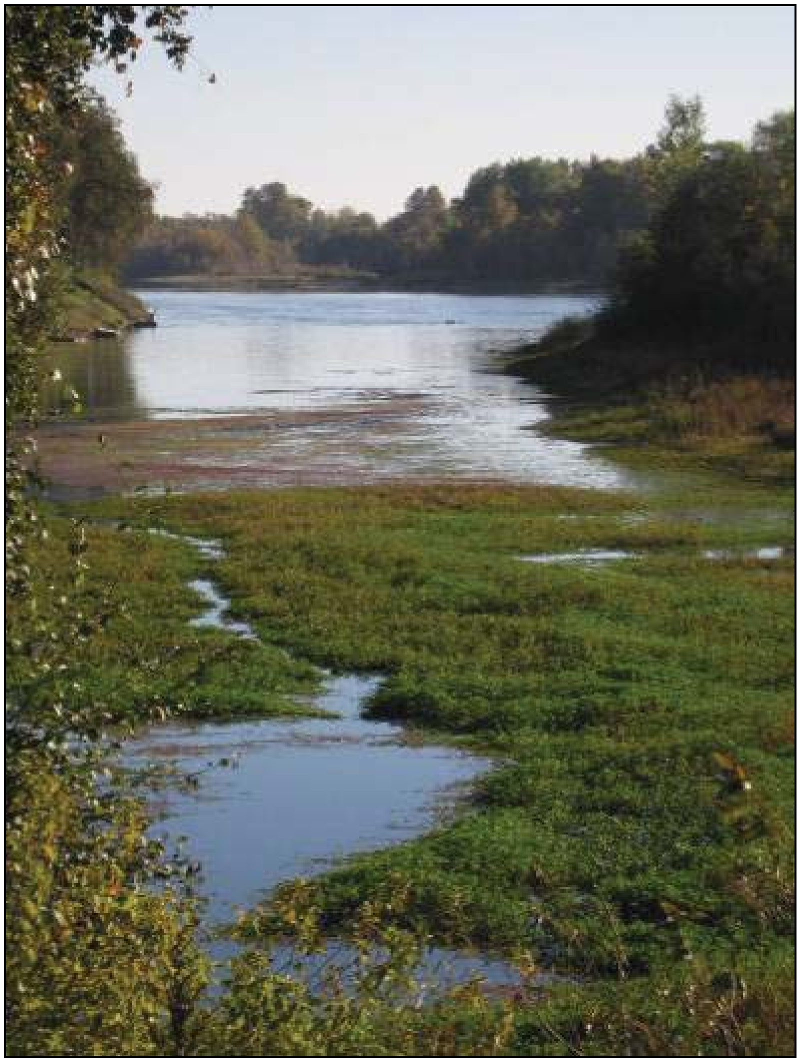


Figure C-44. Dense emergent aquatic vegetation at the confluence of Butler Slough and the Sacramento River.

Figure C-45. Grasses and other terrestrial vegetation along the active channel bed in Reach 1 of Butler Slough.

Figure C-46. Potential barrier B3. A debris dam identified in Reach 1 of Butler Slough (fall 2009 survey).

Figure C-47. Potential barrier B1. A beaver dam identified in Reach 1 of Butler Slough (fall 2009 survey).

Figure C-48. Potential barrier B2. Wide, shallow channel in Reach 1 of Butler Slough (fall 2009 survey).

Figure C-49. Potential barrier B4. Excavation of alluvial sediment in Reach 1 of Butler Slough.

Figure C-50. Potential barrier B5. Dry channel in Reach 2 of Butler Slough (fall 2009 survey).

Figure C-51. Potential barrier B7. A road-stream crossing in Reach 2 of Butler Slough.

Figure C-52. Potential barrier B6. A road-stream crossing in Reach 2 of Butler Slough.

Figure C-53. Potential barrier B8. Beaver dam in the lower segment of Reach 2 in Butler Slough.

Figure C-54. Potential barrier B9. Beaver dam in the lower segment of Reach 2 in Butler Slough.

Figure C-55. Potential barrier B10. Beaver dam in the lower segment of Reach 2 in Butler Slough.

Figure C-56. Potential barrier B11. Dense aquatic vegetation at the mouth of Butler Slough.

Figure C-57. Deeply entrenched channel with intermittent flow in Reach 1 of New Creek.

Figure C-58. Channel is influenced by backwater from the Sacramento River in Reach 2 of New Creek.

Figure C-59. Reach 2 of New Creek.

Figure C-60. Potential barrier N3. Dry channel in Reach 1 of New Creek.

Figure C-61. Potential barrier N1. Beaver dam immediately upstream of Cone Grove Road in Reach 1 of New Creek (fall 2009 survey).

Figure C-62. Potential barrier N2. Beaver dam in Reach 1 of New Creek.

Figure C-63. Potential barrier N1. The partially collapsed beaver dam upstream of Cone Grove Road in Reach 1 of New Creek (Spring 2010 survey).

Figure C-64. Dry channel in Reach 2 of New Creek.

Figure C-65. A shallow riffle near the upstream end of Reach 2 of New Creek.

Figure C-66. Monitoring site 4 (Craig Creek at State Route 99) on 10 October 2010 showing summer baseflow at a water surface elevation slightly lower than the transducer.

Figure C-67. Monitoring Site 4 (Craig Creek at State Route 99) on 10 October 2010 showing baseflow at a water surface elevation slightly lower that the transducer.

Figure C-68. Monitoring Site 1 (Antelope Creek at Cone Grove Road) on 10 October 2010 showing summer baseflow at a water surface elevation slightly lower that the transducer.

Figure C-69. Inset channel excavated within a wide and shallow plane bed reach to concentrate low flow and increase flow depths.

Appendix D

Rearing Habitat Characteristics

Geomorphic reach	General characteristics						Cover characteristics of pools and runs											
	Habitat unit number	Habitat type	Mean wetted width (ft)	Mean depth (ft)	Max depth (ft)	Hydraulic control depth (ft)	Cover complex. (L, M, H)	Total cover (%)	Undercut bank	Swd (<12")	LWD (>12")	Root mass	Terr. Veg.	Aqua. veg	Bubble curtain	Bldr.	Bx
Antelope																		
1	61	RUN w/Steps	40	1.2	1.7		H	70					100				
	62	RIF	25	0.8	1.3		M	40					100				
	63	RUN	35	1.2	2.2		M	30					80	20			
	64	MCP	50	2.8	5.5	1	L	10					100				
	65	RUN	60	2.5	4	0.8	L	10					100				
	66	MCP	40	2.5	>4	1.3	L	10					100				
	67	RUN															
	68	LSP															
	69	RIF															
	70	RUN/GLD	40	2	3		L	5					100				
	71	RIF	20	0.08	1.8		M	35					50		50		
	72	RUN	40				L	15					100				

Geomorphic reach	General characteristics						Cover characteristics of pools and runs										
	Habitat unit number	Habitat type	Mean wetted width (ft)	Mean depth (ft)	Max depth (ft)	Hydraulic control depth (ft)	Cover complex. (L, M, H)	Total cover (%)	Undercut bank	Swd (<12")	LWD (>12")	Root mass	Terr. Veg.	Aqua. veg	Bubble curtain	Bldr.	Bx
2	1	MCP	40	3	4.5	1.5	L	5	5				90	5			
	2	GLD	40	2.2	3.5	0.5	M	15	10				70	20			
	3	RUN	30	0.5	0.7		H	70					100				
	4	GLD	40	2.3	3.3	1	M	25					40	60			
	5	GLD	40	1.5	2		H	50					40	60			
	6	DMP	40	3.4	>4.0		M	40			10		70	20			
	7	GLD	40	2.8	3.5	0.5	M	30					60	40			
	8	RUN	14	1.4	0.5		L	<5					100				
	9	RUN	40	0.8			L	5					100				
	10	RIF	20	0.2			L	5					100				
	11	GLD	40	0.6	0.8	0.3	L	<5					100				
	12	RUN	40	0.7	2.7		L	10					100				
	13	MCP	63	2.2	3.8	1.2	L	10					100				
	14	DMP			>4.5		L	15					70	30			
	15	RIF	45	0.2	0.3		L	<5					100				
	16	RUN	30	1.5	1.8	0.5	L	10					100				
	17	POOL	35	2.3	4.5	0.3	M	30					20	80			
	18	RUN	30	1.2	2.6		M	35						100			
	19	RUN		2.3	4.5		M	25					25	75			

Geomorphic reach	General characteristics						Cover characteristics of pools and runs											
	Habitat unit number	Habitat type	Mean wetted width (ft)	Mean depth (ft)	Max depth (ft)	Hydraulic control depth (ft)	Cover complex. (L, M, H)	Total cover (%)	Undercut bank	Swd (<12")	LWD (>12")	Root mass	Terr. Veg.	Aqua. veg	Bubble curtain	Bldr.	Bx
3	20	RUN		1.5	>4		L	10					50	50			
	21	GLD	40	0.8	3.5	0.2	M	30					20	80			
	22	CAS	5	0.1	0.2		L	0									
	23	RUN	22	1.3	2.3		L	10					100				
	24	RIF	15	1.1	2.8		L	5					60		20	20	
	25	MCP	60	>3	>5		L	5					100				
	26	GLD	30	1.3	2.5		L	20					70	30			
	27	RUN	8	0.5	0.9		L	10						100			
	28	MCP	50	>3	>4		L	10						100			
	29	RIF					L	<5					100				
	30	MCP		>3	>5												
	31	RIF	10	0.4	0.6		L	0									
	32	GLD	22				L	0									
	33	MCP	40	>3	>5		L	5					100				
	34	RUN	25	0.8	2.5		L										

Geomorphic reach	General characteristics						Cover characteristics of pools and runs											
	Habitat unit number	Habitat type	Mean wetted width (ft)	Mean depth (ft)	Max depth (ft)	Hydraulic control depth (ft)	Cover complex. (L, M, H)	Total cover (%)	Undercut bank	Swd (<12")	LWD (>12")	Root mass	Terr. Veg.	Aqua. veg	Bubble curtain	Bldr.	Bx
4	35	RUN	25	2	3		L	10		40	40		20				
	36	POOL	35	>3	>4		L	<5			100						
	37	RUN	20	1.2	>3	0.2	L	5		10	20		70				
	38	LSP LWD	32	2.7	>4		M	30			100						
	39	RUN	25	1.5	>4	0.2	L	10		30	50		20				
	41	RIF	15	0.1	0.4		L	5					100				
	42	RUN	20	1	2.7		L	5			20		80				
	43	MCP	25	1.7	3.7		L	10		70	30						
	44	RUN	25	0.9	1.8		L	10		20			80				
	45	MCP				0.5											
	46	RUN	20	0.7	2.5		L	10					100				
	47	MCP/CCP	45	>3	>4		L	5					100				
	48	RUN	35	1.2	2.7		L	5					100				
	49	MCP	45	>3	>4		L	5					100				
	50	RUN															
	51	MCP	65	>3	>4		M	40					10	90			
	52	MCP	50	>3	>4	0.7	L						100				
	53	RUN					M						100				
	54	MCP	55	>3	>4	NA	M							100			
	55	RUN/POOL	45	3	>4	NA	M							100			
5	56	RUN/GLD	40	2.1	>4												
	57	GLD/VEG	40	2.3	>4												
6	58	GLD/VEG	40	1.7	>4												
	59	WETLAND	150+	NA	NA												
	60	CONFLUENCE	200	NA	NA - DEEP												

Geomorphic reach	General characteristics						Cover characteristics of pools and runs										
	Habitat unit number	Habitat type	Mean wetted width (ft)	Mean depth (ft)	Max depth (ft)	Hydraulic control depth (ft)	Cover complex. (L, M, H)	Total cover (%)	Undercut bank	Swd (<12")	LWD (>12")	Root mass	Terr. Veg.	Aqua. veg	Bubble curtain	Bldr.	Bx
Craig Creek																	
1	1	RIF	35	0.6	1.3		L	15							100		
	2	GLD	35				L	5					100				
	3	RIF	20	0.6	1.4		L	10							100		
	4	RUN	35				L	5					100				
	5	RIF	35	0.3	1.3		L	0									
	6	RUN	35	2.3	4.1		L	5					100				
2	7	RUN	8	3.8	10		M	30							10		90
	8	POOL	60	2	7		L	15									100
3	9	RUN	35	1.2	2.2		L	10					50				50
	10	MCP	50	3	>4	NA	L	5									100
	11	RUN	30	1.1	2.3		M	30		50	50						
	12	MCP LWD	40	3.4	8.5	0.8	M	40			80		20				
	13	LSP	40	2.5	4.5	0.7	L	10			100						
	14	RUN	25	1.4	2.2		L	10			100						
	15	LSP LWD	35	2.5	6	0.7	M	35			100						
	16	RUN	30	1.2	2.7		M	30									100
	17	POOL	25	1.7	>4	NA	M	30		100							
	18	RUN	25	1.7	3.2	NA	M	35		50	50						
	19	MCP	65	2.3	>4	1.2	M	30		30	30			40			
	20	RUN	25	0.7	1.9	0.7	L	10					100				
	21	MCP	40	2.5	4	0.6	L	10	20				20	60			
	22	RUN															
	23	RUN	75	1.6	3.2		L						50	50			

Geomorphic reach	General characteristics						Cover characteristics of pools and runs										
	Habitat unit number	Habitat type	Mean wetted width (ft)	Mean depth (ft)	Max depth (ft)	Hydraulic control depth (ft)	Cover complex. (L, M, H)	Total cover (%)	Undercut bank	Swd (<12")	LWD (>12")	Root mass	Terr. Veg.	Aqua. veg	Bubble curtain	Bldr.	Bx
Butler Slough																	
1	1	RUN	20	0.6	3.5		M	20					50	50			
	2	POOL	40	0.8	3.2	0.1	L	10		50			50				
	3	RUN	15	0.7	2.3	0											
2	4	DRY															
	5	RUN					L	10		50			50				
	6	RUN WET/DRY	Variable		0.7		L	0									
	7	RUN					L	0									
	8	DRY					L	0									
3	9	MARSH					H	90						100			
New Creek																	
	1	RUN	20	0.6	3.5		M	20					50	50			
	2	POOL	40	0.8	3.2	0.1	L	10		50			50				
	3	RUN	15	0.7	2.3	0											
	4	DRY															
	5	RUN					L	10		50			50				
	6	RUN WET/DRY	Variable		0.7		L	0									
	7	RUN					L	0									
	8	DRY					L	0									
	9	MARSH					H	90						100			

Appendix E

Mean Daily Stage and Stream Temperature at Monitoring Sites during WY2010

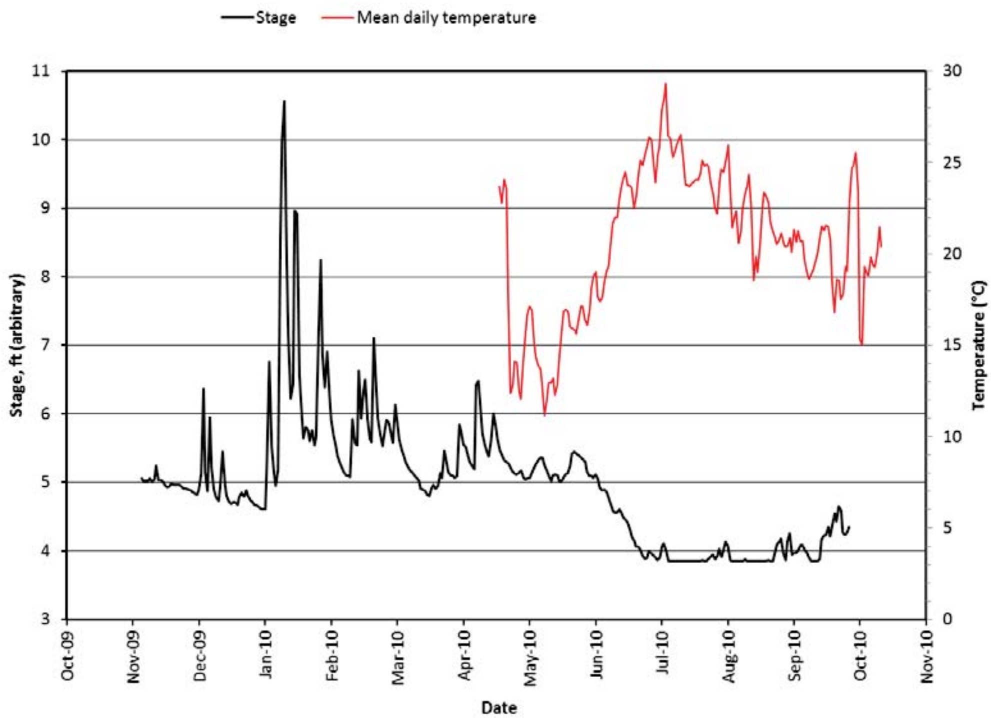


Figure E-1. Mean daily stage and stream temperature at ACG during WY2010.

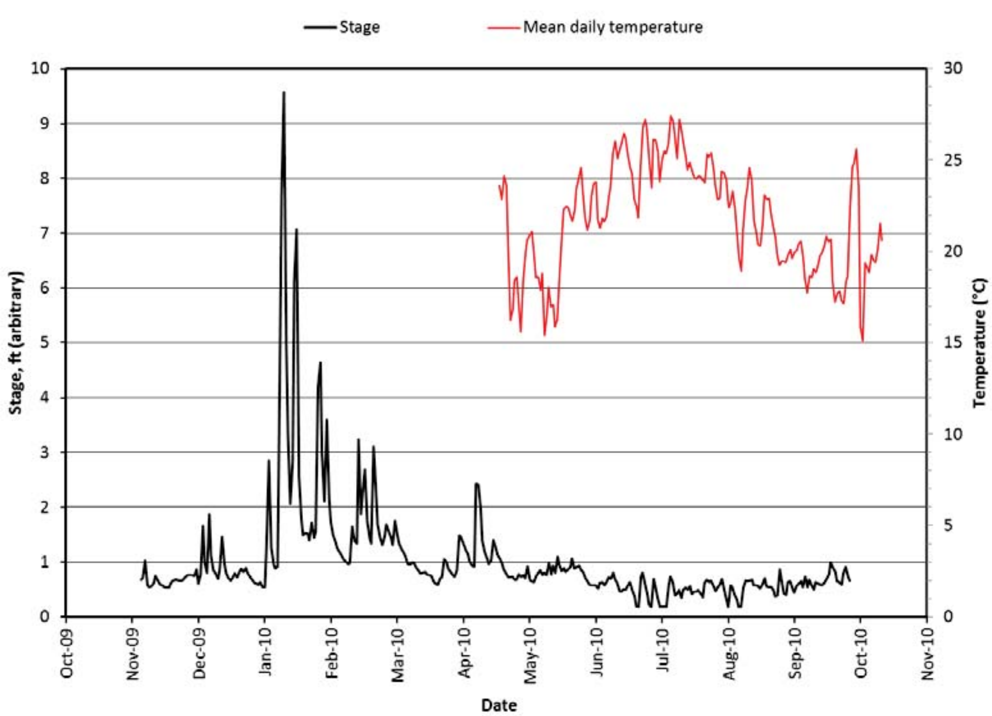


Figure E-2. Mean daily stage and stream temperature at ACK during WY2010.

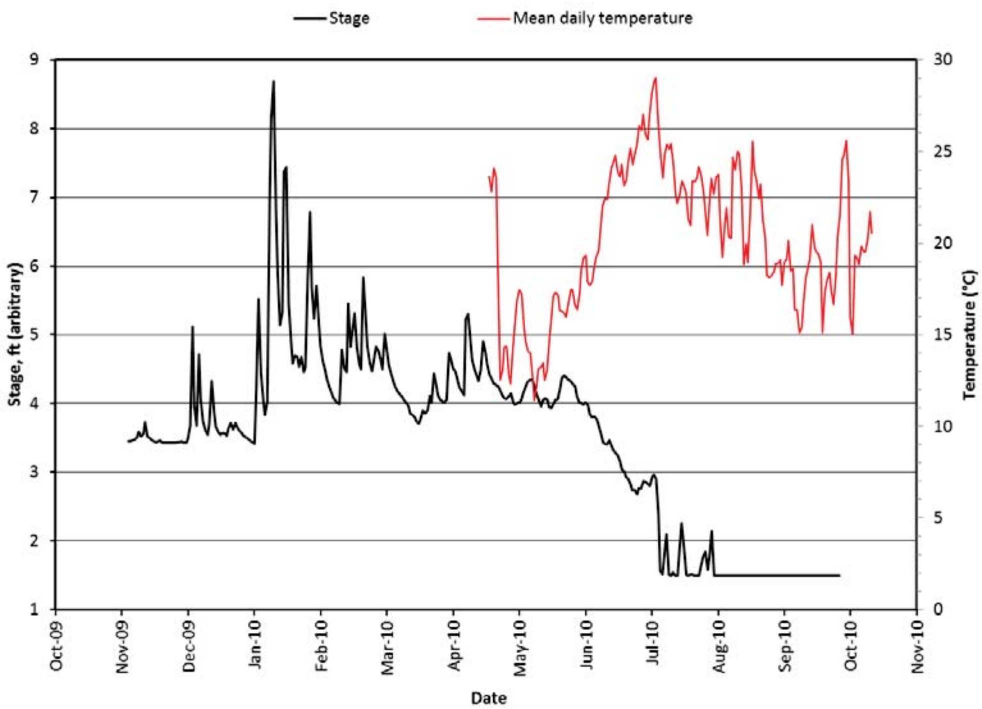


Figure E-3. Mean daily stage and stream temperature at CRC during WY2010.

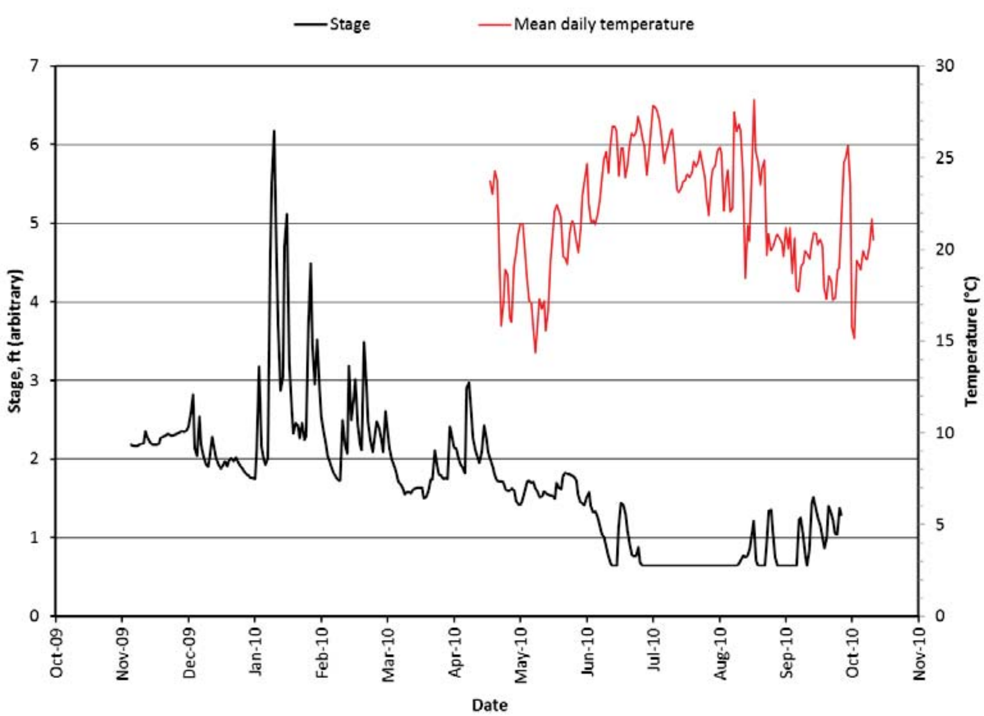


Figure E-4. Mean daily stage and stream temperature at BTS during WY2010.

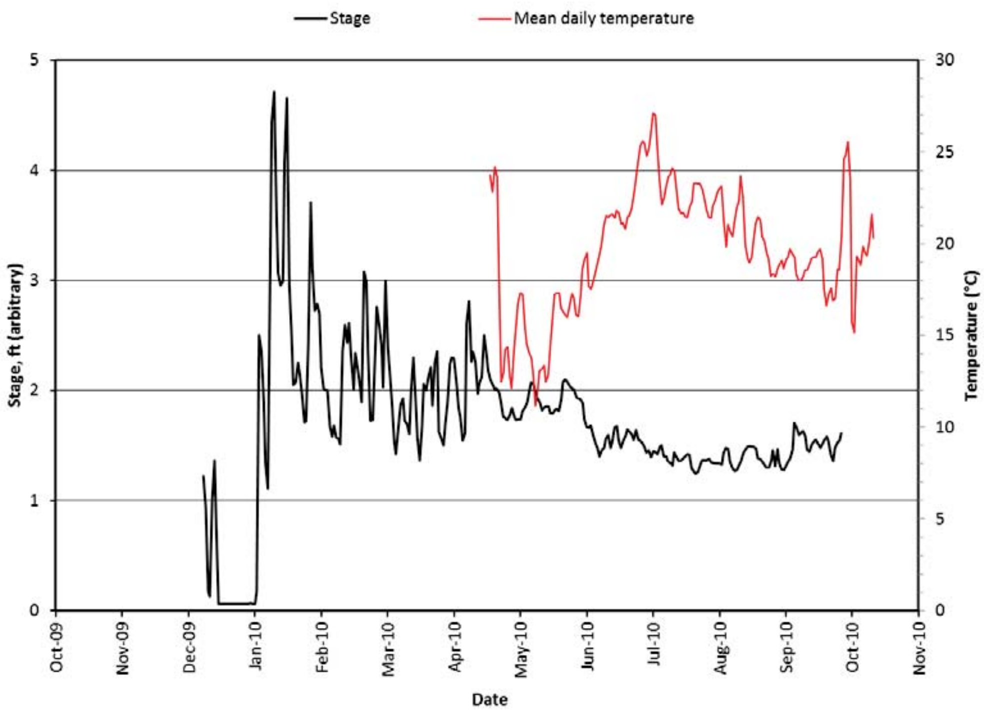


Figure E-5. Mean daily stage and stream temperature at NEW during WY2010.

Appendix F

Discharge Measurements Collected for Rating Stations

Table F-1. Discharge measurements collected in WY 2013 for rating stations.

Site ID	Date	Stage (ft)	Discharge (cfs)	Method
UAC	20-Oct-12	51.12	38	AA
	3-Dec-12	53.66	565	ADCP
	16-Jan-13	51.39	70	Pygmy
	13-Mar-13	51.37	71	Pygmy
	25-Jun-13	51.17	43	Pygmy
ACG	3-Dec-12	93.78	553	ADCP
	19-Dec-12	92.15	106	Pygmy
	8-Jan-13	91.84	71	Pygmy
	13-Mar-13	91.44	36	Pygmy
	16-May-13	90.99	10	Pygmy
	25-Jun-13	90.93	3	Pygmy
CRC	2-Dec-12	84.67	1859	ADCP
	3-Dec-12	81.25	364	ADCP
	16-Jan-13	79.24	52	Pygmy
	14-Feb-13	79.34	64	AA
	28-Mar-13	79.04	41	Pygmy
	5-Apr-13	79.61	89	Pygmy
	16-May-13	78.84	10	AA
	25-Jun-13	78.26	5	Pygmy
ACK	25-Sep-12	79.38	4	Pygmy
	3-Dec-12	81.53	149	ADCP
	4-Jan-13	79.71	16	Pygmy
	25-Jan-13	79.81	20	Pygmy
	25-Jun-13	79.43	6	Pygmy

Site ID	Date	Stage (ft)	Discharge (cfs)	Method
NEW	19-Dec-12	82.75	12	Pygmy
	25-Jan-13	82.83	15	Pygmy
	14-Feb-13	82.54	4	Pygmy
	5-Apr-13	82.93	24	Pygmy
	16-May-13	82.45	2	Pygmy
BTS	2-Dec-12	101.49	698	ADCP
	4-Jan-13	95.83	11	Pygmy
	25-Jan-13	95.9	14	Pygmy
	26-Mar-13	95.45	3	Pygmy
LAC	27-Nov-12	95.25	5	Pygmy
	3-Dec-12	95.83	34	Pygmy
	8-Jan-13	95.33	8	Pygmy

Appendix G

Mean Daily Discharge and Stream Temperature at Monitoring Sites during WY2013

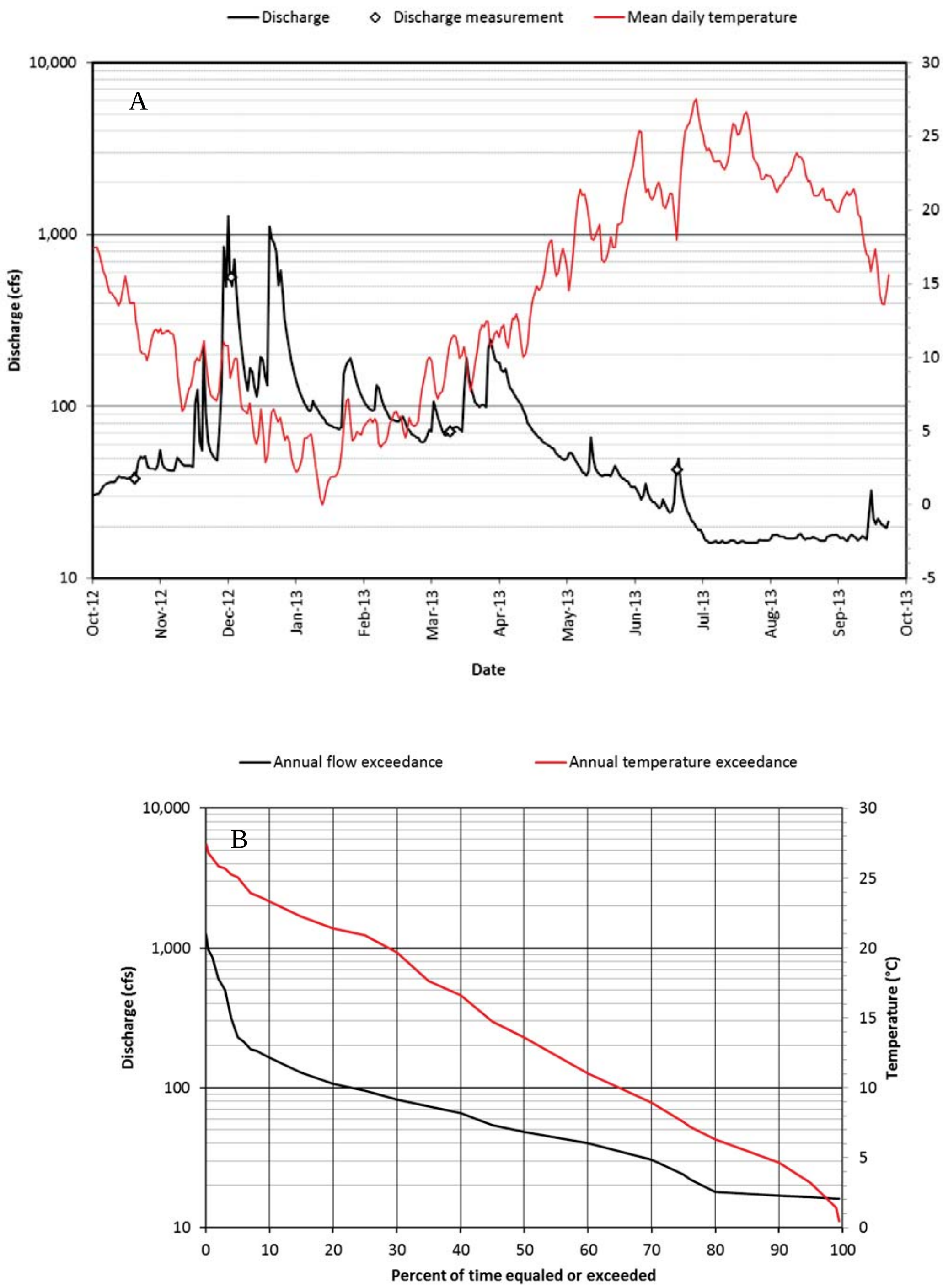


Figure G-1. Mean daily discharge and mean daily stream temperature (A) and flow and temperature exceedance (B) at UAC during WY2013.

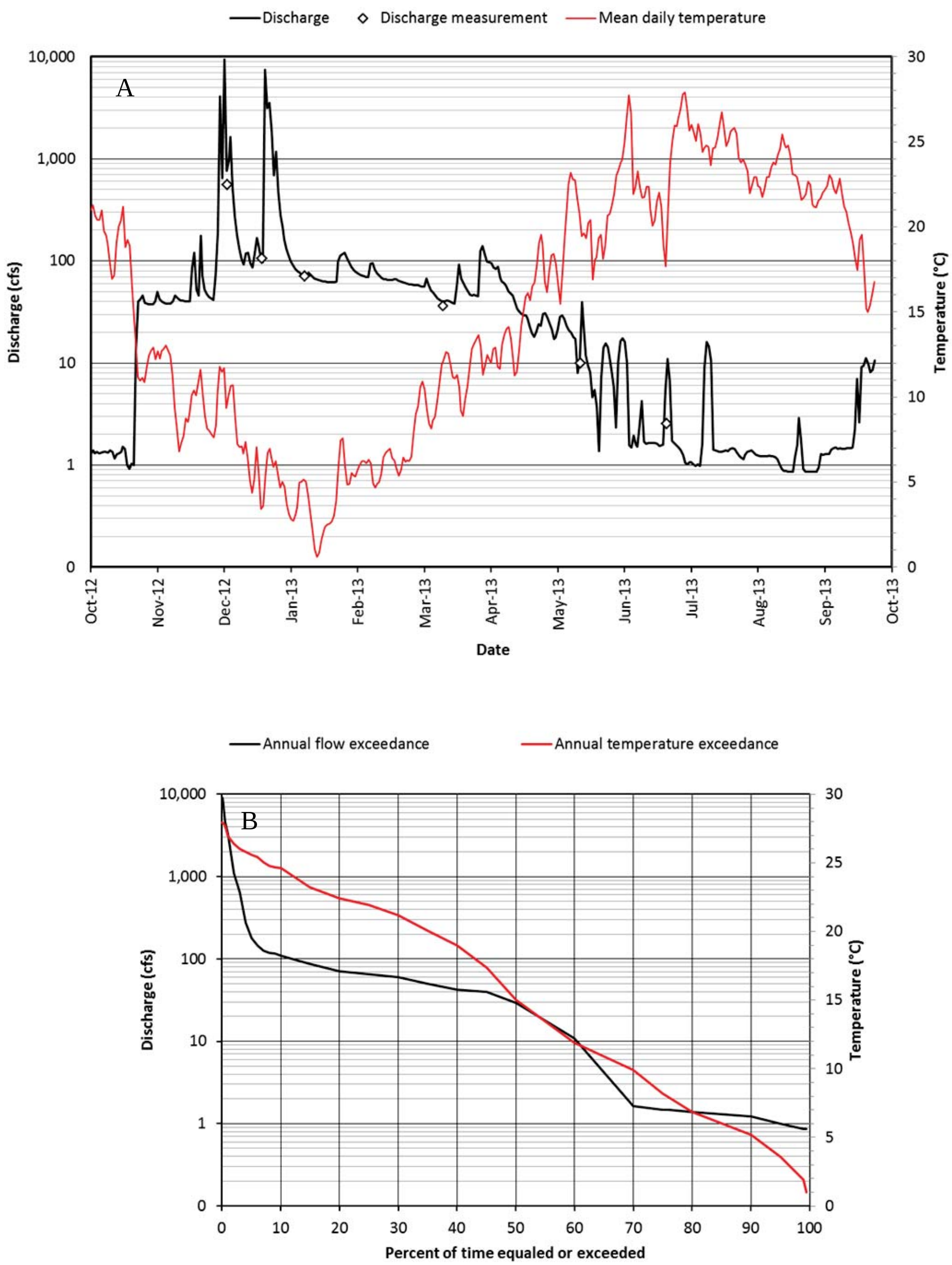


Figure G-2. Mean daily discharge and mean daily stream temperature (A) and flow and temperature exceedance (B) at ACG during WY2013.

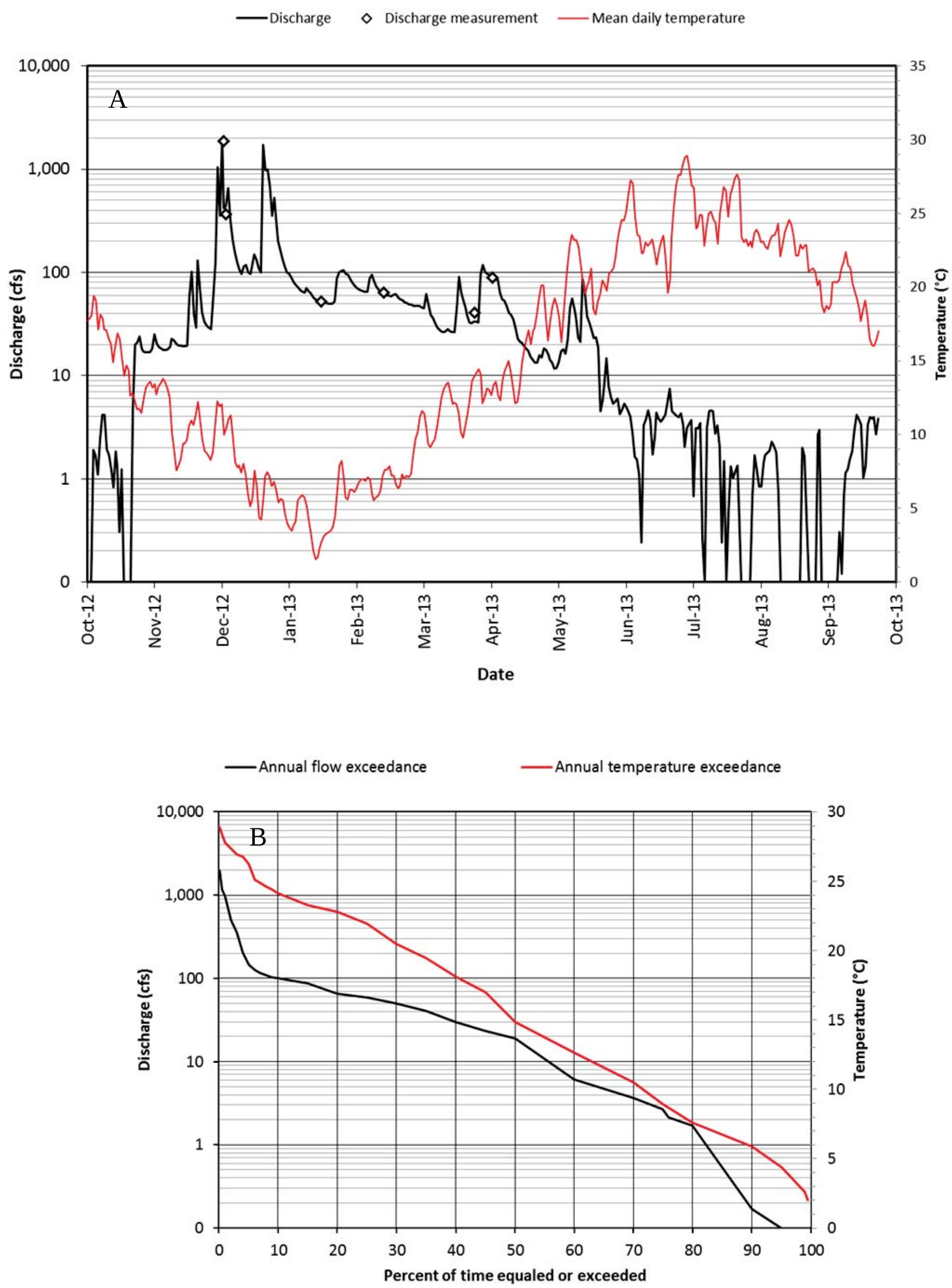
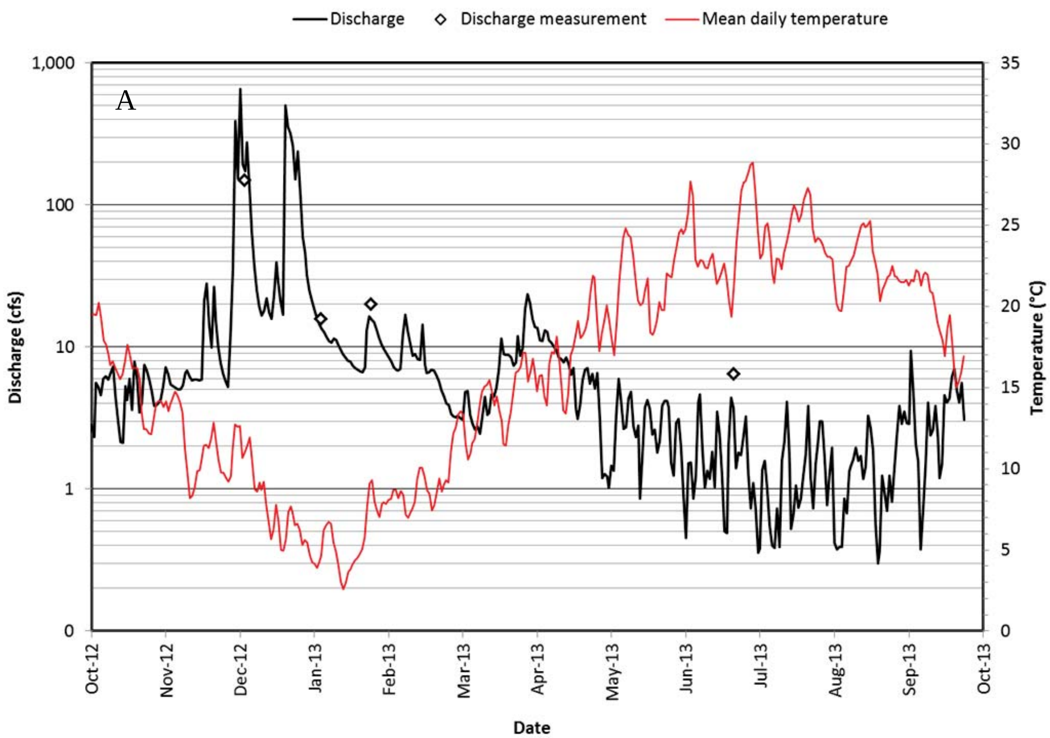


Figure G-3. Mean daily discharge and mean daily stream temperature (A) and flow and temperature exceedance (B) at CRC during WY2013.



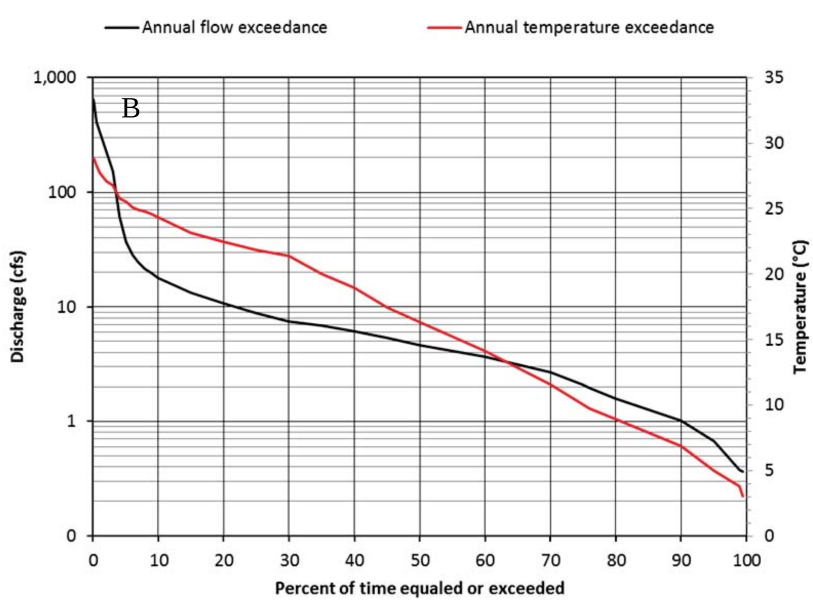


Figure G-4. Mean daily discharge and mean daily stream temperature (A) and flow and temperature exceedance (B) at ACK during WY2013.

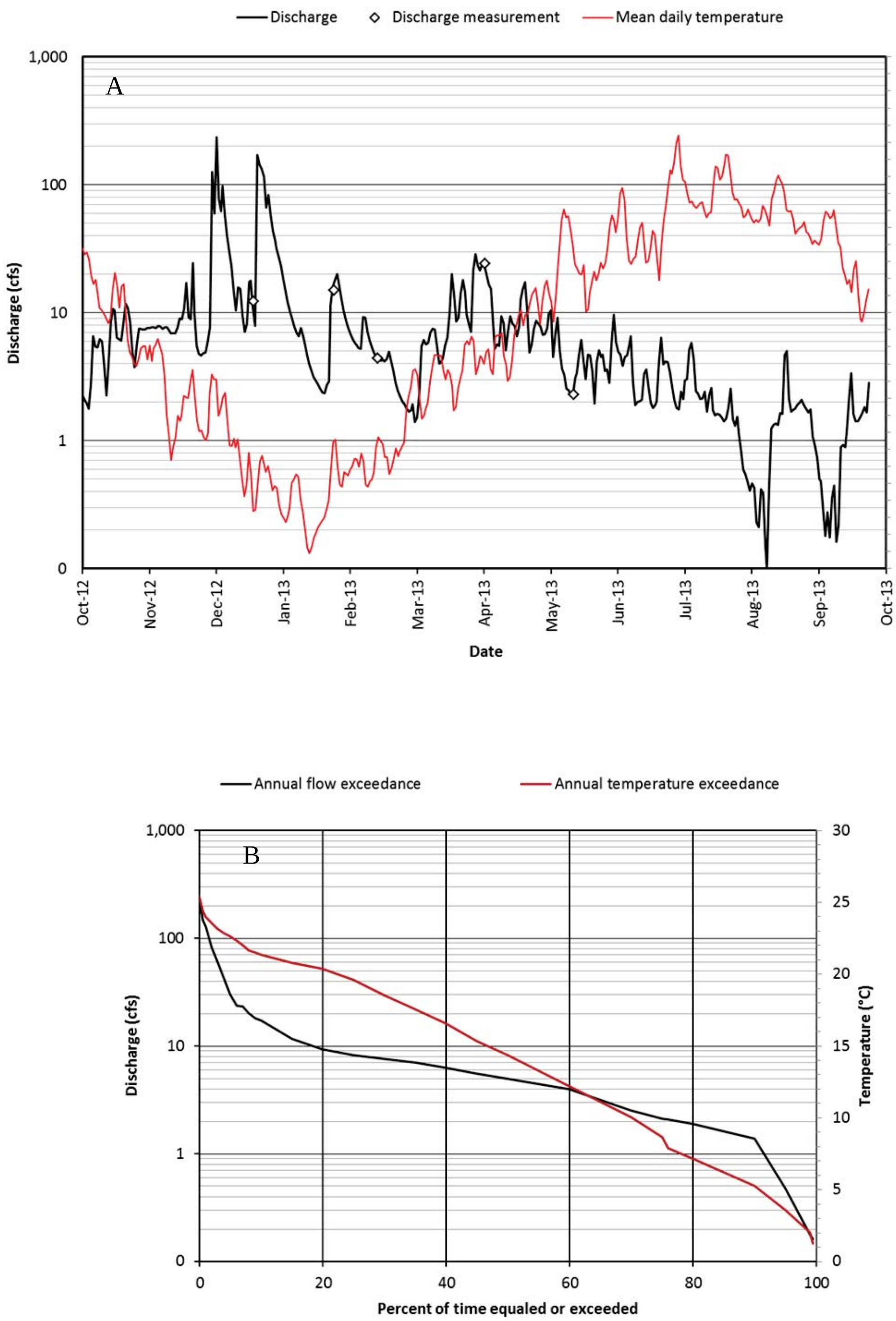
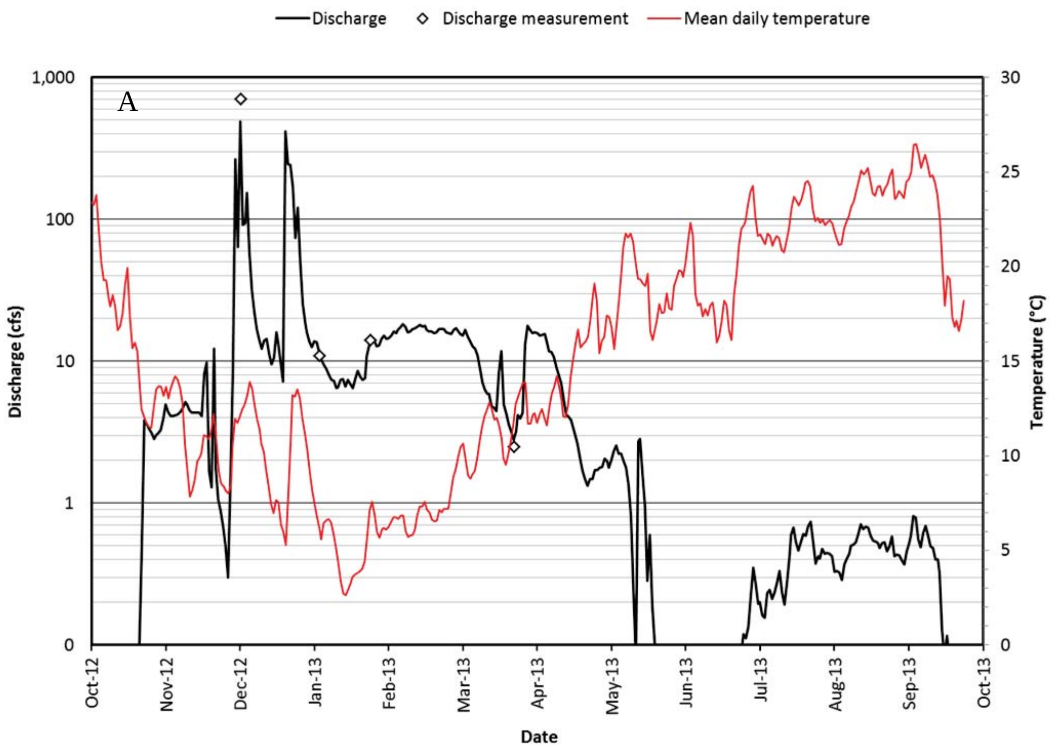


Figure G-5. Mean daily discharge and mean daily stream temperature (A) and flow and temperature exceedance (B) at NEW during WY2013.



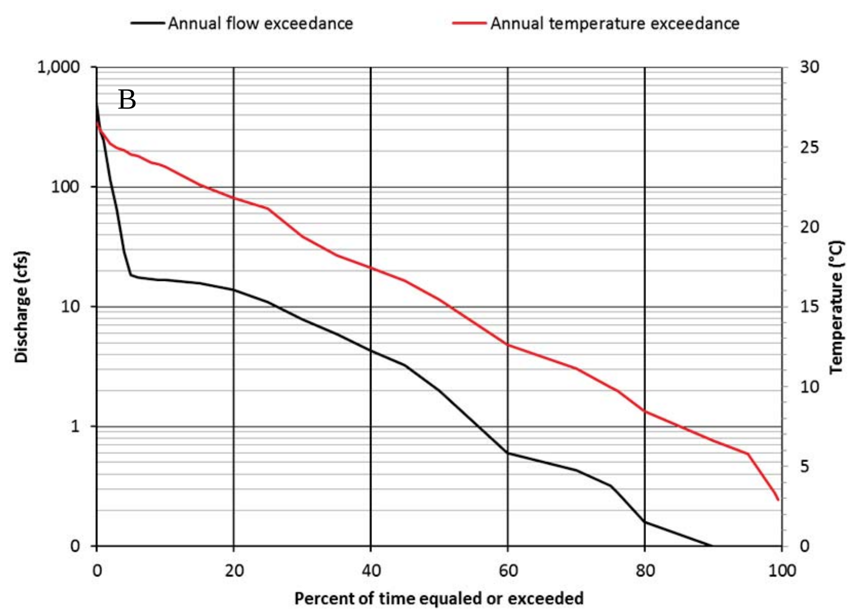


Figure G-6. Mean daily discharge and mean daily stream temperature (A) and flow and temperature exceedance (B) at BTS during WY2013.

Appendix H

Water Quality Monitoring Methods and Results

Table H-1. Pre- and post- sampling calibration results for the YSI 6920 and YSI 600XL *in situ* meters.

<table>
<tr><th rowspan="2">YSI</th><th rowspan="2">Parameter</th><th colspan="4">Pre-Calibration</th><th colspan="4">Post-Calibration</th></tr>
<tr><th>Std. Temp</th><th>Std. Value</th><th>Pre-Cal. Value</th><th>Post-Cal. Value</th><th>Std. Temp</th><th>Std. Value</th><th>Pre-Cal. Value</th><th>Post-Cal. Value</th></tr>
<tr><td colspan="6">6/4/2013</td><td colspan="4">-</td></tr>
<tr><td rowspan="4">6920</td><td>Cond. (uS/cm)</td><td>23.9</td><td>1,000</td><td>1,025</td><td>1,000</td><td colspan="4" rowspan="4">No calibration performed</td></tr>
<tr><td>DO (% Sat.)</td><td>23.9</td><td>100</td><td>99.6</td><td>100.1</td></tr>
<tr><td>pH 7</td><td>23.9</td><td>7.00</td><td>7.03</td><td>7.00</td></tr>
<tr><td>pH 10</td><td>23.9</td><td>10.00</td><td>10.01</td><td>10.01</td></tr>
<tr><td colspan="6">6/4/2013</td><td colspan="4">-</td></tr>
<tr><td rowspan="4">600XL</td><td>Cond. (uS/cm)</td><td colspan="4" rowspan="4">No calibration performed</td><td colspan="4" rowspan="4">No calibration performed</td></tr>
<tr><td>DO (% Sat.)</td></tr>
<tr><td>pH 7</td></tr>
<tr><td>pH 10</td></tr>
<tr><td colspan="6">9/17/2013</td><td colspan="4">-</td></tr>
<tr><td rowspan="4">6920</td><td>Cond. (uS/cm)</td><td>25.8</td><td>10,000</td><td>9,955</td><td>10,000</td><td colspan="4" rowspan="4">No calibration performed</td></tr>
<tr><td>DO (% Sat.)</td><td>27.1</td><td>100</td><td>98.5</td><td>99.3</td></tr>
<tr><td>pH 7</td><td>25.2</td><td>7.00</td><td>7.01</td><td>7.00</td></tr>
<tr><td>pH 10</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td colspan="6">9/18/2013</td><td colspan="4">9/19/2013</td></tr>
<tr><td rowspan="4">600XL</td><td>Cond. (uS/cm)</td><td>22.4</td><td>10.00</td><td>10.34</td><td>10.00</td><td>23.1</td><td>10,000</td><td>9,979</td><td>10,000</td></tr>
<tr><td>DO (% Sat.)</td><td>23.1</td><td>100</td><td>99.6</td><td>99.6</td><td>24.1</td><td>100</td><td>99.3</td><td>99.3</td></tr>
<tr><td>pH 7</td><td>22.5</td><td>7.00</td><td>6.86</td><td>7.00</td><td>22.8</td><td>7.00</td><td>7.01</td><td>7.00</td></tr>
<tr><td>pH 10</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
</table>

Table H-2. Water quality analytical methods and reporting limits.

Parameter/Constituent	Method	Units	MDL	MRL
***In situ* water quality**				
Stream temperature (YSI 6560 Sensor)	EPA 170.1	ºC	0.1	-
Specific Conductivity (YSI 6560 Sensor)	SM 2510-B	uS/cm	1.0	-
DO (YSI 6562 Rapid Pulse Sensor)	SM 4500-O(G)	mg/L	0.1	-
pH (YSI 6565 Sensor)	SM 4500-H	s.u.	0.1	-
Analytical water quality				
NH_3 as N	EPA 350.1	ug/L	30	50
Unionized NH_3 as N	EPA 350.1	ug/L	0.012–12.2	0.02–20.3
Total dissolved solids (TDS)	SM 2540C	mg/L	3	6
Total sulfide[1]	SM 4500S D	ug/L	10	20
Dissolved sulfide[2]	SM 4500S D	ug/L	10	20

MDL = method detection limit
MRL = method reporting limit
1 Total sulfide = dissolved H_2S + HS^- + acid volatile metallic sulfides present in particulate matter.
2 Dissolved sulfide = sulfide remaining after suspended solids have been removed by flocculation and settling.

Table H-3. Stream temperature and pH during morning, afternoon, and evening grab samples at all monitoring sites during June 2013[1].

Site ID	Temperature (°C)	pH (S.U.)	Temperature (°C)	pH (S.U.)
	06/05/13 Morning Sample (8–10 AM)		**06/06/13 Morning Sample (8–10 AM)**	
UAC	22.1	7.9	23.2	8.2
ACG	22.6	7.2	22.8	7.1
NEW	19.8	7.4	20.5	7.5
CRC	23.0	7.5	23.7	7.7
ACK	22.6	7.3	22.8	7.2
	06/05/13 Afternoon Sample (12–2 PM)		**06/06/13 Afternoon Sample (12–2 PM)**	
UAC	24.0	8.8	25.7	9.2
ACG	25.7	7.7	28.1	8.1
NEW	22.0	7.7	23.2	8.0
CRC	24.6	8.0	26.4	8.5
ACK	26.0	7.5	28.1	7.6
	06/05/13 Evening Sample (5–7 PM)		**06/06/13 Evening Sample (5–7 PM)**	
UAC	25.8	9.4	26.6	9.4
ACG	27.2	8.2	28.6	8.3
NEW	22.7	8.1	23.5	8.0
CRC	26.9	9.1	27.8	8.9
ACK	27.1	7.8	28.3	7.7
Min temperature (all data) =	19.8		Min pH (all data) =	7.1
Max temperature (all data) =	28.6		Max pH (all data) =	9.4

1 Dissolved oxygen and conductivity were not monitored as part of grab sampling during June 2013.

Table H-4. Stream temperature, pH, dissolved oxygen, and conductivity during morning, afternoon, and evening grab samples at all monitoring sites during September 2013.

Site ID	Temperature (°C)	pH (S.U.)	DO (mg/L)	DO (% sat)	Conductivity (uS/cm)	Temperature (°C)	pH (S.U.)	DO (mg/L)	DO (% sat)	Conductivity (uS/cm)
	9/18/13 Morning Samples (8–10 AM)					9/19/13 Morning Sample (8–10 AM)				
UAC	18.6	8.1	10.1	108	147	17.6	8.0	9.7	102	138
ACG	19.1	7.1	6.6	74	182	19.0	7.1	6.3	68	177
NEW	18.1	7.7	8.4	89	171	17.3	7.3	8.8	92	169
CRC	20.6	7.7	7.6	85	203	19.2	7.6	7.6	83	194
ACK	19.4	7.3	6.8	73	234	17.9	7.4	7.3	77	225
	9/18/13 Afternoon Sample (12–2 PM)					9/19/13 Afternoon Sample (12–2 PM)				
UAC	20.3	8.6	11.7	129	152	19.0	8.4	12.8	137.9	147
ACG	21.4	7.2	8.5	97	195	20.9	7.1	7.7	86.3	197
NEW	18.7	7.8	9.2	99	175	19.0	7.8	9.7	105.2	176
CRC	20.3	7.8	8.0	88	202	20.0	7.6	8.9	97.8	198
ACK	20.4	7.4	7.6	85	240	19.8	7.4	8.3	90.9	235
	9/18/13 Evening Sample (5–7 PM)					9/19/13 Evening Sample (5–7 PM)				
UAC	20.3	8.5	7.2	79	151	19.9	8.5	11.0	120.1	152
ACG	22.0	7.3	6.6	76	204	22.5	7.3	10.3	118.7	208
NEW	20.4	7.9	6.9	76	184	20.3	7.9	9.5	105.4	182
CRC	21.6	7.9	6.9	78	206	21.6	7.7	9.3	106.1	202
ACK	21.3	7.4	6.1	69	229	20.7	7.5	8.7	96.5	239
Min temperature (all data) =	17.3		Min DO (mg/L) (all data) =			6.1	Min Conductivity (all data) =			138
Max temperature (all data) =	22.5		Max DO (mg/L) (all data) =			12.8	Max Conductivity (all data) =			240
Min pH (all data) =	7.1		Min DO (% sat) (all data) =			68				
Max pH (all data) =	8.6		Max DO (% sat) (all data) =			138				

Table H-5. Total ammonia (NH_3 as N), unionized ammonia (NH_3 as N), TDS, total sulfide, and dissolved sulfide in morning, afternoon, and evening grab samples at all monitoring sites during June 2013.

Site ID	Total ammonia (NH_3 as N) (ug/L)	Unionized ammonia (NH_3 as N) (ug/L)	TDS (mg/L)	Total sulfide (ug/L)	Dissolved sulfide (ug/L)	Total ammonia (NH_3 as N) (ug/L)	Unionized ammonia (NH_3 as N) (ug/L)	TDS (mg/L)	Total sulfide (ug/L)	Dissolved sulfide (ug/L)
	06/05/13 Morning Sample (8–10 AM)					**06/06/13 Morning Sample (8–10 AM)**				
UAC	40[a]	1.62[a]	97	< 10	< 10	40[a]	2.97[a]	80	15[a]	< 10
ACG	70	0.632	122	< 10	< 10	60	0.432	125	10[a]	< 10
NEW	60	0.691	118	< 10	< 10	50	0.619	121	< 10	< 10
CRC	60	1.10	120	< 10	< 10	60	1.43	99	< 10	< 10
ACK	120	1.22	151	23	16[a]	170	1.38	145	25	13[a]
ACK-DUP	150	1.53	146	27	19[a]	-	-	-	-	-
	06/05/13 Afternoon Sample (12–2 PM)					**06/06/13 Afternoon Sample (1–3 PM)**				
UAC	40[a]	9.37[a]	95	< 10	< 10	< 30	< 11.6	100	< 10	< 10
ACG	80	9.55	119	< 10	< 10	70	6.61	112	< 10	< 10
NEW	50	1.17	119	< 10	< 10	60	3.26	121	< 10	< 10
CRC	80	4.97	118	< 10	< 10	90	15.1	119	14[a]	< 10
ACK	130	2.30	146	19[a]	13[a]	180	5.13	152	23	14
	06/05/13 Evening Sample (5–7 PM)					**06/06/13 Evening Sample (5–7 PM)**				
UAC	60	23.2	99	15[a]	< 10	50	18.8	104	16[a]	< 10
ACG	60	5.25	110	< 10	< 10	110	12.6	91	< 10	< 10
NEW	80	5.39	116	< 10	< 10	50	2.33	125	15[a]	< 10
CRC	40[a]	16.2[a]	118	< 10	< 10	50	18.4	124	< 10	< 10
ACK	140	5.81	147	40	16[a]	190	6.06	156	17[a]	10
Blank	-	-	-	-	-	< 30	< 0.01	< 3	< 10	< 10
Min total ammonia (all data) =			< 30	Min TDS (all data) =		< 3	Min total sulfide (all data) =			< 10
Max total ammonia (all data) =			190	Max TDS (all data) =		156	Max total sulfide (all data) =			40
Min unionized ammonia(all data) =			< 0.01				Min dissolved sulfide (all data) =			< 10
Max unionized ammonia (all data) =			23.2				Max dissolved sulfide (all data) =			19

[a] Result between the method detection limit (MDL) and the method reporting limit (MRL).

Table H-6. Total ammonia (NH_3 as N), unionized ammonia (NH_3 as N), TDS, total sulfide, and dissolved sulfide during morning, afternoon, and evening grab samples at all monitoring sites during September 2013.

Site ID	Total ammonia (NH_3 as N) (ug/L)	Unionized ammonia (NH_3 as N) (ug/L)	TDS (mg/L)	Total sulfide (ug/L)	Dissolved sulfide (ug/L)	Total ammonia (NH_3 as N) (ug/L)	Unionized ammonia (NH_3 as N) (ug/L)	TDS (mg/L)	Total sulfide (ug/L)	Dissolved sulfide (ug/L)
	9/18/13 Morning Sample (8–10 AM)					**9/19/13 Morning Sample (8–10 AM)**				
UAC	40[a]	2.0[a]	126	< 10	< 10	< 30	< 0.9	122	< 10	< 10
ACG	50	0.2	163	< 10	< 10	220	1.1	161	24	< 10
NEW	50	0.8	144	< 10	< 10	40[a]	0.8[a]	147	< 10	< 10
CRC	40[a]	0.9[a]	159	< 10	< 10	70	1.1	158	14[a]	< 10
ACK	100	0.8	196	20	12[J]	70	0.6	204	< 10	< 10
	9/18/13 Afternoon Sample (12–2 PM)					**9/19/13 Afternoon Sample (12–2 PM)**				
UAC	< 30	< 4.3	120	< 10	< 10	< 30	< 2.6	124	17[a]	< 10
ACG	< 30	< 0.2	161	12[a]	11[a]	380	3.7	188	12[a]	< 10
NEW	50	1.3	151	< 10	< 10	50	1.2	151	12[a]	< 10
CRC	60	1.4	162	< 10	< 10	40[a]	0.7[a]	160	< 10	< 10
ACK	100	0.9	204	20	< 10	70	0.7	204	< 10	< 10
	9/18/13 Evening Sample (5–7 PM)					**9/19/13 Evening Sample (5–7 PM)**				
UAC	30[a]	3.5[a]	123	< 10	< 10	< 30	< 3.9	118	14[a]	< 10
ACG	50	0.5	162	12[a]	< 10	500	8.7	213	38	11[a]
NEW	< 30	< 0.9	145	11[a]	11[a]	40[a]	1.2[a]	142	< 10	< 10
CRC	< 30	< 1.1	159	12[a]	< 10	50	1.3	170	< 10	< 10
CRC-DUP	30	1.1[a]	158	< 10	< 10	-	-	-	-	-
ACK	70	0.8	205	33	31	90	1.1	197	29	< 10
Blank	-	-	-	-	-	< 30	< 2.3	9	14[a]	< 10
Min total ammonia (all data) =			< 30	Min TDS (all data) =	120			Min total sulfide (all data) =		< 10
Max total ammonia (all data) =			500	Max TDS (all data) =	213			Max total sulfide (all data) =		38
Min unionized ammonia (all data) =			< 0.2					Min dissolved sulfide (all data) =		< 10
Max unionized ammonia (all data) =			8.7					Max dissolved sulfide (all data) =		31

[a] Result between the method detection limit (MDL) and the method reporting limit (MRL).

Table H-7. Calculated stream temperature and pH-dependent CMC and CCC values for total ammonia (NH_3-N) nitrogen for grab samples collected during June and September 2013.

Site ID	Total NH_3 as N (ug/L)[a]				CMC Total NH_3 as N (ug/L) where salmonids are present (USEPA 2013)				CCC Total NH_3 as N (ug/L) where fish early life stages are present (USEPA 2013)			
	6/5/13	6/6/13	9/18/13	9/19/13	6/5/13	6/6/13	9/18/13	9/19/13	6/5/13	6/6/13	9/18/13	9/19/13
	Morning Sample (8-10 AM)				**Morning Sample (8-10 AM)**				**Morning Sample (8-10 AM)**			
UAC	40[b]	40[b]	40[b]	< 30	3,662	1,962	3,352	5,157	737	451	689	963
ACG	70	60	50	220	10,549	11,783	16,933	16,979	1,422	1,494	1,944	1,954
NEW	60	50	50	40[b]	10,253	9,521	8,395	15,675	1,484	1,406	1,349	1,961
CRC	60	60	40[b]	70	6,866	5,269	6,495	8,424	1,116	939	1,112	1,333
ACK	120	170	100	70	9,912	10,648	12,762	13,193	1,377	1,423	1,682	1,766
ACK-DUP	150	-	-	-	9,912	10,648	-	-	-	-	-	-
	Afternoon Sample (1-3 PM)				**Afternoon Sample (1-3 PM)**				**Afternoon Sample (1-3 PM)**			
UAC	40[b]	< 30	< 30	< 30	671	273	1,251	2,006	177	78	299	448
ACG	80	70	< 30	380	4,174	1,558	12,766	14,598	790	380	1,606	1,732
NEW	50	60	50	50	5,886	2,825	5,956	6,228	1,028	604	1,065	1,096
CRC	80	90	60	40[b]	2,480	891	6,008	7,522	546	234	1,059	1,230
ACK	130	180	100	70	5,867	3,910	11,022	11,451	970	738	1,526	1,577
	Evening Sample (5-7 PM)				**Evening Sample (5-7 PM)**				**Evening Sample (5-7 PM)**			
UAC	60	50	30[b]	< 30	233	216	1,420	1,420	68	64	335	333
ACG	60	110	50	500	1,584	1,095	10,713	9,515	384	284	1,453	1,352
NEW	80	50	< 30	40[b]	2,384	3,147	4,982	4,937	528	656	929	924
CRC	40[b]	50	< 30	50	304	391	3,971	5,584	88	112	784	997
CRC-DUP	-	-	30	-	-	-	3,971	-	-	-	784	-
ACK	140	190	70	90	3,177	3,592	9,322	9,238	650	697	1,370	1,377

[a] See also Table 7 and Table 8.
[b] Result between the method detection limit (MDL) and the method reporting limit (MRL).

Appendix I

Description of Work to be Completed with Fisheries Restoration Grant Program Funds

Table I-1 Summary of project features to be implemented with FRGP grant funds and the associated benefits to anadromous salmonids.

Site description	Description of improvement	Benefits			Ways benefits achieved				Benefits to salmonids during drought conditions
		Improved habitat	Unimpeded passage	Minimized entrainment and injury	Diversion management	Fish Ladder management	Fish exclusion infrastructure management	Instream flow management	
East Diversion (LMMWC Headgate)	Changes and modifications to canal head gate structures to better manage diversion flows, changes to the existing fish ladder to improve operational and hydraulic control and eliminate gate leakage. These changes will better convey flow releases to downstream reaches of Antelope Creek's mainstem.	*	*		*	*		*	New gate will improve control of diversion rates enabling more precise instream flow management during pulse flows and fish ladder flow requirements. Existing gate leakage will be eliminated. Better control and minimization of diversion is especially beneficial at low creek flows, such as during the ongoing drought.
Combined LMMWC-Edwards Fish Screen	Replace existing screen and install new NMFS- and CDFW-approved, screen structure with automatic cleaning assembly.		*	*			*		New screen will be designed to operate better at low flows than existing screen.
LMMWC-Edwards Combined Fish Screen Bypass Piping	Construct bypass from downstream end of new screen to Antelope Creek downstream of diversion dam. System designed to NMFS and CDFW criteria.		*	*			*		Eliminates existing entrapment problem. Bypass will be designed to safely convey juveniles to creek over a range of very low (drought conditions) to high creek flows and diversion rates.

Site description	Description of improvement	Benefits			Ways benefits achieved				Benefits to salmonids during drought conditions
		Improved habitat	Unimpeded passage	Minimized entrainment and injury	Diversion management	Fish Ladder management	Fish exclusion infrastructure management	Instream flow management	
Edwards Ditch Supply Siphon	Construct siphon from LMMWC Ditch to Edwards Ditch downstream of new screen, with control gate and flow measurement.	*	*	*	*			*	Siphon connection will allow existing West Diversion gates to remain closed (except when the New Creek bypass is operating and extra capacity needed), eliminating one of the two existing points of entrainment.
Edwards Ditch Fish Screen Bypass Piping	Construct bypass from downstream end of new screen to New Creek downstream of diversion dam. System designed to NMFS and CDFW criteria.		*	*			*		Eliminates existing entrapment problem. Bypass will be designed to safely convey juveniles to New Creek under conditions when the West Diversion is allowed to operate (high flows).
Edwards Ditch Parshall Flume	Add communication equipment to existing flume to provide remote monitoring of diverted flow rate in order better manage division rates and assure diverters adherence to allocated water rights.	*			*	*		*	Accurate diversion measurement and real-time access to data will enable more precise and timely control of diversion gates and minimization of diversion quantity. This is especially beneficial at low flow conditions during droughts.
West Diversion (Edwards Headgate)	Implement improvements to existing headgate in order to improve operational and hydraulic control and eliminate gate leakage.	*			*	*		*	Improvements will be made to headgate infrastructure to better control water diversion rates thus enabling more precise in stream flow management when the New Creek bypass is operating and extra capacity needed.

Site description	Description of improvement	Benefits			Ways benefits achieved				Benefits to salmonids during drought conditions
		Improved habitat	Unimpeded passage	Minimized entrainment and injury	Diversion management	Fish Ladder management	Fish exclusion infrastructure management	Instream flow management	
Antelope Creek Flow Measurement	Install measurement sites at the Edwards Diversion Dam structure to accurately measure flows at various stages. As described under the projects monitoring program above.	*	*		*	*		*	Together with improved diversion measurement, adding creek flow measurement will enhance precision and timeliness of flow adjustments. Especially valuable at low flow conditions.

KEY: Check mark (☐) indicates benefits during drought (low flow) conditions. Asterisk (*) indicates benefits during non-drought (moderate to high flow) conditions.

4.1.3 Flow splits at the Antelope Creek-Craig Creek distributary junction

Understanding the flow split at the Antelope Creek–Craig Creek distributary junction over a range of discharges is critical to evaluating instream flow requirements for fish passage in lower Antelope Creek and determining instream flow releases that may be needed at Edwards Diversion Dam to continuously meet those requirements downstream to the Sacramento River. A two-dimensional hydraulic model (River2D) was developed to simulate flow splits over a range of mainstem Antelope Creek flows (USFWS 2014). Topographic data were collected in the vicinity of the distributary junction using a survey-grade RTK GPS and robotic total station. Topographic data were processed using the R2D_Bed software, where breaklines were added to produce smooth bed topography. The resulting data set was converted to a computational mesh using the R2D_Mesh software. Bed roughness used in the model was based on observed substrate sizes and cover types. The hydraulic model had two inflow boundaries (mainstem Antelope Creek and Little Antelope Creek) and three outflow boundaries (Craig Creek, the Antelope Creek distributary, and the overflow channel). Flows and water surface elevations were measured for all five boundaries at three different flows in 2012 (Table 4-5). The flow split was simulated for mainstem Antelope Creek inflows ranging from 10 to 150 cfs, the typical range of baseflows during adult and juvenile spring-run Chinook salmon migration and juvenile steelhead emigration (April through June). Little Antelope Creek inflows were estimated by linear interpolation of measured flows (Table 4-5).

Table 4-5. Streamflows measured in Antelope Creek and Little Antelope Creek during development of the hydraulic model at the Antelope Creek-Craig Creek distributary junction.

Date	Measured Streamflow, cfs	
	Antelope Creek	Little Antelope Creek
16 and 17 April 2012	148	23
14 May 2012	56	0
10 July 2012	1.3	0
December 3, 2012	553	34
January 8, 2013	71	7.5

Modeling results indicate that mainstem Antelope Creek inflows up to approximately 60 cfs route past the distributary junction and down Craig Creek, with little flow moving out-of-bank into distributaries (Figure 4-9). Above mainstem inflows of 60 cfs, appreciable flow begins to move out-out-of-bank and into distributaries. During WY 2013, streamflow at ACG (located just upstream of the Antelope Creek–Craig Creek distributary junction) equaled or exceeded 60 cfs for 11 days (12 percent of the time) during the adult spring-run Chinook salmon migration period from April through June. The flow split at this location will change over time due to the influence of bed scour, coarse sediment deposition, and riparian vegetation on channel morphology and hydraulics in the vicinity of the distributary junction. Hydraulic modeling results support the conclusion drawn from historical information, field surveys, and streamflow and temperature monitoring that Craig Creek conveys the majority of mainstem baseflow and is the most likely adult spring-run Chinook salmon migration path.

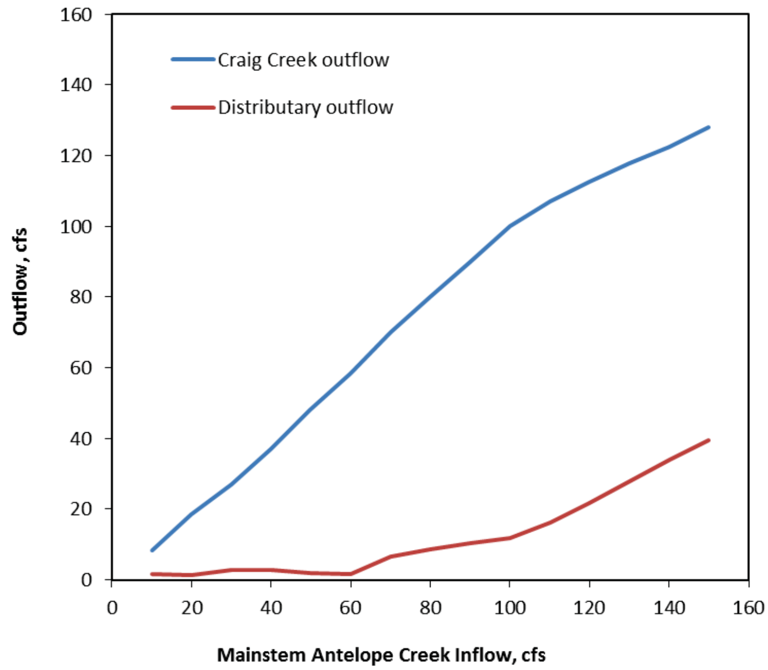


Figure 4-9. Hydraulic modeling results of flow splits at the Antelope Creek-Craig Creek distributary junction.

4.1.4 Streamflow and stream temperature influences on salmon and steelhead

Flow and temperature records during fish migration are critical pieces of information that can be used in combination with observations of fish movement to determine the timing and duration over which spring-run Chinook salmon and steelhead were capable of migrating through lower Antelope Creek. Adult salmon and steelhead typically require a day or less to travel the approximately 4.6 miles from the Sacramento River to Edward Diversion Dam, and typically do not hold in lower Antelope Creek for extended periods if conditions are suitable for passage. An observation of an adult fish moving past Edward Diversion Dam therefore indicates that conditions were generally suitable for passage in lower mainstem Antelope Creek during the previous 24 to 48 hours. This does not necessarily mean, however, that passage conditions were simultaneously met in all reaches of lower mainstem Antelope Creek during that time period.

The following sections analyze the time period that adult fish were likely capable of migrating through lower Antelope Creek during WY 2013 based on preliminary minimum instream flow criteria and generally accepted temperature criteria. The analysis focuses on WY 2013, which is the first and only complete water year that streamflow and water temperature were continuously monitored in the mainstem and distributary channels of lower Antelope Creek upstream and downstream of the diversion dam. Flow exceedance and temperature exceedance during spring-run Chinook salmon migration and juvenile steelhead emigration (April–June) in WY 2013 is shown in Figure 4-10 and Figure 4-11, respectively. CDFW did not operate video monitoring equipment to document steelhead and spring-run Chinook salmon movement past Edwards Diversion Dam during WY2013.

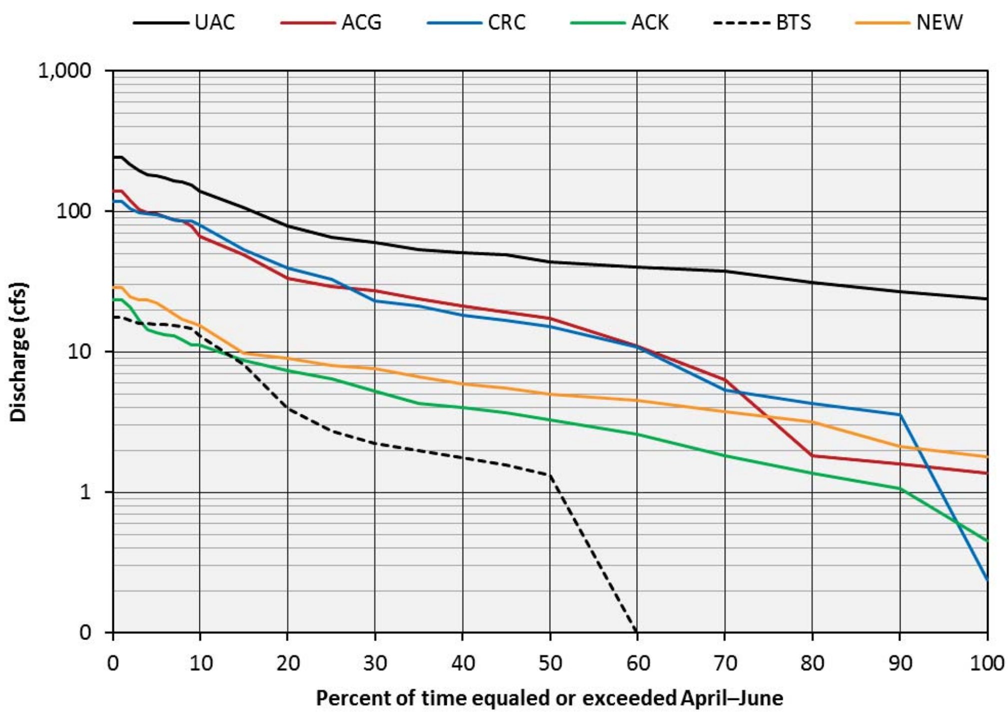


Figure 4-10. Flow exceedance during spring Chinook salmon migration and juvenile steelhead emigration (April—June, 2013)

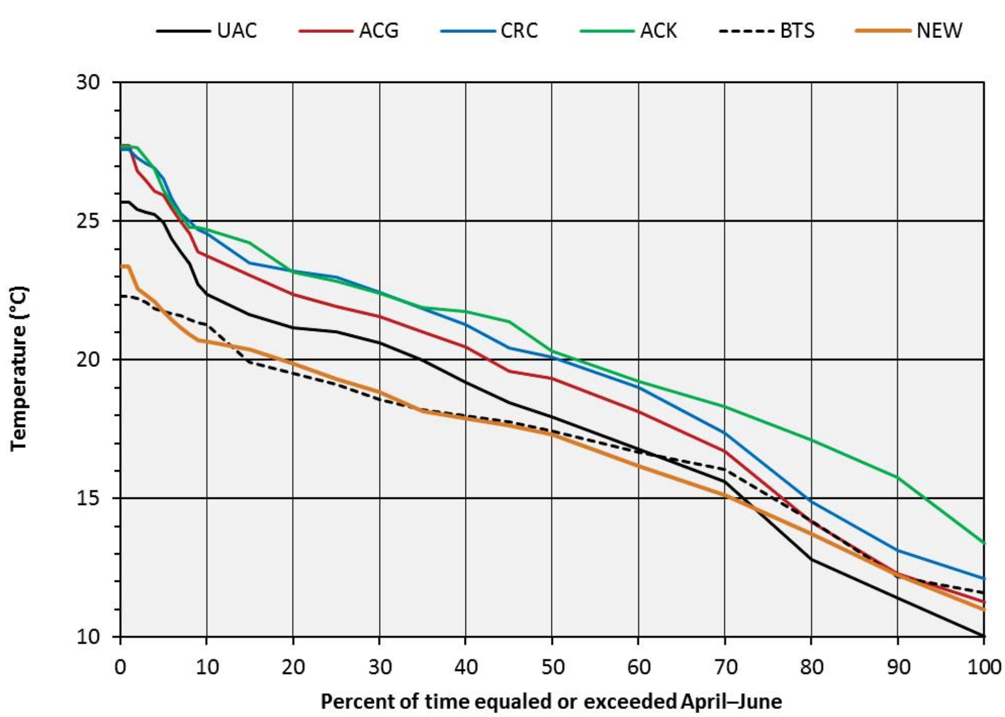


Figure 4-11. Temperature exceedance during spring-run Chinook salmon migration and juvenile steelhead emigration (April—June 2013)

During WY 2014, CDFW continued operating several priority flow and temperature monitoring stations (UAC,ACG, and CRC), documented fish movement at Edwards Diversion dam with video monitoring equipment, and surveyed fish passage conditions in the mainstem channel. 2014 was the first year in which streamflow, temperature, and fish movement were simultaneously observed on lower Antelope Creek, and although complete records for 2014 were not available at the time this report was completed, relevant information from 2014 was incorporated into the analysis, where possible.

4.1.4.1 Instream flow criteria for fish passage

Anticipating low flow conditions resulting from a Critically Dry Water Year during a prolonged drought, State and Federal resource agencies in spring 2014 specified emergency baseflow and pulse flow recommendations for Chinook salmon and steelhead passage in lower Antelope Creek in Resolution No. 2014-0023 and in voluntary agreements with diverters (Table 4-6). In developing drought emergency flow recommendations, State and Federal resource agencies drew upon information presented in this report, other data and literature associated with instream flows and fish biology, and the professional experience of CDFW and USFWS field staff. Drought emergency baseflow criteria for lower Antelope Creek were developed based on the best available information at the time, but with little information correlating fish movement to streamflow, site-specific hydraulics, temperature, and other factors influencing fish passage.

Table 4-6. Drought emergency minimum instream flow criteria for Antelope Creek specified in State Water Resources Control Board Resolution No. 2014-0023.

Time period	Conditions	Baseflow[a] (cfs)	Pulse flow[b]		
			Magnitude[a] (cfs)	Duration[c] (hrs)	Conditions
April 1 up to June 30	Adult spring-run Chinook present	35	70	min 24 max 72	(1) average daily full natural flow upstream of diversion dam ≤70 cfs for 3 consecutive days; or (2) SWRCB approves request by CDFW or NMFS for pulse flow.
June 1 up to June 30	Juv. spring-run Chinook or juv. steelhead present	35	70	min 24 max 72	(1) CDFW or NMFS observes juv. spring-run Chinook or steelhead in lower Antelope Creek in June; and (2) SWRCB approves request by CDFW or NMFS for pulse flow.
October–March 31	Adult steelhead present	35	na	na	na
November 1–June 30	Juv. spring-run Chinook or juv. steelhead present, Adult spring-run Chinook or adult steelhead not present	20	na	na	na

[a] Specified flow or full flow without diversions, whichever is less.
[b] Pulse flows are in lieu of base flow requirements.
[c] Timing and duration based on fish observed and desired migration movements.

Video monitoring equipment installed at Edwards Diversion Dam on 15 October 2013 and operated through 30 June 2014 documented seven spring-run Chinook salmon moving past the dam between March 10 and April 26 (Figure 4-11) (preliminary data, M. Johnson, CDFW, pers. comm., 2014). Immigration was triggered by several high flow events that occurred between February 25 and March 7. The first adult spring-run Chinook passed Edwards Diversion Dam on March 11 (416 cfs at ACG), the day after the annual peak flow. The second was counted on March 24 (12 cfs at ACG) when flow was rapidly receding. The remaining five fish migrated past Edwards Diversion Dam between April 2 and April 26 during the receding limb of the last high flow event of the year. These fish moved on flows ranging from 32 to 194 cfs and temperatures ranging from 10 to 17°C at ACG. After April 29, flows remained less than 30 cfs and temperatures remained 18°C or greater at ACG.

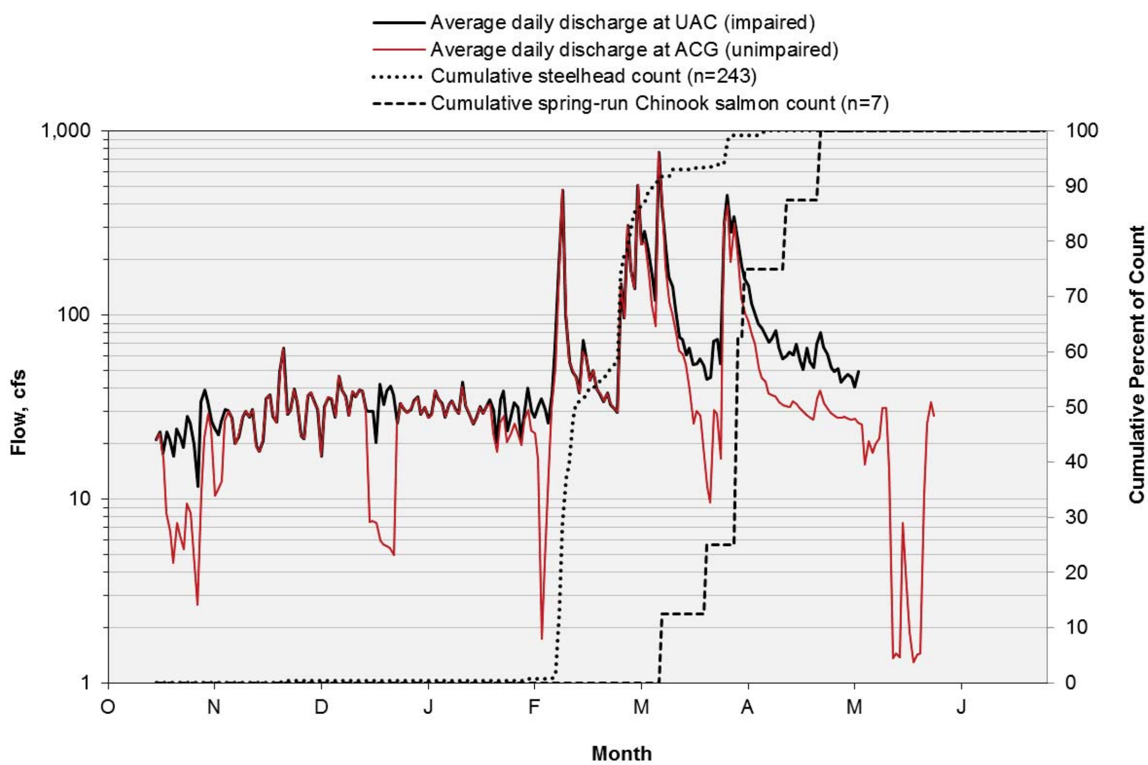


Figure 4-12. Streamflow at UAC (unimpaired) and ACG (impaired) shown with spring-run Chinook salmon and steelhead run counts in Antelope Creek during WY2014.

A pulse flow of 31 cfs was released at Edwards Diversion Dam on May 15 and 16, 2014 without completely shutting down diversions. No fish were observed passing Edwards Dam during the pulse flow. Edwards Ranch and LMMWD stopped diverting on October 24, after which most of the unimpaired flow remained in-channel downstream of the diversion. On November 7, CDFW field staff documented unimpeded fish passage conditions in mainstem Antelope Creek and Craig Creek from Edwards Diversion Dam to its confluence with the Sacramento River, when flow at Cone Grove Park was approximately 30 to 35 cfs. Twenty-eight fall-run Chinook salmon redds were observed during the survey, most of which were located in Craig Creek (M. Johnson, CDFW, pers. comm., 2014).

Potential instream flow criteria evaluated in Table 4-7 are based on drought emergency flow recommendations developed by State and Federal resource agencies as part of the 2014 Voluntary Drought Agreement for lower Antelope Creek, field observations of fish passage conditions between 2009 and 2014, measurements taken at flow monitoring sites during WY 2010 and WY 2103, and hydraulic modeling in the vicinity of the Antelope Creek-Craig Creek distributary junction. Flows in the mainstem channel downstream of the diversion during WY2013 met the 35 cfs criteria during about half the days in April (16 days at ACG and 15 days at CRC) but few days thereafter. Mainstem flows downstream of the diversion met the 20 cfs criteria during much of April (28 days at ACG and 19 days at CRC) and nearly half the days in May (11 days at ACG and 14 days at CRC) but none thereafter. Flows equal to or exceeding the pulse flow recommended by CDFW and USFWS for adult and juvenile spring-run Chinook salmon migration (70 cfs) occurred downstream of the diversion 8 days in April and 1 day in May. These conclusions do not consider the potential effects of stream temperature on fish migration.

Table 4-7. Number of days that mean daily discharge exceeded potential instream flow criteria for salmon and steelhead passage during WY2013.

Site	Flow threshold[a], cfs	Number of days ≥ flow threshold						
		April	May	June	July	August	September	1–15 October
UAC	70	21	0	0	0	0	0	0
	35	30	31	7	0	0	0	9
	20	30	31	30	4	0	9	15
ACG	70	8	0	0	0	0	0	0
	35	16	1	0	0	0	0	0
	20	28	11	0	0	0	0	0
CRC	70	8	1	0	0	0	0	0
	35	15	7	0	0	0	0	0
	20	19	14	0	0	0	0	0
ACK	35	0	0	0	0	0	0	0
	20	2	0	0	0	0	0	0
NEW	35	0	0	0	0	0	0	0
	20	5	0	0	0	0	0	0
BTS	35	0	0	0	0	0	0	0
	20	0	0	0	0	0	0	0

[a] Potential flow criteria are based on instream flow recommendations developed by CDFW and USFWS as part of the 2014 Voluntary Drought Agreement, field observations of fish passage conditions during fall 2009 and spring 2010, measurements taken at flow monitoring sites during WY 2013, and hydraulic modeling in the vicinity of the Antelope Creek-Craig Creek distributary junction. Flow criteria will be refined based on results of a future instream flow study.

4.1.4.2 Temperature criteria for fish passage

A commonly accepted temperature standard to protect against long-term chronic (i.e., sublethal) effects is the maximum 7-day running average of the daily mean temperatures (MWAT) (Brungs and Jones 1977, Armour 1991, NMFS and USFWS 1997, Sullivan et al. 2000). Use of MWAT assumes fish can tolerate moderate temperature fluctuations as long as potential lethal temperatures do not occur for prolonged periods (Sullivan et al. 2000) and that optimal temperatures are not necessary or realistic at all times to sustain viable fish populations (NAS and NAE 1973).

Three thermal zones define expected physiological responses of each species and life stage: optimal, suboptimal, and chronic to acute stress. At ***optimal temperatures***, feeding and growth occur without lethal or sublethal temperature effects. Exposure to ***suboptimal temperatures*** may diminished success (e.g., reduced fitness, viability, or growth) of a particular life stage but does not cause direct mortality. Temperatures in the ***Chronic to Acute Stress*** zone result in physiological and behavioral adjustments that are determined by the magnitude and duration of temperature exposure. Exposure to temperatures at the low end of this range typically leads to sublethal (i.e., chronic) effects such as reduced growth, reduced competitive ability, behavioral alterations, and increased susceptibility to disease (Sullivan et al. 2000). Exposure at higher temperatures can result in acute (i.e., lethal) effects. The upper limit of the **optimal** range serves as a threshold to avoid sublethal effects, while the upper limit of the **suboptimal** range serves as a threshold to avoid chronic or acute effects.

The California Regional Water Resources Control Board (RWQCB) provides a temperature objective of 13.3°C (56°F) to protect beneficial uses of the Sacramento River from Keswick Dam to Hamilton City. The RWQCB does not currently provide temperature objectives for lower Antelope Creek. The USEPA Region 10 criteria (EPA 2003) recommend that the 7-day moving average of the daily maximum temperatures should not exceed 16°C (61°F) for salmon and steelhead juvenile rearing and 18°C (64°F) for Chinook salmon emigration and non-core steelhead juvenile rearing. Harvey–Arrison (2009) found that during 2006–2008, 99% of the adult spring-run Chinook salmon migration into Mill Creek occurred by the time maximum temperatures reached 19.4°C, and from these results, inferred a thermal migration barrier between 18.3 and 19.4°C.

Based on review of available information, temperature criteria for spring-run Chinook salmon and steelhead and the period that criteria apply are summarized by life stage in Table 4-8. Comparison of the MWAT for the period of concern with respect to recommended temperature criteria for each species and life stage is a key metric for managing instream flows that maintain suitable conditions for adult and juvenile passage in lower Antelope Creek and for pulsing flows to transport fish during the latter part of the run.

Table 4-8. Recommended temperature criteria for spring-run Chinook salmon and steelhead migration in Antelope Creek.

Species and life stage	Primary time period	Temperature			Sources
		Optimal[1]	Suboptimal[2]	Chronic to acute stress[3]	
Spring-run Chinook salmon					
Adult immigration	Apr–Jun	<13.3°C (<56°F)	13.3–18.3°C (56–65°F)	>18.3°C (>65°F)	Bell (1986); Hallock et al. (1970), Bumgarner et al. (1997), both as cited in McCullough (1999).
Fry & juvenile rearing and emigration	May–June, mid Nov–Dec	<15.6°C (<60°F)	15.6–18.3°C (60–65°F)	>18.3°C (>65°F)	Rich (1987), NOAA (2002, as cited in DWR 2004), FERC (1993)

Species and life stage	Primary time period	Temperature			Sources
		Optimal[1]	Suboptimal[2]	Chronic to acute stress[3]	
Steelhead					
Adult immigration	Oct–Dec	<11.1°C (<52°F)	11.1–21°C (52–70°F)	>21°C (>70°F)	NMFS (2000), McEwan and Jackson (1996), Lantz (1971, as cited in Beschta et al. 1987)
Fry & juvenile rearing and emigration	May–July, Nov–Jan	<18.3°C (<65°F)	18.3–20°C (65–68°F)	>20°C (>68°F)	NMFS (2000), FERC (1993)

[1] Feeding and growth occur; growth dependent on food availability
[2] No direct mortality, but may result in a higher probability of diminished success, depending on magnitude of temperature and duration of exposure.
[3] Chronic exposure at the low end of the range results in sublethal effects, including reduced growth, reduced competitive ability, behavioral alterations, and increased susceptibility to disease. At higher temperatures in this zone, short-term exposure (minutes to days) results in death.

The number of days that MWAT was less than or equal to temperature criteria for spring-run Chinook salmon and steelhead migration from 1 April to 15 October WY2013 is shown in Table 4-9. Stream temperatures generally increase with distance downstream of the diversion, with the exception of New Creek, which had significantly cooler average daily temperatures than all other sites during June of 2011 and during April, May, and June of 2013 (Figure 4-13). Based on these data and relevant life-history timing for salmonids in lower Antelope Creek (Section 2.3), elevated stream temperatures during May–October 2013 had the potential for short-term and long-term effects on adult and juvenile spring-run Chinook and juvenile steelhead throughout lower mainstem Antelope Creek, Craig Creek, and the New Creek and Antelope Creek distributaries.

Table 4-9. Number of days that MWAT was less than or equal to temperature crieria for spring-run Chinook salmon and steelhead migration from 1 April to 15 October WY2013.

Site	Temperature threshold[a], °C	Number of days ≤ temperature threshold						
		April	May	June	July	Aug	Sept	1–15 Oct
UAC	13.3	19	0	0	0	0	0	0
	15.6	25	2	0	0	0	4	9
	18.3	30	19	1	0	0	12	15
	20	30	26	3	0	0	17	15
ACG	13.3	14	0	0	0	0	0	0
	15.6	20	1	0	0	0	3	0
	18.3	27	10	1	0	0	8	3
	20	30	19	2	0	0	12	7
CRC	13.3	11	0	0	0	0	0	0
	15.6	19	0	0	0	0	0	1
	18.3	27	6	0	0	0	7	13
	20	28	15	1	0	0	17	15
ACK	13.3	0	0	0	0	0	0	0
	15.6	8	0	0	0	0	2	1
	18.3	23	4	0	0	0	8	10
	20	27	13	1	0	2	13	14

Site	Temperature threshold[a], °C	Number of days ≤ temperature threshold						
		April	May	June	July	Aug	Sept	1–15 Oct
NEW	13.3	14	0	0	0	0	0	0
	15.6	27	4	0	0	0	3	6
	18.3	30	24	8	0	0	13	12
	20	30	27	17	0	3	23	15
BTS	13.3	14	0	0	0	0	0	0
	15.6	20	1	0	0	0	0	0
	18.3	28	18	15	0	0	7	5
	20	30	25	23	0	0	9	10

[a] Temperature criteria:
13.3°C, upper end of the optimal range for adult spring-run Chinook immigration;
15.6°C, upper end of the optimal range for fry and juvenile spring-run Chinook emigration;
18.3°C, upper end of the suboptimal range for spring-run Chinook migration, upper end of the optimal range for fry and juvenile steelhead emigration;
20°C, upper end of the suboptimal range for fry and juvenile steelhead emigration.

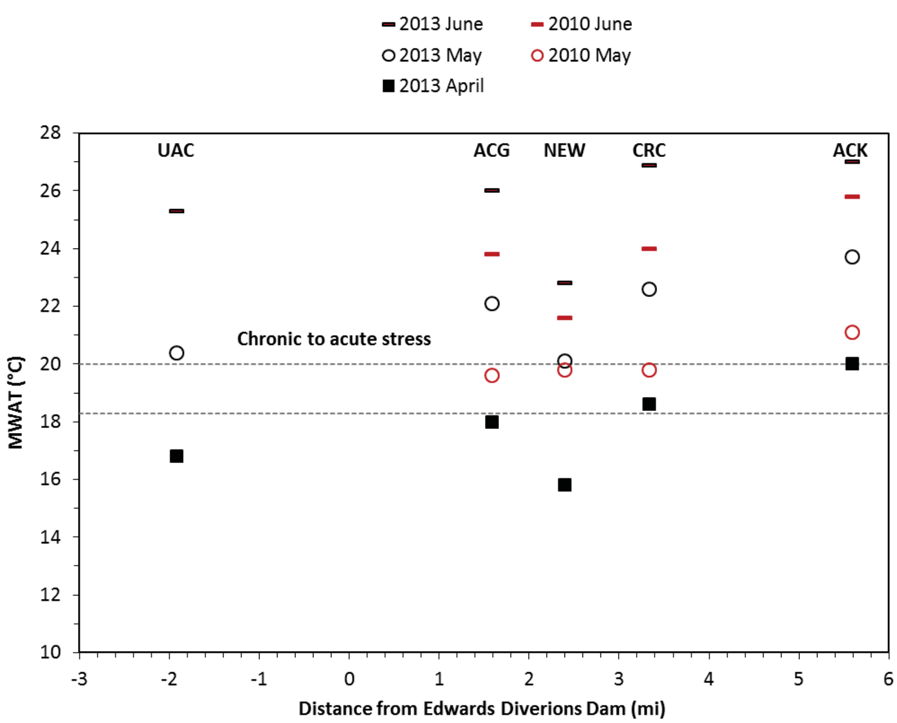


Figure 4-11. Monthly MWAT during spring-run Chinook salmon migration and juvenile steelhead emigration (April—June), WY2010 and WY2013. Monitoring during WY2010 began May 1 and was not conducted at UAC due to access constraints. Horizontal lines indicate upper suboptimal water temperature thresholds for adult, fry, and juvenile spring-run Chinook salmon (18.3°C) and fry and juvenile steelhead (20°C).

4.1.4.3 Combined flow and temperature criteria for fish passage

The following section evaluates the timing and duration of suitable fish passage conditions in lower Antelope Creek during WY2013 based on the combined occurrence of potential minimum baseflows for salmon and steelhead migration identified in Table 4-7 (20 cfs and 35 cfs) and temperature criteria based on the upper end of the suboptimal temperature range for adult, fry, and juvenile spring-run Chinook salmon (18.3°C) and fry and juvenile steelhead (20°C) identified in Table 4-9. Combined flow and temperature criteria for Chinook salmon and steelhead passage were met at UAC (unimpaired) during all of April 2013 (Table 4-10). The combined criteria were also met during May at UAC for 19 days at a criterion of 35 cfs and 26 days at a criterion of 20 cfs, but for only a few days thereafter in June. At a flow criterion of 35 cfs, the combined criteria were met during April for 15 days at CRC (impaired) and 16 days at ACG (impaired). At a flow criterion of 20 cfs, the combined criteria were met during April for 25 to 28 days at CRC (18.3°C and 20°C temperature criteria, respectively) and 19 days at ACG. Using criteria of 35 cfs and 18.3°C, conditions for passage were not met at these sites at any time in May or thereafter, although passage conditions were met for a short time in May (≤ 3 days) using the less restrictive criteria. The combined criteria were met for very few days (≤ 5 days) in distributary channels (ACK, NEW, and BTS) during April and no days thereafter, where lack of flow was the limiting factor. Information about fish movement past Edwards Diversion Dam and elsewhere in lower Antelope Creek is not available for WY2013. For purposes of evaluating the probable effect of these conditions in lower Antelope Creek, 55% of the 2010 spring-run Chinook salmon count in Mill Creek had migrated through the Sacramento Valley reaches by the end of April and 85% of the count had migrated through by the end of May (Figure 3-1).

Table 4-10. Number of days that streamflow and temperature criteria were met for spring-run Chinook salmon and steelhead migration from 1 April to 15 October WY2013.

Site	Criteria[1]		Number of days Q and T criteria were met						
	Q, cfs	T, °C	Apr	May	June	July	Aug	Sept	1–15 Oct
UAC	20	18.3	30	19	1	0	0	9	15
		20	30	26	3	0	0	9	15
	35	18.3	30	19	1	0	0	0	9
		20	30	26	2	0	0	0	9
ACG	20	18.3	25	5	0	0	0	0	0
		20	28	9	0	0	0	0	0
	35	18.3	16	0	0	0	0	0	0
		20	16	1	0	0	0	0	0
CRC	20	18.3	19	1	0	0	0	0	0
		20	19	3	0	0	0	0	0
	35	18.3	15	0	0	0	0	0	0
		20	15	1	0	0	0	0	0
ACK	20	18.3	2	0	0	0	0	0	0
		20	2	0	0	0	0	0	0
	35	18.3	0	0	0	0	0	0	0
		20	0	0	0	0	0	0	0
NEW	20	18.3	5	0	0	0	0	0	0
		20	5	0	0	0	0	0	0
	35	18.3	0	0	0	0	0	0	0
		20	0	0	0	0	0	0	0

Site	Criteria[1]		Number of days Q and T criteria were met						
	Q, cfs	T, °C	Apr	May	June	July	Aug	Sept	1–15 Oct
BTS	20	18.3	0	0	0	0	0	0	0
		20	0	0	0	0	0	0	0
	35	18.3	0	0	0	0	0	0	0
		20	0	0	0	0	0	0	0

[1] Instream flow (Q) criteria from field observations of fish passage conditions during fall 2009 and spring 2010, and from recommendations specified in SWRCB Resolution No. 2014-0023 and in Voluntary Drought Agreements. Temperature (T) criteria: 18.3°C is upper suboptimal for adult, fry, and juvenile spring-run Chinook salmon migration and upper optimal for fry and juvenile steelhead emigration; 20°C is upper suboptimal for fry and juvenile steelhead emigration. Metrics are based on average daily streamflow and temperature values.

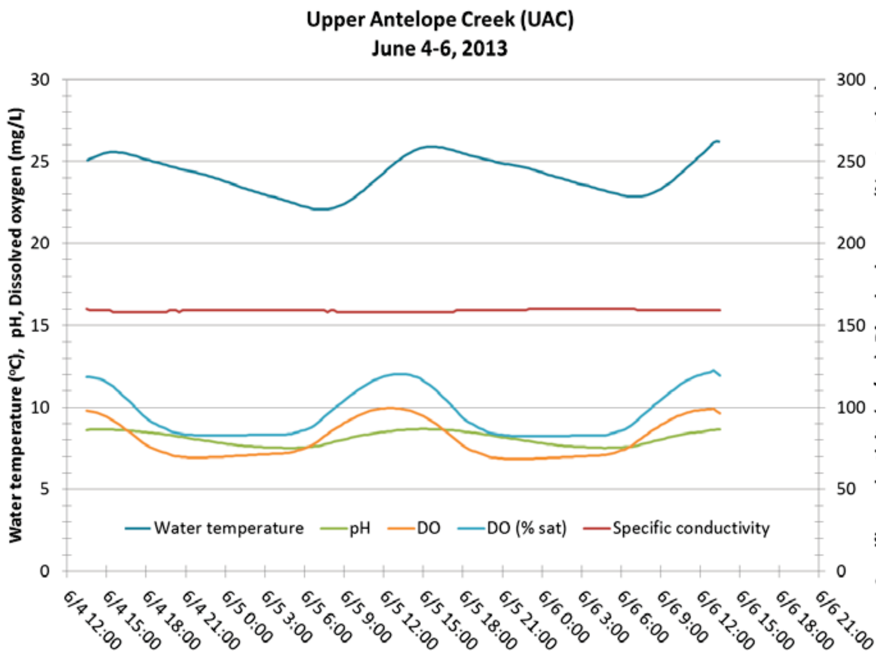
4.2 Water Quality

Lower Antelope Creek flows through a landscape intensively managed for agricultural production and sparsely populated by residential dwellings serviced by a network of county roads and State highways. The potential effects of high water temperatures in combination with non-point source pollutants on anadromous salmonids in lower Antelope Creek prompted an investigation of water quality during 2013. Continuous and synoptic water quality data were collected at five monitoring sites in Antelope Creek in June 2013 and September 2013 (17‑19). Grab samples were collected three times daily (morning, afternoon, and evening) at all monitoring sites for analysis of total NH_3 as N, unionized NH_3 as N, total dissolved solids (TDS), total sulfide, and dissolved sulfide. Standard grab sampling techniques were used in collecting surface samples. Since the unionized NH_3 concentration in surface water is temperature and pH dependent, *in situ* stream temperature and pH were recorded along with grab samples using a calibrated YSI 600XL (Appendix G). Continuous monitoring of four *in situ* parameters (stream temperature, specific conductivity, dissolved oxygen, and pH) occurred at 15-minute intervals over a 48-hour period at two monitoring sites (UAC and CRC) using a calibrated YSI 6920 water quality Sonde. Continuous *in situ* parameters were measured at approximately 0.1 m (0.5 ft) below the water surface. Grab samples were placed on ice in the field and hand-delivered within 48 hours to Basic Laboratories (Chico, CA) for analysis. Appendix H includes water quality methods, reporting limits, calibrations, and results. The implications of water quality monitoring results to anadromous salmonids are discussed below.

4.2.1 Dissolved oxygen

Atmospheric oxygen is slightly soluble in water, with concentrations influenced by biotic photosynthesis and respiration and mixing of atmospheric oxygen into the water column. The Central Valley Basin Plan (CVRWQCB 1998) states that dissolved oxygen concentrations shall not be reduced below 5.0 mg/L to protect existing warm freshwater habitat (WARM) and 7.0 mg/L to protect existing cold freshwater habitat (COLD), as well as spawning, reproduction, and/or early development (SPWN). WARM, COLD, and SPWN are all designated beneficial uses for Antelope Creek. Low dissolved oxygen concentrations were observed in lower Antelope Creek during evening and early morning hours in both June and September 2013 (Figures 4-14 and 4-15, Appendix H). In June 2013, dissolved oxygen concentrations monitored over a 48 hour period fell below 7.0 mg/L for 10 hours at UAC and 7 hours at CRC. Dissolved oxygen remained above 5.0 mg/L during spring sampling. In September 2013, dissolved oxygen concentrations monitored over a 48-hour period remained above 7.0 mg/L at UAC but fell below this threshold for 31 hours at CRC. September grab samples showed generally high dissolved oxygen at UAC

(Appendix I). Dissolved oxygen concentrations dropped below 7.0 mg/L but remained above 5.0 mg/L at all sites on 18 September 2013. Overall, monitoring results indicate that lower Antelope Creek does not consistently support the COLD designated beneficial use with respect to dissolved oxygen concentrations during spring and late summer/early fall. Low dissolved oxygen concentrations in the evening and early morning hours suggest intense respiration by aquatic organisms, such as attached algae or periphyton. Based on the life history timing of spring-run Chinook salmon and steelhead in lower Antelope Creek, the diurnal decreases in dissolved oxygen during June and September could result in potential effects on migrating adult and juvenile spring-run Chinook salmon and emigrating juvenile steelhead.



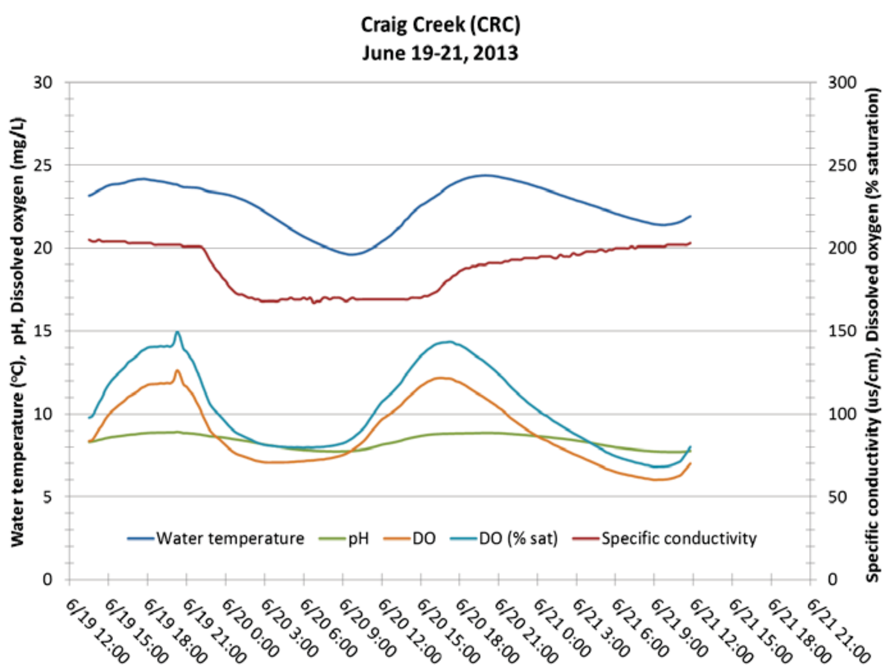
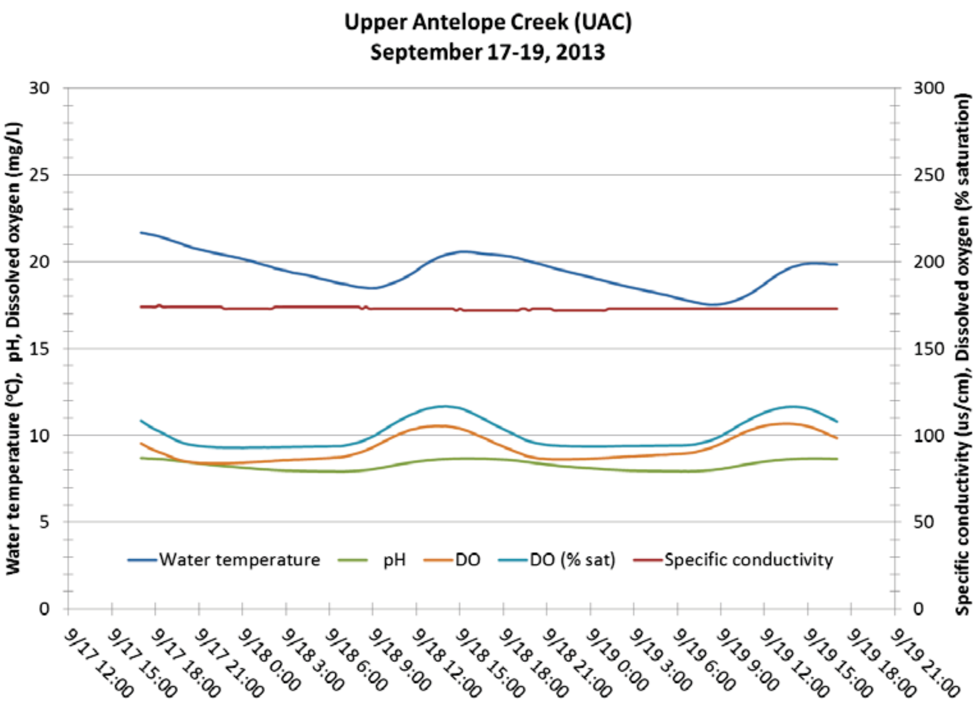


Figure 4-12. Continuous *in situ* water quality monitoring results at UAC and CRC during June 2013.



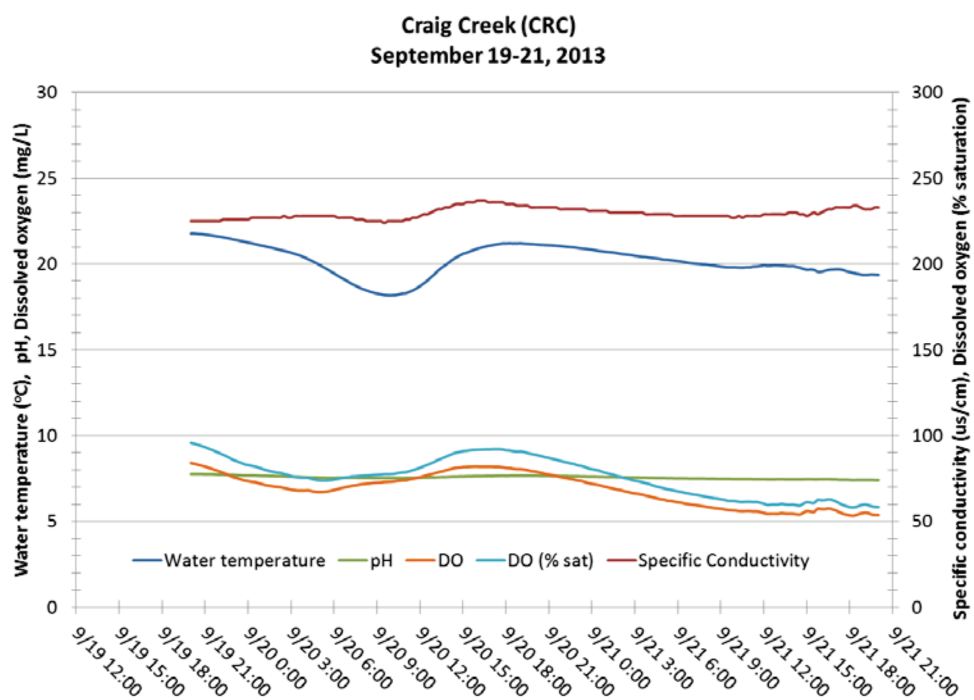


Figure 4-13. Continuous *in situ* water quality monitoring results at UAC and CRC during September 2013.

4.2.2 pH

The pH of surface water is controlled primarily by atmospheric CO_2, as well as carbonate buffering, photosynthesis, and respiration. pH mediates chemical speciation of important compounds, such as ammonium (NH_4^+) and unionized ammonia (NH_3), the latter which is toxic to fish (USEPA 2000). High pH can increase the solubility of minerals and metals, which can adversely affect fish and other aquatic organisms. Chronically high pH can decrease activity levels of salmonids, create stress responses, decrease or cease feeding, and lead to a loss of equilibrium (Murray and Ziebell 1984; Wagner et al. 1997). High rates of algal photosynthesis and respiration can create diel fluctuations in pH on the order of 0.5 to 1 pH units. Algal blooms and subsequent die-off can cause variations in both average daily pH and diel fluctuations in pH on a time scale of weeks (Horne and Goldman 1994, Wetzel 2001). The Central Valley Basin Plan states that pH shall not be depressed below 6.5 nor raised above 8.5 at any time (CVRWQCB 1998).

High pH values were observed in lower Antelope Creek during afternoon and evening hours in both June and September 2013 (Figures 4-14 and 4-15, Appendix H). Continuous monitoring in June 2013 indicated pH levels greater than 8.5 for 14.5 of 48 hours at UAC and 21.5 of 48 hours at CRC. High pH levels corresponded to high dissolved oxygen concentrations (i.e., 100-120% saturation), suggesting high levels of algae or periphyton photosynthesis. Grab samples remained below pH 8.5 during June and September, with the exception of UAC, where pH exceeded 8.5 for 10.5 of 48 hours during September. Overall, elevated pH levels observed during both June and September suggest that lower Antelope Creek may not consistently support designated beneficial use with respect to pH. Based on the life history timing of spring-run Chinook salmon and steelhead in lower Antelope Creek, diurnal increases in pH could result in potential chronic effects on adult and juvenile spring-run Chinook salmon and emigrating juvenile steelhead.

4.2.3 Ammonia

Ammonia is a known toxicant to fish. As noted in the previous section, pH affects the equilibrium speciation of ammonium (NH_4^+) and unionized ammonia (NH_3), with high pH levels causing conversion of NH_4^+ to the toxic unionized form. In general, ammonia toxicity is temperature and pH dependent; however, recent data indicate that vertebrate sensitivity to unionized ammonia is independent of temperature, while invertebrate sensitivity to ammonia decreases as temperature decreases (USEPA 2013). Acute exposure to unionized ammonia in fish may cause mortality, while prolonged exposure to sub-lethal levels (i.e., chronic exposure) may result in skin and gill hyperplasia, respiratory problems, stress, and conditions which support proliferation of opportunistic bacteria and parasites (USEPA 2013). While the Basin Plan does not include a numeric criterion for ammonia toxicity, the USEPA (2013) recommends a 1-hr average maximum concentration (CMC) and a 3-day rolling average chronic concentration (CCC) for freshwater aquatic biota. For pH 7.0 and stream temperature at 20 ^oC, the total ammonia nitrogen CMC is 17 mg/L and the CCC is 1.9 mg/L. Appendix H includes temperature and pH-dependent calculations for the CMC and CCC. Based on pH and stream temperatures measured along with the grab samples, total ammonia CMC and CCC values for June and September 2013 are one to three orders of magnitude greater than measured concentrations (Figures 4-16 and 4-17, Appendix H), indicating little to no potential for ammonia toxicity to fish in Antelope Creek.

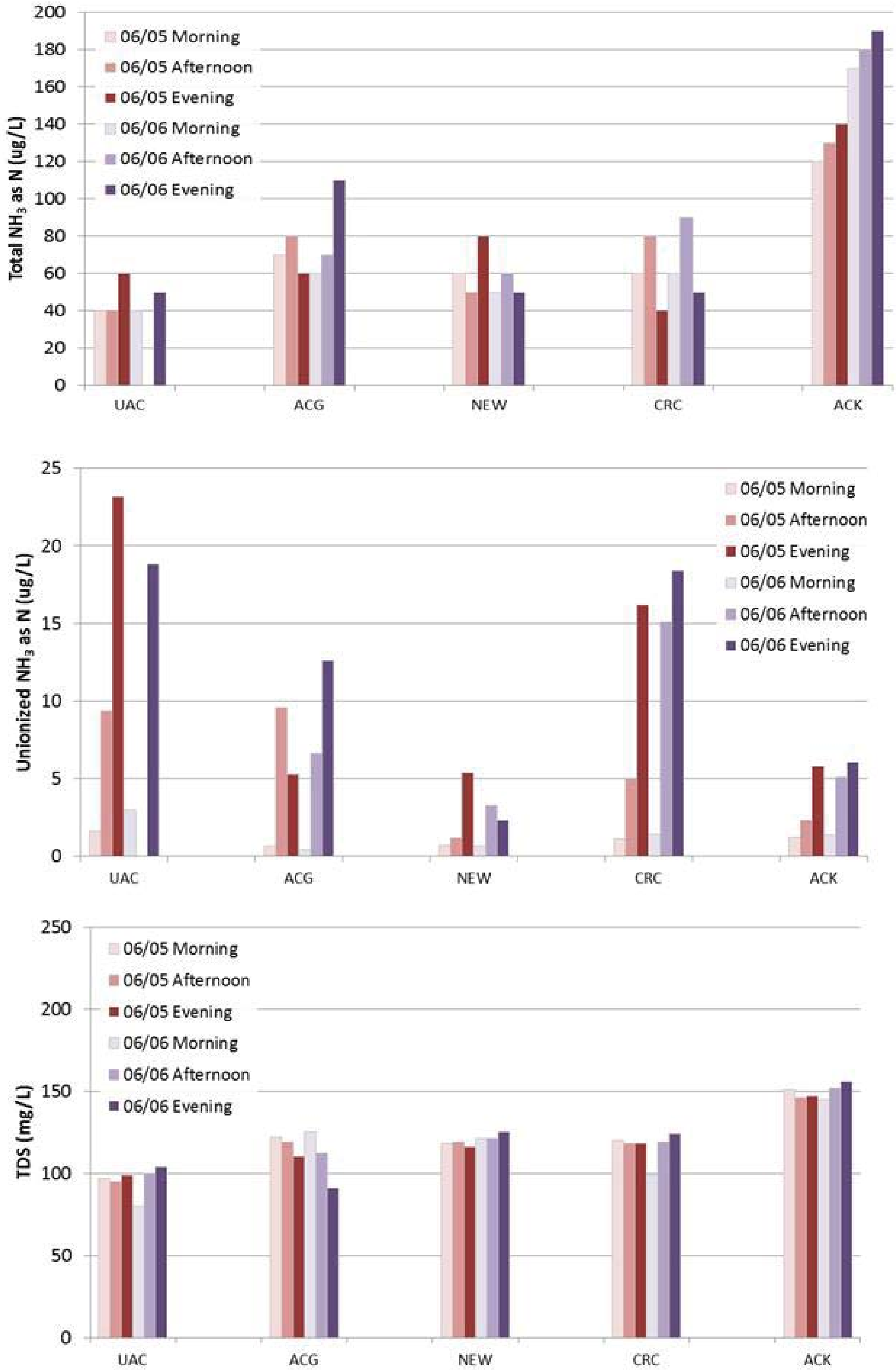


Figure 4-14. Total ammonia (NH_3 as N), unionized ammonia (NH_3 as N), and TDS during morning, afternoon, and evening grab samples at all monitoring sites during June 2013.

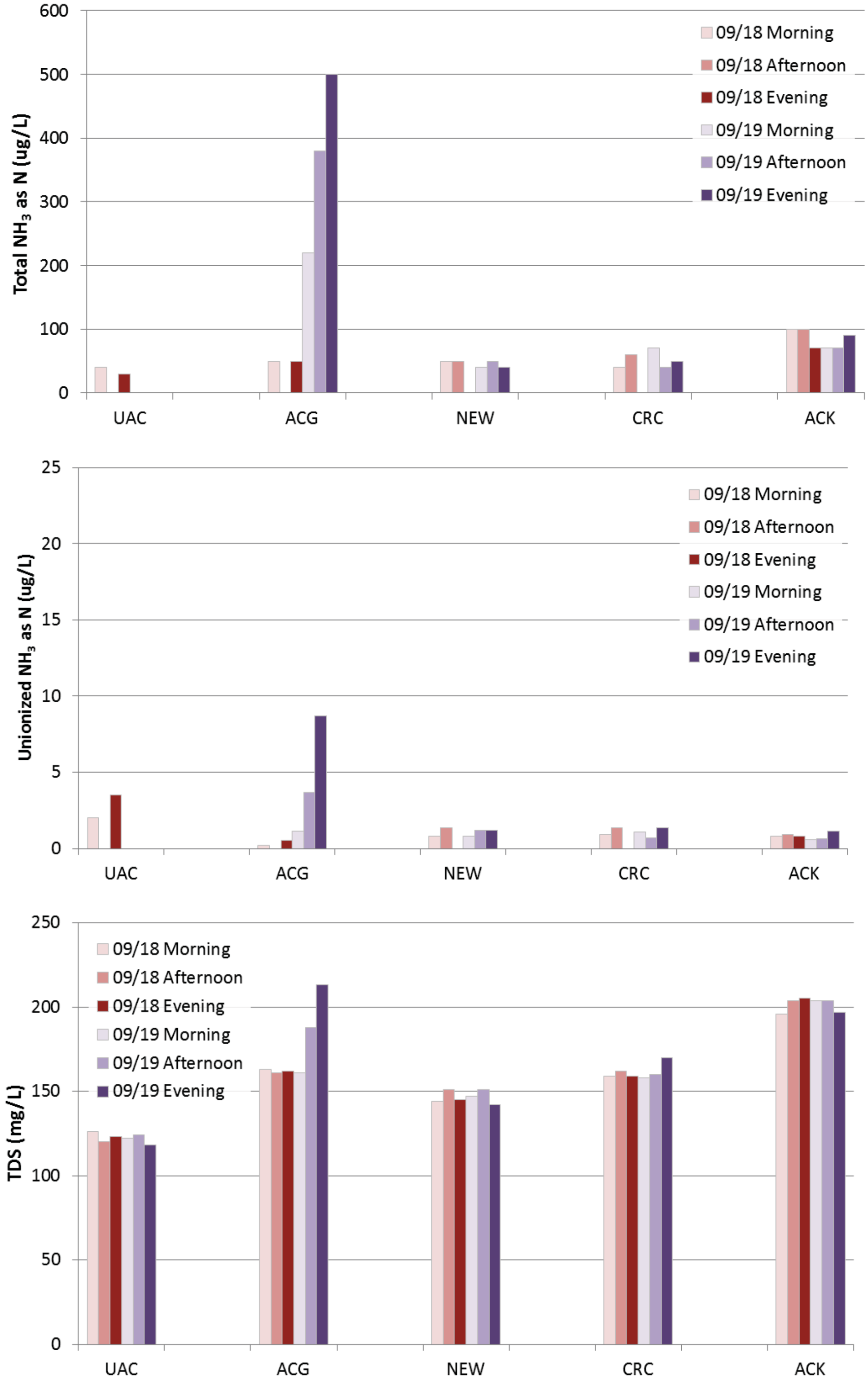


Figure 4-15. Total ammonia (NH_3 as N), unionized ammonia (NH_3 as N), and TDS during morning, afternoon, and evening grab samples at all monitoring sites during September 2013.

4.2.4 Hydrogen sulfide

Dissolved hydrogen sulfide (H_2S) is produced in suboxic (low oxygen) or anoxic (no oxygen) aquatic environments by naturally occurring sulfate-reducing bacteria. These bacteria use sulfate from the water column or surrounding sediments in place of oxygen in cellular respiration, producing hydrogen sulfide as a waste product. Hydrogen sulfide is typical in wetlands and deeper lake sediments, particularly where there is an abundance of organic carbon from high rates of primary productivity (i.e., algae), but it can also occur in stream environments with low dissolved oxygen and high carbon availability. Hydrogen sulfide acute toxicity to fish ranges from 14.9 ug/L for fathead minnow to 44.8 ug/L for bluegill (76 FR 64022). There is no national recommended water quality CMC for freshwater aquatic life for dissolved hydrogen sulfide (USEPA 1986). The national recommended water quality CCC for freshwater aquatic life is 2.0 ug/L (USEPA 1986). Chronic effects of hydrogen sulfide exposure include reduced swimming endurance, slower growth, increased mortality, reduced fecundity, and anatomical malformations (Colby and Smith 1967, Aldelman and Smith 1970, Smith and Oseid 1972). Approximately 80% of the dissolved sulfide measurements in lower Antelope Creek were below the 10 ug/L, and most of the remaining measurements were 10 to 20 ug/L (Appendix H). These results suggest that hydrogen sulfide concentrations could result in chronic toxicity to fish.

5 IMPROVING FISH PASSAGE

Surveys of fish passage conditions and habitat; flow and temperature monitoring, and hydraulic modeling described in Sections 1-3 of this report indicate that the mainstem reaches of lower Antelope Creek (i.e., Antelope Creek from Edwards Diversion Dam to the Antelope Creek–Craig Creek junction and Craig Creek downstream of the junction) offer the best conditions for salmon and steelhead migration due to a combination of higher spring and summer baseflows, cooler temperatures, higher quality habitat, and relatively unobstructed fish passage compared to distributaries. The most important factors limiting Chinook salmon and steelhead migration in mainstem reaches of lower Antelope Creek are: (1) water diversions that lead to insufficiently deep instream flow conditions for continuous adult and/or juvenile passage between Edwards Diversion Dam and the Sacramento River, (2) entrainment of fry and juvenile fish in the two diversion canals at Edwards Diversion Dam, and (3) high water temperatures that limit the duration of the migration period. Managing these factors for optimal passage conditions in mainstem reaches is complicated by a lack of information correlating flow, hydraulic, and temperature conditions to Chinook salmon and steelhead movement in lower Antelope Creek; challenges in engineering an effective bypass to return juvenile fish entrained in the diversion canals back to Antelope Creek, and dynamic flow splits at distributary junctions that influence instream flow available for fish passage in downstream reaches.

An effective strategy for improving adult and juvenile fish passage in lower Antelope Creek will therefore require integrating four major components:

1. Improving infrastructure at Edwards Diversion Dam to minimize juvenile entrainment and efficiently and accurately manage instream flow releases;
2. Providing adequate high quality instream flow that allows continuous passage in mainstem reaches of Antelope Creek between Edwards Diversion Dam and the Sacramento River during Chinook salmon and steelhead migration periods;
3. Modifying and maintaining channel conditions at critical locations in mainstem reaches downstream of Edwards Diversion Dam to ensure desirable flow splits at distributary junctions and hydraulic conditions that allow continuous passage during migration periods;
4. Implementing a monitoring program to assess the effectiveness of instream flow on fish passage during a migration period, as well as the long-term effects of management actions on Chinook salmon and steelhead populations in the watershed.

The following sections describe each of the four components and the associated prioritized actions to improve fish passage conditions in reaches of lower Antelope Creek.

5.1 Infrastructure Improvements at Edwards Diversion Dam

Edwards Diversion Dam enables water diversions into two separate, screened canals: the West Diversion (headgate capacity of 50 cfs) serving Edwards Ranch and the East Diversion (headgate capacity of 80 cfs) serving the Edwards Ranch and lands owned by shareholders of the LMMWC. The 80 cfs capacity of the existing East Diversion head-gate provides more water than is cumulatively diverted by both canals during the typical irrigation season from April 1 through October 31. The existing fish screens in the West and East diversion canals are not equipped with bypasses to return fish from the screen bays to Antelope Creek. Fish trapped in the screen bays die from lethal water temperatures or predation if they aren't manually captured and released downstream of the diversion. In 2013, CDFW rescued 1,118 juvenile Chinook salmon, 138 juvenile steelhead, and 4 adult steelhead from the screen bays of the two diversions (Manji 2013). In 2014, CDFW rescued 191 juvenile steelhead, and 7 adult steelhead (preliminary data, M. Johnson, CDFW, pers. comm., 2014). This fish passage problem and the need for remediation have been identified by various state and federal resource agencies (USFWS 2008, NMFS 2014). Engineering a bypass from the fish screen in the West Diversion is complicated by the location of New Creek, which flows between the two canals and separates the West Diversion from Antelope Creek.

In addition to juvenile entrainment in the diversion canals, maximum allowable diversion rates have the potential to create migration barriers and/or dewater downstream reaches of mainstem Antelope Creek and Craig Creek during spring and fall salmon and steelhead migration periods, especially in Dry and Critically Dry Years (Figure 2-5). Ad hoc instream flow management for fish passage and temperature control in mainstem reaches is currently achieved by reducing flow diversion rates at the canal headgates, allowing imprecise increases in flow to move through the fish ladder and into the downstream Antelope Creek channel. Existing infrastructure limits the ability to accurately control flow diversion rates and effectively measure inflows and outflows in the vicinity of the diversion.

The TCRCD in cooperation with the U.S. Fish and Wildlife Service, National Marine Fisheries Service, and California Department of Fish and Wildlife completed a study in 2013 of the diversion dam and related water distribution infrastructure in order to develop a retrofit design that would minimize juvenile entrainment, provide reliable and measurable instream flow releases necessary for fish passage in downstream reaches during critical adult and juvenile migration periods, and allow diverters to utilize most if not all of their respective water allocations outside of these critical migration periods. The preferred design concept, selected from a range of alternatives by CDFW and USWS, would consolidate water diversions into a single canal (i.e., the East Diversion) (Figure 5-1). New screens would be installed in the East Diversion, which would be sized to meet its current 80 cfs diversion capacity. A bypass pipe would be installed at the downstream end of the screens to return fish to Antelope Creek, and a siphon would be installed downstream of the screens to convey the Edwards Ranch share of water under New Creek to the existing West Diversion canal. To maintain the maximum combined diversion allowance of 130 cfs, the existing West Diversion headgate would remain in place but closed until diverters require more than 80 cfs. Use of the West Diversion headgate to obtain additional water would be conditional, and require that New Creek convey sufficient flow to provide unimpeded juvenile fish passage to the Sacramento River. A bypass pipe would be installed at the downstream end of the fish screen in the West Diversion to deliver fish to New Creek.

Figure 5-1. Preferred design concept for improving juvenile fish passage at Edwards Diversion Dam.

A suite of complimentary applications have been submitted to the Fisheries Restoration Grant Program (FRGP), Integrated Watershed Management Program (IWMP), and Anadromous Fish Screen Program (AFSP) to support design and implementation of infrastructure improvements that will minimize juvenile salmonid entrainment in diversion canals and enable more accurate measurement and management of inflows and outlflows at Edwards Diversion Dam.

FRGP funds will support developing detailed engineering designs, construction plans, and specifications for the preferred design concept developed in 2013 by the TCRCD and partnering resource agencies. An Options Analysis will be performed based largely on an existing Preliminary Concept Report prepared under the direction of the Tehama County Resource Conservation District with consultation from CDFW, USFWS, and NMFS (VESTRA Resources and TCRCD 2011, TCRCD 2014). Options to be identified in the analysis include the following:

1. New fish screens upstream of the existing diversion headgates,
2. A bypass siphon under New Creek,
3. A bypass crossing over New Creek,
4. Consolidation of the West and East Diversions, and
5. A new bypass for the existing East Diversion fish screen only.

A Basis of Design Report will then be prepared to establish consensus among project stakeholders regarding the final design criteria and concepts. The features to be addressed in the Basis of Design Report are:

- Diversion headgates: design capacity, gate type and material, high and low water elevations, actuator, access, etc;
- Fish screens: allowable velocities, screen type and material, size, location, and orientation;
- Fish screen debris management;
- Fish screen bypass: allowable velocities, inlet and outlet configurations, alignment, etc;
- Siphon connection: maximum capacity, inlet and outlet connections and flow control;
- Antelope Creek and diversion canal flow measurement and remote monitoring; and
- Operation criteria.

The last step will involve preparing 30%, 65%, 90% and 100% designs. Additional site investigations will be conducted to augment existing information, including a comprehensive topographic survey, inventories of existing features and structures, stream gaging and related hydraulic surveys, hydraulic modeling, and a geotechnical investigation. Appendix I summarizes the project elements described above and explains how each element would benefit anadromous salmonids.

IWMP and AFSP grant funds will support constructing the improvements at Edwards Diversion Dam (excluding fish screens and any improvements to the existing fish ladder), environmental analysis and permitting, environmental monitoring, and mitigation of any construction impacts. Portions of the necessary environmental analysis and permitting work have been completed during prior phases (e.g., cultural resources investigation, draft environmental assessment, draft mitigated negative declaration document, and draft biological characterization report). A streambed alteration agreement and Section 401 and 404 permits have been initiated. It is anticipated that the 65% design drawings will accompany permit applications. IWMP grant funds will also support procurement and installation of equipment to remotely monitor flow rates in Antelope Creek and in the Edwards Ranch and LMMWC diversions. The improvements will add communication equipment to both existing Parshall flumes to more accurately measure and remotely monitor diversion and bypass flow rates. Real-time access to data will enable more precise control of diversion gates to better optimize diversions and better manage minimum instream flows for fish passage in mainstem Antelope Creek and Craig Creek. These improvements will be especially beneficial at low flow conditions during the summer irrigation period and under drought conditions. Monitoring of streamflow and diversion flow rates at Edwards Diversion Dam will supplement existing stream flow monitoring in Antelope Creek improved to enhance the joint management of diversions and stream flows (refer to Section 5.4 for a discussion of upgrades to and continued operation of streamflow and temperature monitoring stations).

5.2 Instream Flow

The mainstem reaches of lower Antelope Creek are the most viable corridor for Chinook salmon and Steelhead migration between the Edwards Diversion Dam and the Sacramento River during April through October. To achieve streamflow and temperature conditions suitable for Chinook salmon and juvenile steelhead passage in the Antelope Creek and Butler Slough distributaries during this period would require removal or modification of existing barriers as well as flow augmentation that exceeds unimpaired baseflow. Diverters therefore have little capacity to significantly influence streamflow and temperature conditions in distributary channels April through October. Adult steelhead may utilize these distributaries for short periods during peak winter flows. Edwards Diversion Dam has little effect on peak flows and diverters therefor have little capacity to manage flows for improved passage in these distributaries during the winter period. Augmenting flow in these distributary channels has the potential to increase the risk of stranding fish between storm events and in the spring when flows recede.

Flow augmentation in New Creek may be a viable option for improving spring-run Chinook salmon passage during critical migration periods, as well as delivering fish captured by screens in the West Canal back to the Sacramento River. Little is known about channel conditions in New Creek between Cone Grove Road and Edwards Diversion Dam, however, and the concrete weir at the head of New Creek is currently a complete barrier to adult immigration. Flow over the weir and into New Creek occurs only when adequate flow also exists for fish passage in lower mainstem reaches of Antelope Creek, recedes rapidly between high flow events, and cannot be effectively controlled with existing infrastructure.

Based on the above considerations, flow management objectives for lower Antelope Creek include the following:

- Provide minimum instream baseflows necessary for unimpeded passage of immigrating adult spring- and fall-run Chinook salmon and steelhead, and emigrating juvenile Chinook and steelhead in mainstem Antelope Creek and Craig Creek during critical migration periods;
- Create suitable temperature conditions in mainstem Antelope Creek and Craig Creek during critical migration periods; and
- Release pulse flows to attract fish and promote movement during critical migration periods.

Minimum instream flow requirements for successful fish migration are informed by correlating instream habitat conditions (channel hydraulics and temperature) and observed fish movement over a range of flows during the migration period. These data can be essential in establishing minimum instream flow criteria and efficiently managing instream flow releases based on the real-time flow and temperature needs of fish moving in or out of the system at any given time. Correlations between instream flow, habitat conditions, and fish movement are very limited for lower Antelope Creek compared with other nearby watersheds with spring-run Chinook salmon and steelhead populations (e.g., Mill Creek). CDFW reinitiated video monitoring at Edwards Diversion Dam in 2013 and will continue the program through at least 2018. Seven gaging stations were established in lower Antelope Creek in 2012 to monitor streamflow and temperature, four of which CDFW and their partners continued operating during WY2014. WY2014 is the only year in which flow and temperature monitoring occurred upstream and downstream of Edwards Diversion Dam coincident with video monitoring of fish movement at the dam. An application to the Integrated Watershed Management Program (IWMP) for funding to continue operating the four priority gaging stations during WY2016 andWY 2017 is pending. Refer to Section 5.4 for more information regarding monitoring of flow, temperature, and fish movement.

Drought emergency baseflows and pulse flows for adult and juvenile spring-run Chinook salmon and juvenile steelhead passage in lower Antelope Creek were developed by the State Water Resources Control Board (SWRCB) in Resolution No. 2014-0023 and in voluntary drought agreements between State and Federal resource agencies and diverters (Table 4-6). In developing drought emergency flows, the SWRCB and partnering State and Federal resource agencies drew upon information presented in this report (e.g., barrier mapping, habitat mapping, streamflow and temperature data), limited observations of spring-run Chinook salmon and steelhead movement past Edwards Diversion Dam, and other data and literature associated with instream flows and fish biology. Minimum instream flows specified by SWRCB ranged from 20 to 35 cfs (refer to Table 4-6 for conditions under which minimum instream flows were to be released). Drought emergency baseflows were established based on the best available information, but with little information correlating fish movement to flow, site-specific hydraulics, temperature, and other factors influencing salmon and steelhead passage in lower Antelope Creek.

Surveys of channel and fish passage conditions during Fall 2010 indicated unimpeded fish passage in mainstem reaches at a discharge of approximately 20 cfs, although flow depths were at or near the threshold for adult passage (0.6 ft) for extended lengths at this flow. Subsequent field surveys of mainstem reaches in Fall 2014 at approximately 30 to 35 cfs indicated that conditions provided continuous unimpeded passage for adult and juvenile salmon and steelhead (M. Johnson, CDFW, pers. comm., 2014). These observations establish with reasonable confidence that minimum instream flows in the range of 20 to 35 cfs likely provide unimpeded fish passage in mainstem reaches of lower Antelope Creek. Section 4.1.4.1 discusses the duration over which flows within this range occurred in mainstem reaches of lower mainstem Antelope Creek during WY2013.

Water temperature is an important influence on salmon biology, including growth and feeding, metabolism, development of embryos and alevins and timing of life history events such as upstream migration, spawning, and rearing (Carter 2005). Based on a review of available information, the upper suboptimal temperature threshold for adult, juvenile, and fry spring-run Chinook salmon is 18.3°C (65°F) (Table 4-8). Temperatures exceeding 18.3°C likely inhibit adult Chinook salmon immigration. CDFW documented adult spring-run Chinook salmon passing Edwards Diversion Dam between March 10 and April 26, 2014 at mean daily temperatures up to 17°C. An MWAT of 18.3°C in mainstem Antelope Creek downstream of Edwards Diversion Dam (e.g., the ACG or CRC monitoring stations) is therefore a defensible initial criterion for determining when to provide pulse flows to attract the later part of the spring Chinook salmon run upstream and/or cease minimum flow releases for passage in the spring (typically in late April or May).

State Water Resources Control Board Resolution No. 2014-0023 specified the following pulse flows for Antelope Creek:

- *From April 1 up to June 30 when adult spring-run Chinook salmon are present*: 70 cfs for minimum of 24 hours and maximum of 72 hours when (1) average daily full natural flow upstream of Edwards Diversion Dam is ≤70 cfs for 3 consecutive days; or (2) SWRCB approves request by CDFW or NMFS for pulse flow.
- *From June 1 up to June 30 when Juvenile spring-run Chinook salmon or Juvenile steelhead are present:* 70 cfs for minimum of 24 hours and maximum of 72 hours when (1) CDFW or NMFS observes juvenile spring-run Chinook salmon or steelhead in lower Antelope Creek in June; and (2) SWRCB approves request by CDFW or NMFS for pulse flow.

Additional criteria for determining when to provide pulse flows to attract spring Chinook salmon upstream and/or cease minimum flow releases for passage may also include observations of fish moving past Edwards Diversion Dam and elsewhere in lower Antelope Creek, site-specific hydraulic conditions (e.g., depth and wetted width) in critical channel reaches, and unimpaired streamflow upstream of the diversion dam.

Integrated Watershed Management Program grant funds will support a detailed instream flow study during WY2016 and WY2017 to refine minimum instream flow and pulse flow recommendations, maximum temperature thresholds, and other operational criteria for improving salmon and steelhead migration in lower Antelope Creek. The instream flow study will focus the passage assessment on flows of approximately 20–35 cfs. Up to eight sites with the highest potential to limit fish passage in mainstem Antelope Creek and Craig Creek will be identified for study. Potential study sites include: (1) bedrock controlled riffles between Edwards Diversion Dam and Cone Grove Park, (2) the gravel plane bed channel immediately downstream of the Antelope Creek–Craig Creek distributary junction, (3) the narrow and incised bedrock channel immediately downstream of Craig Avenue, and (4) mobile gravel bedded riffles downstream of Highway 299 (Figure 5-2, Table 5-1). Transects will be monumented and hydraulic measurements (e.g., stage height and discharge, wetted width and depth, flow velocity, water surface slope, and critical channel length) conducted over a range of flows at each study location. Field measurements of hydraulic conditions will be coordinated with video monitoring of spring-run Chinook salmon and steelhead migration in lower Antelope Creek at Edwards Diversion Dam, flow and temperature data from the four priority gaging stations in lower Antelope Creek, and other field observations of fish presence downstream of the dam. If suitable flows do not occur during the project period, hydraulic modeling will be used to supplement the empirical analysis. The instream flow study will consider the influence of stream temperature during adult and juvenile salmonid passage windows and establish flow thresholds for evaluating periodic channel maintenance requirements based on streamflow monitoring (refer to Section 5.4 below for details regarding monitoring). A technical memorandum will present results of the instream flow analysis and discuss additional factors potentially important in establishing instream flow requirements for lower Antelope Creek (e.g., migration cues, travel distances and times, and hydrograph components important for maintaining critical habitats).

Figure 5-2. Potential instream flow study sites in mainstem Antelope Creek and Craig Creek.

Table 5-1. Potential instream flow study sites in mainstem Antelope Creek and Craig Creek.

Site	Channel	Location[1]		Description
		latitude	longitude	
1	Antelope Creek	40°11'10.73"N	122° 8'1.08"W	Bedrock controlled riffle upstream of Cone Grove Park
2	Antelope Creek	40°11'2.89"N	122° 7'56.64"W	Bedrock controlled riffle upstream of Cone Grove Park
3	Antelope Creek	40°10'59.95"N	122° 7'51.59"W	Bedrock controlled riffle upstream of Cone Grove Park
4	Antelope Creek	40°10'54.89"N	122° 7'45.06"W	Bedrock controlled riffle upstream of Cone Grove Park
5	Antelope Creek	40°10'52.39"N	122° 7'43.08"W	Bedrock controlled riffle upstream of Cone Grove Park
6	Antelope Creek	40°10'49.75"N	122° 7'40.27"W	Bedrock controlled riffle upstream of Cone Grove Park
7	Antelope Creek	40°10'47.78"N	122° 7'38.19"W	Bedrock controlled riffle upstream of Cone Grove Park
8	Antelope Creek	40°10'37.64"N	122° 7'48.56"W	Bedrock controlled riffle upstream of Cone Grove Park
9	Antelope Creek	40°10'26.55"N	122° 7'53.63"W	Bedrock controlled riffle upstream of Cone Grove Park
10	Craig Creek	40° 9'31.74"N	122° 8'12.53"W	Gravel plane bed channel downstream of the Antelope Creek–Craig Creek distributary junction
11	Craig Creek	40° 9'1.71"N	122° 8'11.31"W	Incised bedrock channel downstream of Craig Ave.
12	Craig Creek	40° 8'44.19"N	122° 8'23.64"W	Gravel bedded riffle downstream of SR 99
13	Craig Creek	40° 8'41.07"N	122° 8'24.66"W	Gravel bedded riffle downstream of SR 99
14	Craig Creek	40° 8'36.91"N	122° 8'29.53"W	Gravel bedded riffle downstream of SR 99
15	Craig Creek	40° 8'27.11"N	122° 8'27.64"W	Gravel bedded riffle downstream of SR 99
16	Craig Creek	40° 8'15.73"N	122° 8'28.30"	Gravel bedded riffle downstream of SR 99

[1] All latitude and longitude are reported in WGS84.

5.3 Channel Conditions

No permanent man-made structures (e.g., dams, wiers, culverts, diversions, pump intakes, or engineered channels) prohibited fish passage downstream of Edwards Diversion Dam. There were also no apparent barriers to adult or juvenile salmon and steelhead migration observed during field surveys of mainstem reaches (i.e., Antelope Creek from Cone Grove Park to the Antelope Creek-Craig Creek distributary junction and Craig Creek from the junction to the Sacramento River) at flows of approximately 20 cfs. However, a number of temporary barriers and/or impediments to migration (e.g., beaver dams and low flow conditions) exist or have the potential to exist in both mainstem and distributary channels downstream of the diversion.

5.3.1 Mainstem channels

Field surveys of mainstem reaches (i.e., Antelope Creek from Cone Grove Park to the Antelope Creek–Craig Creek distributary junction and Craig Creek from the junction to the Sacramento River) in 2009 at approximately 20 cfs and in 2014 at approximately 30 to 35 cfs indicated that conditions provided continuous unimpeded passage for adult and juvenile salmon and steelhead.

IWMP grant funds will support a detailed instream flow study during WY 2016 and WY 2017 to refine the target minimum instream flows necessary to provide continuous unimpeded salmon and steelhead passage in lower Antelope Creek based on hydraulic criteria correlated to monitoring of flow, temperature and fish movement past Edwards Diversion Dam (refer to Section 5.2). Up to eight sites with the highest potential to limit fish passage in mainstem Antelope Creek and Craig Creek will be identified for study. Potential study sites include: (1) bedrock controlled riffles between Edwards Diversion Dam and Cone Grove Park, (2) the gravel plane bed channel immediately downstream of the Antelope Creek–Craig Creek distributary junction, (3) the narrow and incised bedrock channel immediately downstream of Craig Avenue, and (4) mobile gravel bedded riffles downstream of Highway 299 (Figure 5-1, Table 5-3). Site-specific channel modifications and/or maintenance may be required or desirable in critical reaches to ensure passable conditions are maintained at the target minimum instream flows. Potential periodic maintenance and/or more permanent modifications that may be necessary or desirable to achieve fish passage in these reaches will be identified based on the analysis and results of the detailed instream flow study.

5.3.2 Antelope Creek-Craig Creek distributary junction

The geomorphic and vegetation characteristics at the Antelope Creek–Craig Creek distributary junction downstream of the Edwards Diversion Dam (Figure 2-8) largely control the distribution of flow (i.e., flow splits) between mainstem and distributary channels in lower Antelope Creek. Relatively small changes in channel morphology due to erosion or sedimentation and changes in roughness due to riparian vegetation establishment and growth, debris accumulation, and beaver activity at this location can have large effects on the flow split. Creating and maintaining conditions at this distributary junction that route baseflows to mainstem reaches with the best conditions for continuous fish passage during the low flow period (April through October) is critical to effective instream flow management with efficient use of limit water.

The most cost-effective and environmentally benign approach to achieving desirable flow splits at this distributary junction is to periodically maintain conditions in the mainstem channel and high flow channel entrances. A channel maintenance program would include a monitoring protocol and schedule, a decision framework based on monitoring results and associated hydraulic analyses, and a suite of appropriate permitted channel maintenance actions. The need for channel maintenance would be determined based on a schedule of periodic monitoring. Periodic monitoring would occur during minimum passage flows in the spring in years with large, bed-mobilizing flow events (i.e., a 2-year flood recurrence or greater lasting at least 6 hours). Periodic monitoring would include inspection of flow splits into distributary channels, channel morphology, riparian vegetation, and debris accumulation in the mainstem channel and high flow channel entrances. If an initial assessment indicates that a greater proportion of mainstem flow routes into distributaries than occurred when instream flows were established, a channel topographic survey would be conducted with an RTK GPS and total station to document changes in the elevations of hydraulic controls, bar forms, and other features influencing local hydraulics. Topographic surveys would need to extend at least 500 feet (150 m) upstream and downstream of the junction in the mainstem channel and a similar distance down the two high flow channels. The new topographic data would be used to update the existing computational mesh, and the existing hydraulic model (refer to Section 4.1.3) would be used to simulate current flow splits over the range of baseflows during adult and juvenile spring-run Chinook salmon migration and juvenile steelhead emigration (April through June). A determination of what channel changes may be necessary to restore the desired flow splits would then be made based on field observations and hydraulic modeling results. Channel maintenance may include (1) excavating any increased quantity of stored sediment and shaping the channel to achieve desirable bed elevations and channel geometry, (2) selectively managing riparian vegetation growing on the channel bed and banks in the vicinity of the junction, and (3) modifying or removing beaver dams and other accumulated debris, as needed. The level of anticipated periodic channel maintenance could likely be achieved with an excavator operating over a period of 1 to 3 days. An appropriate entity would need to be identified to conduct monitoring, determine required maintenance activities, and conduct channel maintenance work.

An engineered structure, such as a fixed or adjustable weir, could also be constructed to establish a more permanent hydraulic control in the vicinity of the overflow channel entrances at the Antelope Creek-Craig Creek distributary junction. An engineered approach may reduce the need for long-term maintenance but would require more detailed topographic, hydraulic, and geotechnical analyses to develop a design that (1) optimizes baseflow routing to desired locations, (2) allows unimpeded flood conveyance in all existing mainstem and distributary channels without increasing the frequency or extent of flooding, (3) maintains long-term continuity in sediment transport in the vicinity of the distributary junction, and (4) minimizes potential environmental impacts. The preliminary survey work and hydraulic modeling analyses at the Antelope Creek–Craig Creek distributary junction suggest that an engineering approach to establishing permanent hydraulic controls may not be justified if instream flows required for mainstem passage do not exceed 60 cfs, the discharge at which appreciable flow begins moving out of bank and into distributary channels.

5.3.3 Distributary channels

A number of persistent channel-spanning beaver dams and reaches with shallow, intermittent flow currently prohibit or limit fish passage in distributaries (i.e., New Creek, Antelope Creek downstream of the Antelope Creek–Craig Creek distributary junction, and Butler Slough) during the adult and juvenile spring-run Chinook salmon and juvenile steelhead migration periods. These channels intermittently convey high flows for brief periods during the winter runoff season from December through March (refer to annual hydrographs and flow duration curves for NEW, ACK, and BTS in Appendix G), during which time adult and juvenile fish may migrate through all or a portion of these channels. Adult steelhead are the most likely anadromous salmonid species and life stage to use these migration corridors during winter high flows, although no information is available to assess how many, how often, or under what flow conditions adult steelhead use them. High flow in these reaches typical occurs for short periods (e.g., a few days up to a week), and fish have a high potential of becoming stranded between impassable reaches when the flood hydrograph recedes. Edwards Diversion Dam passes the majority of unimpaired flow outside the irrigation season and has little or no effect on the magnitude, timing, or duration of winter high flows in these channel reaches. There is therefore little opportunity to effectively manage instream flows to improve conditions for fish passage in these reaches during these time periods.

Flow and temperature in distributary channel reaches during April through October is typically insufficient to provide conditions for continuous fish passage to the Sacramento River (Table 4-10, Appendix G). Adult and juvenile Chinook salmon and juvenile steelhead are far more likely to migrate in mainstem reaches (Antelope Creek upstream of the Antelope–Craig Creek junction and Craig Creek from the junction to the Sacramento River) that convey the majority of the baseflow, provide better habitat, and have cooler temperatures during this time period. Antelope Creek above the diversion does not provide sufficient unimpaired flow nor does the size of the impoundment at Edwards Diversion Dam provide sufficient storage capacity to effectively manage instream flows to improve conditions for fish passage in distributary reaches during these time periods.

In addition, numerous existing barriers (i.e., persistent, channel-spanning beaver dams and reaches with shallow, intermittent flow) that currently limit or prohibit fish passage in distributaries during low flows would require treatment and ongoing maintenance and monitoring. In some cases, it may be possible to modify existing channel morphology to create an inset channel with a width-to-depth ratio more suitable for fish passage during low flow. An example of this approach exists in Reach 3 of Antelope Creek immediately downstream of barrier A5 (Appendix C, Figure C-69), where an inset channel was excavated within a wide and shallow plane bed reach to concentrate low flow and increase flow depths. This approach is potentially applicable in Reaches 2 and 3 of Antelope Creek and Reach 1 of Butler Slough where channel segments with plane bed morphology have wide and shallow low flow conditions that limit fish passage but otherwise have adequate flow for passage and no other barriers. Four sites in Reaches 2 and 3 of Antelope Creek and 2 sites in Reach 1 of Butler Slough have shallow, intermittent flow potentially limiting fish passage (Figure 3-3, Tables 3-4 and 3-5). These reaches, however, are typically bedrock channels that would be difficult to excavate, have numerous beaver dams that limit passage, and substantial lengths of dry channel in downstream reaches (e.g., Reach 2 of Butler Slough) that would require flow augmentation to provide minimum depths necessary for passage. Construction of low-flow channels may be an effective measure to locally improve passage in some discrete reaches, but large-scale channel modification by itself would not be an effective or feasible means of providing longitudinally continuous fish passage in distributaries.

As many as 10 beaver dams potentially prohibit or limit fish passage in distributaries (six in Antelope Creek and four in Butler Slough) during the low flow period from April through October. To provide fish passage in these reaches, all of these dams would need to be modified, and beaver activity would need to be controlled. If all of the beaver dams were removed and the population of beavers controlled, flow augmentation would likely still be required to provide passage in some channel segments with intermittent flow. Beaver are native to the Sacramento River valley, and beaver dams were present in lower Antelope Creek prior to European settlement. Beaver dams create ponds that provide high quality rearing habitat for juvenile salmonids (if stream temperatures are suitable), support relatively diverse wetland and riparian ecosystems compared to the surrounding landscape, and can help moderate the effects of low flow by storing and slowly releasing surface water and groundwater to downstream reaches. Removing existing beaver dams would dewater the associated ponds that currently provide wetland and riparian habitat and high quality rearing habitat for juvenile salmonids and could exacerbate dry conditions in downstream channel reaches.

Development and implementation of a vegetation management plan could also improve channel morphology and habitat conditions that influence salmon and steelhead migration and use in lower Antelope Creek distributaries. Removal of dense stands of invasive riparian vegetation growing within the active channel of Antelope Creek and Butler Slough would reduce hydraulic roughness, increase conveyance capacity, and reduce chronic sedimentation that contributes to wide, shallow flow and in some cases subsurface flow. This measure would be most effective in Reach 4 of Antelope Creek. Planting native riparian vegetation to increase streamside cover and shading may help reduce summer stream temperatures, particularly in Reach 2 and 3 of Antelope Creek, Reach 1 of Butler Slough, and Reach 1 of Craig Creek. Connectivity between the Sacramento River and the lower reaches of Antelope Creek and Butler Slough could be improved by creating open water corridors through the existing dense mattes of invasive aquatic vegetation. Removal of invasive, non-native species could also benefit other species and ecosystem processes.

In summary, there is little opportunity to improve fish passage conditions in distributary reaches by managing instream flows during low flow periods. There is limited opportunity, however, to improve the quality and continuity of spring and summer rearing habitats by modifying channel morphology and managing riparian vegetation on a local scale in select reaches. It would also be valuable to understand under what conditions steelhead typically utilize these channels during higher flows, and selectively maintain and/or modify channel morphology at site-specific locations to ensure that passage conditions are met during these times over a range of water year types.

5.4 Monitoring

It's imperative that an effectiveness monitoring program be established in lower Antelope Creek to simultaneously collect streamflow, temperature, and observations of fish movement (e.g., video or acoustic monitoring at Edward Diversion Dam) during migration periods. These data are necessary to correlate observations of successful fish movement in response to instream flow conditions and to effectively manage instream flow conditions during migration periods. To the extent possible, real-time access to flow, temperature, and fish movement information over a three to five year effectiveness monitoring period would allow diverters and resource agency staff to fine-tune the timing, magnitude, and duration of instream flow releases to optimize passage conditions with efficient use of limited water resources. Long-term records of flow, temperature, and run timing can be used to evaluate the effectiveness of flow management actions on Chinook salmon and steelhead populations. Much of the instrumentation required for this monitoring is in place, with data collection underway.

Seven gages were established in lower Antelope Creek in 2012 with the objective of characterizing streamflow and temperature conditions in mainstem, tributary, and distributary channels during the adult and juvenile spring-run Chinook salmon migration and steelhead emigration periods (Stillwater Sciences 2014). The California Department of Fish and Wildlife and their partners continued operation of four sites during WY 2014 (Figure 5-2). These four priority stations measure streamflow and stream temperature in mainstem Antelope Creek upstream of the Edwards Diversion Dam (UAC), mainstem Antelope Creek downstream of the dam at Cone Grove Park (ACG), Craig Creek at State Route 99 (CRC), and the Antelope Creek distributary at Kauffman Avenue (ACK).

Figure 5-3. Antelope Creek streamflow monitoring sites.

An application has been submitted to the Integrated Watershed Management Program for funding to continue operation of the four gaging stations that monitor streamflow and stream temperature in the lower Antelope Creek channel network. The existing ACG gage will be relocated to a suitable location within the approximately 0.75-mile reach immediately downstream of the dam and upstream of the Little Antelope Creek confluence. Relocation of the existing ACG gage, made possible by access through the Edwards Ranch, will enable more accurate measurement of flow releases into the mainstem channel at the diversion dam without the confounding influence of accretion from Little Antelope Creek. The existing UAC gage, located upstream of the dam in the vicinity of the former USGS gage site, and the site relocated downstream of the dam will be upgraded with more permanent infrastructure (e.g., stilling well, intake piping, walkway, pressure transducer, and data logger) and radio telemetry equipment for real-time data transmission. The project will support operation of these two stations, along with the existing CRC and ACK stations, during WY 2016 and WY 2017. Operation will include maintaining the stations, conducting discharge measurements, updating rating curves, performing QAQC on the data collected, computing discharge records, and preparing related documentation. Flow and temperature monitoring will support improved accuracy, precision and timing of irrigation diversions as well as assessment of the influence of flow and stream temperature on run timing, site-specific hydraulic analysis at instream flow study sites, and determination of flow thresholds (e.g., bed mobilizing flow) for evaluating periodic channel maintenance requirements.

CDFW has intermittently operated video monitoring equipment at Edwards Diversion Dam since 2007 to count adult salmon and steelhead escapement, better understand run timing, and ultimately improve water management for anadromous fish passage (M. Johnson, CDFW, pers. comm., 2014). A Section 1602 Streambed Alteration Agreement issued to Edwards Ranch in 2013 required reinstatement of video monitoring at the diversion dam over a five year period from 2013 to 2018. Video monitoring equipment was reinstalled on 15 October 2013 and ran through 30 June 2014. Monitoring was reinstated on 14 October 2014, but was damaged by high flows on 6 December 2014 (M. Johnson, CDFW, pers. comm., 2014). Since video monitoring will be implemented at Edwards Diversion Dam through 2018, there are tremendous advantages to continuing coincident flow and temperature monitoring at existing sites in lower Antelope Creek upstream and downstream of the diversion during this period. This five year monitoring period would likely describe a reasonable range of conditions to sufficiently evaluate the effectiveness of instream flow management practices intended to improve passage conditions for adult and juvenile salmon and steelhead in lower Antelope Creek.

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