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1 Recommendations of flow and Water Temperature for
2 Chinook Salmon and Steelhead in Clear Creek, California

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10 Revised Draft
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EXECUTIVE SUMMARY

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The 35-mile long Clear Creek, a tributary to the Sacramento River, is located near Redding, California. Clear Creek, historically supported spring-run and fall-run Chinook salmon (*Oncorhynchus tshawytscha*) and steelhead trout (*O. mykiss*), has been severely degraded over the past 150 years, particularly since 1912 when McCormack-Saeltzer Dam was built (the dam was removed in 2000) and 1963 when Whiskeytown Dam was built. These dams not only blocked fish from accessing the upper Clear Creek, but also reduced flow. Operations of Whiskeytown Dam essentially eliminated flow conditions that flush silt from gravel, deposit new spawning gravel, facilitate timely juvenile out-migration, attract adult salmon into the stream, and prevent riparian vegetation encroachment. The operations also caused summer low flows in the creek that resulted in harmful temperatures for spring-run Chinook spawning adult and their eggs, and possibly for immigrating steelhead adult and rearing juveniles. Both spring-run Chinook and steelhead are listed as threatened species under the Endangered Species Act. Spring-run Chinook were extirpated from Clear Creek for 30 years until they were reintroduced in the early 1990s.

Protecting and recovering threatened spring-run Chinook and steelhead from extinction in Clear Creek requires the restoration of populations to sustainable levels. To help achieve the goal, it is necessary to take the following actions: 1) Operating Whiskeytown Reservoir to provide flows mimicking natural flow patterns, which the species have evolved from and adapted to; 2) Providing adequate water temperatures for various life stages of the species; 3) Providing suitable and sufficient physical habitat for spawning and rearing; and 4) Monitoring responses from the actions and making adjustments accordingly.

This report discusses fundamental principles that underpin these proposed actions and describes comprehensive approaches for developing flow regime, managing water temperature, and enhancing physical habitat for all salmonid species in Clear Creek. Although the focus of the report is on Clear Creek, the principles and approaches described in this report are applicable to other watersheds.

Stream flow and temperature are critical factors in the protection and recovery of endangered or threatened anadromous fish species. These factors are interrelated as temperature is often controlled by streamflow, particularly in rivers regulated by reservoirs. Streamflow in Clear Creek has changed considerably as a result of flow regulation by Whiskeytown Dam. The pre- and post-dam streamflow data (from water year 1941 to 2009) in Clear Creek were analyzed to assess flow magnitude, frequency, timing, duration, and change of rates using the Indicator of Hydrological Alteration method. The 1-day median maximum flows decreased from 5000 cfs for the pre-dam period (1941-1960) to 1500 cfs for the post-dam period (1963-2009), and the 7-day median maximum flows decreased from 2800 cfs for the pre-dam period to 700 cfs for the post-dam periods. There were 21 small floods (about 7000 cfs) for the pre-dam period, occurring once a year on average, whereas only 6 small floods for the post-dam period, occurring once every 8 years on average.

1 The flow regime approach was used to develop flows required for anadromous fish. The
2 approach recognizes that biologically relevant flows can't be defined by flow magnitude alone.
3 The frequency, timing, duration, and rate of change of flows are also biologically important.
4 However, this does not mean to restore the pre-dam hydrology of Clear Creek; rather it is to
5 mimic the pattern of the pre-dam hydrology. The important features of a flow pattern include
6 baseflow and functional flow. The baseflow occurs after a rainfall event or snowmelt period has
7 passed and associated surface runoff from the catchment has subsided. The seasonally varying
8 baseflow in a river imposes a fundamental constraint on river's aquatic communities because it
9 determines the amount of aquatic habitat available for most of the year. Functional flows are
10 required for maintaining or improving important ecosystem functions, for example, migration
11 cues, habitat connectivity and diversity, and stream channel morphology and geometry.
12 Combining baseflows with functional flows provides seasonal and interannual variability, to
13 which anadromous fish species have evolved and adapted.

14
15 The flow developed from the flow regime approach is incomplete if water temperature
16 requirements for listed fish species are not considered. Water temperature influences growth and
17 feeding rates, metabolism, development of embryos and alevins, timing of life history events,
18 and the availability of food. For protecting and recovering vulnerable populations, such as
19 endangered or threatened fish species, optimal water temperatures are needed for each of their
20 life stages. These optimal temperatures serve as the base of setting water temperature criteria for
21 the listed species. Flows for sustaining optimal water temperatures are particularly important in
22 warm seasons when flow is low and air temperature is high. Water temperature data in Clear
23 Creek were analyzed and compared with temperature criteria. Statistical methods were used to
24 develop flow-temperature models, which were used to estimate the flow required to meet the
25 established temperature requirements in Clear Creek.

26
27 The recommended environmental flow is the integration of the baseflow, the water temperature
28 sustaining flow, and the functional flow. Combination of the baseflow with the temperature
29 sustaining flow is referred to as instream flow. The recommended instream flows in Clear Creek
30 from November through May were based on the 50th, 75th, and 90th percentile baseflows, while
31 the instream flows from June through October were based on the 75th, 90th, and 95th percentiles
32 meeting water temperature requirements.

33
34 Functional flows include channel flushing flows and channel maintenance flows. The flushing
35 flow in Clear Creek is recommended to be about 700 cfs with a frequency of 2-3 times a year
36 from January to May. The duration of the flows would be 3-5 days with a rise rate of 200 cfs/day
37 and a fall rate of -100 cfs/day. This flow magnitude would allow the removal and transport of
38 fine sediments from riverbed. The channel maintenance flow in Clear Creek is recommended to
39 be about 6000-7000 cfs with a frequency of once every two or three years between January and
40 March. The duration of the flow may span 10 days with a rise rate of 1700 cfs/day, and a fall rate
41 of -1000 cfs/day.

42
43 Potential water costs were evaluated when the recommended environmental flows were
44 implemented in Clear Creek. The annual additional water use was about 23,000 acre feet for the
45 50th and 90th percentiles and 28,000 acre feet for the 75th percentile. If the additional water
46 allocated to Clear Creek goes directly to powerplants, it could generate, on average, hydropower

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1 of 1.54 to 1.85 MW (about 1% of the plant capacity of 180 MW) at Springs Creek Powerplant
2 and 0.22 to 0.26 MW (about 0.2% of the plant capacity of 117 MW) at Keswisk Powerplant.

3
4 The effectiveness of the recommended flow releases from Whiskeytown Reservoir in achieving
5 targeted benefits can only be realized through implementing the actions and consistent
6 monitoring. Implementation of actions and monitoring programs should occur in parallel. A
7 monitoring plan should include the collection and management of data for reservoir release,
8 streamflow, water temperature, stream morphology, weather conditions, and fish biology. The
9 information gained from monitoring are used to better refine flow recommendations for the
10 following season and inform recommendations for other management actions.

11
12

1 **1 Introduction**

2 Alterations to the natural hydrologic systems in the California’s Central Valley include the
3 construction of a number of dams or diversion structures. The upstream dams were generally
4 constructed with no ladders for fish passage, and anadromous fish have been blocked from
5 accessing the upper reaches of streams. As the upper stream reaches, serving as adequate
6 spawning and rearing habitat, are not available, the populations of salmonids including spring-,
7 fall-, and winter-run Chinook salmon and steelhead trout have declined dramatically in the area.
8

9 Clear Creek is a tributary to the Sacramento River originating in the Trinity Mountains between
10 the Trinity River and the Sacramento River watersheds. The 35-mile long creek historically
11 supported spring-run and fall-run Chinook salmon and steelhead trout. Clear Creek has been
12 severely degraded over the past 140 years of gold mining, gravel extraction, and dam
13 construction, which adversely changed the stream channel, fish habitat, and riparian conditions.
14 In 1912, McCormack-Saeltzer Dam was built on the creek to supply water for gold mining and,
15 later, agriculture. This dam made it impossible for Chinook salmon and steelhead to migrate
16 upstream for spawning (the dam was removed in 2000).
17

18 In 1963, Whiskeytown Dam was built on Clear Creek to provide hydroelectric power, flood
19 control, and municipal, industrial and agricultural water supply. Whiskeytown Dam not only
20 blocked fish from accessing the upper Clear Creek, but also dramatically reduced streamflow
21 downstream of Whiskeytown Reservoir. Operations of Whiskeytown Dam essentially eliminated
22 flow conditions that flush silt from gravel, deposit new spawning gravel, facilitate timely
23 juvenile out-migration, attract adult salmon into the stream, and prevent riparian vegetation
24 encroachment. The operations also caused summer low flows in the creek that resulted in
25 harmful temperatures for spring-run Chinook spawning adult and their eggs, and possibly for
26 immigrating steelhead adult and rearing juveniles. Both spring-run Chinook and steelhead are
27 listed as threatened species under the Endangered Species Act. In fact, spring-run Chinook were
28 extirpated from Clear Creek until they were reintroduced in the early 1990s.
29

30 Since 1992, the U.S. Bureau of Reclamation (USBR) and the U.S. Fish and Wildlife Service
31 (FWS) have worked cooperatively to implement the Central Valley Project Improvement Act
32 (CVPIA) in Clear Creek. Implementation of the CVPIA included increased streamflow, removal
33 of McCormick-Saeltzer Dam, gravel placement, erosion control, and channel restoration in the
34 lower reaches. Although these actions have helped increase the abundance of spring-run Chinook
35 salmon in Clear Creek, they are still at an abundance level that makes the population vulnerable
36 to extirpation from demographic stochasticity. As such, the population would fall into the high
37 risk of extinction category (NMFS 2009a).
38

39 Protecting and recovering threatened spring-run Chinook and steelhead from extinction in Clear
40 Creek requires the restoration of populations to sustainable levels (*e.g.*, double populations). To
41 help achieve the doubling goal, the following actions should be taken:
42

- 43 • Operating Whiskeytown Reservoir to provide adequate flows, mimicking natural flow
- 44 patterns, which the species have evolved from and adapted to,
- 45 • Providing adequate water temperatures for various life stages of the species,

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- Providing suitable and sufficient physical habitat for spawning and rearing, and
- Monitoring responses from the actions and making adjustments accordingly.

This report discusses fundamental principles to support for taking these actions and describes comprehensive approaches for developing flow regime, managing water temperature, and enhancing physical habitat for all three salmonid species in Clear Creek. The report also assesses the feasibility of taking the actions by analyzing water cost and infrastructure constraints. It is important to recognize that mimicking nature flow patterns does not mean restoring historical flows. The principles of the approaches described in this report are applicable to any other watersheds although the focus of the report is on Clear Creek.

1 **2 Clear Creek and Whiskeytown Reservoir**

2 **2.1 Clear Creek**

3 **2.1.1 Geography**

4 Clear Creek situates in the northwestern portion of the upper Sacramento River basin in
5 California. Clear Creek originates near 6,000 ft elevation in the Trinity Mountains, and flows
6 south between the Trinity River basin to the west and the Sacramento River basin to the east, and
7 into Whiskeytown Reservoir (elevation 1,210 ft) at Oak Bottom. It flows approximately 35
8 miles, with a drainage area of 238 square miles, until it meets the Sacramento River (**Figure 1**).
9

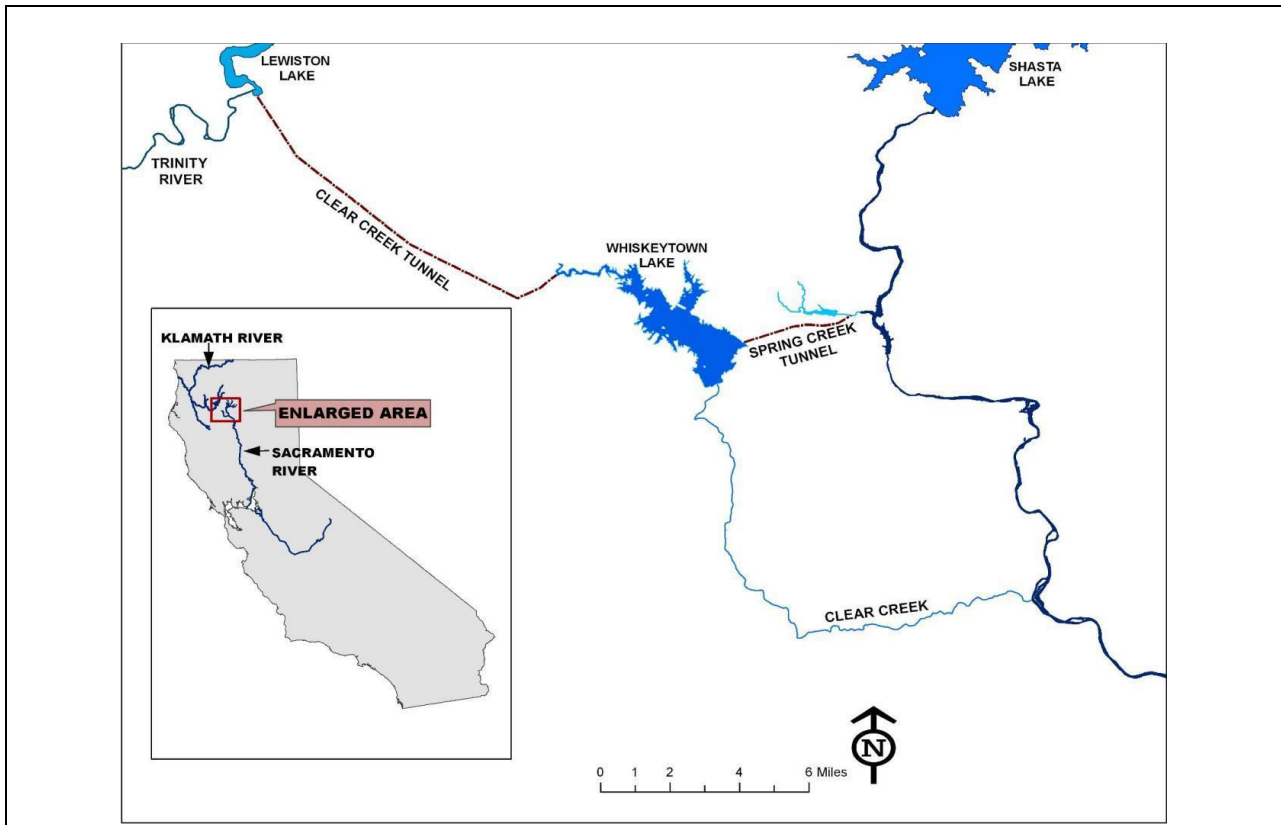


Figure 1. Map showing Clear Creek, Whiskeytown Reservoir, and vicinity (After Matt Brown 2010)

10
11 Average annual precipitation in the Clear Creek watershed varies from 20 inches near the
12 confluence with the Sacramento River to more than 60 inches in the upper watershed. Most
13 precipitation falls into this watershed as rainfall. Most of the watershed's rainfall occurs between
14 November and April, with little or none occurring during the summer months. The ambient air
15 temperatures range from approximately 32°F (0°C) in winter to summer highs in excess of 115°F
16 (46°C).

17
18 The maximum watershed elevation is approximately 6,000 ft, but a majority of the watershed
19 area is below the 4,000 ft snow line, so high flow hydrology is driven by rainfall and rain-on-

1 snow events, which typically occur during the winter months. The unimpaired snowmelt
2 hydrograph is small in magnitude; the snowmelt peak is typically less than 1,500 cfs.
3 Unimpaired summer/fall baseflows were low because the imperviousness of the Klamath
4 Mountains terrain minimizes shallow and deeper groundwater storage to the point where no
5 significant springs exist to maintain high baseflows. This imperviousness, combined with
6 periodic high intensity rainstorms, results in extremely flashy streamflow response to rainfall
7 events.

8
9 The lower portion of Clear Creek, starting at Whiskeytown Dam at river mile 18.4, flows south
10 before changing direction and flowing east approximately 8.5 miles upstream of the Sacramento
11 River confluence. The drainage area between Whiskeytown Dam and the confluence with the
12 Sacramento River is 49 square miles (**Figure 1**). “Clear Creek” used in this report refers to the
13 lower portion of the creek downstream of Whiskeytown Dam.

14
15 Separated at the Clear Creek Road Bridge, the upper and lower reaches of the creek are
16 geologically distinct (Giovannetti and Brown 2008). The upper reach flows south from
17 Whiskeytown Reservoir almost 10 miles. The stream bedrock in the upper reach is composed
18 primarily of Paleozoic to Mesozoic igneous, metasedimentary, and metamorphic rocks that are
19 largely resistant to erosion. The stream is more constrained by canyon walls and a bedrock
20 channel and has a higher gradient, less spawning gravels, and greater pool depths than the lower
21 portion of Clear Creek.

22
23 The lower reach flows in an easterly direction to the Sacramento River for approximately 8.4
24 miles. The stream bedrock in the lower reach is composed of sedimentary rocks that are much
25 less resistant to erosion. The stream meanders through a less constrained alluvial flood plain, and
26 has a lower gradient, more spawning gravels, and fewer deep pools (Giovannetti and Brown
27 2008).

28 **2.1.2 Changes of Fish Habitat in Clear Creek**

29 In 1848, gold was first discovered in Shasta County. Through the 1940s, placer, hydraulic, and
30 dredge mining significantly altered the lower Clear Creek watershed. The dredging process
31 significantly disturbed floodplains and terraces and removed all riparian and upland vegetation
32 along the corridor as prospectors searched for gold. Piles of dredger tailings were left along the
33 corridor and are still seen today, confining Clear Creek in some locations, and, in other locations,
34 discouraging the natural recovery of riparian and upland plant species.

35
36 Through the mid-1980s, commercial instream gravel mining in the lower reaches of Clear Creek
37 removed most of the gravel (several hundred thousand cubic yards) within a 1.8-mile reach. An
38 additional 1-mile reach was significantly altered by disposal of dredger tailings. Impacts to
39 channel morphology and salmonid habitat were significant. The bankfull channel was destroyed
40 and floodplains removed, leaving wide, shallow channels and interspersed deep pits. Excessive
41 gravel removal exposed a clay hardpan over much of the channel bottom, directly removing
42 salmonid spawning and fry-rearing habitat. Equally important was the lost channel confinement,
43 allowing both adult and juvenile salmonids to stray into adjacent pits and be stranded.

1 Historically, there were about 347,000 ft² of spawning habitat from Whiskeytown Dam to
2 [former] Saeltzer Dam in Clear Creek as surveyed in 1956 (pre-Whiskeytown Dam). It was
3 decreased to about 29,000 ft² of habitat in 1971, indicating a 91% reduction. In 2000, the same
4 reaches were revisited and 98% of the gravels that were present in 1956 were gone. Previously
5 classified spawning habitat was replaced by stretches of unproductive coarse sand deposits, due
6 to the reduced gravel carrying capacity of the stream and accelerated erosion and sediment
7 delivery by tributaries (*i.e.*, Paige Boulder Creek and South Fork Clear Creek). Sediment supply
8 from Paige Boulder Creek is primarily decomposed granite as coarse sand, which accounted for
9 30% in 1971, comparing with 50% in 1997 and 1998 (McBain *et al.* 2001).

10

11 **2.2 Whiskeytown Reservoir**

12 The reservoir, about 8 miles west of Redding, has a capacity of 241,100 acre feet with a surface
13 area of 3,458 acres. Construction of the earth-fill dam - 263 feet tall - began in 1959 and was
14 completed in 1963. President John F. Kennedy dedicated Whiskeytown Dam on September 28,
15 1963 before a crowd of over 10,000 people. He spoke briefly of the development of the
16 American West and the significance of Whiskeytown Dam and its relationship to the Central
17 Valley Project. The reservoir is owned and operated by USBR. Its purpose is to provide flood
18 control, irrigation, electricity generation, and fish and wildlife benefits (pursuant to CVPIA).
19 There are also recreational activities available including camping, swimming, boating, water
20 skiing, and fishing.

21

22 A majority of the reservoir water comes from Lewiston Reservoir supplied by the Trinity River
23 downstream of Trinity Lake. Before entering Whiskeytown Reservoir through the Clear Creek
24 Tunnel, the water generates hydroelectricity at the 184-MW Judge Francis Carr Powerplant. A
25 large portion of the Reservoir water leaves through the Spring Creek Tunnel, which delivers the
26 water to the 180-MW Spring Creek Powerplant, whose tailrace empties into Keswick Reservoir.
27 The 117-MW Keswick Powerplant at Keswick Dam empties into the Sacramento River (USBR
28 2004). There is no powerplant on Whiskeytown Dam. The outlet at the bottom discharges water
29 to Clear Creek at rates up to 1200 cfs and also supplies the City of Redding drinking water.

30

31 Whiskeytown Dam entirely blocked fish from accessing the upper stream and dramatically
32 altered hydrology downstream of Whiskeytown Reservoir. Furthermore, the reservoir, acting as a
33 sediment (gravel) trap, has starved the lower Clear Creek of its gravel. Combined with years of
34 gravel and gold mining below the dam and channel scouring by high flows, sediment starvation
35 has limited the amount of gravel available to spawning salmonids for building redds. In some
36 areas of the Clear Creek channel only clay hardpan or bedrock remains.

37

38 In addition, the 15-foot-tall and 200-foot-long McCormack-Saeltzer Dam was built in 1912
39 approximately 10 miles downstream of the Whiskeytown Dam to supply water for gold mining
40 and, later, agriculture. Despite efforts to provide access to 10 miles of upstream spawning habitat
41 using fish ladders and fish tunnels, the dam remained essentially impassable to salmonids. To
42 restore fish access to the reach between Saeltzer and Whiskeytown Dams, Saeltzer Dam was
43 removed in 2000 (Ferry and Miller 2003).

44

45

3 Anadromous Salmonids in Clear Creek

Clear Creek supported populations of fall-run (including late fall-run) and spring-run Chinook salmon and steelhead trout. Life history adaptations and different spatial distributions allowed these runs to utilize the entire watershed to the fullest extent possible. The cumulative effects of gold mining, dams, gravel extraction, timber harvest, land development, and roads in the Clear Creek watershed have led to loss of suitable habitat and degradation of stream channel and riparian conditions and contributed to the continuous decline of the Clear Creek salmonids. Spring-run Chinook and steelhead have been impacted the most from flow alteration and habitat loss.

3.1 Central Valley Spring-run Chinook

Central Valley Spring-run Chinook salmon were listed as a threatened species on September 16, 1999 and the threatened status was reaffirmed on June 28, 2005. The ESU includes all naturally spawned populations of spring-run Chinook salmon in the Sacramento River and its tributaries in California, including the Feather River, as well as the Feather River Hatchery spring-run Chinook program.

It was estimated that the Central Valley had supported spring-run Chinook salmon as large as 600,000 fish between the late 1880s and 1940s (CDFG 1998). The median population of spring-run from 1986 to 2007 was 10,652, with two thirds from independent populations (NMFS 2009a). Of the 19 independent populations of spring-run that occurred historically, only three remains in Deer, Mill, and Butte Creeks, respectively. The populations in other tributaries (*e.g.*, Battle, Antelope, Big Chico Creeks, and Feather River) and the mainstem Sacramento River below Keswick Dam are considered dependent populations, which rely on the three independent populations for continued existence at this time (NMFS 2009a).

In 1998, the population estimate on Butte Creek was between 18,742 and 20,259 salmon; in 1999 it was between 3,529 and 3,679 (CDFG 2000a). In 1998 at Deer Creek, the population was estimated at 1,879 adult spring-run salmon; in 1999 there were an estimated 1,591 spring-run salmon. Mill Creek had a population estimate of 424 salmon in 1998 and 560 in 1999. Big Chico Creek had a population estimate of 369 salmon in 1998 and 27 in 1999.

After 30 years of extirpation of spring-run Chinook salmon from Clear Creek, 35 spring-run adults reappeared in 1999 in the lower reaches of the creek. The adult counts showed an increasing trend from 1999 to 2008 (Giovannetti and Brown 2009) but decreased after 2008 and plunged to a low level in 2010 (**Figure 2**). Both redd and carcass counts appeared increasing from 2003 to 2008. The juvenile population for spring-run Chinook, ranging from 110,000 to 150,000 (Earley *et al.* 2010), showed a pattern similar to the redd counts (**Figure 2**). The population of spring-run Chinook in Clear Creek is considered at high risk of extinction (NMFS 2009a; NMFS 2009b).

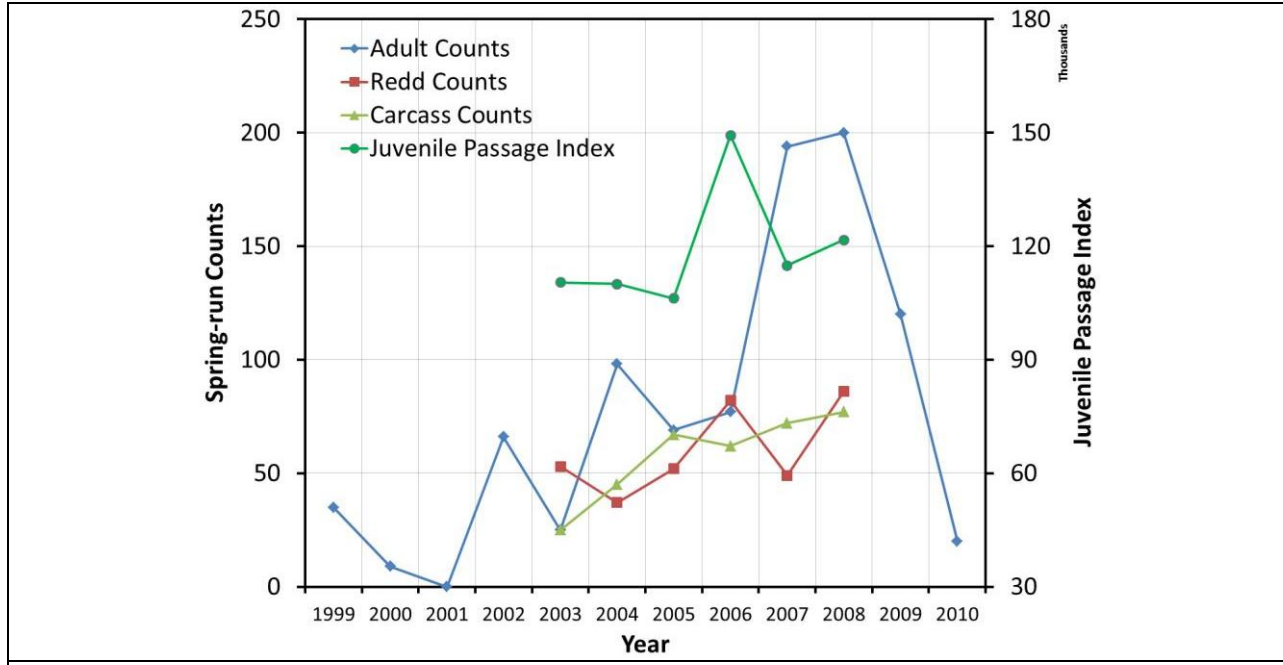


Figure 2. Estimated yearly number of spring-run Chinook adults, carcasses, redds, and juveniles in Clear Creek

1
 2 Spring-run Chinook salmon exhibits a stream-type life history. Adults enter freshwater in the
 3 spring, hold over the summer, spawn in the fall, and juveniles typically spend a year or more in
 4 freshwater before emigrating (**Figure 3**). Adult spring-run salmon leaves the ocean to begin their
 5 upstream migration in late January and early February and enters the Sacramento River between
 6 March and September, primarily in June and July. They utilize mid- to high-elevation streams
 7 that provide appropriate temperature, sufficient flow, cover, and pool depth to allow for over-
 8 summer holding (from May through September) while conserving energy and allowing their
 9 gonadal tissue to mature.

10
 11 Spring-run salmon spawning occurs between September and October depending on water
 12 temperature. Fries emerge on the gravel bed from November to March. The fries seek areas of
 13 shallow water and low velocities while finishing absorbing the yolk sac and transition to
 14 exogenous feeding. Many also will disperse downstream during high-flow events. Spring-run
 15 juveniles may rear over a year in natal streams or the lower reaches of non-natal tributaries in the
 16 Sacramento River watershed. As they grow larger, juveniles tend to use microhabitats with
 17 heavy cover and deeper water.

18
 19 The outmigration period for spring-run juveniles extends from November to April. It was
 20 observed that up to 70 percent of the young-of-year (YOY) fish emigrated through the lower
 21 Sacramento River and Delta during this period. The peak movement of the juveniles at Knights
 22 Landing in the Sacramento River occurs in December for yearlings, and in March and April for
 23 YOY (NMFS, 2009; (NMFS 2009b).

24

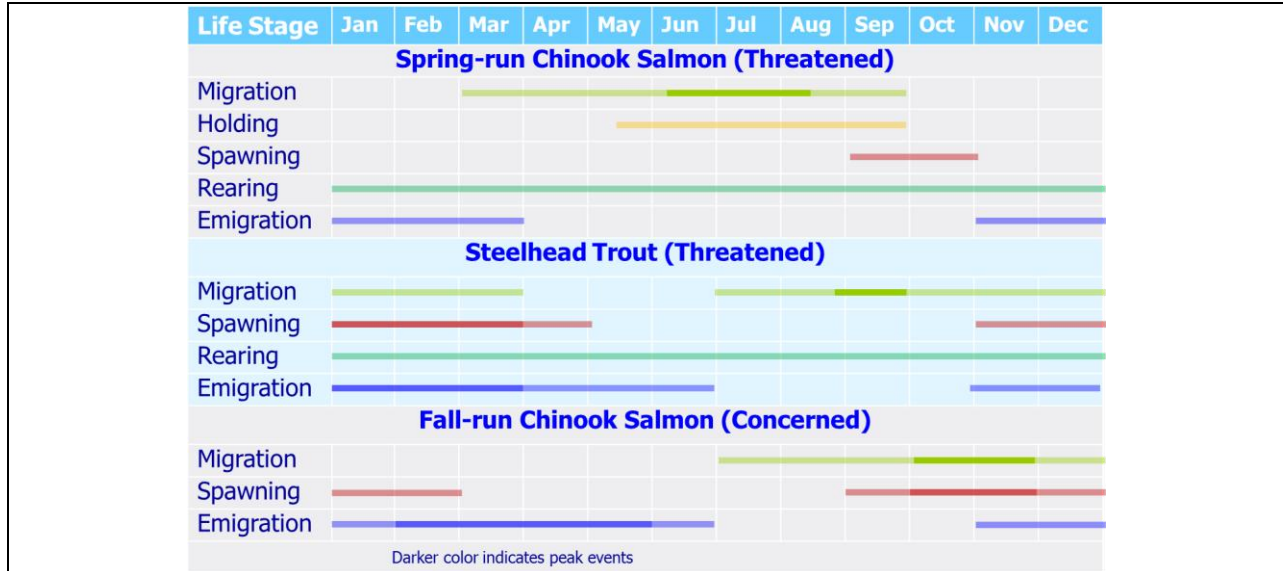


Figure 3. Life history of spring-run and fall-run Chinook and steelhead in Clear Creek

1

2 **3.2 California Central Valley Steelhead**

3 California Central Valley steelhead were listed as a threatened species on March 19, 1998;
 4 threatened status reaffirmed on January 5, 2006. This Distinct Population Segment (DPS)
 5 includes all naturally spawned anadromous steelhead populations below natural and manmade
 6 impassable barriers in the Sacramento and San Joaquin Rivers and their tributaries, excluding
 7 steelhead from San Francisco and San Pablo Bays and their tributaries, as well as two artificial
 8 propagation programs: the Coleman National Fish Hatchery and the Feather River Fish
 9 Hatchery.

10

11 The population numbers returning to the Red Bluff Diversion Dam fish ladders had decreased
 12 substantially since 1966. In the late 1960's, roughly 20,000 fish passed through the fish ladders;
 13 in 1994, only 2,000 returned. These statistics include hatchery fish from the Coleman National
 14 Fish Hatchery. The average estimated spawning population size above the mouth of the Feather
 15 River in the Sacramento River system was 20,540 fish in the 1950's. In 1991-1992, the annual
 16 run size for the total Sacramento River system was likely less than 10,000 adult fish (Butte
 17 County Association of Governments (BCAG) 2011a).

18

19 In Clear Creek, steelhead redd counts showed an increasing trend from 2003 to 2010
 20 (Giovannetti and Brown 2010) (**Figure 4**) although there were no adult counts available. Only a
 21 few carcasses were identified from 2003 to 2009. The juvenile population seemed increasing
 22 from 1999 to 2009 (Earley *et al.* 2010), following a similar pattern to the redd counts.

23

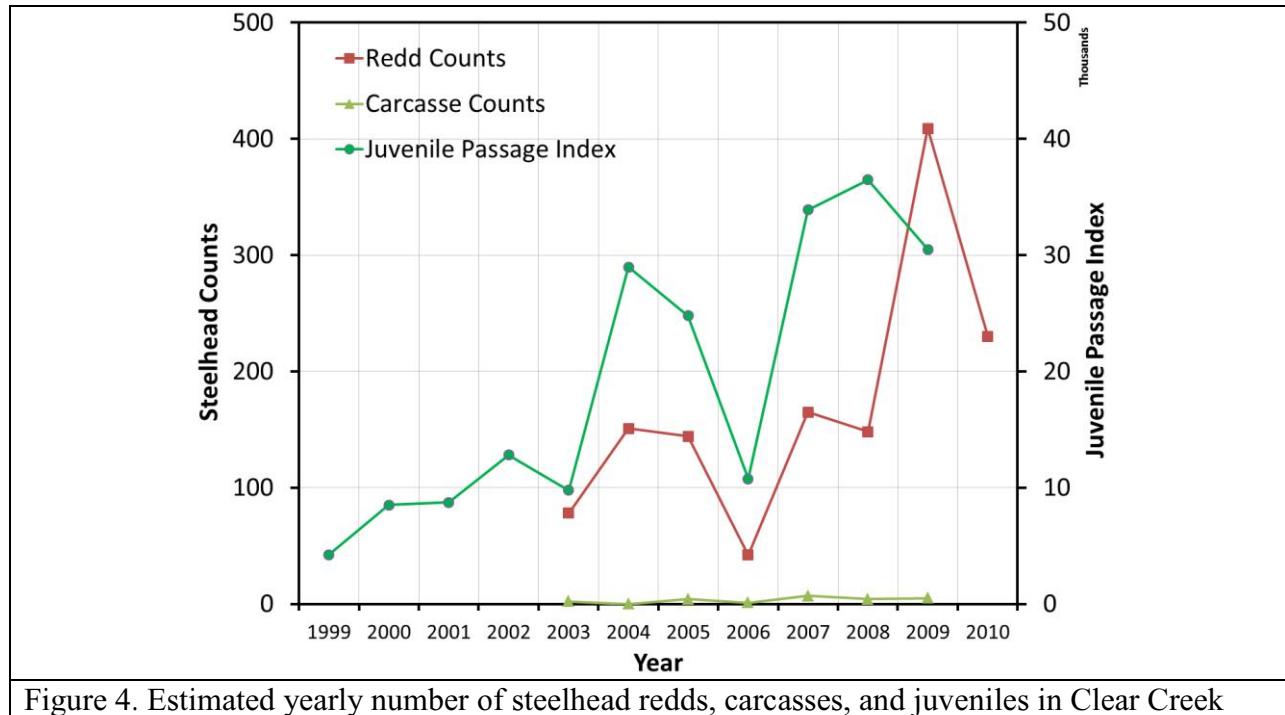


Figure 4. Estimated yearly number of steelhead redds, carcasses, and juveniles in Clear Creek

1
2 Adult steelhead enter freshwater in fall and winter (September to December) and spawn in winter
3 (January to March) (Figure 3). After eggs hatch, fry emerge from the gravel in late May to early
4 June. Juvenile steelhead often move to deeper water as they grow and will remain in freshwater
5 for an average of 2 years before migrating to the ocean, which usually occurs from November to
6 April.

7
8 The peak migration into the upper Sacramento River above the mouth of the Feather River from
9 1953 to 1959 was in late September. Adult counts at Clough Dam on Mill Creek for a 10-year
10 period beginning in 1953 indicated that the peak of adult migration into that stream occurred in
11 late October, with a smaller peak about mid-February. Examination of adult steelhead counts at
12 Red Bluff Diversion Dam indicates that run timing on the upper Sacramento River does not
13 appear to have changed appreciably: adult counts from 1969 to 1982 also show this same pattern,
14 as do counts from 1983 to 1986 (McEwan 2001).

15
16 Juvenile steelhead migrated downstream during most months of the year, but the peak period of
17 emigration occurred in spring, with a much smaller peak in fall. The emigration period for
18 naturally spawned steelhead juveniles migrating past Knights Landing on the lower Sacramento
19 River in 1998 ranged from late December through early May, and peaked in mid-March. Most
20 naturally-produced Central Valley steelhead rear in freshwater for two years before emigrating to
21 the ocean. Scale analysis indicated that 70% had spent two years in freshwater before emigrating
22 to the ocean, 29% had spent one year, and 1% had spent three years (McEwan 2001).

23
24 Photoperiod, stream flow, and temperature appear to influence emigration timing. Juvenile
25 steelhead may spend several weeks in the coastal lagoon or estuary of a stream before entering
26 the ocean. They reside in the ocean for 2 to 3 years before returning to their natal stream to
27 spawn, although in wet years steelhead may return to spawn after only one year in the ocean.

1 The adults can spawn more than once, although most do not spawn more than twice (McEwan
2 2001).

4 **3.3 Central Valley Fall-run Chinook**

5 Central Valley fall-run Chinook were classified as a Species of Concern on April 15, 2004 due to
6 specific risk factors. The ESU includes all naturally spawned populations of fall-run Chinook
7 salmon in the Sacramento and San Joaquin River Basins and their tributaries, east of Carquinez
8 Strait, California.

9
10 Fall-run Chinook salmon in the Sacramento River have been artificially propagated in hatcheries
11 and released into the rivers and bays since 1872. In the last 50 years, 1.6 billion fall-run fish have
12 been released from hatcheries into Central Valley waterways. State hatcheries on the American
13 and Feather rivers now transport young fish to salt water to avoid mortality in the Delta, but it is
14 thought that this increases straying of adults when they return to spawn (Butte County
15 Association of Governments (BCAG) 2011b).

16
17 Fall-run Chinook salmon are the most abundant run in the Central Valley. From 1981 to 2010,
18 in-river (non-hatchery) adult escapement averaged 240,971 per year. Escapement peaked in 2002
19 (766,668 individuals) and declined to historical lows in 2009 (30,426 individuals). In 2010, in-
20 river adult escapement was estimated at 111,455 fish (Butte County Association of Governments
21 (BCAG) 2011b).

22
23 In Clear Creek, fall-run Chinook abundance has fluctuated widely since 1951, from an estimated
24 10,000 adults in 1963 to fewer than 100 fish in 1978, but has generally been the most abundant
25 run in Clear Creek. Three of the latest five years have exceeded the fall-run Chinook salmon
26 escapement target of 7,100 adults set by the Anadromous Fish Restoration Program (McBain *et*
27 *al.* 2001). Fall-run redd counts increased from 2000 to 2005 (Gard 2009) while juvenile
28 populations showed no appreciable changes from 1998 to 2008 except for 2000 when the
29 population peaked (about 15 millions) (Earley *et al.* 2010) (**Figure 5**).

30
31 Fall-run Chinook enter the Sacramento and San Joaquin Rivers from July through December and
32 spawn from September through February. They generally utilized mainstem habitats for
33 spawning and rearing during fall through spring. Juveniles emigrate as early as in November
34 predominantly as fry and sub-yearlings and remain off the California coast during their ocean
35 migration.

36
37 Primarily fall-run Chinook salmon in the Sacramento River have been artificially propagated in
38 hatcheries and released since 1872. In the last 50 years, 1.6 billion fall-run fish have been
39 released in the Central Valley. State hatcheries on the American and Feather rivers now
40 transport young fish to salt water to avoid mortality in the Delta. This increases straying of
41 adults when they return to spawn.

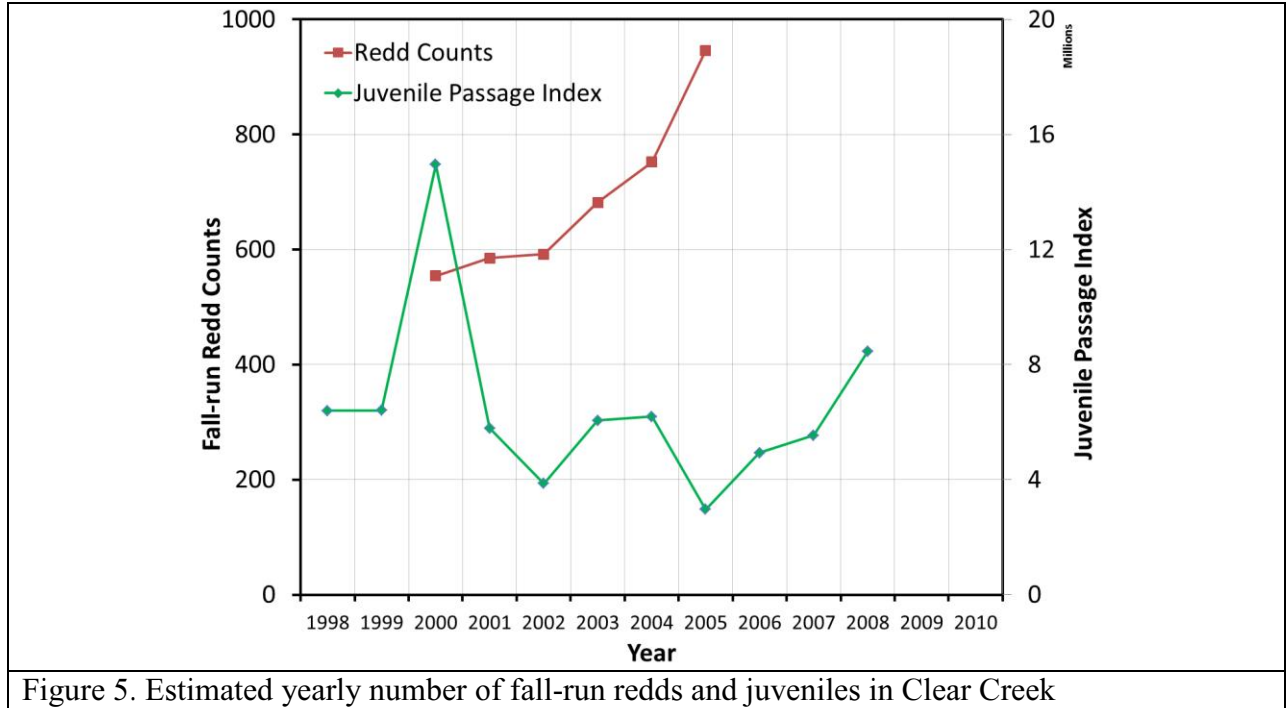


Figure 5. Estimated yearly number of fall-run redds and juveniles in Clear Creek

1
2

4 Streamflow for Salmonids

4.1 Hydrologic Alteration and Flow Regime

From the beginning of the 20th century, the construction of dams in the United States were prompted by promises of cheap electrical power and of transforming land into agriculturally fit regions through easy irrigation. There are estimated 75,000 dams, of which are 8,100 major dams¹ in the US in 2005. These dams blocked about 600,000 miles of what had once been free flowing rivers, which is about 17% of rivers in the nation.

There are about 1,400 federal and state jurisdictional dams in California. Approximately 200 of these fall under federal jurisdiction. Ten reservoirs have storage capacity greater than 1 million acre-feet, while 910 reservoirs have capacity less than 1 thousand acre-feet. These dams are owned and operated by a variety of entities including the USBR, US Army Corps of Engineers, California Department of Water Resources (DWR), cities, counties, individual water and power districts, private water and power providers, and individual landowners.

As river flows are depleted or otherwise altered, ecological degradation results and society loses benefits provided by healthy, functioning ecosystems, such as commercial and subsistence fisheries, water purification, flood storage, recreation and esthetic values (Poff *et al.* 1997). Dams block almost every major river system in the West. These dams and the growing diversion of water from rivers and streams posed a grave threat to aquatic life (Poff and Hart 2002; Poff *et al.* 2007). Many of these dams have destroyed important spawning and rearing habitat for salmonids. In some once productive salmon river systems (such as the Sacramento River), less than 5% of their original habitat is now still available to salmon (<http://www.pcffa.org/dams.htm>). In the Columbia River Basin, once the most productive salmon river system in the world, less than 70 miles of that once great river still remains free flowing (<http://www.pcffa.org/dams.htm>).

Dam construction and operation changed natural streamflow regimes, which adversely affected water temperature, chemistry, sediment transport, floodplain vegetation communities, downstream estuaries, deltas, and coastal zones. Dams can heavily modify the volume of water flowing downstream, change the timing, frequency, and duration of high and low flows, and alter the natural rates at which rivers rise and fall during runoff events (Richter and Thomas 2007). As summarized by Bunn and Arthington (Bunn and Arthington 2002), the ecological consequences of hydrologic alteration include the following:

- (1) Adversely changing physical habitats (*e.g.*, riffles, pools, and bars in rivers and floodplains) that determine the distribution, abundance, composition, and diversity of aquatic communities;
- (2) Leading to recruitment failure and loss of biodiversity of native species as aquatic species have evolved life history strategies (*e.g.*, timing of reproduction) in direct response to natural flow regimes;

¹ The National Inventory of Dams defines a major dam as being 50 feet (15 m) tall with a storage capacity of at least 5,000 acre-feet (6.17 million cubic meters or 1.63 billion U.S. gallons), or of any height with a storage capacity of 25,000 acre-feet or more (30.8 million m³ or 8.15 billion gallons).

- 1 (3) Losing longitudinal and lateral connectivity that can lead to isolation of populations,
2 failed recruitment, and local extinction of aquatic species; and
3 (4) Facilitating the invasion of exotic and introduced species in river systems.
4

5 There is broad acceptance that human water demands must be balanced with the needs of rivers
6 themselves - consider rivers (and other freshwater systems) as legitimate “users” of fresh water.
7 It is widely recognized that the full range of natural flow variation – ranging from baseflows to
8 high-flow pulses and floods – play important ecological roles in a river ecosystem. In fact,
9 environmental flow has been defined as “the quantity, timing, and quality of water flows
10 required to sustain freshwater and estuarine ecosystems and the human livelihoods and wellbeing
11 that depend on these ecosystems” (Poff *et al.* 2010). While the science and practice of
12 environmental flow has been studied during the past half century and much progress has been
13 made in environmental flow protection and management, it has proven quite difficult for
14 scientists to describe the full range of flow variability necessary to support a healthy river
15 ecosystem, which can be practically implemented by water managers. And it still remains a
16 daunting challenge to answer these practical questions: “How much can we change the flow
17 regime of a river before the aquatic ecosystem begins to show decline?” or “how should we
18 manage the daily flows, floods, and interannual patterns of variability to achieve desired
19 ecological outcomes?”
20

21 **4.2 Instream Flow Methods**

22 A variety of methods have been developed for prescribing environmental flows; each has its
23 strengths and weaknesses with varying levels of effort and cost. These methods can be grouped
24 into three categories: standard-setting rules, habitat approach, and integrated approach (Annear *et*
25 *al.* 2004; Petts 2009; Tharme 2003).

26 **4.2.1 Standard-setting Rules**

27 Following the reservoir and water development era of the mid-twentieth century, resource
28 agencies became concerned over the loss of fisheries in the west. Consequently, several states
29 began issuing rules for protecting existing stream resources from future depletions. Many
30 assessment methods appeared during the 1960's and early 1970's based on hydrologic analysis of
31 the water supply coupled with empirical observations of habitat quality and an understanding of
32 riverine fish ecology. These efforts led to a class of flow techniques meant to help reserve water
33 within the channel for the benefit of fish and other aquatic life.
34

35 These standard-setting methods include the Tennant method, the aquatic baseflow standard
36 method, and the flow duration curve method. Hydrologic data were used to establish a flow rate
37 that should be met or exceeded, based upon statistical evaluation of historical flows. Using these
38 methods, flow targets can be developed for the year as a whole, or for individual seasons or
39 months. These methods are designed to protect some portion of the overall flow in a river (*e.g.*,
40 30% of mean or median annual flow). Application of these methods usually resulted in a single
41 'minimum' flow value for a stream reach, below which water may not be withdrawn for
42 consumptive use. The minimum flow is almost always less than the optimal habitat condition for
43 native fish species. These 'reservations' of water form the basis for issuing water permits in many
44 states. While useful for their ease of application at minimal cost, these methods have been

1 criticized because they do not adequately reflect the full range of variability in flows that is
2 essential for sustaining river-dependent species and ecosystem processes.

3 **4.2.2 Habitat Approach**

4 This group of methods includes the instream flow incremental method (IFIM) and Meso-
5 HABSIM. The IFIM method was developed by the USFWS in the late 1970s (Bovee *et al.*
6 1998). The method relies on three principles:

- 7 (1) the chosen species exhibits preferences within a range of habitat conditions that it can
8 tolerate;
- 9 (2) these ranges can be defined for each species; and
- 10 (3) the area of stream providing these conditions can be quantified as a function of discharge
11 and channel structure.

12
13
14 The method involves two distinct stages: data collection through field investigation and
15 computer simulation. Field investigations include selecting stream reaches, establishing
16 transects, and measuring the depth and velocity of the river along each transect at high, medium
17 and low flows. These hydrological and physical data are collected for each life stage of a target
18 species (*e.g.*, holding, spawning, or rearing). In the meantime, biological data of the species also
19 need to be collected at each transect.

20
21 The data collected from field investigations are used to establish curves relating weighted usable
22 area (WUA) with flow for each life stage of a fish species and this is done with computer
23 simulation. The core of the simulation is the Physical HABitat SIMulation (PHABSIM) that
24 integrates the changing hydraulic conditions with discharge and the habitat preferences of one
25 selected species. Since the IFIM focuses on the needs of a single species and generally on one
26 critical life stage, it does not address the need of high flows that move sands and gravels
27 downstream and prevent seedlings from germinating and taking hold on the river banks
28 (Barinaga 1996). The IFIM requires quality field data and this is often time consuming,
29 expensive, and impossible at times, to obtain. The output is location specific. Some fish
30 population data must be collected on-site to calibrate effective habitat simulations. Also, this
31 method does not address the flow needed for meeting water temperature requirements. This
32 method is most appropriate for in-depth, site-specific analysis of flow needs, but is not intended
33 for prescribing flow standards (Annear *et al.* 2004).

34
35 Recently, a meso-scale physical habitat modeling method – Mesohabitat Simulation Model
36 (Meso-HABSIM) offer advantages over PHABSIM, involving modeling of depth and velocity
37 separately (Parasiewicz 2001; Parasiewicz 2007a; Parasiewicz 2007b; Parasiewicz 2008;
38 Parasiewicz and Walker 2007). MesoHABSIM requires smaller expenditure resources and field
39 efforts (*e.g.*, 10 days to collect data from a 20 km-long reach with MesoHABSIM as opposed to
40 50 days of using PHABSIM). MesoHABSIM modifies the data acquisition technique and
41 analytical approach of similar models by changing the scale of resolution from micro- to meso-
42 scales. The model takes variations in stream morphology along the river into account and is more
43 applicable to large-scale issues.

4.2.3 Integrated Approach

After extensive research and development of environmental flow during the past 15 years, it is now generally accepted by the scientific community that to protect freshwater biodiversity and maintain the valuable goods and services provided by rivers, it is essential to mimic components of natural flow variability, taking into consideration the magnitude, frequency, timing, duration, and rate of change of flow events (Petts 2009; Poff *et al.* 1997; Richter *et al.* 1996; Richter *et al.* 1997). These five critical components of the flow regime regulate ecological processes in river ecosystems. They can be used to characterize the entire range of flows and specific hydrologic phenomena such as floods and low flows. Furthermore, by defining flow regimes in these terms, the ecological consequences of particular human activities that modify one or more components of the flow regime can be considered and addressed explicitly.

For analysis of the five flow regime components, Richter *et al.* (1996) introduced the Indicators of Hydrologic Alteration (IHA) method. This method analyzes daily streamflow data using 32 hydrologic parameters such as monthly flows, 1-day annual maximum flows, timing of the 1-day annual maximum flow, and frequency and duration of maximum flows. The latest version of the IHA software includes 34 new flow parameters – the environmental flow components (The Nature Conservancy 2009). The software program examines 66 ecologically relevant statistics such as the timing and maximum flow of each year's largest flood or lowest flows, then calculates mean or median and variance of these values over some period of time. The IHA method can be used to quickly pinpoint aspects of a hydrologic regime that needs to be addressed to restore ecosystem integrity (Annear *et al.* 2004). More than 1,000 water resource managers, hydrologists, ecologists, researchers, and policy makers from around the world have used this method to assess how current flow patterns differ from the system's natural flow regime.

Understanding hydrologic alterations between pre- and post-dam is the first step to restore a degraded aquatic system. Richter *et al.* (1997) extended the IHA method and proposed the Range of Variability Approach (RVA). The RVA employs pre-dam or natural flows to establish IHA target ranges (*i.e.*, 1 standard deviation from the mean or percentiles from the median) for each of the 32 IHA parameters. This allows initial river management decisions to be made when no or limited long-term ecological or biological data are available (Annear *et al.* 2004). This method has been widely used to incorporate regime based flows in water resources and environmental management in the U.S. and other countries (Petts 2009).

Most recently, Poff *et al.* (Poff *et al.* 2010) developed a new framework for assessing environmental flow needs for many streams and rivers simultaneously to foster development and implementation of environmental flow standards at the regional scale. This framework, the ecological limits of hydrologic alteration (ELOHA), is a synthesis of a number of existing hydrologic techniques and environmental flow methods that are currently being used to various degrees and that can support comprehensive regional flow management.

4.3 Recent Flow Criteria Development in the Central Valley

Based on the same principles and/or concepts as described in sections 4.1 and 4.2.3, both SWRCB and CDFG developed flow criteria for the Sacramento River inflow, San Joaquin River inflow, and Delta outflow (CDFG 2010a; SWRCB 2010).

1
2 The SWRCB's Delta flow criteria were developed using information on unimpaired flows,
3 historical impaired inflows that support more desirable ecological conditions, statistical
4 relationships between flow and native species abundance, and/or ecological functions-based
5 analyses for desirable species and ecosystem attributes (Fleenor *et al.* 2010). In an attempt to
6 more closely reflect the variation of the natural hydrograph (*i.e.*, magnitude, frequency, duration,
7 timing, and rate of change of flows) (Delta Environmental Flows Group 2010), the SWRCB
8 recommended that, when possible, the flow criteria be expressed as a percentage of the
9 unimpaired flow. To develop criteria in this way, the unimpaired flow rate for a specified time
10 period (*e.g.* average monthly flow over a range of months) was plotted on an exceedance
11 probability graph along with the flow recommendations and desired return frequencies. The
12 unimpaired flow rates were also plotted such that the associated water year type can be identified
13 and their percent exceedance estimated. A percentage of unimpaired flow was selected by trial
14 and error so that the desired flow rate and exceedance frequency was achieved (SWRCB 2010).

15
16 The SWRCB developed Sacramento River inflow criteria with an attempt to mimic the natural
17 hydrograph to protect emigrating juvenile Chinook salmon. While emigration of some runs may
18 occur outside of this period, peak emigration is generally believed to occur between November
19 through June. To achieve the attributes of a natural hydrograph, the criteria were recommended
20 as a percentage of unimpaired flow on a 14-day average, to be provided generally on a
21 proportional basis from the tributaries to the Sacramento River. The 14-day average is intended
22 to better capture the peaks of actual flows compared to a 30-day average time-step, while still
23 allowing for a time-step at which facilities can be operated. The SWRCB concluded that flow
24 criteria equal to 75% of unimpaired flows from November through June, on average, would
25 provide favorable conditions for juvenile Chinook salmon in at least 50% of years (assuming
26 25,000 cfs flows at Rio Vista) (SWRCB 2010).

27 28 **4.4 History of Flow Criteria Development in Clear Creek**

29 Streamflow in Clear Creek changed dramatically after the construction of Whiskeytown Dam
30 began in 1959. Water rights permits issued by the SWRCB specified minimum flows from
31 Whiskeytown Dam. The 1960 Memorandum of Agreement with CDFG established minimum
32 flows in Clear Creek (**Table 1**). The 1963 release schedule from Whiskeytown Dam was
33 proposed by FWS. Although this release schedule was never formalized, USBR has operated the
34 dam according to the FWS schedule since May 1963. Historically, streamflows below
35 Whiskeytown Dam were set 50 cfs from January to October and 100 cfs from November to
36 December during an average water year.

37
38 Denton (1986) conducted a flow study in Clear Creek from 1982-1983 using the IFIM method.
39 He found that flow should be 300 cfs from mid-May to mid-October and 200-250 cfs from Mid-
40 October to March 31 (Denton 1986) (**Table 1**). However, these flow recommendations were
41 never implemented in Clear Creek.

42
43 In response to Central Valley steelhead being listed as threatened on March 19, 1998 under the
44 Endangered Species Act, minimum summer flows were increased to 150 cfs to provide suitable
45 rearing habitat for steelhead pursuant to the AFRP. After spring-run Chinook salmon was listed

1 as threatened on September 16, 1999, flows were further increased to provide suitable spawning
 2 habitat for spring-run in September and October. Thus, Whiskeytown releases were set at 150 cfs
 3 on June 1, increased to 200 cfs on September 7, increased to 250 cfs on September 10, and
 4 decreased to 200 cfs on October 1 (Newton and Brown 2004). This flow schedule was based
 5 largely on the Denton study in 1986.

6
 7 Table 1. Evolution of minimum flows in Clear Creek

Period	Flow (cfs)
1960 MOA minimum flows	
January 1 – February 18 (29)	50
March 1 – May 31	30
June 1 – September 30	0
October 1 – October 15	10
October 15 – October 31	30
November 1 – December 31	100
1963 FWS proposed flows (Normal year – Critical year)	
January 1 - October 31	50 - 30
November 1 - December 31	100 - 70
1986 Denton study for steelhead and fall-run	
January 1 – March 31	200
April 1 – May 15	230
May 16 – October 15	300
October 16 – December 31	250
1999 CVPIA AFRP Implementation	
October 1 – June 30	200
July 1- September 30	150

8
 9
 10 The FWS conducted a multiyear study on flow criteria in Clear Creek from 1995 to 2001.
 11 They used PHABSIM to generate water surface elevations with a wide range of simulation
 12 flows. The PHABSIM generated water surface elevations were used as input to a 2D hydraulic
 13 and habitat model (RIVER2D). The 2D model predicts available habitat at various simulations
 14 flows. The predicted available habitat was described with optimum depth, velocity, and
 15 substrate. From the RIVER2D output, the optimum flow can be identified, at which maximum
 16 habitat is achieved. The results of the flow study are summarized in **Table 2**. Flows greater than
 17 600 cfs in the upper canyon reaches are needed from September through December to increase
 18 spring-run habitat availability for spawning. At the flow rate of 200 cfs, only 50% of the habitat
 19 in the upper reach, and 30% of the habitat in the lower reach (to Clear Creek Road Bridge) are
 20 available for spring-run spawning.

DRAFT

1 Table 2. Recommended flows for Clear Creek based on the 7-year flow investigation conducted
2 by USFWS from 1995 to 2001

Stream Reach	Life Stage	Spring-run	Steelhead	Fall-run	Publication Year
Upper (Whiskeytown Dam to Clear Creek Road Bridge)	Spawning	650-900	350-600		2007
	Rearing	600-900	650-900		2010
Lower (Clear Creek Road Bridge to the Sacramento River)	Spawning		300	300	2011
	Rearing		NA	NA	Unpublished

3 NA = Not Available

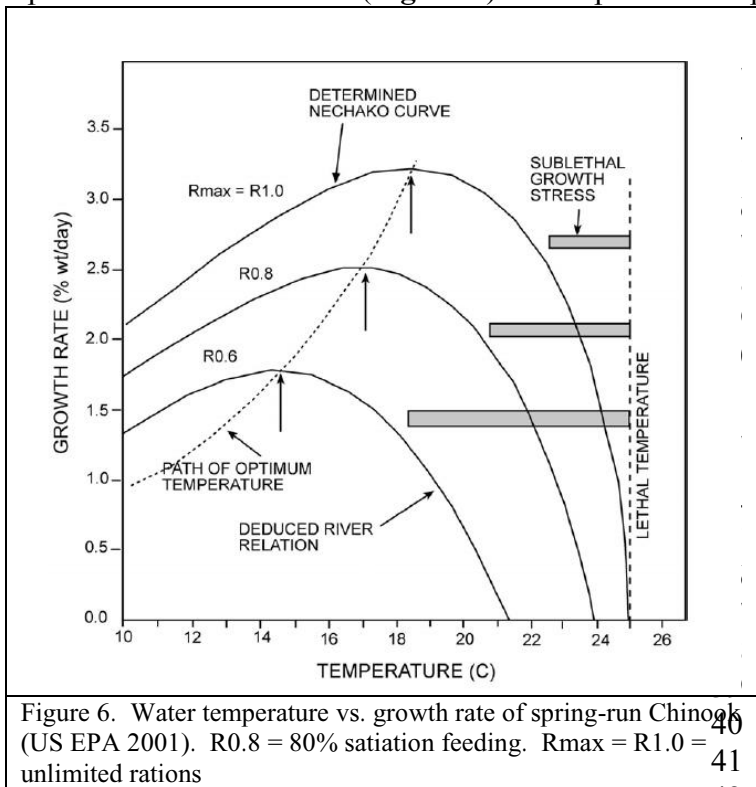
4

1 **5 Water Temperature for Salmonids**

2 **5.1 Water Temperature and Salmonids**

3 Water temperature influences the survival of salmonids at all life stages of the life cycle,
 4 including growth and feeding rates, metabolism, development of embryos and alevins, timing of
 5 life history events such as upstream migration, spawning, freshwater rearing, and seaward
 6 migration, and the availability of food (CDFG 2010b; McCullough 1999; Myrick and Cech
 7 2001; US EPA 2003). Further, the stressful impacts of water temperatures on salmonids are
 8 cumulative and positively correlated to the duration and severity of exposure. The longer the
 9 salmonid is exposed to thermal stress, the less chance it has for long-term survival (Carter 2008;
 10 US EPA 2001). It may be possible for healthy fish populations to endure some of these chronic
 11 impacts with little appreciable loss in population size. However, for vulnerable fish populations
 12 such as the endangered or threatened salmonids of the Central Valley, these sub-lethal effects
 13 can reduce the overall health and size of the population, making the survival and eventual
 14 recovery of these listed species more uncertain. It is therefore imperative to recognize that
 15 optimal water temperatures should be provided to those listed fish species whenever and
 16 wherever possible.

17
 18 The general response of salmonids to temperature is that growth increases as temperature
 19 increases to an optimum, at which growth is maximized, followed by a rapid decline in growth as
 20 temperatures increase further (**Figure 6**). The optimum temperature for growth is dependent to



some degree on the availability of food. At ration levels lower than the maximum (Rmax), the optimal temperature for growth is reduced because of the effects of temperature on metabolic rates and the subsequent maintenance metabolic demands for energy inputs (Brett *et al.* 1982 as cited in US EPA 2001).

While considering salmonids' responses, water temperatures may be described as optimal, sublethal, and lethal (**Figure 6**). Physiologically optimal temperatures are those where physiological functions (*e.g.*, growth, swimming, heart performance) are optimized. At optimal temperatures, growth rates, expressed as weight gain

per unit of time, are maximal for a life stage. These temperatures are generally determined in laboratory experiments. Ecologically optimal temperatures are those where fish do best in the

1 natural environment, considering food availability, competition, predation, and fluctuating
 2 temperatures (US EPA 2003).

3
 4 Exposure to water temperatures above the optimal range results in increased severity of harmful
 5 effects, often referred to as sublethal or chronic effects such as decreasing juvenile growth that
 6 results in smaller, more vulnerable fish; increasing susceptibility to disease that can lead to
 7 mortality, affecting reproduction, inhibiting smoltification, and decreasing ability to compete
 8 and avoid predation (McCullough *et al.* 2009; US EPA 2003). All of these responses, even those
 9 not resulting in immediate death, can lead to mortality prior to reproduction or reduced
 10 fecundity. These factors result in reduced productivity of a stock and reduced population size.
 11 In addition to the seasonal probability of consecutive days of critical maxima, consecutive years
 12 with serious cumulative thermal effects over significant portions of a species' range for one or
 13 more life stages can lead to dramatic reduction in stock viability (McCullough 1999).

14
 15 Growth rates at temperatures above the optimum plummet with increasing temperature and
 16 rapidly reach zero. As temperatures rise to some point, they become lethal. Lethal temperatures
 17 are those that cause direct mortality within an exposure period of less than one week. One of the
 18 measures for lethal temperatures is the upper incipient lethal temperature (UILT), at which 50%
 19 mortality occurs (McCullough 1999; US EPA 2001).

20 **5.2 Water Temperature Criteria for Salmonids**

21 There were several metrics used for evaluating the effect of temperature on salmonids. The
 22 maximum weekly average temperature (MWAT) is a measure of chronic exposure of
 23 temperature. MWAT is the mean of multiple, equally spaced, average daily temperatures over a
 24 running seven-day consecutive period. The instantaneous maximum temperature is a measure of
 25 acute effects to salmonids. The 7-day average of the daily maximum (7DADM) temperatures is
 26 the daily maximum temperature over a running seven-day consecutive period. The 7DADM was
 27 recommended by the US Environmental Protection Agency (USEPA) in 2003 because it
 28 describes the maximum temperatures in a stream, but is not overly influenced by the maximum
 29 temperature of a single day. Thus, it reflects an average of maximum temperatures that fish are
 30 exposed to a weeklong period. Since this metric is oriented to daily maximum temperatures, it
 31 can be used to protect against acute effects, such as lethality and migration blockage conditions.
 32 This metric can also be used to protect against sub-lethal or chronic effects (*e.g.*, temperature
 33 effects on growth, disease, smoltification, and competition) (USEPA 2003).

34
 35 Table 3. EPA water temperature criteria (7DADM) for Chinook and steelhead

Designated Uses for Life Stages	°C	°F
Adult Migration	20	68.0
Adult Migration plus Non-core Juvenile Rearing*	18	64.4
Adult holding	16	60.8
Spawning, Egg Incubation, and Fry Emergence	13	55.4
Core Juvenile Rearing**	16	60.8
Steelhead Smoltification	14	57.2

1 *This use is generally found in the mid and lower part of a river basin, downstream of the Core
2 Juvenile Rearing use.

3 **This use is generally found in the mid-to-upper reaches of a river basin.

4
5 The US EPA water temperature criteria (**Table 3**) have been adopted by the states of Oregon and
6 Washington. The criteria have been used to develop the 303(d) list and/or total maximum daily
7 loads in the North Coast Region (Carter 2008) and Central Valley Region (CVRWQCB 2009).
8 The criteria were supported and used by CDFG to develop flow criteria in the San Joaquin River
9 basin (CDFG 2010a; CDFG 2010b). They were also used to analyze the effects of the long-term
10 operations of the Central Valley Project and State Water Project, and to develop the reasonable
11 and prudent alternative actions to address temperature-related issues in the Stanislaus River
12 (NMFS 2009a).

13
14 The use of the US EPA 2003 criteria for listing water temperature impaired water bodies in the
15 Central Valley is scientifically justified. It has been recognized that salmonid stocks do not tend
16 to vary much in their life history thermal needs, regardless of their geographic location. There is
17 not enough significant genetic variation among stocks or among species of salmonids to warrant
18 geographically specific water temperature standards (US EPA 2001). Based upon reviewing a
19 large volume of thermal tolerance literature, McCullough (1999) concluded that there appears to
20 be little justification for assuming large genetic adaptation on a regional basis to temperature
21 regimes. Prior to adoption of the revised water temperature standards for Oregon streams in
22 1996, there were separate water temperature standards assigned to salmon habitat in the western
23 vs. the eastern portions of the state. Salmon-bearing streams in the western Cascades and Coast
24 Range were assigned a standard of 14.4°C, but salmon-bearing streams in northeastern Oregon
25 had a standard of 20.0°C, largely on the assumption that they would be adapted to the warmer air
26 temperature regimes of the region. The large (5.6°C) difference in adaptation that would be
27 required, however, is not supportable by any known literature (McCullough 1999).

28
29 Varying climatic conditions could potentially have led to evolutionary adaptations, resulting in
30 development of subspecies differences in thermal tolerance. However, the literature on genetic
31 variation in thermal effects indicates occasionally significant but very small differences among
32 stocks and increasing differences among subspecies, species, and families of fishes. Many
33 differences that had been attributed in the literature to stock differences are now considered to be
34 statistical problems in analysis, fish behavioral responses under test conditions, or allowing
35 insufficient time for fish to shift from field conditions to test conditions (US EPA 2001).

36
37 Although many of the published studies on the responses of Chinook salmon and steelhead to
38 water temperature have been conducted on fish from stocks in Oregon, Washington, and British
39 Columbia, a number of studies were reported for the Central Valley salmonids. Myrick and
40 Cech (2001, 2004) performed a literature review on the temperature effects on Chinook salmon
41 and steelhead, with a focus on Central Valley populations. Summarized in **Table 4** is a
42 comparison of thermal responses between northern and Central Valley stocks.

1
2 Table 4. Similar thermal responses of the Central Valley (CV) and northern stocks of salmonids

Parameter	Water Temperature (°C)	Response	Note
Egg incubation	13.9	82% mortality	CV Fall-run
	>12	Increased mortality	CV Fall-run
	>13.3	Increased mortality	CV Winter-run
	13	Optimal	US EPA (2003)
Growth	17-20	Max growth	CV Fall-run, 100% satiation
	19	Max growth	CV Fall-run, 100% satiation
	18.9-20.5	Max growth	Northern Chinook, 100% satiation
	15	Max growth	60% satiation
	16	Optimal	US EPA (2003)
Upper thermal limit	25	50% mortality	7 day exposure, northern Chinook
	24	50% mortality	8 day exposure, CV Chinook

3
4 It is evident that the difference in thermal response is minimal in terms of egg incubation,
5 growth, and upper thermal limit. Healey (1979 as cited in Myrick and Cech 2004) concluded
6 that Sacramento River fall-run Chinook salmon eggs did not appear to be any more tolerant of
7 elevated water temperature than eggs from more northern races. Myrick and Cech (2001)
8 concluded that it appears unlikely that there is much variation among races with regard to egg
9 thermal tolerance because data from studies on northern Chinook salmon races generally agree
10 with those from California. They further concluded that fall-run Central Valley and northern
11 Chinook growth rates are similarly affected by water temperature. There was one study on water
12 temperature effects on the Central Valley steelhead growth. When American River steelhead
13 were fed to satiation at water temperatures of 11, 15, and 19 °C, the growth rate was highest at 19
14 °C (Myrick and Cech 2001; Myrick and Cech 2004; Myrick and Cech 2005). The optimum
15 water temperature for steelhead growth is expected to be lower at lower ration levels (*e.g.*, 60%
16 satiation). Myrick and Cech (2001) also cautioned that the maximum growth rate at 19 °C was
17 based on a single study and clear conclusions would not be possible until large-scale experiments
18 were conducted.

19
20 US EPA indicated that these numeric criteria apply to the warmest times of the summer, the
21 warmest years (except for extreme conditions), and the lowest downstream extent of use.
22 Because of the conservative nature of this application, US EPA believes that it is appropriate to
23 recommend numeric criteria near the warmer end of the optimal range for uses intended to
24 protect high quality development and growth of salmonids. Adopting a numeric criterion near the
25 warmer end of the optimal range is likely to result in temperatures near the middle of the optimal
26 range for most of the spring through fall period in the segments where most of the rearing use
27 occurs. If the criterion is met at the summer maximum, then temperatures will be lower than the
28 criterion during most of the year. Because the criterion would apply at the furthest point

1 downstream where the use is designated, temperatures will generally be colder across the full
2 range of the designated use (USEPA 2003).
3

4 **5.3 Water Temperature Modeling**

5 To address the problem of elevated stream temperatures, it is necessary to incorporating stream
6 temperature objectives in reservoir operations as high stream temperatures can be manipulated
7 by releasing coldwater from an upstream reservoir. This requires the ability of predicting stream
8 temperature with normal reservoir operations. Based on the prediction, decisions can be made to
9 release additional water to improve the stream temperature to a target level appropriate for
10 salmonids. In addition, a water temperature model will help better understand the relationship
11 between physical landscape characteristics, weather conditions, and water temperature.
12

13 Numerous models have been developed for stream temperature prediction. Discussed below are
14 two types of the models: Statistical and physical process based models.

15 **5.3.1 Statistical Models**

16 Statistical models use statistical methods including regression and artificial neural network.

17 **5.3.1.1 Regression**

18 Stream temperature generally increases with an increase of air temperature, and the impact is
19 more significant for low streamflows during summer. Most regression models that predict water
20 temperatures use univariate or multivariate regression techniques. Univariate regression models
21 use air temperature as an explanatory variable because stream temperature often has a high
22 statistical correlation with ambient air temperature. Multivariate regression models are based on
23 many variables including stream characteristics (*e.g.*, elevation, stream morphology, streamflow,
24 channel aspect, riparian shade), ambient climate conditions (air temperature and solar radiation),
25 and reservoir operations.
26

27 A univariate regression model was developed to evaluate the relationship between air
28 temperature and stream temperature at a geographically diverse set of streams. The majority of
29 streams showed an increase in water temperature of about 0.6-0.8°C for every 1°C increase in air
30 temperature, with very few streams displaying a linear 1:1 air-water temperature trend. For most
31 of the streams, a nonlinear model produced a better fit than did a simple linear model (Morrill *et*
32 *al.* 2005). Modeling maximum daily stream temperatures using regression models to relate air
33 and water temperatures was carried out in Catamaran Brook, a small stream in New Brunswick,
34 Canada. The regression model, a logistic type function, predicted water temperatures on a
35 weekly basis with a root mean square error (RMSE) of 1.93°C (Caissie *et al.* 2001).
36

37 A multivariate regression model was developed to predict daily maximum stream temperatures
38 in the Truckee River in California and Nevada for the summer period (Neumann *et al.* 2003).
39 The model used a stepwise linear regression procedure to select significant explanatory variables.
40 The stepwise procedure selected daily maximum air temperature at Reno and average daily flow
41 at Farad as the variables to predict maximum daily stream temperature at Reno. The model was
42 validated using three years of historical data. The model can be used to determine the amount of
43 required additional flow to meet a target stream temperature with a desired level of confidence.

1
2 Multivariate regression models were developed on the basis of available stream temperature data
3 to predict temperatures for unmeasured periods of time and for unmeasured streams in the Lower
4 Klamath River in northern California (Flint and Flint 2008). The most significant factor in
5 matching measured minimum and maximum stream temperatures was the seasonality of the
6 estimate. Adding minimum and maximum air temperature to the regression model improved the
7 estimate. The addition of simulated solar radiation and vapor saturation deficit to the regression
8 model significantly improved predictions of maximum stream temperature but was not required
9 to predict minimum stream temperature. The average standard error in estimated maximum daily
10 stream temperature for the individual basins was $0.9 \pm 0.6^{\circ}\text{C}$ at the 95% confidence interval. In a
11 similar study, it was found that air temperature was the most important variable in stream
12 temperature prediction; however, the prediction performance efficiency was higher if solar
13 radiation was included (Sahoo *et al.* 2009).

14 **5.3.1.2 Artificial Neural Network**

15 The advantages of artificial neural network (ANN) models in modeling stream temperature lie in
16 their simplicity of use, low data requirement, and good performance, as well as their flexibility in
17 allowing many input and output parameters.

18
19 ANN models were developed to estimate water temperatures in small streams using data
20 collected at 148 sites throughout western Oregon from June to September 1999 (Risley *et al.*
21 2002). The sites were located on 1st-, 2nd-, or 3rd-order streams having undisturbed or
22 minimally disturbed conditions. Data collected at each site for ANN model development
23 included continuous hourly water temperature and description of riparian habitat. Additional data
24 pertaining to the landscape characteristics of the basins upstream of the sites were assembled
25 using geographic information system (GIS) techniques.

26
27 Clustering analysis was used to partition 142 sites into 3 groups. Separate ANN models were
28 developed for each group. Critical input variables included riparian shade, site elevation, and
29 percentage of forested area of the basin, and hourly meteorological data. The output variable was
30 the hourly water temperature for the June to September period. Approximately one-third of the
31 data sets were used for ANN training, and the remaining two-thirds were used for ANN testing.
32 Coefficient of determination and RMSE for the models ranged from 0.88 to 0.99 and 0.05 to 0.59
33 $^{\circ}\text{C}$, respectively. The models were validated using historical temperature time series, habitat, and
34 basin landscape data from 6 sites that were separate from the 142 sites that were used to develop
35 the models.

36
37 ANNs were used to develop models for predicting both the mean and maximum daily water
38 temperature (Jean-Francois and Daniel 2008). Eight models were investigated using a variety of
39 input parameters. Of these models, four predicted mean daily water temperature and four
40 predicted maximum daily water temperature. The best model for mean daily temperature had
41 eight input parameters: minimum, maximum and mean air temperatures of the current day and
42 those of the preceding day, the day of year and the water level. This model had a RSME of 0.96
43 $^{\circ}\text{C}$, a bias of 0.26°C and a coefficient of determination $R^2 = 0.971$. The model that best
44 predicted maximum daily water temperature was similar to the first model but excluded mean

1 daily air temperature. Good results were obtained for maximum water temperatures with an
2 overall RMSE of 1.18 °C, a bias of 0.15 °C and $R^2 = 0.961$.

3
4 ANNs were used to predict stream temperature from solar radiation and air temperature (Sahoo
5 *et al.* 2009). They developed a four-layer back propagation neural network. The optimal model
6 performance was realized when the solar radiation and air temperature data were presented to the
7 model with a 1-day or 3-day time lag.

8 **5.3.2 Physical Process Based Models**

9 Physical process based models predict water temperature using energy-balance equations.
10 Mathematical equations are used to represent the physical processes of heat transfer among the
11 Sun, stream, and surrounding environment. Meteorological data, including solar radiation, air
12 temperature, wind speed and direction, and humidity, are typical inputs to these models. Water
13 temperature models must be coupled with a hydrologic flow model. After a model has been
14 calibrated and validated with measured data, it is possible to use the model to simulate water
15 temperatures under various flow scenarios.

16
17 It is imperative to recognize that any model should be evaluated to determine whether a model
18 and its results are of sufficient quality to serve as the basis for a decision (USEPA 2009). The
19 process of evaluating a model should include the theoretical foundation of science underlying a
20 model, the quality and quantity of available data, the degree of correspondence with observed
21 conditions, and the appropriateness of a model for a given application (*e.g.*, temporal and spatial
22 scales). The selected model should simulate system responses at temporal and spatial scales
23 approximately one step lower than desired results. For example, to more effectively represent
24 daily conditions, an hourly model at a minimum should be used. The hourly output data from the
25 model can be used to generate daily maximum, minimum, and average. The opposite approach,
26 disaggregation, requires taking longer interval data and attempting to reduce it to shorter time
27 periods (*e.g.*, reducing monthly values to daily values, or daily values to hourly values).
28 Disaggregation, by its very nature, typically introduces appreciable uncertainty into an analysis
29 (Deas and Lowney 2001), making it worse when no description for disaggregating temperature
30 or flow was provided by the user (Stillwater Sciences 2004).

31
32 Chen *et al.* developed a temperature modeling system for the Upper Grande Ronde watershed in
33 northeast Oregon (Chen *et al.* 1998). The system consisted of a hydrologic simulation model
34 (Hydrologic Simulation Program-FORTRAN (HSPF)) and a riparian shading model (SHADE).
35 Solar radiation, diurnal, seasonal, and longitudinal variations were evaluated to verify the
36 accuracy and reliability of SHADE computations. Simulated maximum stream temperatures, on
37 which the riparian restoration forecasts are based, were accurate to 2.6–3.0°C compared with 8–
38 10°C exceedances over stream temperature goals for salmon habitat restoration under the present
39 riparian vegetation conditions. Hourly simulations have approximately the same accuracy and
40 precision. Stream temperature regimes were simulated for different hydroclimatic conditions and
41 hypothetical restoration scenarios of riparian vegetation. Regardless of natural weather cycles,
42 the restoration of riparian vegetation is needed along many headwater streams to significantly
43 alleviate the lethal and sublethal stream temperatures associated with salmon habitat in the
44 watershed.

1 The U.S. Geological Survey (USGS), to support Department of Interior implementation of the
2 Truckee-Carson-Pyramid Lake Water Rights Settlement Act of 1990, developed two physically
3 based water quality models for simulating stream temperature and dissolved solids, for the
4 Truckee River (Taylor 1998). The foundation of these water quality models is the physically
5 based USGS daily flow-routing model of the Truckee River using HSPF. The flow-routing
6 model routes streamflow, which transports heat and dissolved solids along 114 miles of the
7 mainstem Truckee River from just downstream of Lake Tahoe, California to Marble Bluff Dam,
8 just upstream from Pyramid Lake, Nevada.

9 Data to calibrate, validate, and evaluate these models included daily streamflow data; hourly
10 stream temperature and meteorological data; and dissolved solids and specific conductance data
11 covering the period from June 1, 1993 to September 30, 1995. Results of the stream-temperature
12 model were evaluated at three USGS gaging stations along the Truckee River for June 1, 1993 to
13 May 31, 1994 (calibration period) and June 1, 1994 to September 30, 1994 (validation period).
14 The validation period included summer streamflows lower than the calibration period summer
15 flows. In fact, the maximum streamflow for July-September 1994 at the Nixon station was less
16 than the minimum streamflow for the same period in 1993 (38 and 45 cfs respectively).

17 Statistical comparisons at all three stations of simulated and observed values generally showed
18 that during the calibration period mean absolute errors were less than 1°C and there was
19 generally a small negative bias less than 0.5°C. For the validation period, the mean absolute
20 errors were still generally less than 1°C for daily maximum and minimum values. An exception
21 to this was the error in daily maximum stream temperature simulations at Marble Bluff which
22 increased from 0.8°C during the calibration period to 1.8°C during the validation period. There
23 were also increases in the bias and variability of the errors for the validation period.

24 Statistical comparisons were also done by simulated streamflow class and showed that there was
25 a tendency for daily maximum/minimum and hourly model simulation errors to decrease with
26 increasing streamflow. The best simulations were found when simulated streamflow was greater
27 than 500 cfs. When simulated streamflows were greater than 500 cfs, daily and hourly mean
28 absolute errors were 0.4°C to 0.8°C for the calibration and validation periods at all three gaging
29 stations (except daily maximum error at Marble Bluff which was 1.5°C with only 5 values to
30 compare in this flow class) (Taylor 1998).

31 Cox and Bolte developed the WET-Temp (Watershed Evaluation Tool - Temperature) model to
32 estimate stream temperature distribution using spatially explicit data sets. Spatial data sets
33 describing vegetation cover, stream network locations, elevation, stream discharge, and channel
34 characteristics are utilized by WET-Temp to quantify geometric relationships between the sun,
35 stream channel and riparian areas. These relationships are used in conjunction with air
36 temperature, relative humidity and wind speed data to estimate the energy gained or lost by the
37 stream via various heat flux processes (solar and longwave radiation, evaporation, convection
38 and advection). The sum of these processes is expressed as a differential energy balance applied
39 at discrete locations across the stream network. The model describes diurnal stream temperature
40 dynamics at each location and thus temperature distribution across the entire network. WET-
41 Temp was calibrated to McDowell Creek in the western Oregon Cascade Range. Differences
42 between observed and simulated values of maximum daily temperature in McDowell Creek were

1 less than 0.3 °C. The model was then used to estimate temperature distributions in an adjacent
2 watershed, Hamilton Creek, where differences in maximum daily temperature were 1 °C or less.
3 WET-Temp advances the subject of stream temperature modeling through direct incorporation of
4 spatially explicit data sets and treatment of temperature as a network phenomenon (Cox and
5 Bolte 2007).

6
7 Two stream temperature models, SNTEMP and CE-QUAL-W2, were applied to the Speed River
8 in Southern Ontario in order to gauge the effectiveness of various stream temperature
9 management options. Calibrated versions of both models performed well (0.2 °C less than mean
10 absolute error of SNTEMP less than 1.8 °C; 0.5 °C less than mean absolute error of CE-QUAL-
11 W2 less than 1.4 °C). However, CE-QUAL-W2 performed more consistently spatially and
12 temporally. Air temperature and relative humidity were found to be the most sensitive
13 parameters in both models. Management alternatives considered in this study included modifying
14 discharge from upstream dams, removal of in-stream impoundments, allowing the growth of
15 adequate riparian vegetation to provide shade, and reducing stream width during low-flow
16 periods. Of the various management practices investigated, model results suggest that the
17 removal of in-stream impoundments would be the most effective management alternative to
18 reduce summer stream temperatures. Management alternatives involving removal of in-stream
19 impoundments were projected to reduce minimum stream temperatures by up to 2.2 °C, while
20 those not involving the removal of in-stream impoundments were projected to reduce minimum
21 temperatures by less than 0.5 °C (Norton and Bradford 2009).

22
23 Caissie et al. (2007) applied a deterministic water temperature model to two streams in New
24 Brunswick, Canada. Data from 1992 to 1994 were used to calibrate the model, while data from
25 1995 to 1999 were used for the model validation. Results showed equally good agreement
26 between observed and predicted water temperatures during the calibration period for both rivers
27 with a RMSE of 1.49 °C for the Little Southwest Miramichi River compared to 1.51 °C for
28 Catamaran brook. During the validation period, RMSEs were calculated to be 1.55 °C for the
29 Little Southwest Miramichi River and 1.61 °C for Catamaran Brook. Poorer model performances
30 were generally observed early in the season (*e.g.*, spring), especially for the Little Southwest
31 Miramichi River due to the influence of snowmelt conditions, while late summer to autumn
32 performances showed among the best results for both rivers. Late autumn performances were
33 more variable in Catamaran Brook and presumably influenced by the groundwater, geothermal
34 conditions and potentially riparian shading. The geothermal aspect was further investigated at
35 Catamaran Brook (using 1998 data) and results revealed that although geothermal fluxes are
36 present, they explained very little of the unexplained variability (less than 0.1 °C). The net solar
37 radiation was shown to be the dominant energy flux, while the evaporative heat flux contributed
38 significantly to cooling rivers during warmer summers (Caissie *et al.* 2007).

39
40 In the Central Valley, a 1D stream temperature model (sub-hourly time step, sub-kilometer
41 spatial resolution) has been developed for the Upper Sacramento River (Danner and Pike 2011).
42 The model has the capability to both hindcast and forecast water temperatures. The model uses a
43 physically-based heat budgets to calculate the rate of heat transfer to/from the river. The
44 hydrodynamics of the river (flow velocity and channel geometry) are characterized using densely
45 spaced channel cross-sections and flow data. Water temperatures are calculated by considering

1 the hydrologic and thermal characteristics of the river and solving the advection-diffusion
2 equation for heat transport in a mixed Eulerian-Lagrangian framework.

3
4 Modeled hindcasted temperatures for several test periods (May – November 2008, 2009, and
5 2010) substantially improve upon the existing daily-to-monthly mean temperature standards.
6 Modeled values closely approximate both the magnitude and the phase of measured water
7 temperatures. The model results reveal important longitudinal patterns in diel temperature
8 variation that are unique to regulated rivers, and may be critical to salmon habitat. The model can
9 be used to access the forecast model online, run various scenarios of water discharge and
10 temperature under forecasted weather conditions (3-5 days and seasonal), and inform decisions
11 about water releases to maintain optimal temperatures for fishery health (Danner and Pike 2011).

12
13 In the Stanislaus River, a 1D hydrodynamic model has been developed to simulate water
14 temperature downstream of Goodwin Dam (Tetra Tech 2011). The model is based on the
15 Environmental Fluid Dynamics Code (EFDC). The EFDC model simulates water temperature
16 based on meteorological and hydrodynamic conditions and can generate high resolution results
17 in both space and time. The water temperature simulation algorithm in EFDC is based on the
18 physics of heat transport, and user intervention is minimal. The model was calibrated with
19 observed flow and water temperature. The calibration results showed good agreement between
20 the modeled and measured.

21
22 The results of 25 simulation scenarios suggest that releasing cool water from the reservoirs
23 greatly improves water temperatures in the lower Stanislaus River. At Knights Ferry there were
24 expected to be no temperature target exceedances when boundary water temperatures 8 °C, even
25 under the critical dry condition. When water temperature was above 11°C, exceedances were
26 expected to occur throughout the year. Both boundary water temperature and flow govern the
27 water temperature at Orange Blossom Bridge. Decreasing boundary water temperature and
28 increasing flow can dramatically reduce exceedances at Orange Blossom Bridge. The lowest
29 flow and highest boundary water temperature combination expected to achieve no exceedances
30 at both Knights Ferry and Orange Blossom Bridge is the above average flow condition and 9 °C
31 boundary water temperature (Tetra Tech 2011).

32 **5.3.3 Water Temperature Modeling in Clear Creek**

33 The Water Resources and Environmental Modeling Group of the University of California at
34 Davis conducted in 1998 a study on water temperature modeling for Whiskeytown Reservoir and
35 Clear Creek, which was funded by the USBR (Orlob *et al.* 1999). Based on RMA2 and RMA11,
36 the Group developed a one-dimensional hydrodynamic model for simulating water temperatures
37 from Whiskeytown Dam to the confluence of the Sacramento River. The model was calibrated
38 and verified with data from four controlled flows: 50, 100, 150, 200 cfs during the time period of
39 August 12 to 30, 1998. Each of the four controlled flows lasted for 4 days. Actual flows were
40 measured at 6 locations on the third day of each controlled flow along the creek. Water
41 temperatures were measured continuously at 9 locations.

42
43 The model was calibrated for water temperature at the controlled flow of 50 cfs. The primary
44 adjustment in heat exchange rate was in the rate of evaporative heat flux, *i.e.*, in changing the
45 cooling effect of evaporation until the mean simulated water temperature and the diurnal

1 fluctuation, in both magnitude and phase, correspond to observed values. Differences between
2 measured and simulated temperatures were found to be as high as 2 °C, which occurred during
3 the time period of peak temperatures.

4
5 The model was then verified for water temperature at the controlled flows of 100, 150, and 200
6 cfs. Differences between measured and simulated temperatures were found to be as high as 3 °C,
7 which also occurred during the time period of peak temperatures. While integrating the
8 topographic shading to the model, the difference at peak temperatures decreased, whereas the
9 difference at low temperatures increased.

10
11 The application of the model for real-time reservoir operations seems limited as calibration and
12 verification of the model were based on a short period of time and discrepancies between the
13 modeled and observed temperatures were high. However, the study has shed some light on the
14 relationship between flow and water temperature in Clear Creek. Streamflow in Clear Creek
15 should be maintained above 100 cfs to achieve a water temperature target of 16 °C and above
16 200 cfs to achieve 13 °C at Igo under the maximum weather condition. Unfortunately, the report
17 did not specify if the temperature targets were the daily average or daily maximum, and neither
18 define the maximum weather condition.

19
20

6 Flow, Temperature, and Weather Data Used in This report

Field observation data used in this report include streamflow, water temperature, reservoir release, and weather (air temperature, solar radiation, wind speed, and precipitation). The daily streamflow data in Clear Creek were obtained from the USGS gage station (USGS 11372000) near Igo (40.5132 N, -122.5229 W, elevation 673 ft) in Shasta County, California (<http://waterdata.usgs.gov/nwis/uv?11372000>). The station is located under an old highway bridge on Redding-Igo Road, 1.0 mi northeast of Igo, and 10.4 mi upstream from mouth. The flow data are from October 1, 1940 to September 30, 2009. Since the completion of Whiskeytown Dam in May 1963, baseflows were completely regulated by Whiskeytown Reservoir. Transbasin diversion from the Trinity River through Judge Francis Carr Powerplant to Whiskeytown Reservoir began in April 1963. Diversions from Whiskeytown Reservoir to Spring Creek Powerplant began in December 1963.

Water temperature, weather, and reservoir release data were obtained from the California Data Exchange Center (CDEC) (<http://cdec.water.ca.gov>). The hourly water temperature was available at the USGS Igo station beginning September 6, 1996. There are two weather stations within or near the Clear Creek watershed that provide hourly air temperature, solar radiation, and wind speed and daily precipitation beginning November 26, 2001. One station is at Oak Bottom (40.6510, -122.6060, elevation 1326 ft) operated by the National Park Service and the other is at Redding (40.5165, -122.2910, elevation 500 ft) operated by the US Forest Service. However, the wind speed data were not included for use in model development due to high uncertainty observed in the data. Since the Oak Bottom station exhibited more missing data, the data from the Redding station were used in this report. The data of daily reservoir release to Clear Creek were from the Whiskeytown Dam station, which is operated by the USBR. **Table 5** summarizes the basic information of the data used in this report.

The data compiled from the sources described above were checked to assure data quality. For example, any records of data, which showed apparent recording errors (*e.g.*, spikes on streamflow, temperature, or other parameters) or were marked as “missing”, were excluded from use in the report. Any records of data showing zero reservoir release were not included in the report. Any records of data that showed the ratio of the Whiskeytown Reservoir release to streamflow at Igo less than 0.8 or greater than 1.2 were excluded. Since this report focuses on the time period of June through October, any data with daily precipitation greater than 0.2 inch were not included to avoid potential influence of rainfall generated runoff. There were a total of 40 days that had a precipitation ≥ 0.2 inch between June 1 to October 31 from 2002 to 2009, accounting for 3% of the total record days (1224 days).

The daily maximum (DMax) of water temperature, air temperature, solar radiation was derived from the recorded hourly data. The 7-day average of daily maximum (7DADM) is the average of consecutive 7-day daily maximum including the current day, previous three days, and next three days.

1 Table 5. Description of the data used in this report

Parameter	Station Location	Time Step	Start Date	End Date
Air temperature	Redding	Hourly	11/26/2001	9/30/2009
Precipitation	Redding	Hourly	11/26/2001	9/30/2009
Solar radiation	Redding	Hourly	11/26/2001	9/30/2009
Reservoir release	Whiskeytown Dam	Daily	4/1/2000	9/30/2009
Streamflow	Igo	Daily	10/1/1940	9/30/2010
Streamflow	Igo	Hourly	9/6/1996	9/30/2009
Water temperature	Igo	Hourly	9/6/1996	9/30/2009

2

3

1 **7 Analysis of Flow Regime in Clear Creek**

2 Streamflow in Clear Creek has changed as a result of flow regulation by Whiskeytown Dam. The
 3 number of flows greater than 2000 cfs was reduced dramatically after the dam was built in 1963
 4 (**Figure 7**). The number of flows greater than 6000 cfs was 16 from WY1941 to 1962, as
 5 opposed to 5 from 1963 to 2009. Detailed flow change analyses are provided below.
 6

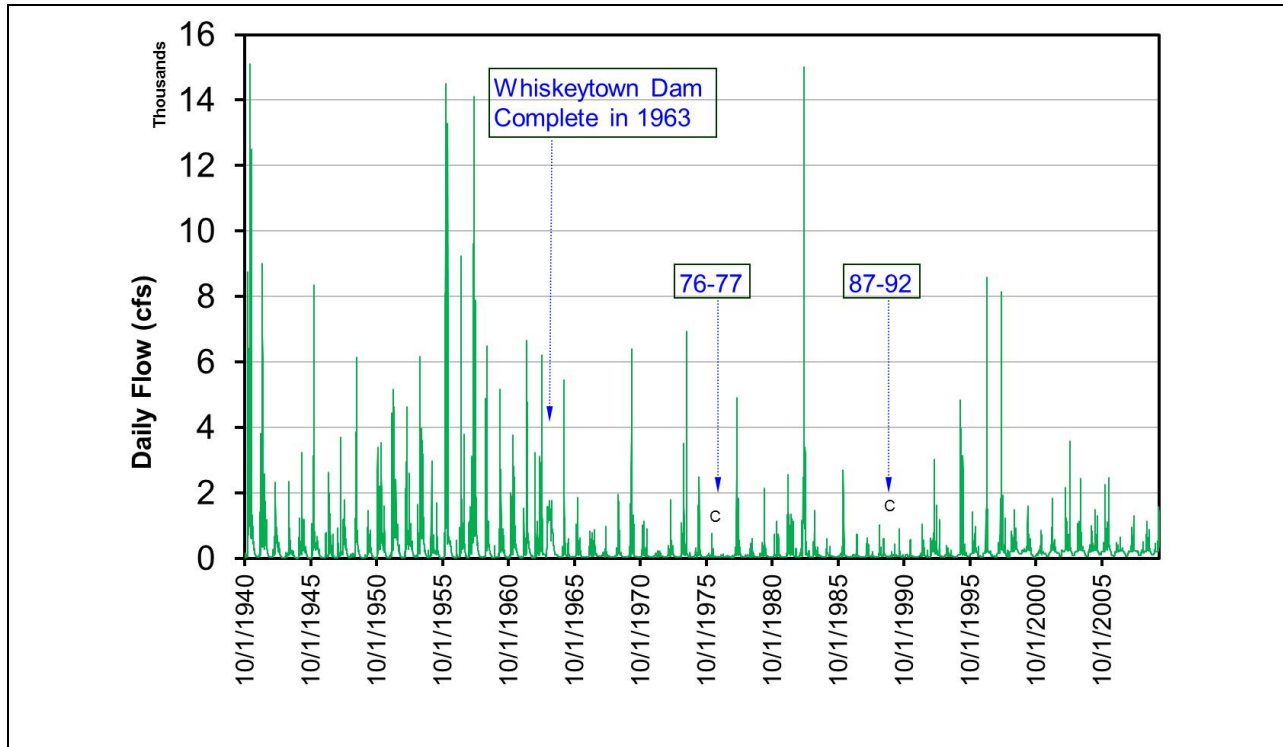


Figure 7. Daily streamflow in Clear Creek from water year 1941-2009. The periods of 1976-1977 and 1987-1992 were critically dry years.

7

8 **7.1 Flow Alteration Analysis**

9 Flow data at Igo in Clear Creek were analyzed using the IHA method (software program version
 10 7.1) (The Nature Conservancy 2009). The IHA method, developed by Richter and others
 11 (Richter *et al.* 1996; Richter *et al.* 1997; Richter *et al.* 1998), characterizes flow variations on the
 12 basis of 32 ecologically relevant statistical parameters. These parameters were compared for two
 13 time periods: pre-dam (1941 to 1960) and post-dam (1963 to 2009). The data from 1961 and
 14 1962 were not used in the analysis due to possible interference from the dam construction. The
 15 IHA parameters were calculated using nonparametric (percentile) statistics because of the
 16 skewed (non-normal) nature of the flow data used in this report.
 17
 18

1 Table 6. Results of hydrologic data analysis and RVA boundaries for Clear Creek (flow rate in
2 cfs)

Hydrologic Parameters	Pre-dam period: 1941-1960			Post-dam period: 1963-2009			RVA Boundaries		Middle HA
	Median	Min	Max	Median	Min	Max	Low	High	
Group #1 Monthly flows (cfs)									
October	36	20	246	56	32	1340	29	47	-0.840
November	65	38	291	121	61	1360	55	111	0.064
December	163	45	1010	144	75	1320	64	351	1.128
January	386	64	2070	159	48	797	164	681	0.117
February	576	132	5010	170	48	1350	320	851	-0.681
March	499	168	1560	185	49	2500	399	670	-0.894
April	393	160	1705	126	49	1535	308	723	-0.905
May	298	80	714	77	48	310	200	391	-0.468
June	131	69	285	63	43	217	109	202	-0.415
July	50	22	126	55	39	155	42	82	0.797
August	29	14	65	53	38	152	23	40	-0.947
September	27	13	49	54	35	1550	20	32	-1.000
Group #2 Magnitude and duration of annual minimum and maximum flows (cfs)									
1-day min	18	9	37	49	30	112	16	22	-1.000
3-day min	18	9	37	49	30	114	17	22	-1.000
7-day min	19	9	38	50	31	114	17	23	-1.000
30-day min	23	12	46	51	38	149	20	33	-1.000
90-day min	35	18	78	54	38	154	29	55	0.383
1-day max	5165	1470	15100	1500	130	15000	3510	6630	-0.681
3-day max	3888	1074	10670	1051	109	13300	2949	5270	-0.734
7-day max	2784	733	7920	695	106	7979	2109	3719	-0.681
30-day max	1506	439	5673	415	99	3477	1047	1958	-0.681
90-day max	1012	324	3379	321	83	1970	670	1165	-0.734
Group #3 Timing of annual 1-day minimum and maximum flows (Julian date)									
Date of min	266	224	290	238	165	305	251	270	-0.734
Date of max	35	7	362	41	1	357	35	55	-0.309
Group #4 Frequency and duration of low and high flow pulses*									
Low pulse count	3	1	5	0	0	8	2	3	-0.905
Low pulse duration (d)	25	6	122	3	1	35	14	53	-0.894
High pulse count	6	1	9	5	0	11	5	7	-0.447
High pulse duration (d)	5	1	167	2	1	13	4	7	-0.734
Group #5 Rate and frequency of flow changes									
Rise rate (cfs/d)	14	4	166	6	2	34	8	18	-0.291
Fall rate (cfs/d)	-9	-22	-5	-3	-12	-1	-12	-8	-0.787
Number of reversals	70	64	87	81	61	104	68	75	-0.622

*The low pulse threshold is 46 cfs. The high pulse threshold is 420 cfs.

3
4
5
6

1 The IHA results for Clear Creek are summarized in **Table 6** for both pre- and post-dam time
 2 periods. The IHA analysis includes 5 groups of hydrologic parameters: Monthly magnitude,
 3 magnitude and duration of annual extremes, timing of annual extremes, frequency and duration
 4 of high and low flows, and rate and frequency of flow changes.

5
 6 From the pre-dam to post-dam period, the median monthly flows from January through June
 7 decreased by 50-80%, while the median monthly flows from August through November
 8 increased by about 100%. The annual maximum flows decreased by 70%, whereas the annual
 9 minimum flows increased by more than 100%.

10 **7.1.1 Magnitude of Monthly Flows**

11 The magnitude of monthly flows provides a general measure of habitat availability for aquatic
 12 organisms and influences water temperature, dissolved oxygen, and photosynthesis in water
 13 column. The median monthly streamflows are presented in **Figure 8**. For the pre-dam
 14 period, the median streamflow in Clear Creek was low in October (36 cfs), increased from
 15 December, reached the highest in February (576 cfs), and gradually decreased from March, and
 16 reached low again in July through September (27 cfs). For the post-dam period, on the other
 17 hand, monthly flows were relatively similar from October through September. Monthly flows
 18 increased starting in the late 1990s when the CVPIA AFRP was implemented in Clear Creek.
 19

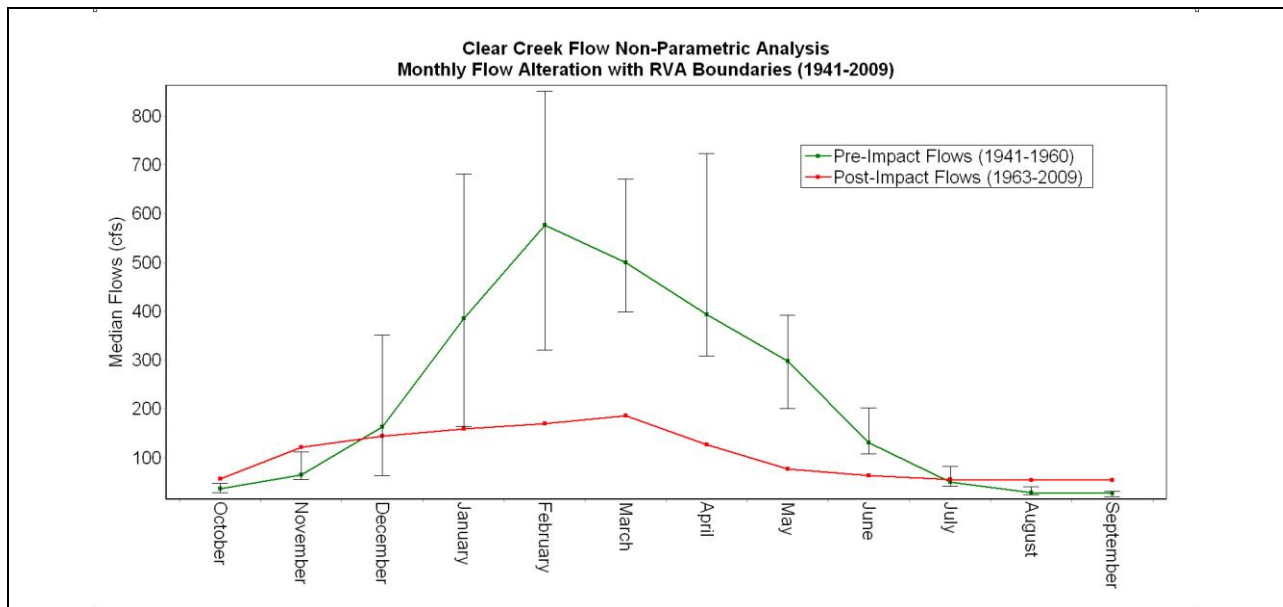


Figure 8. Pre-dam median monthly flow (green line) with error bars indicating the RVA Boundaries - 33rd and 67th percentiles. Also shown is the post-dam median monthly flow (red line).

20

21 **7.1.2 Magnitude and Duration of Annual Extreme Flows**

22 The magnitude and duration of annual extreme flows affect river channel morphology, riverine
 23 vegetation, sediment/gravel transport, and aeration of spawning beds. These extremes may serve
 24 as precursors or triggers for migration and reproduction of salmonids. The durations include the
 25 1-day, 3-day, 7-day (weekly), 30-day (Monthly), and 90-day (seasonal) extremes (**Table 6**). The

1 1-day minimum (or maximum) represents the lowest (or highest) single daily flow occurring
2 during the year. The multi-day minimum (or maximum) represents the lowest (or highest) multi-
3 day average flow occurring during the year. The median minimum flows for the pre-dam period
4 were lower than that for the post-dam periods (**Figure 9**).
5

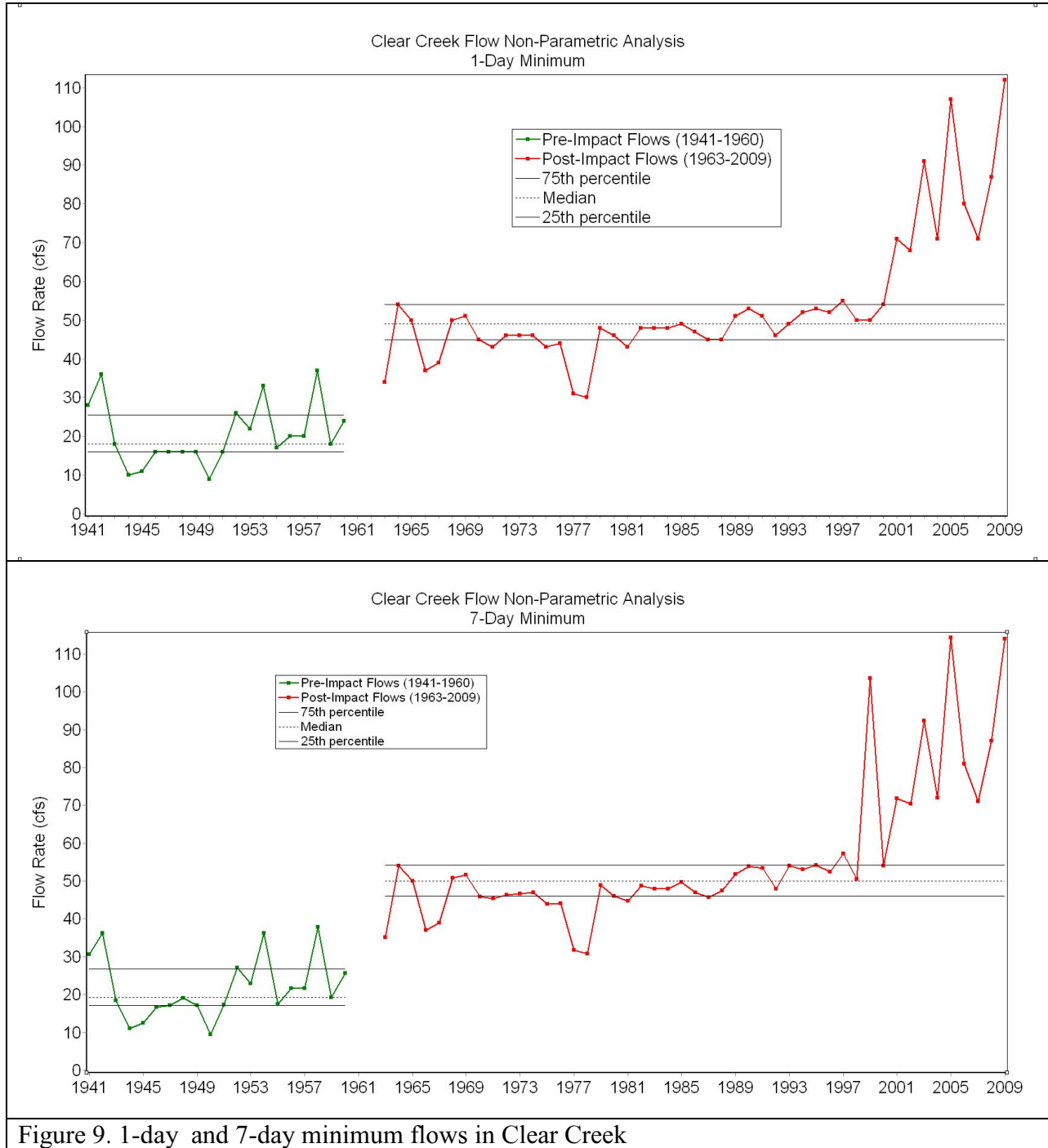


Figure 9. 1-day and 7-day minimum flows in Clear Creek

6

1 The 1-day median maximum flows decreased from 5000 cfs for the pre-dam period to 1500 cfs
 2 for the post-dam periods, and The 7-day median maximum flows decreased from 2800 cfs for the
 3 pre-dam period to 700 cfs for the post-dam periods (**Table 6** and **Figure 10**).
 4

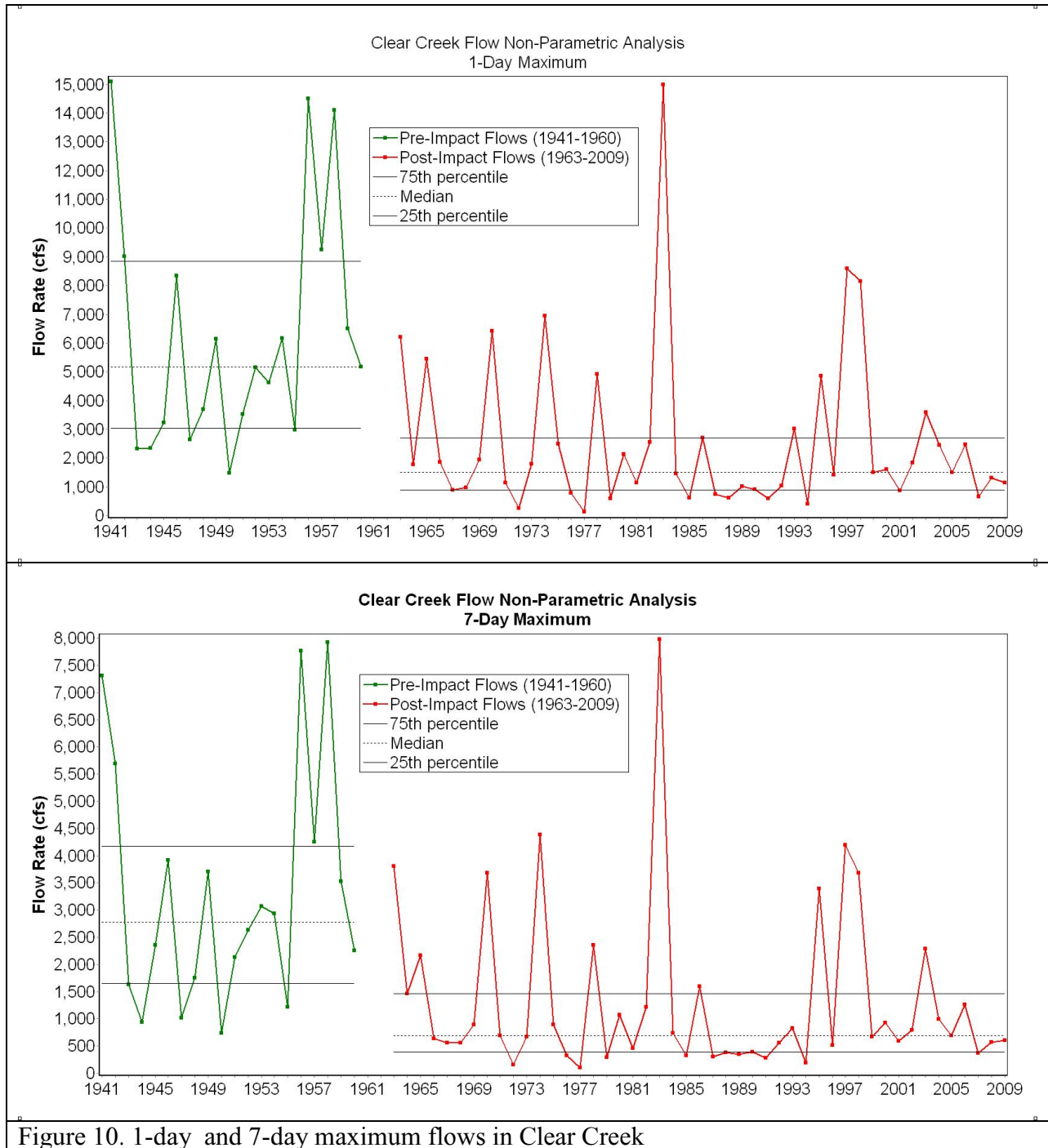


Figure 10. 1-day and 7-day maximum flows in Clear Creek

5 **7.1.3 Timing of Annual Extreme Flows**

6 This is the Julian date of the annual 1-day minimum and 1-day maximum flows. The timing of
 7 annual extreme flows provides spawning cues for anadromous fish, compatibility with life cycles

1 of organisms, and access to special habitats during reproduction or to avoid predation. The
 2 median Julian date for the 1-day minimum flow was 266 (end of September) for the pre-dam
 3 period, comparing to 238 (end of August) for the post-dam period. The inter-annual variation in
 4 timing of the 1-day minimum flow was larger for the post-dam period than for the pre-dam
 5 period, whereas the timing and inter-annual variation in the 1-day maximum flow were similar
 6 between these two periods (**Figure 11**).
 7

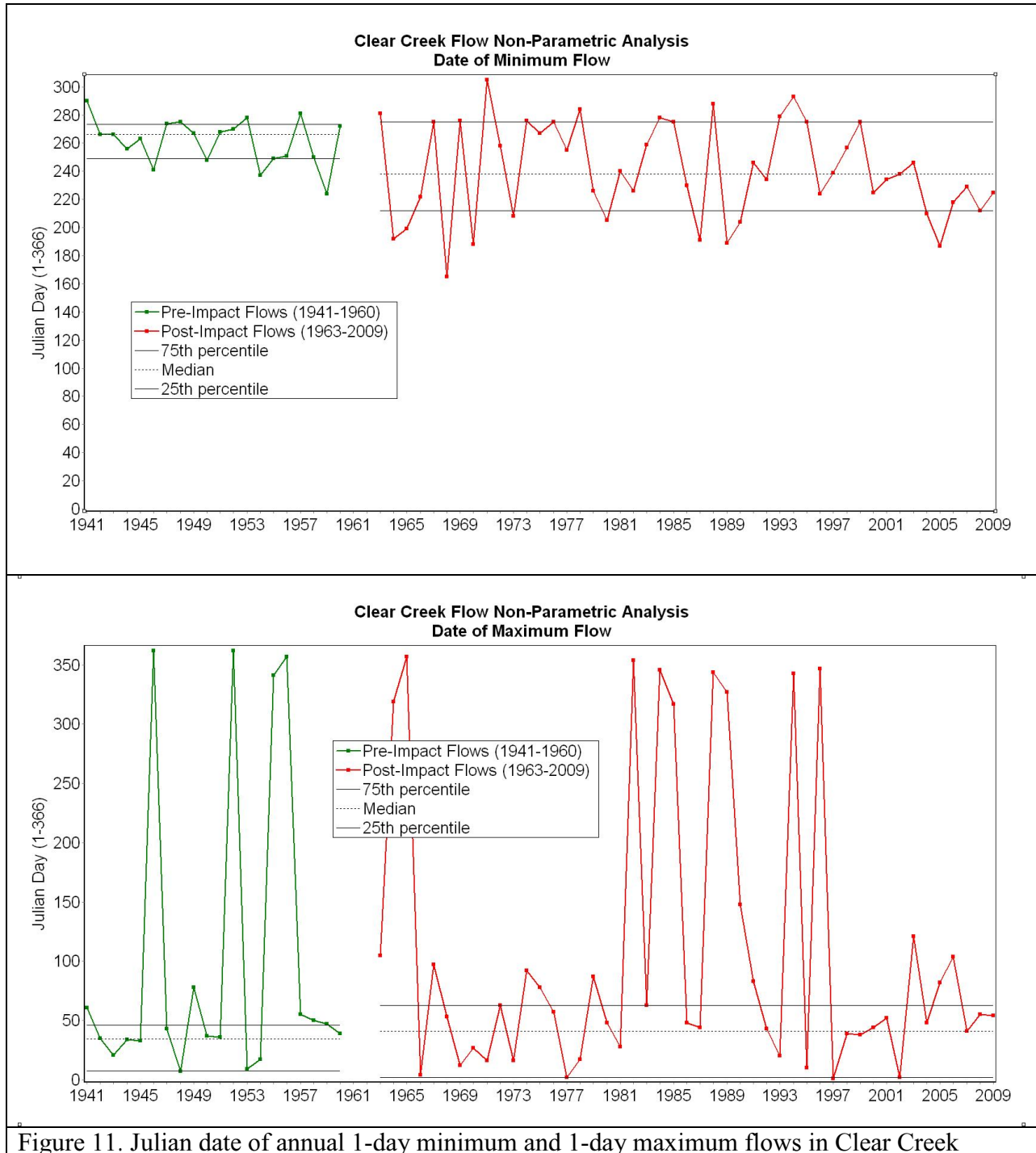


Figure 11. Julian date of annual 1-day minimum and 1-day maximum flows in Clear Creek

1 **7.1.4 Frequency and Duration of High and Low Pulses**

2 The frequency and duration of high and low pulses influence the availability of floodplain
 3 habitat, nutrient exchange between river and floodplain, and sediment/gravel transport.
 4 Hydrologic pulses in this report are defined as those periods within a year in which the daily
 5 average water flow either rises above the 75th percentile (high pulse) or drop below the 25th
 6 percentile (low pulse) of all daily values for the pre-dam period. The low pulse threshold was 46
 7 cfs and the high pulse threshold was 420 cfs. The number of low flow pulses decreased from the
 8 pre-dam period to the post-dam period, whereas the number of high flow pulses was similar
 9 between these two periods (**Figure 12**).

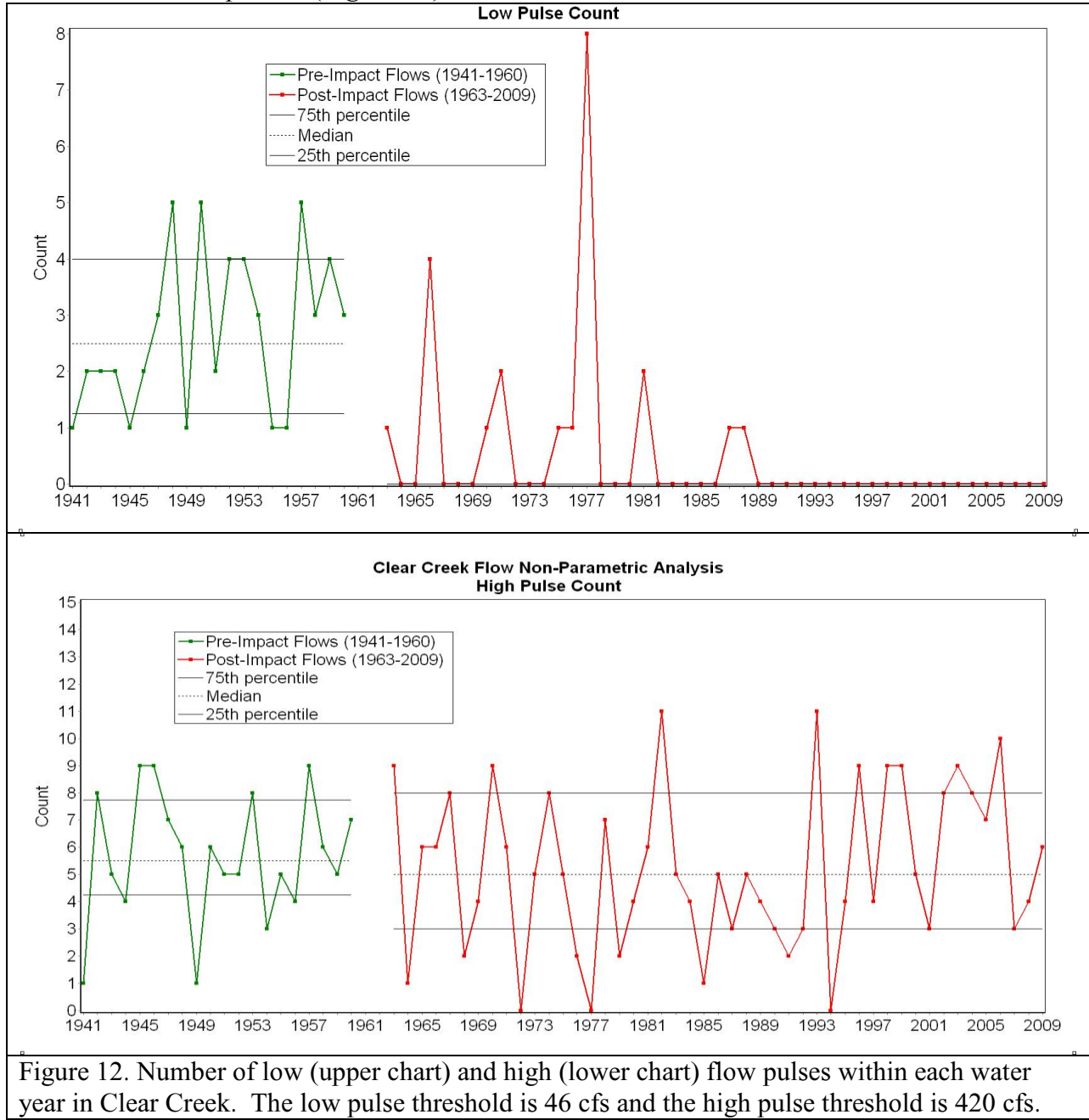


Figure 12. Number of low (upper chart) and high (lower chart) flow pulses within each water year in Clear Creek. The low pulse threshold is 46 cfs and the high pulse threshold is 420 cfs.

- 1 The duration of both low and high flow pulses decreased from the pre-dam period to the post-
- 2 dam period (**Figure 13**).
- 3

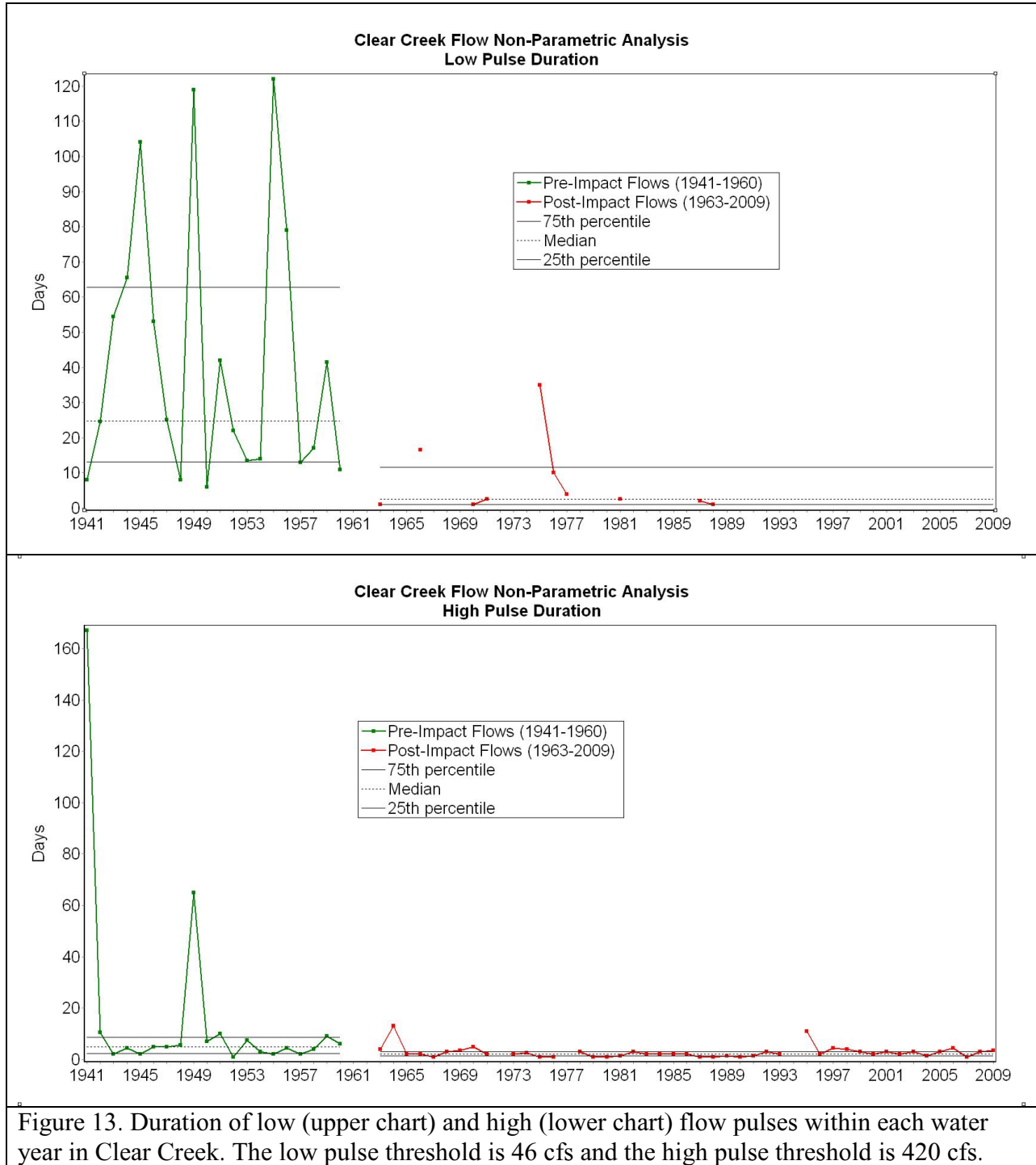


Figure 13. Duration of low (upper chart) and high (lower chart) flow pulses within each water year in Clear Creek. The low pulse threshold is 46 cfs and the high pulse threshold is 420 cfs.

4

1 **7.1.5 Rate and Frequency of Flow Changes**

2 The rate of flow changes includes the rise rate (positive differences between consecutive daily
3 flows) and fall rate (negative differences between consecutive daily flows). Both the rise and fall
4 rates decreased from the pre-dam period to the post-dam period (**Figure 14**).

5

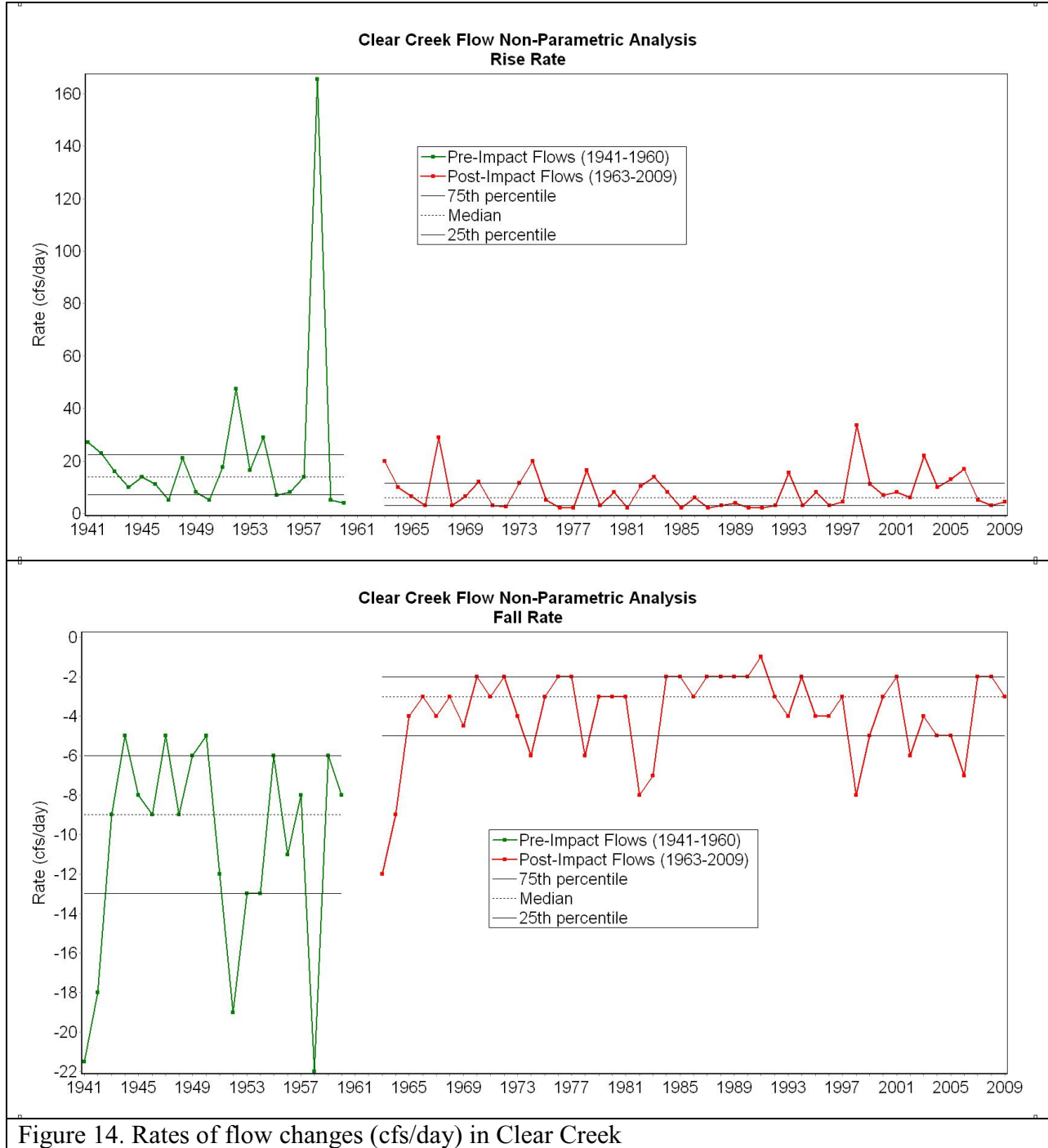


Figure 14. Rates of flow changes (cfs/day) in Clear Creek

6
7

1 Hydrologic reversals are calculated by dividing the hydrologic record into "rising" and "falling"
 2 periods, which correspond to periods in which daily changes in flows are either positive or
 3 negative, respectively. Note that a rising or falling period is not ended by a pair of days with
 4 constant flow, only by a change of sign in the rate of change. The number of reversals is the
 5 number of times that flow switches from one type of period to another. The post-dam period
 6 showed more hydrologic reversals than the pre-dam period (**Figure 15**).
 7

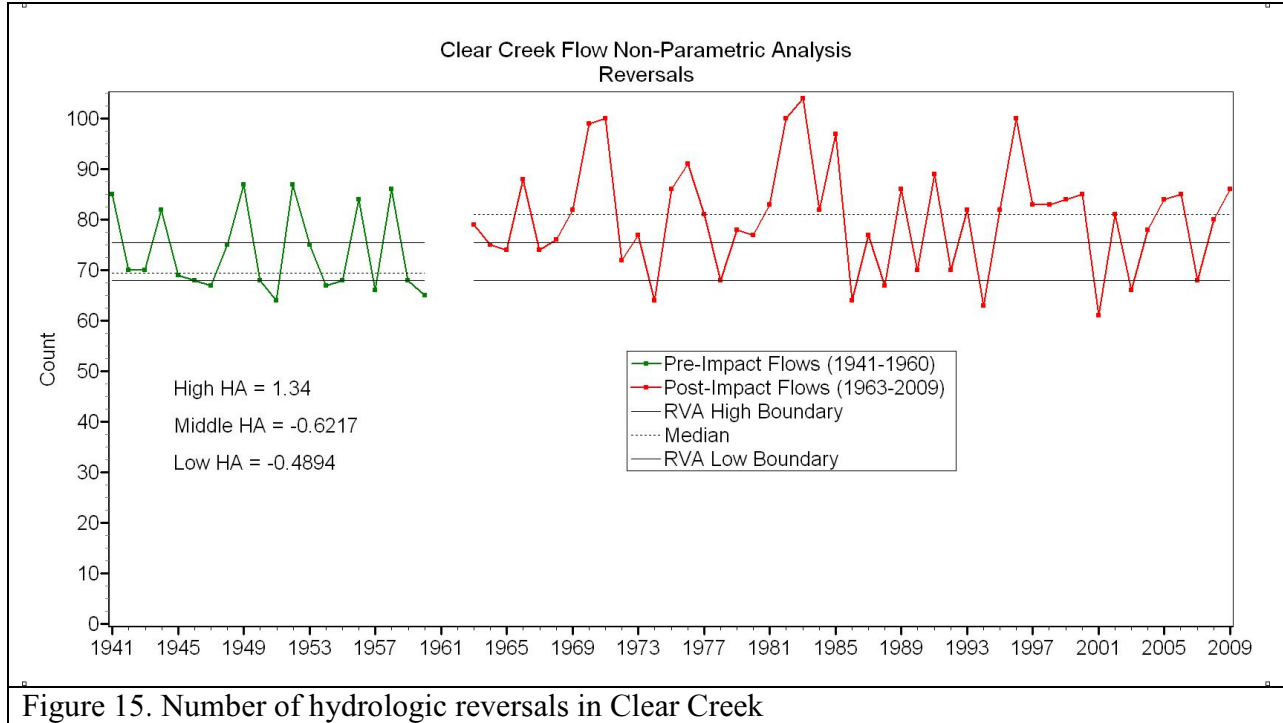


Figure 15. Number of hydrologic reversals in Clear Creek

8

9 **7.1.6 Range of Variation Approach (RVA) Analysis**

10 The RVA was developed to set initial streamflow-based river ecosystem management targets,
 11 which are intended to guide the design of river management strategies (*e.g.*, reservoir operation
 12 rules and habitat restoration) (Richter *et al.* 1997). The RVA targets may be redefined as new
 13 research on the linkage between hydrological characteristics and aquatic ecosystem integrity
 14 becomes available. The management objective is not to have the river attain the targeted range
 15 every year, rather, it is to attain the targeted range at the same frequency as occurred in the pre-
 16 dam flow regime. For example, attainment of an RVA target range defined by the 33rd and 67th
 17 percentiles of a particular parameter would be expected in only 50% of years.

18

19 In an RVA analysis (Richter *et al.* 1997; Richter *et al.* 1998), the full range of pre-dam data for
 20 each parameter is divided into three different categories. The boundaries between categories are
 21 based on percentile values for non-parametric analysis, in which the category boundary is 17
 22 percentiles from the median. This yields an automatic delineation of three categories of equal
 23 size:

24

- 1) the low category that contains all values less than or equal to the 33rd percentile;
- 2) the middle category that contains all values falling in the range of the 34th to 67th percentiles, which is the RVA boundaries as given in **Table 6**; and

26

3) the high category that contains all values greater than the 67th percentile.

The degree, to which the RVA target range is not attained, is a measure of hydrologic alteration. The IHA software program computes the expected frequency, with which the "post-impact" values of the IHA parameters should fall within each category. The expected frequency is equal to the number of values in the category during the pre-dam period multiplied by the ratio of post-dam years to pre-dam years. The program also computes the observed frequency, which is the number of the "post-impact" annual values of IHA parameters fall within each of the three categories. The Hydrologic Alteration (HA) factor is then calculated for each of the three categories as:

$$HA = (\text{observed frequency} - \text{expected frequency}) / \text{expected frequency}$$

When the HA values are close to zero, minimum changes occurred from the pre-dam period to post-dam period. A positive HA value means that the frequency of values in the category has increased from the pre-dam to the post-dam period (with a maximum value of infinity), while a negative HA value means that the frequency of values has decreased (a minimum value of -1).

The RVA boundaries and HA values are given in **Table 6** and shown from **Figures 9 to Figure 16**. For the middle RVA category, most of the 31 parameters showed a decreased frequency from the pre-dam period to the post-dam period (**Figure 16**). Note that even though the monthly flow in August, September, and October increased from the pre-dam to post-dam period, the number of monthly flow values falling within the middle RVA category decreased and the number of monthly flow values falling within the high RVA category increased (**Figure 17**).

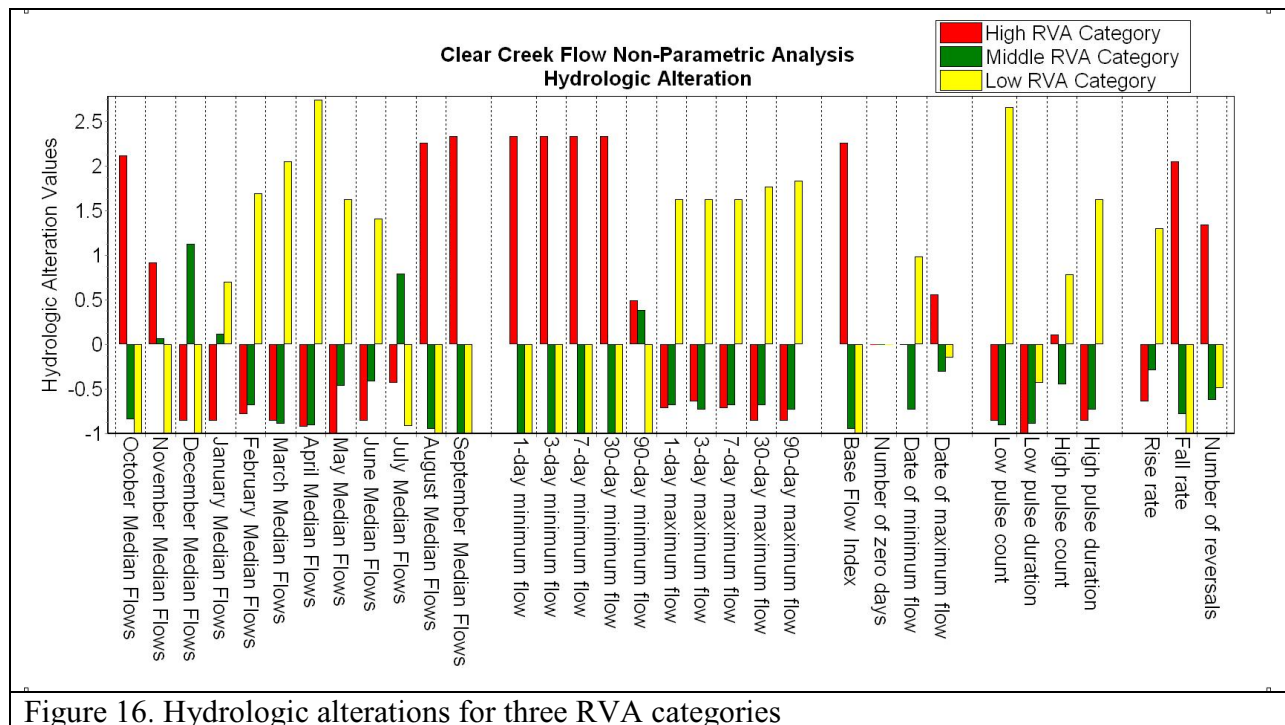


Figure 16. Hydrologic alterations for three RVA categories

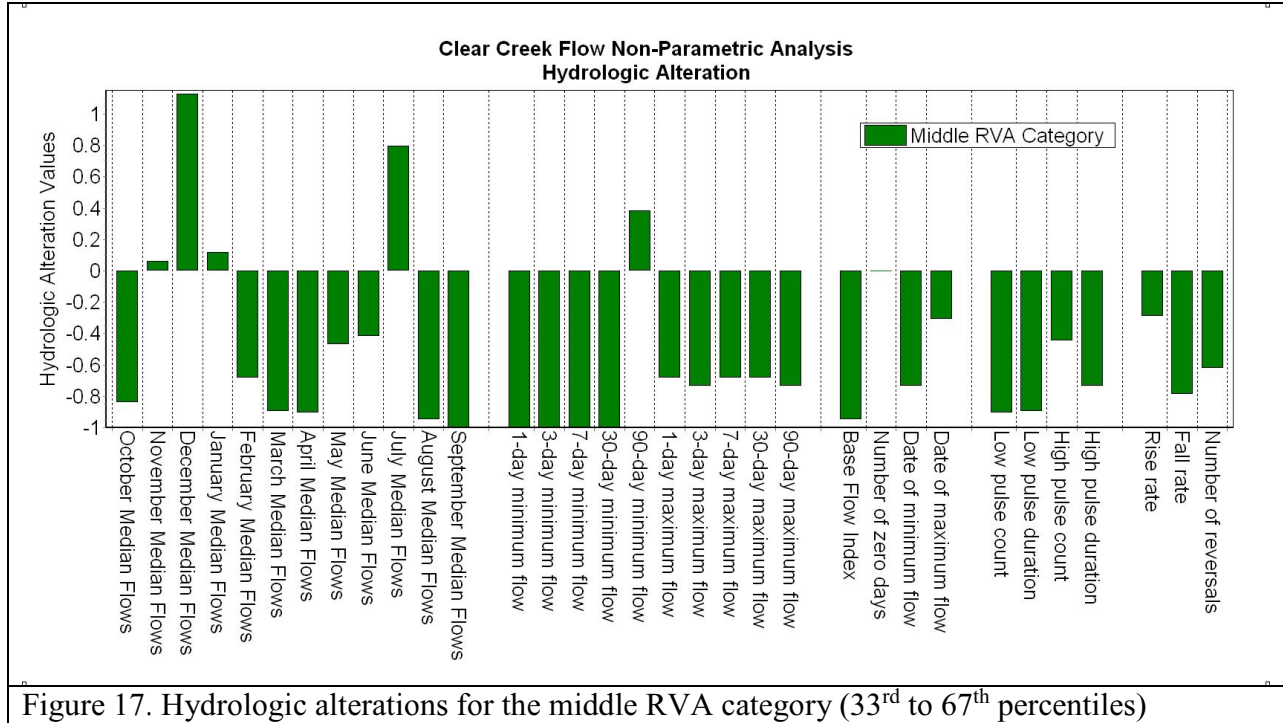


Figure 17. Hydrologic alterations for the middle RVA category (33rd to 67th percentiles)

1

2 **7.2 Environmentally Relevant Flows in Clear Creek**

3 In addition to the hydrologic parameters, the IHA software program also provides parameters for
 4 five types of Environment Flow Components (EFCs): large floods, small floods, high-flow
 5 pulses, low flows, and extreme low flows. This delineation of EFCs is based on the realization
 6 by ecologists that river hydrographs can be divided into a repeating set of hydrographic patterns
 7 that are ecologically relevant (The Nature Conservancy 2009).

8

9 In this report, all flows that exceed 75% of daily flows for the period are classified as initial high
 10 flows. All flows that are below 50% of daily flows for the period are classified as initial low
 11 flows. Between these two flow levels, a high flow will begin when flow increases by more than
 12 25% per day, and will end when flow decreases by less than 10% per day.

13

14 A Small Flood event is defined as an initial high flow with a peak greater than the 2-year return
 15 interval event. A Large Flood event is defined as an initial high flow with a peak greater than the
 16 10-year return interval event. All other initial high flows not classified as Small Floods or Large
 17 Floods will be classified as High-flow Pulses. An Extreme Low Flow is defined as an initial low
 18 flow below 10% of daily flows for the period. All other initial low flows not classified as
 19 Extreme Low Flows will be classified as Low Flows.

20

21 With the criteria described above, the thresholds for the five EFCs were computed for Clear
 22 Creek and listed in **Table 7**. The analysis results for environmental flow components are shown
 23 in **Figure 18**. Each of the five EFCs is discussed below.

24

25

1 Table 7. Thresholds for the five Environmental Flow Components in Clear Creek

EFC	Threshold (cfs)
Large flood	14,460
Small flood	5,165
High-flow pulse	420
Low flow	133
Extreme low flow	26

2

3 **7.2.1 Large Flood**

4 Large floods will typically re-arrange the biological, physical, and chemical structure of a river
 5 and its floodplain, including transport of significant amounts of sediment, large woody debris
 6 and other organic matter, formation of new habitats (*e.g.*, oxbow lakes and floodplain wetlands),
 7 changes in water quality conditions, and flushing of many organisms in the main channel and
 8 floodplain. There were three (3) large floods in Clear Creek from 1940 to 2009, each on March
 9 1, 1941, December 22, 1956, and March 3, 1983, respectively (**Figure 18**).

10

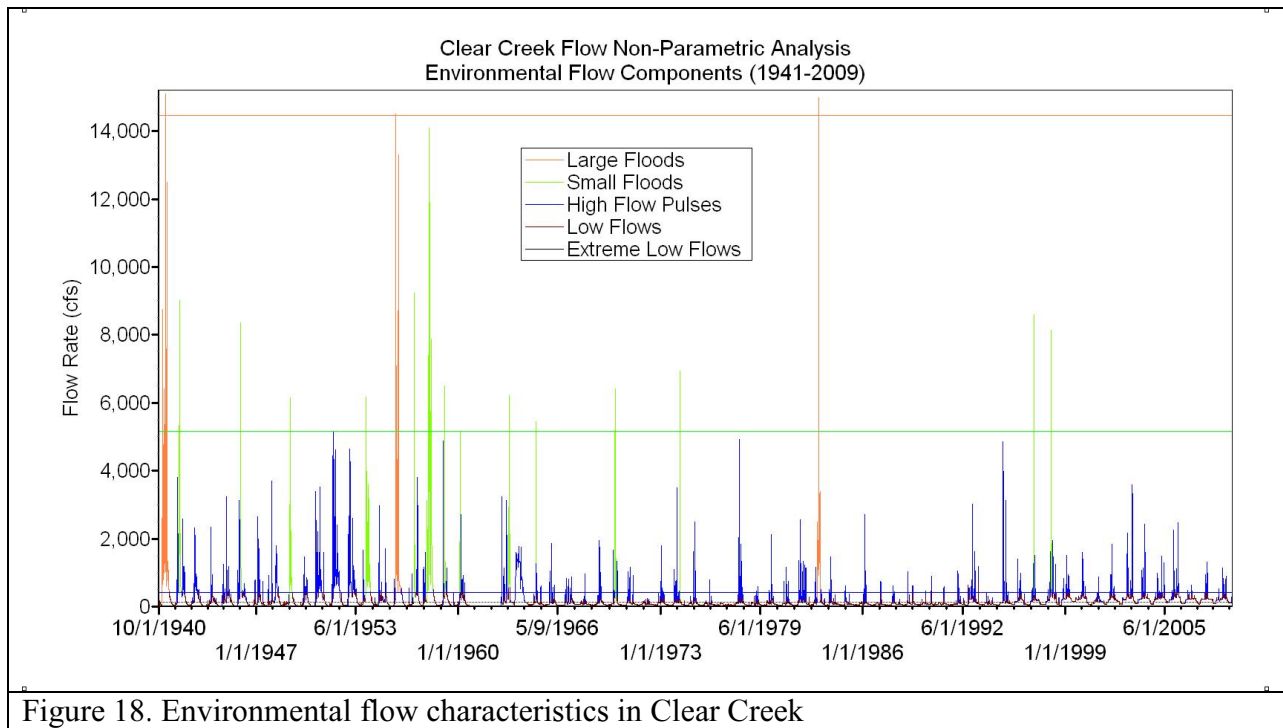


Figure 18. Environmental flow characteristics in Clear Creek

11

12 **7.2.2 Small Flood**

13 Small floods are river flows that overtop the main channel banks and occur frequently (*e.g.*,
 14 every 2 or so years). These floods allow fish and other mobile organisms to access floodplains
 15 and habitats, such as secondary channels, backwaters, sloughs, and wetlands. These areas can

1 provide significant food resources allowing for fast growth, offer refuge from high-velocity,
 2 lower temperature water in the main channel, or be used for spawning or rearing.
 3 There were 21 small floods from 1941 to 1960 (pre-dam period), occurring once a year on
 4 average. On the contrary, there were 6 small floods from 1963 to 2009, occurring once every 8
 5 years on average (**Figure 18**). The characteristics of the pre-dam small floods in Clear Creek are
 6 summarized in **Table 8**. Most pre-dam small floods occurred between late January and late
 7 March. The small flood duration spanned from 5 to 30 days. Their peak flows ranged from 5170
 8 to 14100 cfs. The rise rates ranged from 485 to 8620 cfs/day, while the fall rates ranged from -
 9 2705 to -373 cfs/day.

10
 11 Table 8. Characteristics of pre-dam small floods in Clear Creek

Feature	Median	Middle Range*
Small flood peak (cfs)	7100	6150 - 9240
Small flood duration (day)	11	7 - 14
Small flood timing (Julian day)	47	29 - 77
Small flood rise rate (cfs/day)	1865	1295 - 2745
Small flood fall rate (cfs/day)	-1011	(-1115) – (-696)

12 *Between 25th and 75th percentiles

13 **7.2.3 High-flow Pulse**

14 High-flow pulses may occur during rainstorms or brief periods of snowmelt. Water levels rise
 15 above low-flow levels but do not overtop the channel banks. For many organisms, these short-
 16 term changes in flow may provide necessary respite from stressful low-flow conditions. These
 17 pulses of freshwater may relieve higher water temperatures and low dissolved oxygen
 18 availability typical of low flow conditions, flush wastes, and deliver organic matter that
 19 nourishes the aquatic food web. High-flow pulses typically facilitate improved access to
 20 upstream or downstream areas for mobile organisms.

21 The characteristics of high-flow pulses in Clear Creek are presented in **Figures 19-20** and
 22 summarized in **Table 9**. High-flow pulses in Clear Creek occurred 3-7 times a year between late
 23 December and late February during the pre-dam period. The median duration of the high-flow
 24 pulses was 3.5 days with a median peak flow of 800 cfs, a rise rate of 422 cfs/day, and a fall rate
 25 of -139 cfs/day.

26 The magnitude of high-flow pulses decreased from 800 cfs in the pre-dam period to 400 cfs in
 27 the post-dam period, while the duration, timing, and change rates of high-flow pulses remained
 28 similar between the two periods.

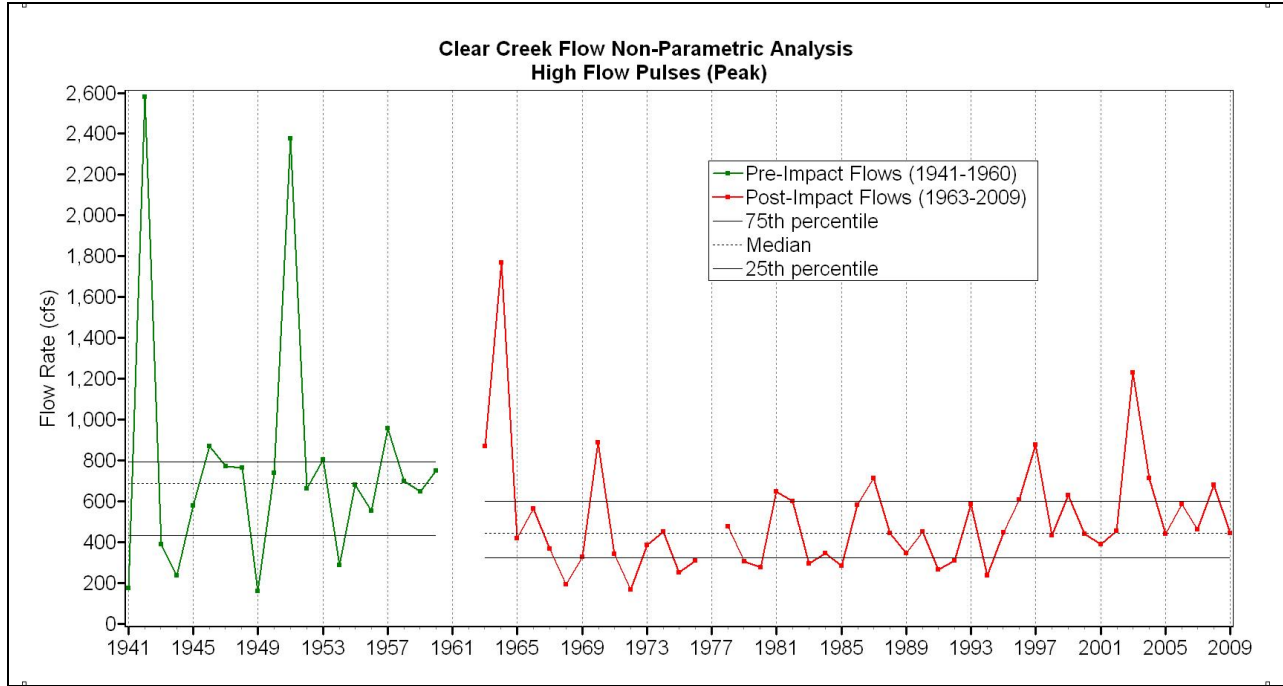


Figure 19. High flow pulse peak (cfs) in Clear Creek

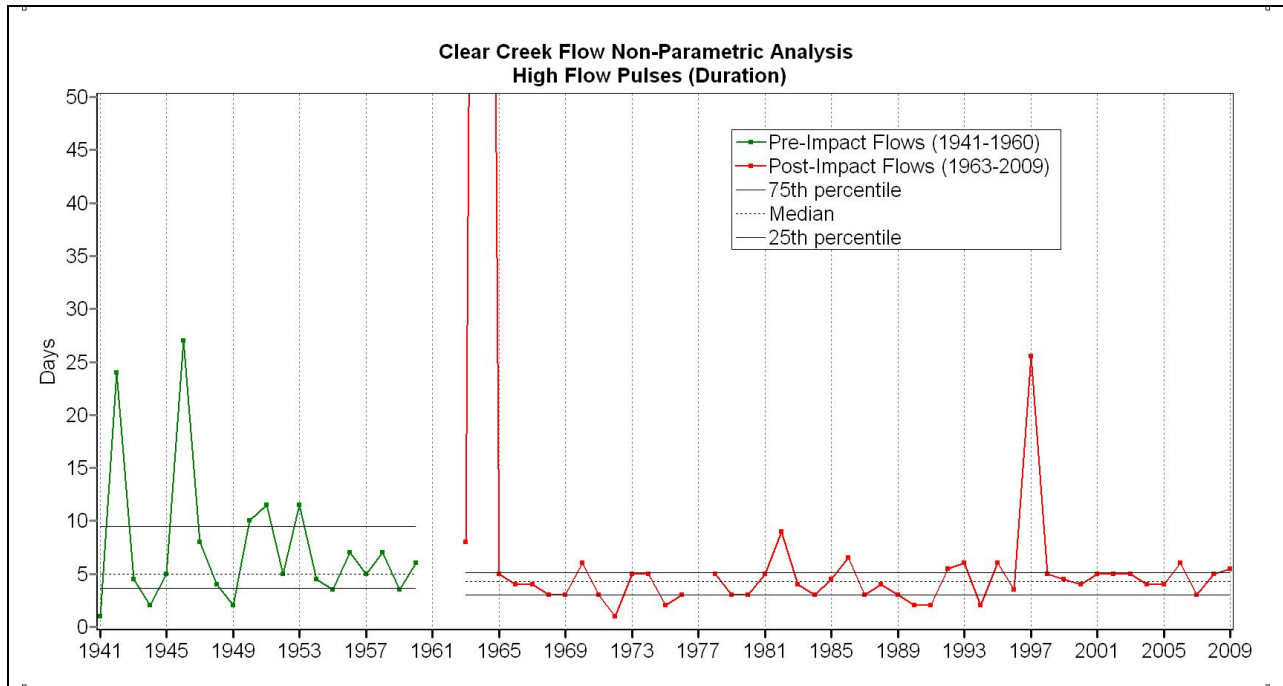


Figure 20. High flow pulse duration (days) in Clear Creek

1

2

1 Table 9. Characteristics of pre-dam high-flow pulses in Clear Creek

Feature	Median	Middle Range*
High flow pulse peak (cfs)	689	431 - 795
High flow pulse duration (day)	5	3 - 9
High flow pulse timing (Julian day)	9	344 - 52
High flow pulse frequency	6	5 - 8
High flow pulse rise rate (cfs/day)	180	124 - 288
High flow pulse fall rate (cfs/day)	-75	(-99) – (-66)

2 * Between 25th and 75th percentiles

3 **7.2.4 Low Flow**

4 In natural rivers, after a rainfall event or snowmelt period has passed and associated surface
 5 runoff from the catchment has subsided, the river returns to its baseflow level. These low-flow
 6 levels are sustained by groundwater discharge into the river. The seasonally varying low flows in
 7 a river impose a fundamental constraint on a river's aquatic communities because it determines
 8 the amount of aquatic habitat available for most of the year. This has a strong influence on the
 9 diversity and number of organisms that can live in the river.

10
 11 The EFC monthly low flows in Clear Creek are presented in **Table 10**. For the pre-dam period of
 12 1941 to 1960, the lower flows occurred in July, August, and September while the higher flows
 13 occurred in March and April. For the post-dam period of 1991 to 2010, the highest flow occurred
 14 in March or April, whereas the lowest flow occurred in August. While the magnitude of flows
 15 from December to June was comparable between the two periods, the post-dam flows from July
 16 through November were higher than the pre-dam flows. The increased flows during the post-
 17 dam period reflect the CVPIA AFRP implementation (beginning 1999) for water temperature
 18 management in Clear Creek.

19
 20 Inter-annual variations in monthly low flows are selectively presented in **Figure 21** (October)
 21 and **Figure 22** (March). The EFC median monthly low flows were lower than the overall IHA
 22 median monthly flows from December through June, while they were similar from July through
 23 November (**Figure 23**).

24

1 Table 10. Monthly low flows (in cfs) as percentiles in Clear Creek

Month	Pre-dam (1941-1960)			Post-dam (1991-2010)		
	50 th	75 th	90 th	50 th	75 th	90 th
October	39	50	80	207	217	264
November	59	100	176	212	215	237
December	123	214	301	226	269	321
January	158	297	391	272	292	337
February	232	348	370	272	277	330
March	301	377	404	271	299	388
April	291	398	413	247	303	336
May	241	346	380	237	274	296
June	112	220	255	171	207	223
July	50	88	104	108	153	211
August	33	47	57	88	116	205
September	33	42	48	156	198	221

2

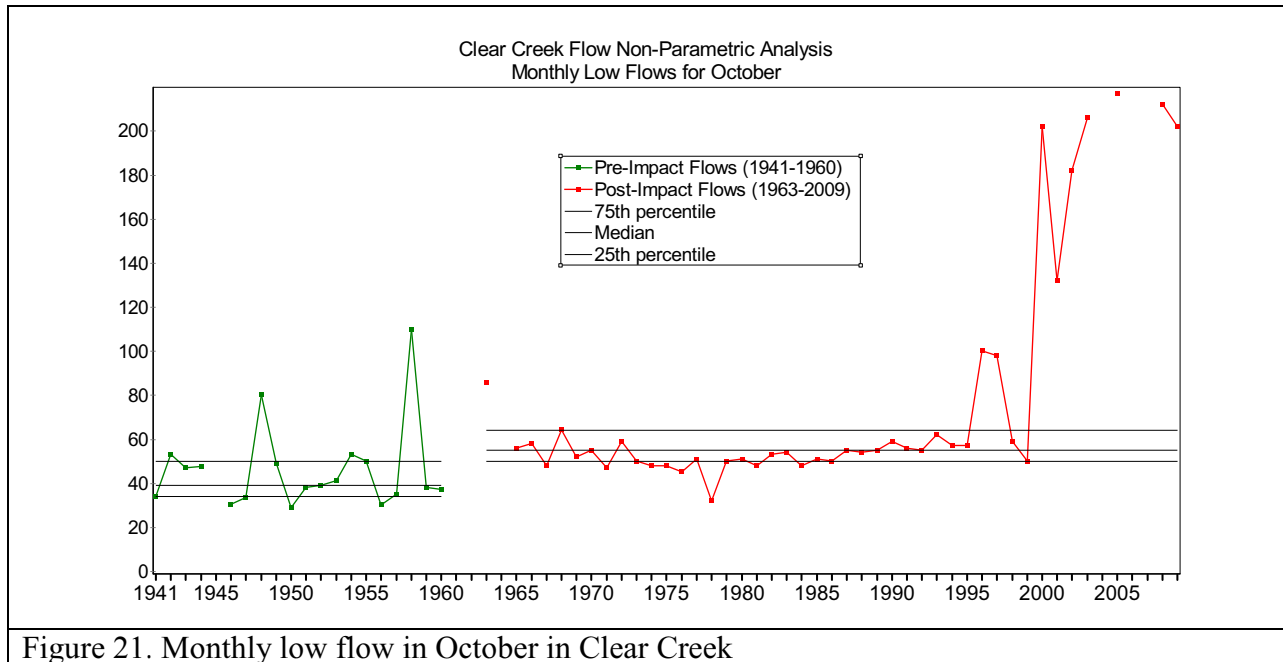


Figure 21. Monthly low flow in October in Clear Creek

3

4

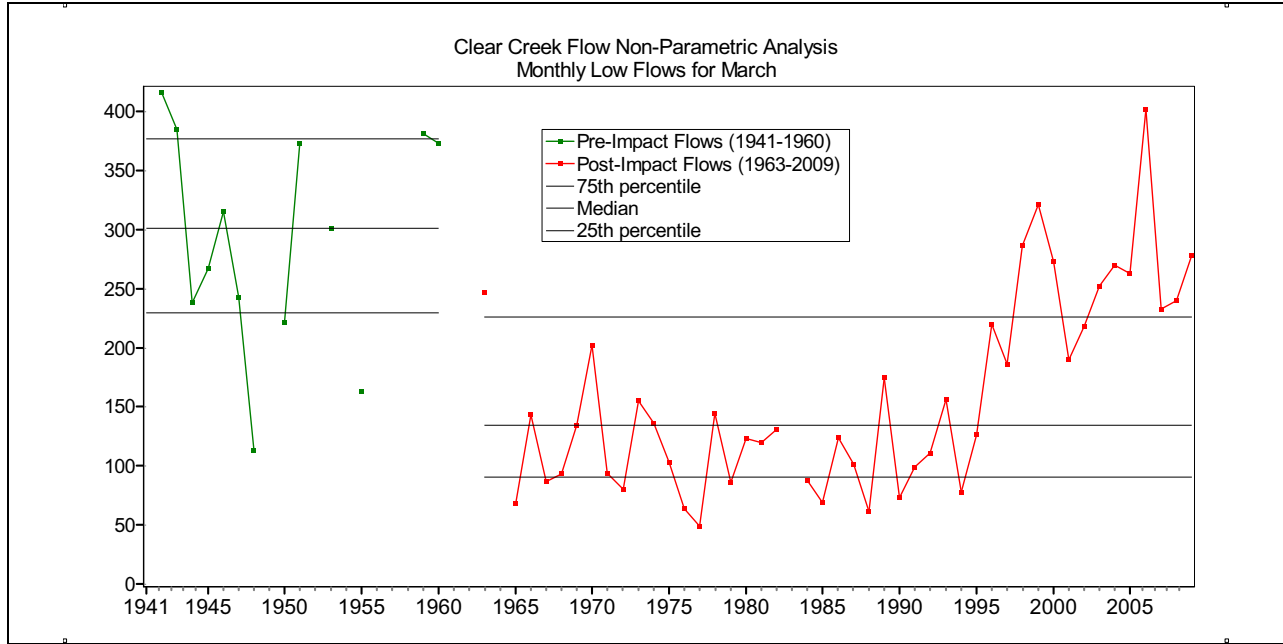


Figure 22. Monthly low flow in March in Clear Creek

1
2

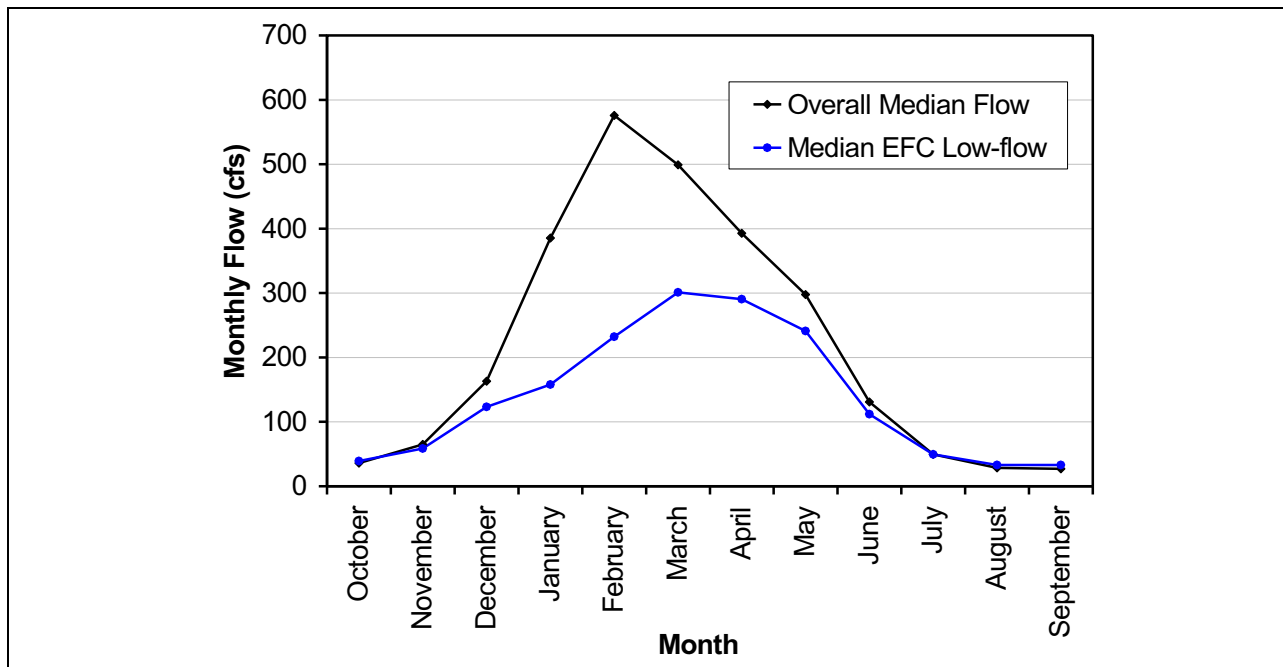


Figure 23. Pre-dam median EFC low-flows comparing with Overall median flows in Clear Creek

3

4 7.2.5 Extreme Low Flow

5 During drought periods, rivers drop to very low levels that can be stressful for many organisms,
 6 but may provide necessary conditions for other species. Water chemistry, temperature, and
 7 dissolved oxygen availability can become highly stressful to many organisms during extreme
 8 low flows, to the point that these conditions can cause considerable mortality. On the other hand,

1 extreme low flows may concentrate aquatic prey for some species, or may be necessary to dry
 2 out low-lying floodplain areas and enable certain species of plants to regenerate.

3
 4 The pre-dam EFC extreme low flows in Clear Creek are presented in **Table 11**. They occurred
 5 once a year on average in September, with a median extreme low flow of 21 cfs in Clear Creek.
 6 These pre-dam summer low flows may have caused elevated water temperatures in some areas of
 7 the creek, but the creek would provide refuge areas with a proper water temperature for fish
 8 through mechanisms such as the cover of debris and riparian vegetation and groundwater
 9 seepage. During the past 50 years of development, the geomorphology and riparian vegetation of
 10 Clear Creek have degraded to such a large degree that higher summer flows have to be
 11 maintained to provide adequate water temperatures for spring-run Chinook salmon. The potential
 12 adverse effects of these increased baseflows may cause changes in the composition and
 13 distribution of riparian vegetation species.

14
 15 Table 11. Characteristics of pre-dam extreme low flows as percentiles in Clear Creek

Feature	25th	50th	75th
Extreme low flow peak (cfs)	17	21	23
Extreme low flow duration (day)	9	15	33
Extreme low flow timing (Julian day)	248	260	274
Extreme low flow frequency	1	1	3

16
 17

1 **8 Water Temperature in Clear Creek**

2 **8.1 Air and Water Temperature**

3 Stream temperature can be affected by many factors including atmospheric conditions,
4 topography, stream discharge, and streambed (Caissie 2006). Atmospheric conditions are the
5 most important factors that are responsible for heat exchange occurring at the air-water interface,
6 and to a lesser degree at the water-streambed interface. Topography or geographical setting
7 influences atmospheric conditions. Stream discharge influences the heating capacity of a stream.
8

9 Air temperature (daily maximum and 7DADM) in Redding and water temperature (daily
10 maximum and 7DADM) from 2002 to 2009 are presented in **Figure 24**. Temperatures were
11 shown from June 1 to October 31 as this period of time is identified to be critical for life stages of
12 spring run Chinook salmon in Clear Creek and likely to have water temperature exceedance.
13 Water temperature in Clear Creek changed with changes in air temperature, but water
14 temperature variations were smaller than air temperature variations. When the data were
15 transformed from daily maximum to 7DADM, their variations were further reduced for both
16 water and air temperatures as displayed in whisker-box plots (**Figure 25**). The horizontal line
17 crossing the inner box is the median. The circle below the median is the mean. The top of the
18 inner box is the third quartile (Q3) – 75% of the data values are less than or equal to this value.
19 The bottom of the inner box is the first quartile (Q1) – 25% of the data values are less than or
20 equal to this value. The upper whisker extends to the highest data value within the upper limit:

$$21 \quad \text{Upper limit} = Q3 + 1.5 (Q3 - Q1)$$

22
23 The lower whisker extends to the lowest value within the lower limit:

$$24 \quad \text{Lower limit} = Q1 - 1.5 (Q3 - Q1)$$

25
26 Values beyond the whiskers are outliers, represented by “*”.

27 Cumulative distribution function graphs (**Figure 26**) were used to estimate the percentage of
28 water temperatures that exceed the water temperature objectives: 60 °F from June 1 to September
29 15 and 56 °F from September 16 to October 31. The graphs include an empirical cumulative
30 distribution function (ECDF) of the temperature data, and a fitted normal cumulative distribution
31 function (CDF) (**Figure 26**). The stepped ECDF resembles a cumulative histogram without bars,
32 while the fitted CDF is based on parameters estimated from the temperature data.

33 The percentage of days exceeding the water temperature objectives were obtained from **Figure**
34 **26** and are summarized in **Table 12**. Water temperature in July was the highest and 90% of the
35 days exceeded 60 °F, which is the temperature protective of adult migration and holding. Ninety
36 six percent of the temperature in September (16th-30th) exceeded 56 °F, which is the
37 temperature protective of spawning.

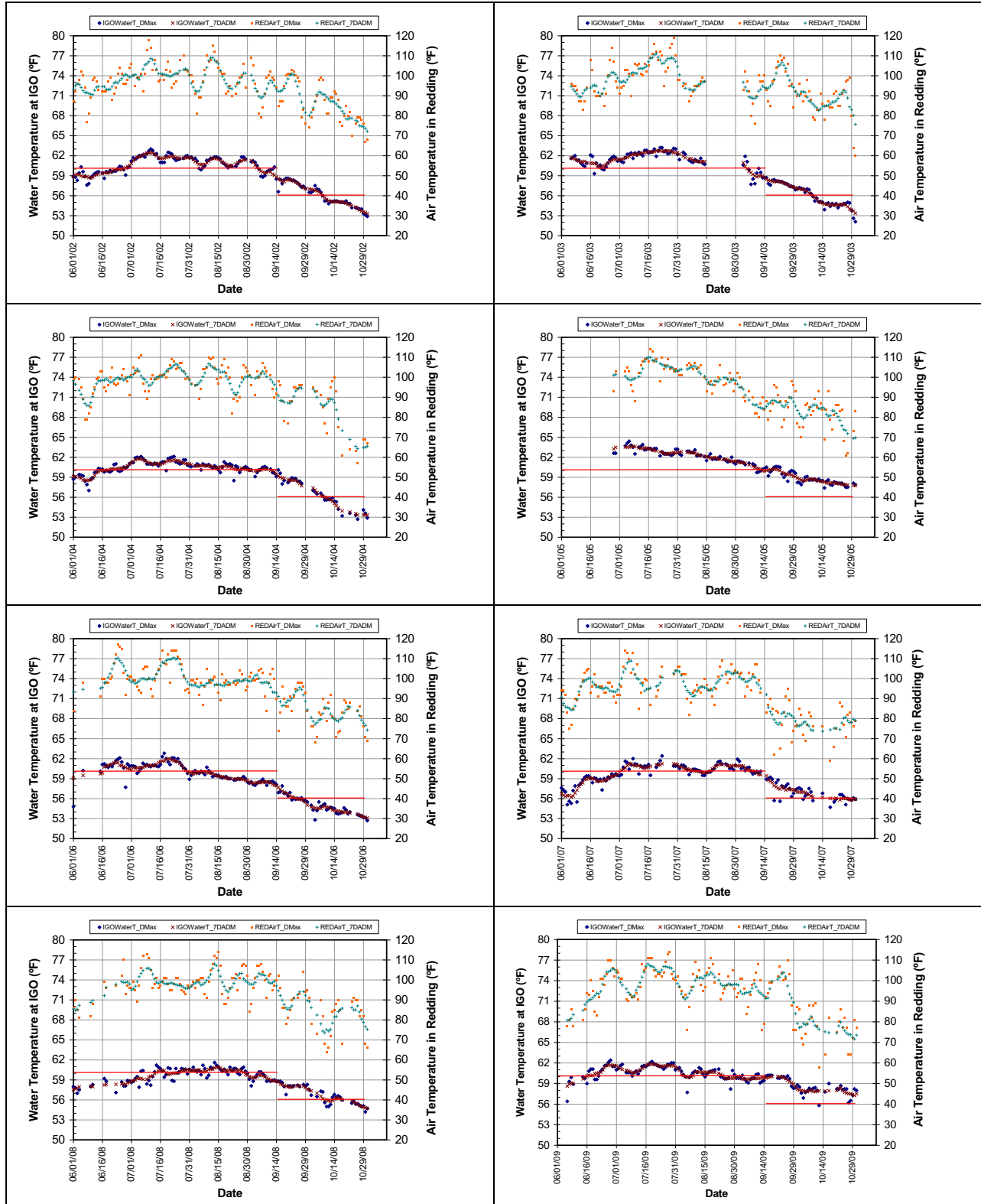


Figure 24. Water temperature at IGO and air temperature in Redding. DMax = Daily maximum. 7DADM = 7-day average of daily maximum. The red lines represent water temperature objectives: 60 °F and 56 °F, respectively.

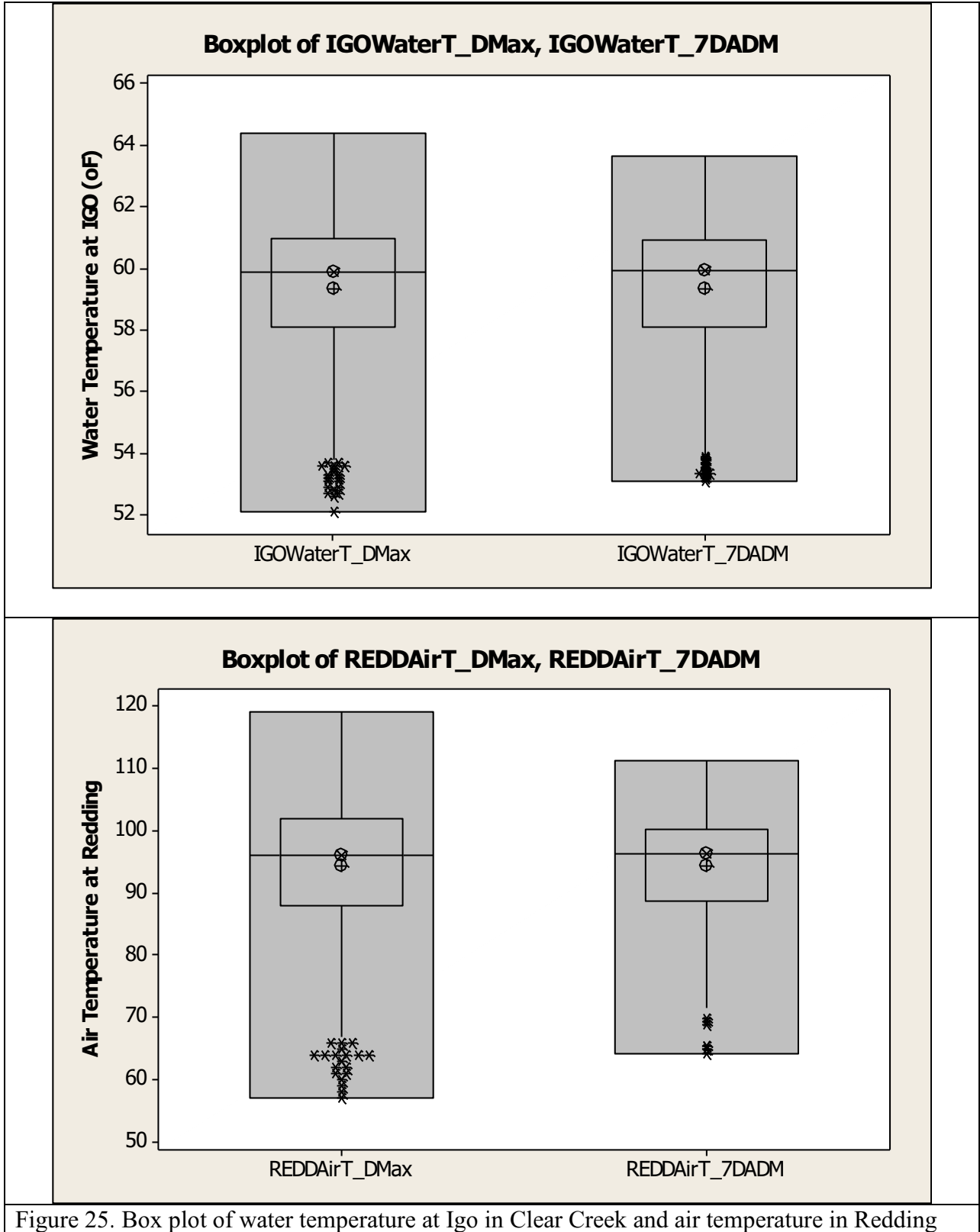


Figure 25. Box plot of water temperature at Igo in Clear Creek and air temperature in Redding

1

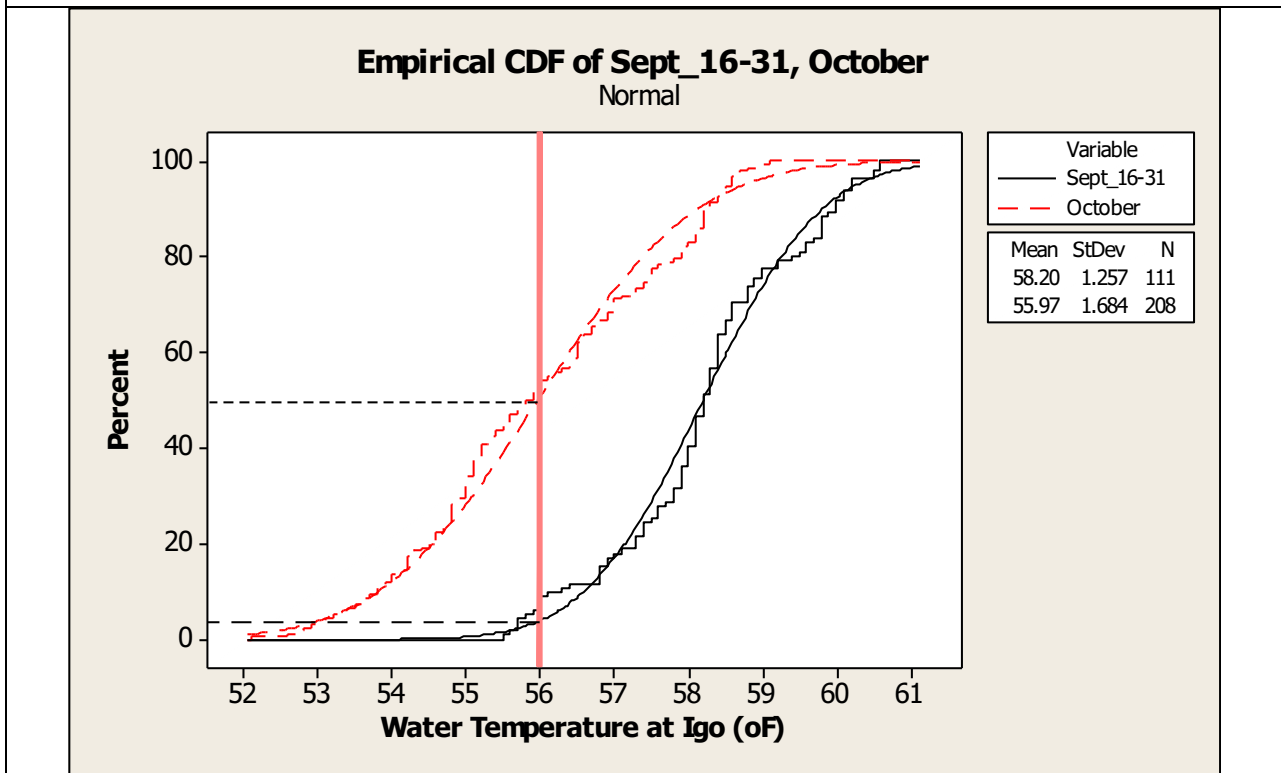
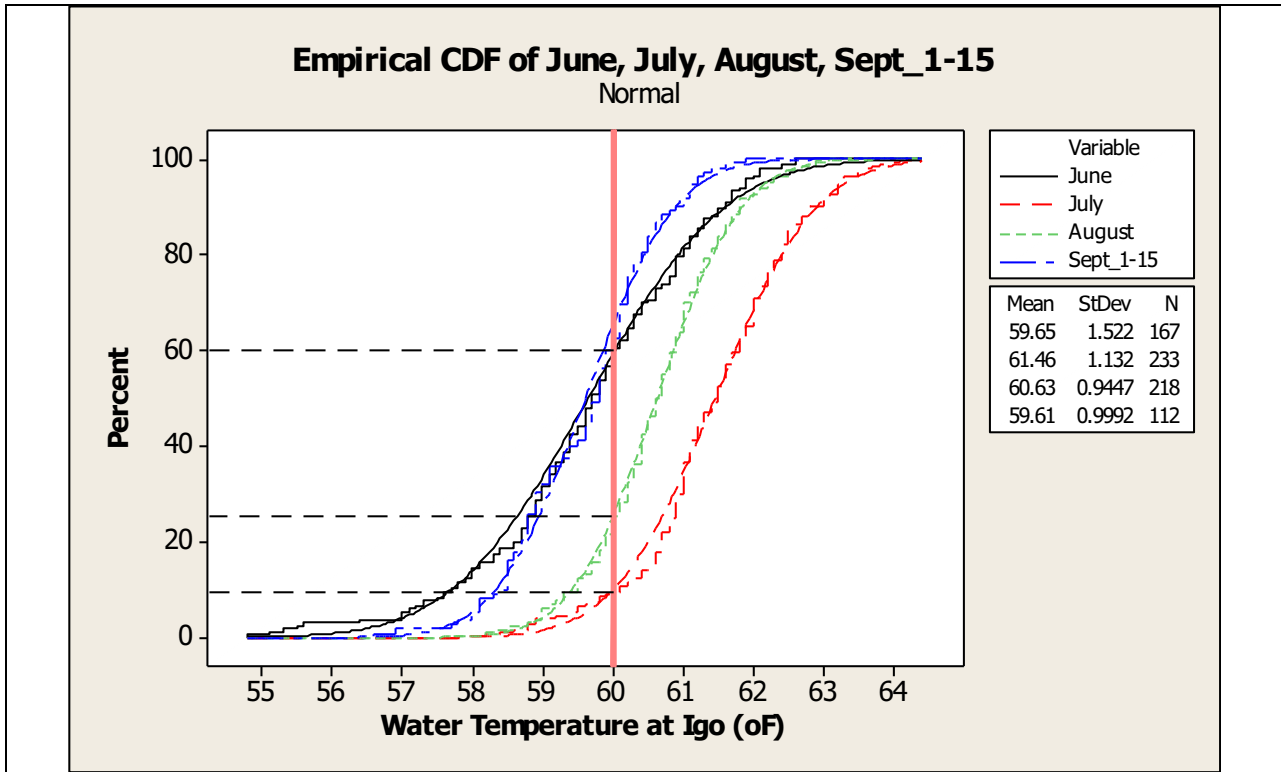


Figure 26. Cumulative distribution of water temperature at Igo in Clear Creek

2

3

1 Table 12. The percentage of days exceeding water temperature objectives in Clear Creek

Month	Days greater than 60 °F (%)	Days greater than 56 °F (%)
June	40	--
July	90	--
August	75	--
September 1-15	35	--
September 16-30	--	96
October	--	50

2
3 Dams directly modify river's thermal regimes by releasing water that differs greatly in
4 temperature to that occurring naturally in the river. The magnitude of thermal alteration depends
5 largely on the stratification of a reservoir, and the depth at which water is released from the
6 reservoir. Dams also modify water temperatures indirectly by influencing processes controlling
7 the delivery, distribution, and retention of heat within the river channel. Changes to discharge
8 and the volume of water in a river, for example, affect the rate at which water heats and cools in
9 response to natural diurnal heat exchange at the air-water and streambed-water interfaces (Olden
10 and Naiman 2010).

11
12 From June 1 to October 31, streamflow in Clear Creek at Igo was largely controlled by the
13 Whiskeytown reservoir release (**Figure 27**). Streamflow in June and October was generally
14 greater than the reservoir release. This may indicate the contribution of lower evaporation and/or
15 tributary flows downstream of the reservoir.
16

17 **8.2 Regression Model for Water Temperature**

18 The scatter plots of water temperature at Igo against reservoir release from Whiskeytown Dam
19 and air temperature and solar radiation at Redding are presented in Figures 28-30. There is a
20 negative correlation between water temperature and reservoir release, and a positive correlation
21 of water temperature with air temperature and solar radiation. Higher reservoir release leads to
22 lower water temperature downstream and higher air temperature or solar radiation leads to higher
23 water temperature.

24 **8.2.1 Model Development**

25 Two steps were used to develop a regression model - possibly the best for prediction. The first
26 step is to use all the observed data, which had been examined with the procedures as described in
27 Section 6, to develop a model. The second step is to perform a diagnostic analysis of the
28 established model.
29

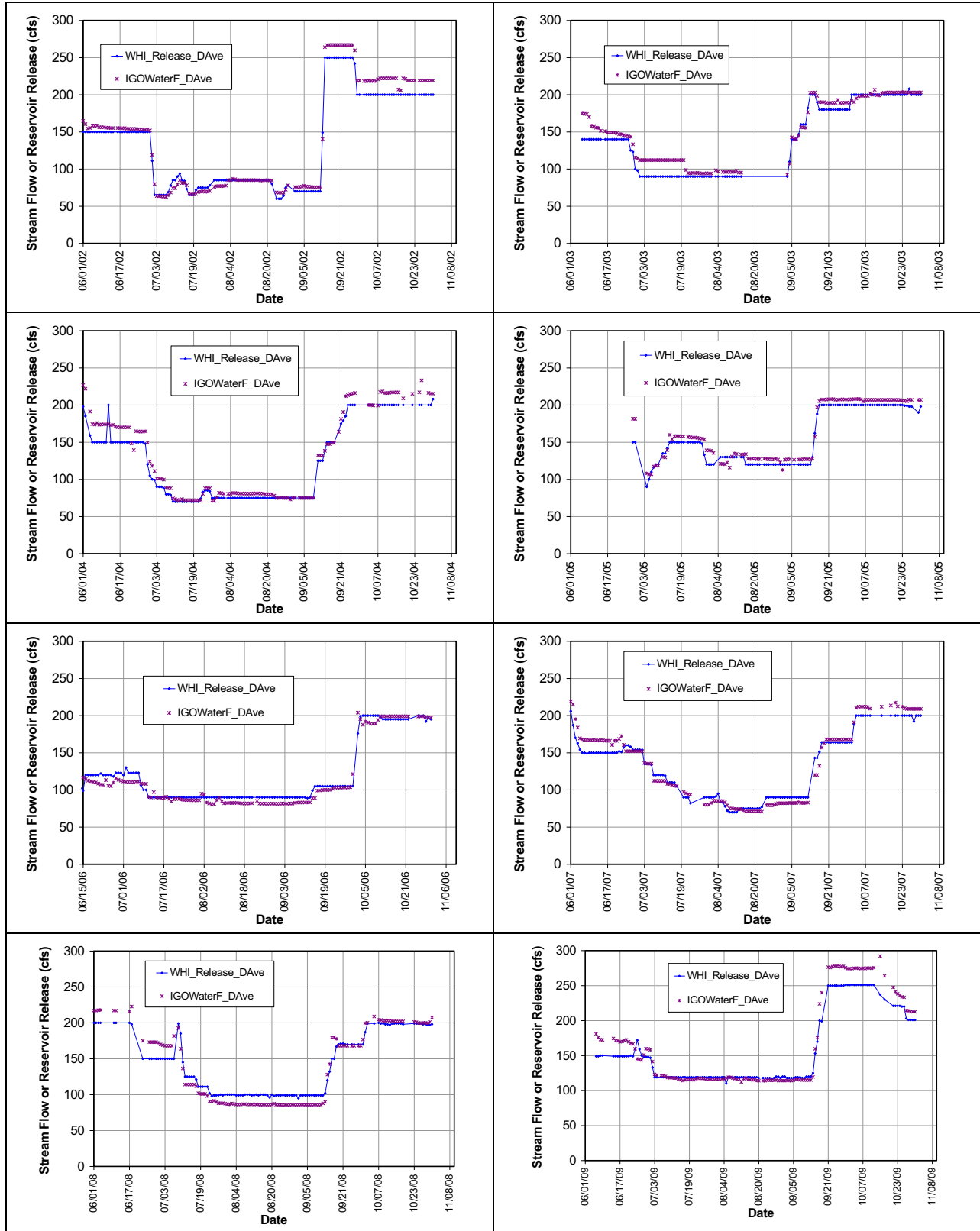


Figure 27. Streamflow at IGO in Clear Creek and reservoir release from Whiskeytown Dam. DAVE = Daily average.

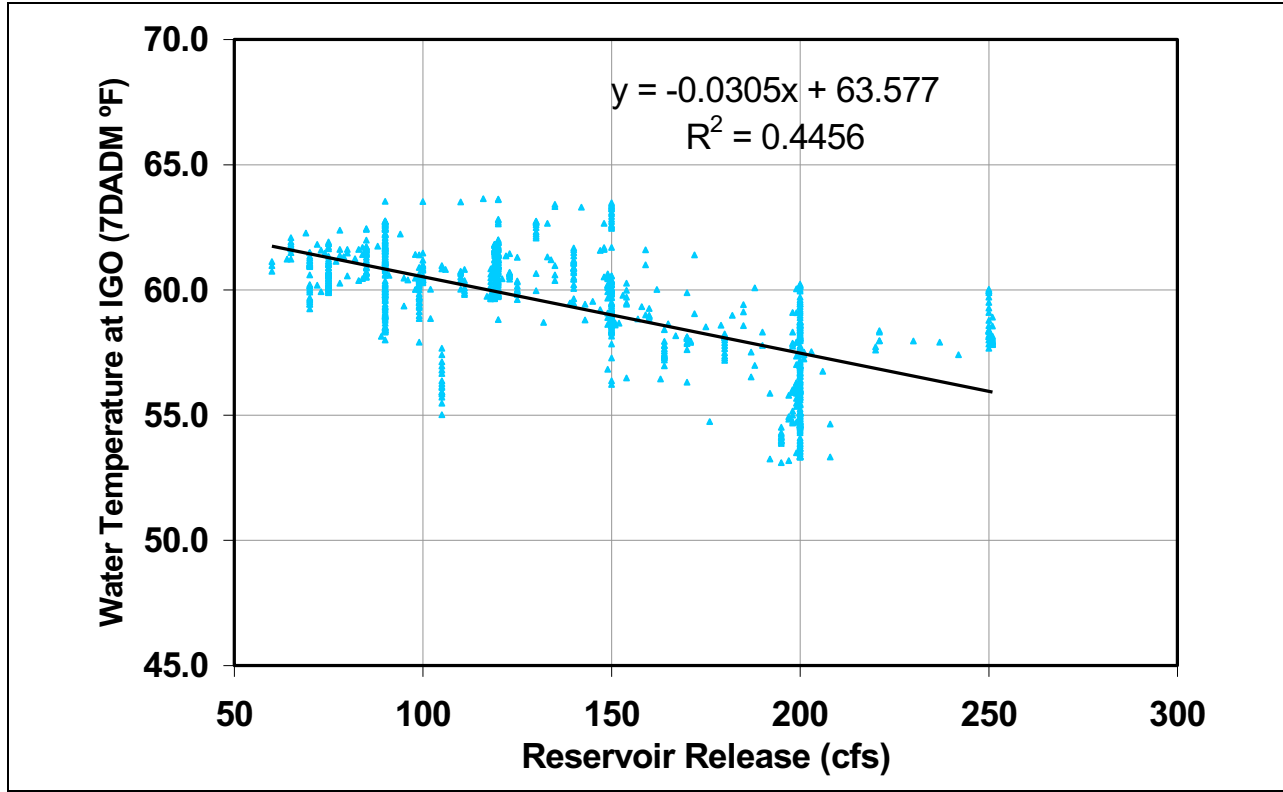


Figure 28. Correlation of water temperature at Igo with reservoir release

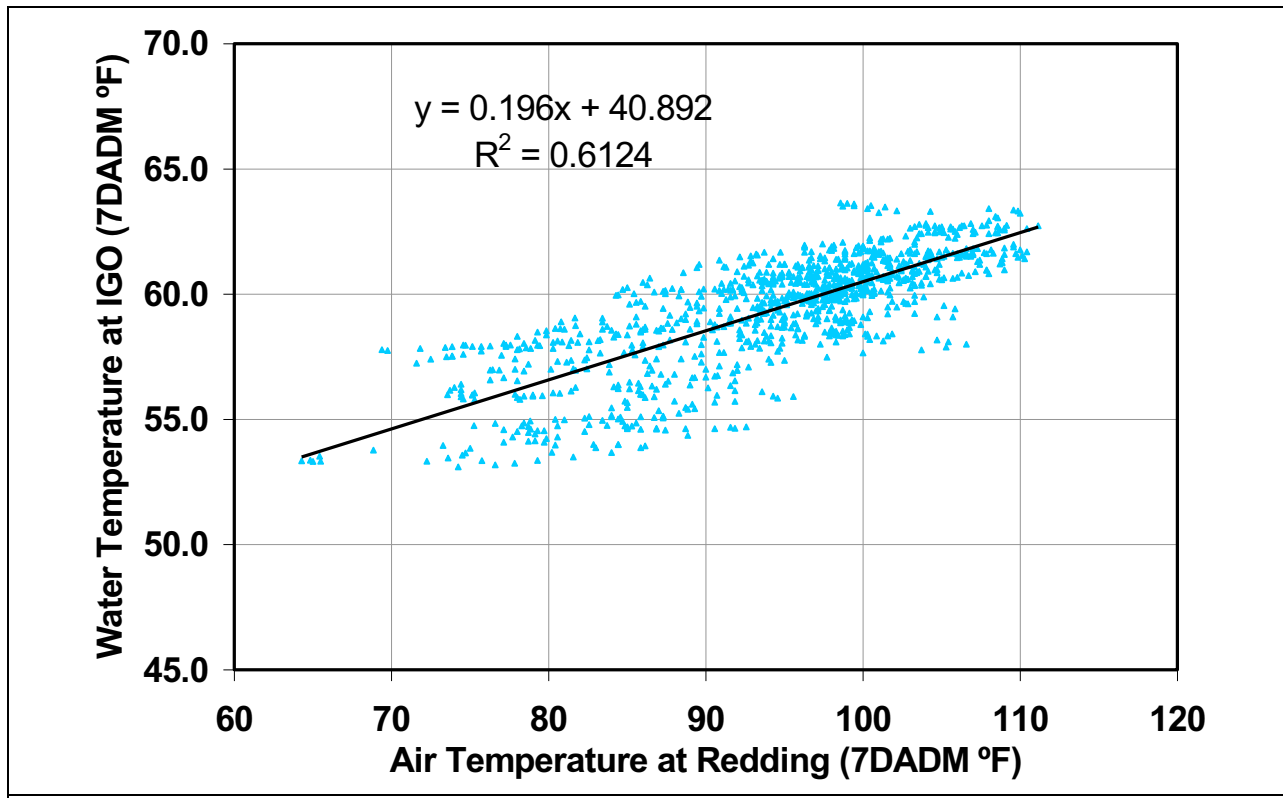
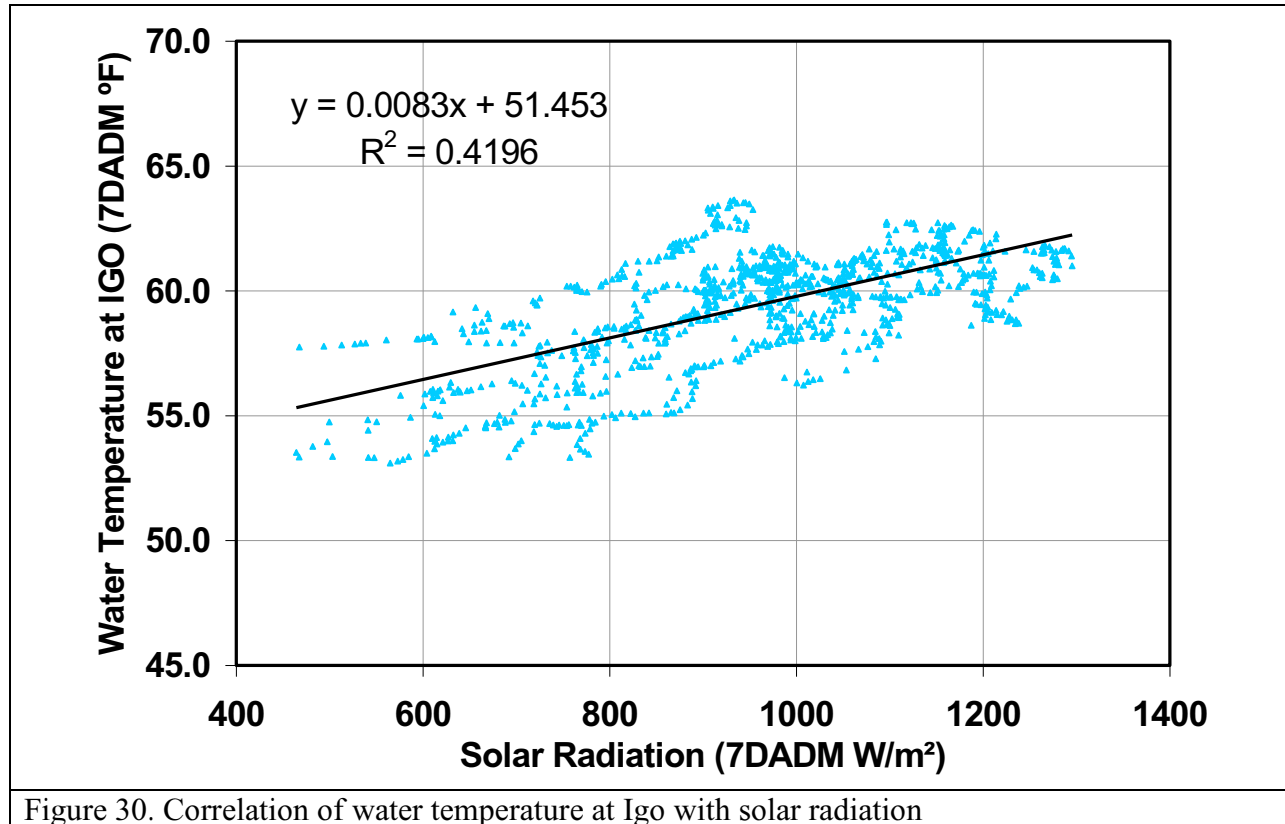


Figure 29. Correlation of water temperature at Igo with air temperature

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2

3

4 The multiple linear regression was used to fit a set of data with the following equation:

5

6

$$\hat{T}_w = a_0 + a_1 Q_r + a_2 T_a + a_3 R_s \quad \text{Eq. 1}$$

7

8 where \hat{T}_w = predicted water temperature (°F); Q_r = reservoir release (cfs); T_a = air temperature
9 (°F); R_s = solar radiation; and a_0, a_1, a_2, a_3 = coefficients.

10

11 The stepwise regression procedure was used to identify the best subset of predictors from the
12 candidate predictors: reservoir release, air temperature, and solar radiation. The stepwise
13 regression alternates between adding and removing variables, checking significance of individual
14 variables within and outside the model. Variables significant when entering the model will be
15 eliminated if later they test as insignificant. The stepwise regression results are presented in
16 **(Table 13)**. The partial t-test was performed by comparing the t statistic for a slope coefficient to
17 a student's t-distribution. For a two-sided test with $\alpha = 0.05$ and sample sizes n of 20 or more, the
18 critical value of t is $|t| \approx 2$. Larger t-statistics (in absolute value) for a slope coefficient indicate
19 significance (Helsel and Hirsch 2002). For all the three predictors in this study, the t-values
20 (absolute values) were greater than 9 and their p-values were less than 0.0005.

21

22

23

Table 13. Multiple linear regression results

4/9/2010 1:06:36 PM

Welcome to Minitab, press F1 for help.
 Retrieving project from file: 'H:\01 CLEAR
 CREEK\CLEAR_CREEK_TEMP_REGRESSION-7DADM_20100119.MPJ'

Stepwise Regression: IGOWaterT_7D versus WHI_Release_, REDAirT_7DAD, ...
 Alpha-to-Enter: 0.15 Alpha-to-Remove: 0.15
 Response is IGOWaterT_7DADM on 3 predictors, with N = 922

Step	1	2	3
Constant	40.76	46.32	46.48
REDAirT_7DADM	0.1982	0.1565	0.1243
T-Value	37.91	24.16	17.55
P-Value	0.000	0.000	0.000
WHI_Release_Dave		-0.0118	-0.0108
T-Value		-10.03	-9.61
P-Value		0.000	0.000
REDSolarR_7DADM			0.00288
T-Value			9.37
P-Value			0.000
S	1.44	1.37	1.31
R-Sq	60.97	64.82	67.89
R-Sq(adj)	60.92	64.74	67.79
Mallows Cp	198.0	89.9	4.0
PRESS	1926.82	1740.73	1592.23
R-Sq(pred)	60.78	64.57	67.59

Regression Analysis: IGOWaterT_7D versus WHI_Release_, REDAirT_7DAD, ...
 The regression equation is

$$\text{IGOWaterT_7DADM} = 46.5 - 0.0108 \text{ WHI_Release_DAve} + 0.124 \text{ REDAirT_7DADM} + 0.00288 \text{ REDSolarR_7DADM}$$

Predictor	Coef	SE Coef	T	P	VIF
Constant	46.4780	0.6946	66.92	0.000	
WHI_Release_Dave	-0.010826	0.001126	-9.61	0.000	1.715
REDAirT_7DADM	0.124302	0.007082	17.55	0.000	2.225
REDSolarR_7DADM	0.0028762	0.0003068	9.37	0.000	1.646

S = 1.31092 R-Sq = 67.9% R-Sq(adj) = 67.8%
 PRESS = 1592.23 R-Sq(pred) = 67.59%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	3	3335.7	1111.9	647.00	0.000
Residual Error	918	1577.6	1.7		
Total	921	4913.3			

Source	DF	Seq SS
WHI_Release_Dave	1	2087.0
REDAirT_7DADM	1	1097.6
REDSolarR_7DADM	1	151.0

1 8.2.2 Model Diagnostics

2 Three diagnostic tools were applied to identify the points of high leverage, influence, or outliers
3 (Helsel and Hirsch 2002).

4 8.2.2.1 Leverage

5 Leverage measures the distance from an observation's x-value to the average of the x-values for
6 all observations in a data set. The leverage (h_i) may be expressed as:

$$7 \quad h_i = \frac{1}{n} + \frac{(x_i - \bar{x})^2}{\sum_{i=1}^n (x_i - \bar{x})^2} \quad \text{Eq. 2}$$

8 where n = number of observations, x_i = the i th x value, and \bar{x} = the mean of all x values.
9

10 Leverage values fall between 0 and 1. Observations with large leverage values may exert
11 disproportionate influence on a model and produce misleading results. For example, a significant
12 coefficient may appear to be insignificant. High leverage values are the values greater than $3p/n$,
13 where p is the number of coefficients (including the constant) and n is the number of
14 observations. The $3p/n$ value in this study is 0.013 ($p = 4$ and $n = 922$).
15

16 By examining the leverage values, any observations with a value greater than 0.01 were excluded
17 from the refined regression analysis described in 8.2.3.

18 8.2.2.2 DFFITS

19 DFFITS is a measure of the influence of each observation on the fitted values in a regression.
20 Influential observations have a disproportionate impact on the model and can produce misleading
21 results.
22

$$23 \quad DFFITS_i = \frac{e_{(i)}\sqrt{h_i}}{s_{(i)}} \quad \text{Eq. 3}$$

24 where $e_{(i)}$ = prediction residual = $e_i/(1-h_i)$, and
25
26

$$27 \quad s_{(i)} = \sqrt{\frac{(n-p)s^2 - [e_{(i)}^2/(1-h_i)]}{n-p-1}} \quad \text{Eq. 4}$$

28 DFFITS represents roughly the number of standard deviations that the fitted value changes when
29 each observation is removed from the data set and the model is refit. An observation is
30 considered to have a high influence if $|DFFITS_i| \geq 2\sqrt{p/n}$, which is 0.13 for this study.
31

32 By examining the DFFITS values, any observations with a value greater than 0.12 were excluded
33 from the refined regression analysis described in 8.2.3.
34
35

1 8.2.2.3 Standardized Residuals

2 The standardized residual equals the value of an actual residual, e_i , divided by an estimate of its
3 standard deviation:

$$4 \quad e_{si} = \frac{e_i}{s \sqrt{1-h_i}} \quad \text{Eq. 5}$$

5 Standardizing residuals is useful because raw residuals can be poor indicators of outliers due to
6 their nonconstant variance: residuals with corresponding x-values that are far from \bar{x} have
7 greater variance than residuals with corresponding x-values closer to \bar{x} . Standardizing controls
8 for this nonconstant variance, and all standardized residuals have the same standard deviation.
9 Since about 70% of the observations in 2005 showed standardized residuals greater than 1.5, the
10 data from 2005 were excluded from the refined regression analysis described in 8.2.3.

11 8.2.3 Refined Regression Model

12 A new data set of observations ($n = 730$) was developed by excluding those observations of high
13 leverage, influence, or possible outliers as described above. The multiple regression results are
14 presented in **Table 14**. This refined model has been improved from the previous model. The
15 overall quality of the regression models from the stepwise procedure can be evaluated by three
16 statistics: Mallows's C_p , PRESS, and adjusted R^2 (R_a^2) (Helsel and Hirsch 2002). The Mallows's C_p
17 is defined as

$$18 \quad C_p = p + \frac{(n-p)(s_p^2 - \hat{\sigma}^2)}{\hat{\sigma}^2} \quad \text{Eq. 6}$$

19
20 where n = the number of observations, p = the number of coefficients (number of explanatory
21 variables plus 1), s_p^2 = the mean square error (MSE) of this p coefficient model, $\hat{\sigma}^2$ = the best
22 estimate of the true error that is the minimum MSE among all possible models. The best model is
23 the one with the lowest C_p value. The C_p values were 649, 284, and 4 for one-, two-, and three-
24 parameter models, respectively (**Table 14**).

25
26 The PRESS statistic is the prediction error sum of squares. PRESS uses $n-1$ observations to
27 develop the equation, then estimates the value of the one left out. It then changes the observation
28 left out, and repeats the process for each observation. The prediction errors are squared and
29 summed. Minimizing PRESS means that the equation produces the least error when making new
30 predictions. In multiple regression it is a very useful estimate of the quality of possible regression
31 models. The PRESS values were 999, 735, and 531 for one-, two-, and three-parameter models,
32 respectively (**Table 14**).

33
34 The R_a^2 is the R^2 value adjusted for the number of explanatory variables (or equivalently, the
35 degrees of freedom) in the model. This adjustment is important because the R^2 for any model
36 will always increase when a new term is added. A model with more terms may appear to have a
37 better fit simply because it has more terms. However, some increases in R^2 may be due to
38 chance alone.

39
40

1 Table 14. Refined regression results

2
3 **4/14/2010 2:31:29 PM**
4 **Stepwise Regression: IGOWaterT_7D versus WHI_Release_, REDAirT_7DAD, ...**

5
6 Alpha-to-Enter: 0.15 Alpha-to-Remove: 0.15

7
8 Response is IGOWaterT_7DADM on 3 predictors, with N = 730

9

Step	1	2	3
Constant	39.56	40.03	48.02
REDAirT_7DADM	0.2098	0.1583	0.0946
T-Value	39.20	28.40	15.59
P-Value	0.000	0.000	0.000
REDSolarR_7DADM		0.00447	0.00456
T-Value		16.26	19.55
P-Value		0.000	0.000
WHI_Release_Dave			-0.01569
T-Value			-16.80
P-Value			0.000
S	1.17	1.00	0.850
R-Sq	67.85	76.43	83.03
R-Sq(adj)	67.81	76.37	82.96
Mallows Cp	649.0	284.1	4.0
PRESS	999.416	734.557	531.198
R-Sq(pred)	67.65	76.23	82.81

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33 **Regression Analysis: IGOWaterT_7D versus WHI_Release_, REDAirT_7DAD, ...**

34 The regression equation is

35 $IGOWaterT_7DADM = 48.0 - 0.0157 WHI_Release_DAve + 0.0946 REDAirT_7DADM$
36 $+ 0.00456 REDSolarR_7DADM$

37

Predictor	Coef	SE Coef	T	P	VIF
Constant	48.0189	0.6046	79.42	0.000	
WHI_Release_Dave	-0.0156865	0.0009339	-16.80	0.000	1.917
REDAirT_7DADM	0.094576	0.006066	15.59	0.000	2.426
REDSolarR_7DADM	0.0045649	0.0002334	19.55	0.000	1.478

38
39
40
41
42
43
44 $S = 0.849931$ $R-Sq = 83.0\%$ $R-Sq(adj) = 83.0\%$

45
46 $PRESS = 531.198$ $R-Sq(pred) = 82.81\%$

47
48 **Analysis of Variance**

49

Source	DF	SS	MS	F	P
Regression	3	2565.38	855.13	1183.76	0.000
Residual Error	726	524.45	0.72		
Total	729	3089.83			

50
51
52
53
54

Source	DF	Seq SS
WHI_Release_Dave	1	1737.70
REDAirT_7DADM	1	551.44
REDSolarR_7DADM	1	276.24

1 The R_a^2 is a useful tool for comparing the explanatory power of models with different numbers of
 2 predictors. The R_a^2 will increase only if the new term improves the model more than would be
 3 expected by chance. It will decrease when a predictor improves the model less than expected by
 4 chance. The model with the highest R_a^2 is identical to the one with the smallest standard error (s)
 5 or its square - the mean squared error (MSE). When p is considerably smaller than n, R_a^2 is a less
 6 sensitive measure than either PRESS or Cp. PRESS has additional advantage of being a
 7 validation criteria. The R_a^2 values in this study are 0.6781, 0.7637, and 0.8296 for one-, two-,
 8 and three-parameter models, respectively (**Table 14**).

9
 10 In addition, the variance inflation factor (VIF) is calculated to diagnose multi-collinearity. Multi-
 11 collinearity is the condition where at least one explanatory variable is closely related to one or
 12 more other explanatory variables. If there is no collinearity, $VIF \approx 1$. Serious problems are
 13 indicated when VIF greater than 10 (Helsel and Hirsch 2002). The VIF values in this study are
 14 less than 2.4 for all the three parameters (**Table 14**).

15
 16 Based on the analysis of the statistics provided above, all the three parameters – reservoir
 17 release, air temperature, and solar radiation are significantly related to water temperature at Igo.
 18 The regression coefficients are $a_0 = 48.02$, $a_1 = -0.0157$, $a_2 = 0.0946$, and $a_3 = 0.00456$. **Figure**
 19 **31** shows the predicted water temperature at Igo plotted against the observed water temperature.

20
 21 The prediction interval is the confidence interval for prediction of an estimate of an individual
 22 response variable. For example, the 95% prediction interval indicates that 95% of the time the
 23 predicted value will be within the interval. Most of the observations are between the upper and
 24 lower prediction interval lines (**Figure 31**).

25 **8.2.4 Model Performance Evaluation**

26 The performance of the regression model was evaluated using the following diagnostics:
 27 normality and random distribution of the residuals. Linear regression theory assumes residuals
 28 are normally distributed and symmetric about the mean. The histogram of the residuals (**Figure**
 29 **32**) shows that the residuals appear to be normally distributed, and centered on zero. The
 30 probability plot of the residuals (**Figure 33**) shows a slight departure from normality.

31
 32 Plotting residuals against predicted data helps to examine if the variance of residuals are
 33 constant. **Figure 34** presents the residuals plot against the predicted water temperature that
 34 shows no curvature or changing variance in residuals, whereas residuals appear to change from
 35 negative to positive when plotted against the observed water temperature (**Figure 35**).

36
 37 An empirically developed multiple linear regression model may fit the data used to estimate the
 38 regression coefficients very well, but it is unknown if the model predicts new data well. The
 39 model was validated using observations not used in fitting the regression to assess the ability of
 40 the model to predict future events. **Figure 36** shows the observed and validated water
 41 temperatures at Igo for 2008. The model predicts the 2008 data very well ($R^2 = 0.9071$).

1

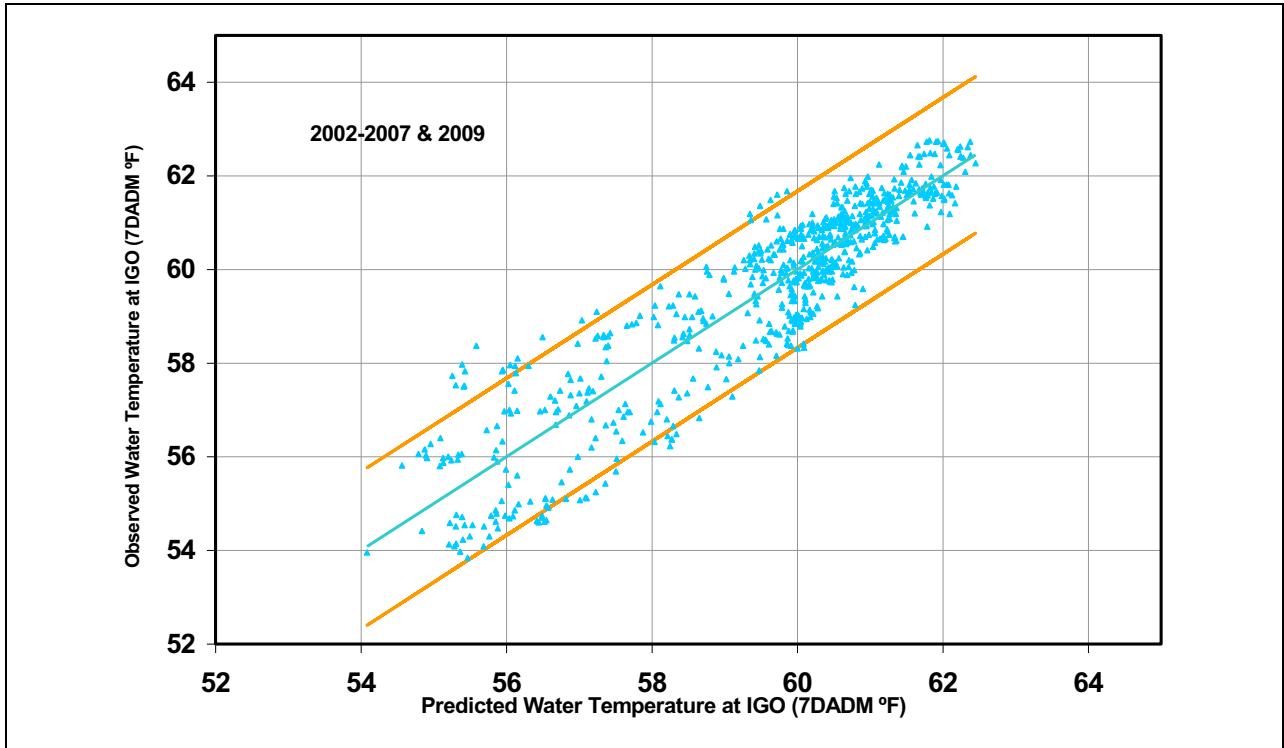


Figure 31. Predicted versus observed water temperature at Igo in Clear Creek. The orange lines represent the 95% prediction interval

2

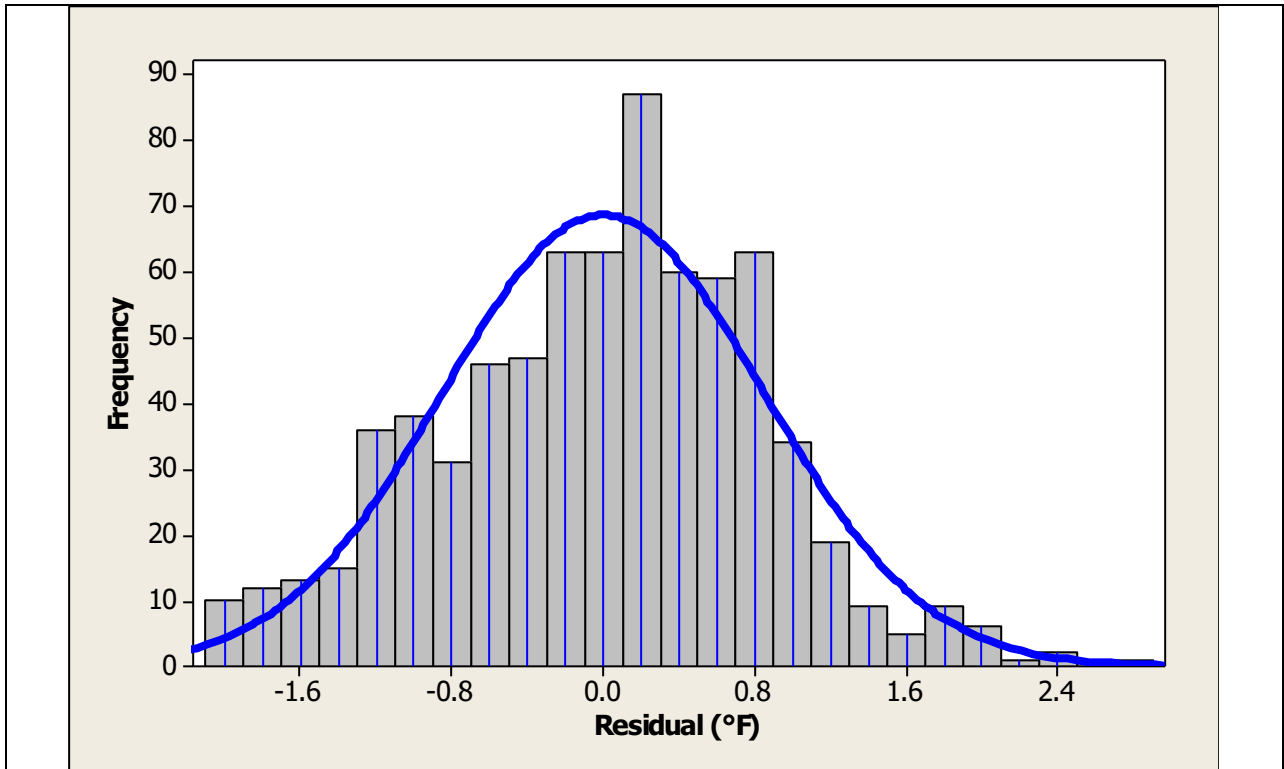


Figure 32. Water temperature prediction residual histogram

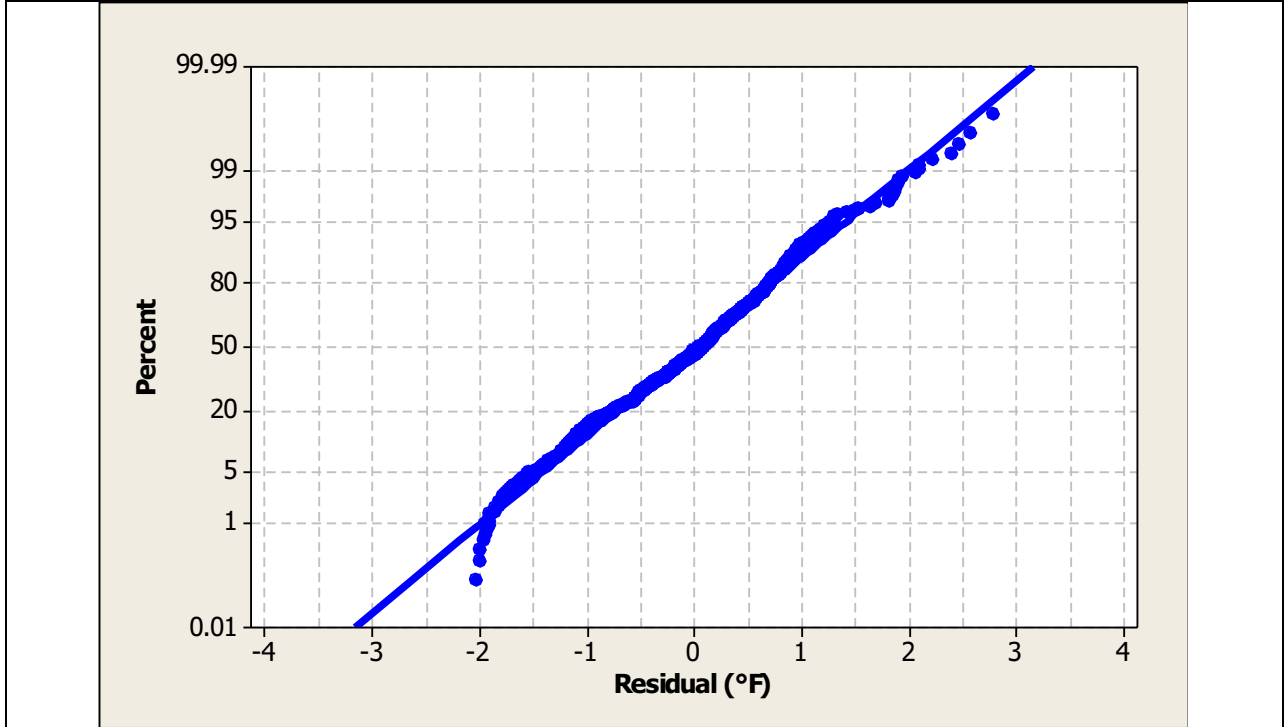


Figure 33. Normal probability plot of water temperature prediction residuals

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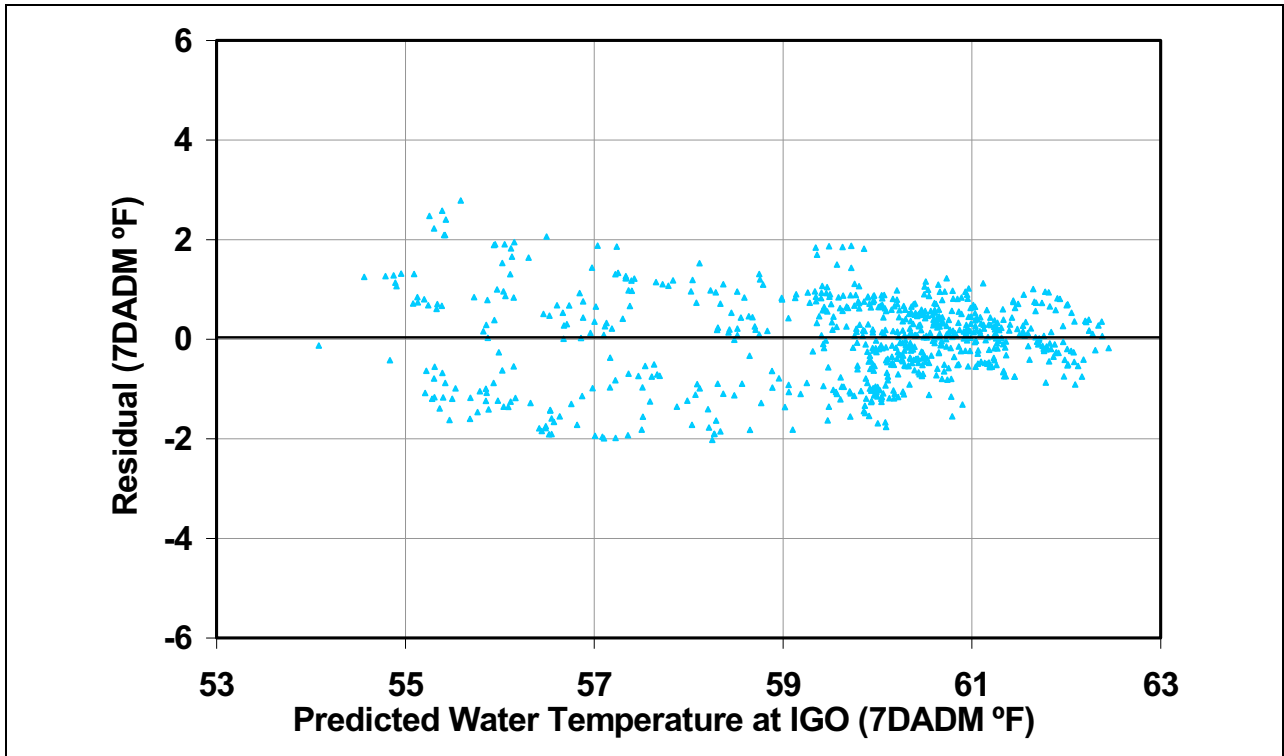


Figure 34. Residual plotted against the predicted water temperature

3
4

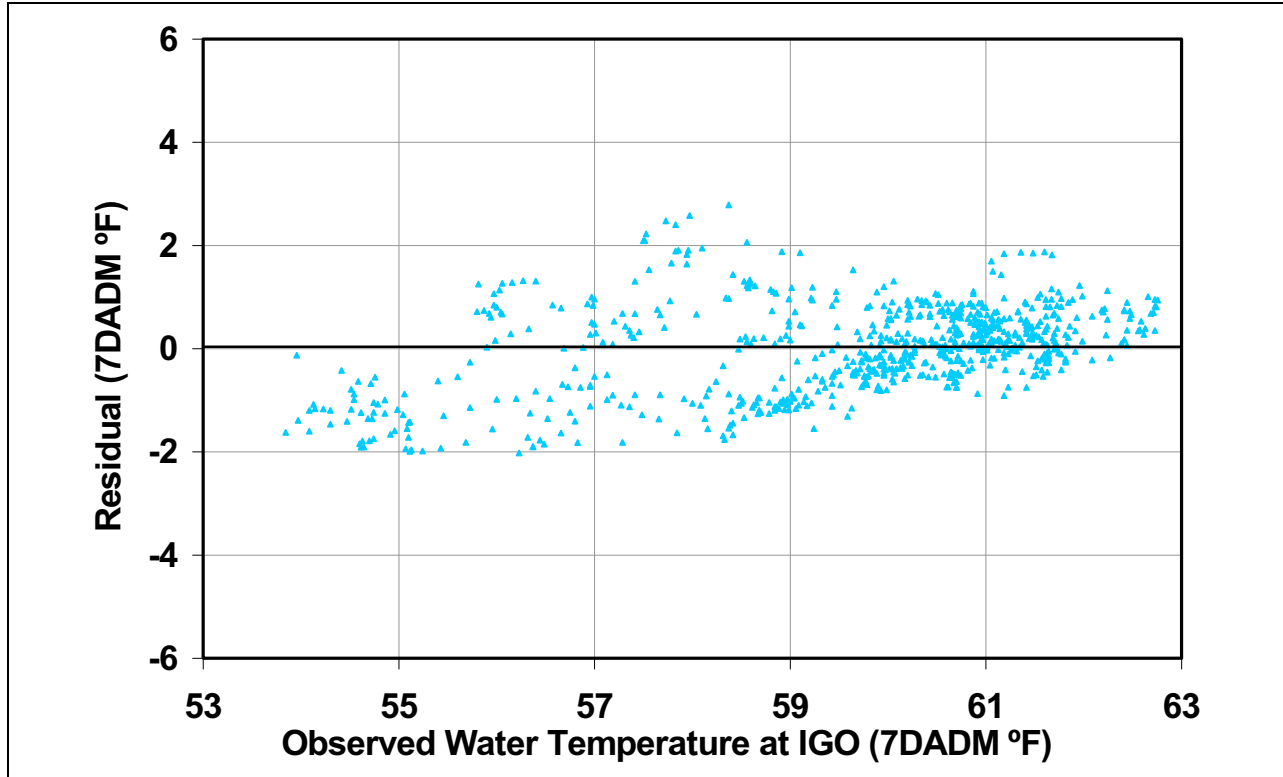


Figure 35. Residual plotted against the observed water temperature

1

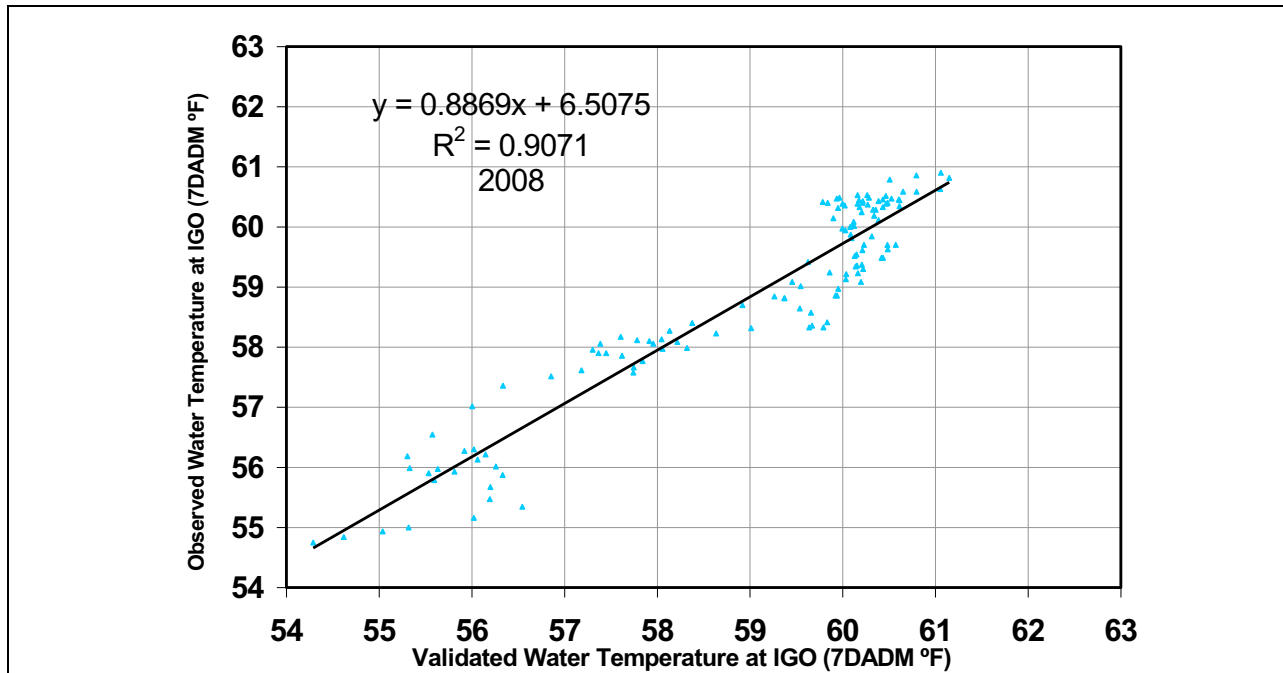


Figure 36. Observed and validated water temperature at Igo in Clear Creek in 2008

2

1 **8.3 Estimation of Reservoir Release to Meet Temperature Requirements**

2 The regression model to predict water temperature from reservoir release, air temperature, and
 3 solar radiation is used to estimate additional water required to lower the water temperature to a
 4 specified target.

5

6 Table 15. Estimated reservoir release using percentile air temperature and solar radiation. $T_{w(target)} = 60$ °F

Percentile	Air Temperature (7DADM °F)	Solar Radiation (7DADM W/m ²)	Estimated Release (cfs)
June			
50	95.8	1100	134
70	98.58	1159	168
75	99.42	1177	178
80	100.26	1195	188
90	102.59	1244	217
95	104.51	1285	240
99	108.12	1361	284
July			
50	102.37	1091	171
70	104.62	1152	202
75	105.3	1170.5	212
80	105.98	1189	221
90	107.86	1241	247
95	109.42	1283	269
99	112.34	1363	310
August			
50	98.27	1017	125
70	100.36	1076	154
75	100.99	1093	163
80	101.62	1110	172
90	103.37	1158	196
95	104.81	1198	217
99	107.52	1272	254
September 1-15			
50	95.84	951	91
70	97.81	1005	118
75	98.41	1022	127
80	99.01	1039	135
90	100.66	1085	159
95	102.03	1123	178
99	104.6	1194	214

1 Rearranging Eq. 1 to solve for reservoir release (\hat{Q}_r) gives

2

$$3 \quad \hat{Q}_r = \frac{T_{w(target)} - a_0 - a_2 T_a - a_3 R_s}{a_1} \quad \text{Eq. 7}$$

4 where $T_{w(target)}$ = specified water temperature target. Since there was a wide range of T_a and R_s ,
 5 their percentile values were computed and used to estimate the reservoir release to meet a
 6 specified temperature target (**Table 15 and Table 16**).

7

8 The estimated reservoir release in cfs is the percentile flow that considers air temperature and
 9 solar radiation. For example, the estimated release of 240 cfs from Whiskeytown Dam in June
 10 would make 95% of water temperatures (7DADM) at Igo lower than 60 °F in June (Table 15),
 11 while the estimated release of 324 cfs from Whiskeytown Dam in the second half of September
 12 would make 75% of water temperatures (7DADM) at Igo lower than 56 °F from September 16 to
 13 30 (**Table 16**).

14

15 Table 16. Estimated reservoir release using percentile air temperature and solar radiation. $T_{w(target)} = 56$ °F

Percentile	Air Temperature (7DADM °F)	Solar Radiation (7DADM W/m ²)	Estimated Release (cfs)
September 16-30			
50	88.44	870	277
70	91.74	924	313
75	92.73	940	324
80	93.73	957	335
90	96.50	1003	365
95	98.79	1040	389
99	103.08	1111	436
October			
50	82.35	757	208
70	85.16	817	242
75	86.01	835	253
80	86.86	853	263
90	89.22	903	292
95	91.17	945	316
99	94.82	1023	360

16

1 **8.4 Integrated Flow Estimates**

2 So far, we developed two parts of flows – one is based on the flow regime approach and the
3 other is based on water temperature requirements from June through October. The overall
4 streamflow for protecting listed fish species is the integration of the flow derived from the flow
5 regime approach with the temperature sustaining flow (**Figure 37**). Flows were increased from
6 June through October to meet water temperature requirements. The highest increase in flow was
7 in the second half of September due mainly to high air temperatures in September and a more
8 stringent water temperature criterion (56 °F) for spawning. The high flow increase in July
9 resulted from high air temperatures.

10
11 Flows showing in **Figure 37** may not be appropriate for fish species as they fluctuate
12 considerably during the warm time period. These flows should be adjusted to remove those flow
13 fluctuations. The adjustment procedure is discussed in Section 9.
14

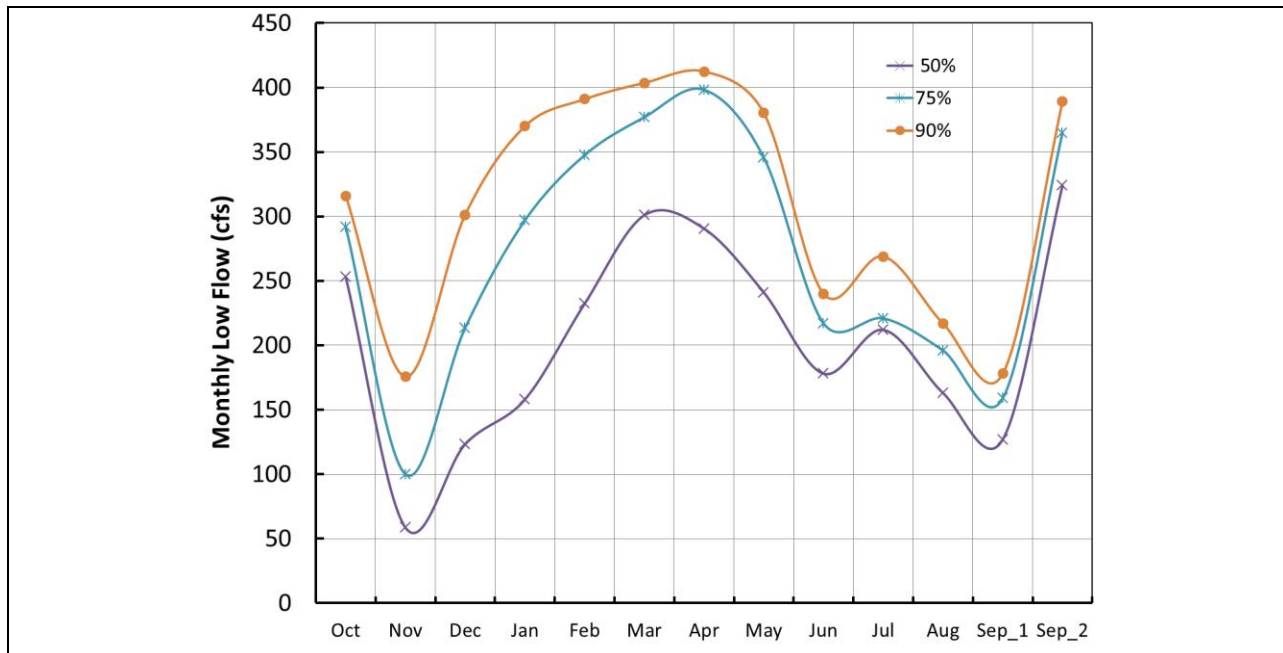


Figure 37. Monthly flow estimates based on the flow regime approach and water temperature requirements in Clear Creek

15
16

9 Recommendation of Flows in Clear Creek

Both streamflow and water temperature are imperative to the survival and growth of salmonids in Clear Creek. Streamflow in Clear Creek should be maintained to 1) mimic the natural flow regime with appropriate magnitude, timing, duration, frequency, and rise/fall rate because salmonids have evolved under these natural flow regimes, 2) provide suitable water temperature for holding and spawning adults and rearing juveniles, and 3) provide suitable physical habitat for spawning and rearing.

9.1 Instream Flow

As presented in Section 7, the analysis of flow data provides a flow pattern that mimics the “natural” flow in Clear Creek before the Whiskeytown Dam was built. To meet water temperature requirements, those flows need to be increased in order to lower water temperatures from June through October as discussed in Section 8. The integration of flows from the flow regime approach and flows for meeting water temperature requirements provides instream flows in Clear Creek. The integrated flows were adjusted to remove some considerable fluctuations. The principle of the flow adjustment is to keep higher flows unchanged and to increase lower flows for smoothing out flow patterns (Figure 38). For example, the highest flow would occur in March. The high flows in July and the second half of September were not changed. The low flows in June, the first half of September, and November were increased. Flows in other months were adjusted slightly (either increase or decrease) to have a similar pattern for the three flow curves (Figure 38).

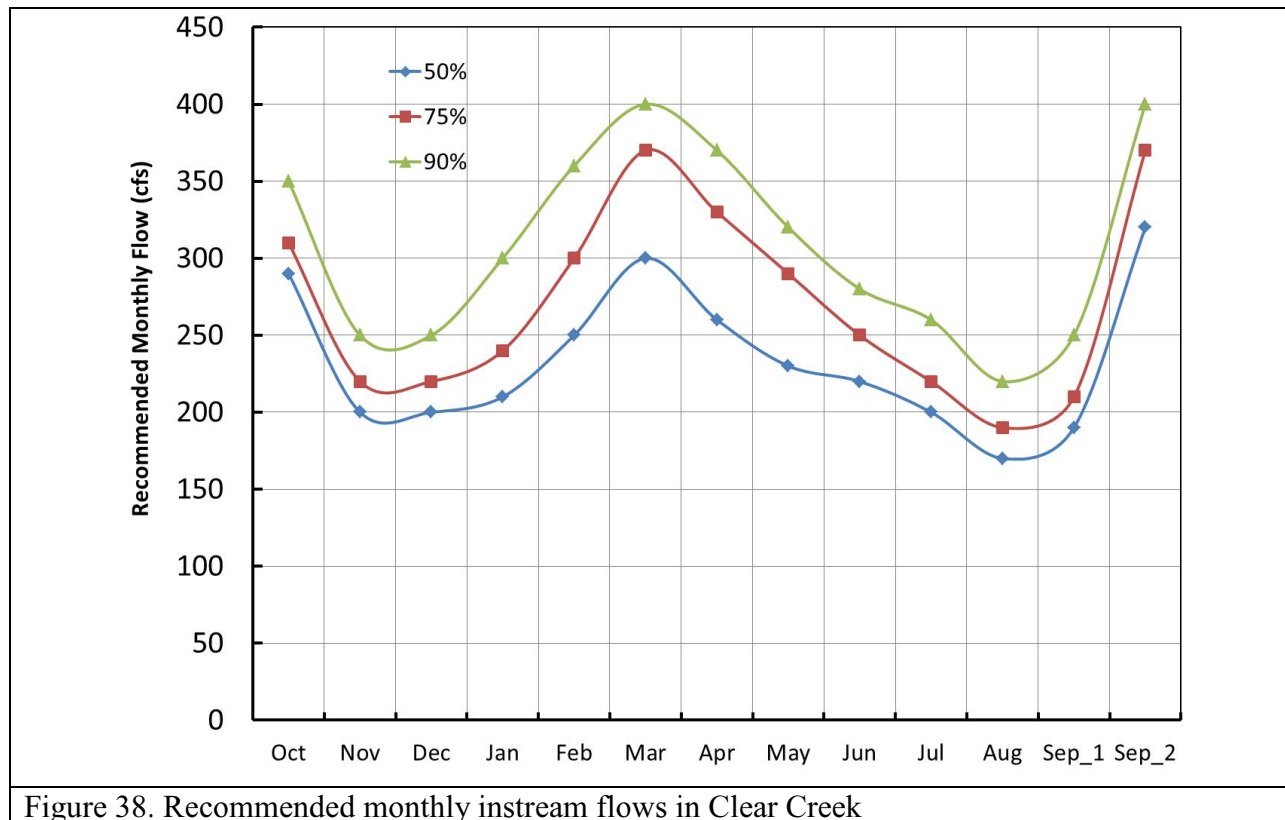


Figure 38. Recommended monthly instream flows in Clear Creek

1 The instream flows from November through May are based on the 50th, 75th, and 90th percentile
 2 baseflows (**Table 10**), while the instream flows from June through October are based on the 75th,
 3 90th, and 95th percentiles meeting water temperature requirements. Even though water
 4 temperature criteria would need to apply nearly all the time, US EPA indicated that it is
 5 reasonable not to apply the numeric temperature criteria during unusually warm conditions for
 6 purposes of determining if a waterbody is attaining criteria. One way to do this is to exclude
 7 water temperature data when the air temperature during the warmest week of the year exceeds
 8 the 90th percentile for the warmest week of the year based on a historical record (*e.g.*, 10 years
 9 or more) at the nearest weather reporting station (USEPA 2003). **Table 17** presents the
 10 recommended monthly instream flows in Clear Creek.

11
 12 Table 17. Recommended monthly instream flows in Clear Creek

Month	Minimal (50 th %ile)	Desirable (75 th %ile)	Optimal (90 th %ile)
October	290	310	350
November	200	220	250
December	200	220	250
January	210	240	300
February	250	300	360
March	290	360	390
April	250	320	370
May	240	290	320
June	220	250	280
July	205	220	260
August	170	190	220
September 1-15	190	210	250
September 16-30	320	370	400

13
 14 **9.2 Channel Flushing Flow**

15 Channel flushing flows are high-flow pulses. They are greater in magnitude than baseflows but
 16 lower than small floods. They are usually shorter in duration (a few days) and contained within
 17 the channel at or above the half of the bankfull discharge level for most streams. Channel
 18 flushing flows are designed to remove fine sediments, organic matter, and detritus from the
 19 interstitial voids in channel coarse substrates and depositional areas (Locke *et al.* 2008). These
 20 flows also facilitate improved access to upstream or downstream areas for adult immigration and
 21 juvenile outmigration.

22
 23 The magnitude of the flushing flow in Clear Creek should be about 700 cfs with a frequency of
 24 2-3 times a year from January to May. The duration of the flows would be 3-5 days with a rise
 25 rate of 200 cfs/day and a fall rate of -100 cfs/day. This flow magnitude would allow the removal
 26 and transport of fine sediments from the riverbed. When the streamflow was 646 cfs in Clear

1 Creek, 95% of particles from bedload measurements were less than 2 mm and the transport rate
 2 of the particles was about 20 tons/day (Graham Matthews & Associates 2003).

3
 4 The combined instream flows and flushing flows are presented in **Figure 39**. Also shown in the
 5 figure is the median daily flow in Clear Creek for the pre-dam period. There were a number of
 6 high-flow pulses of greater than 600 cfs from late January through early April for the pre-dam
 7 period.
 8

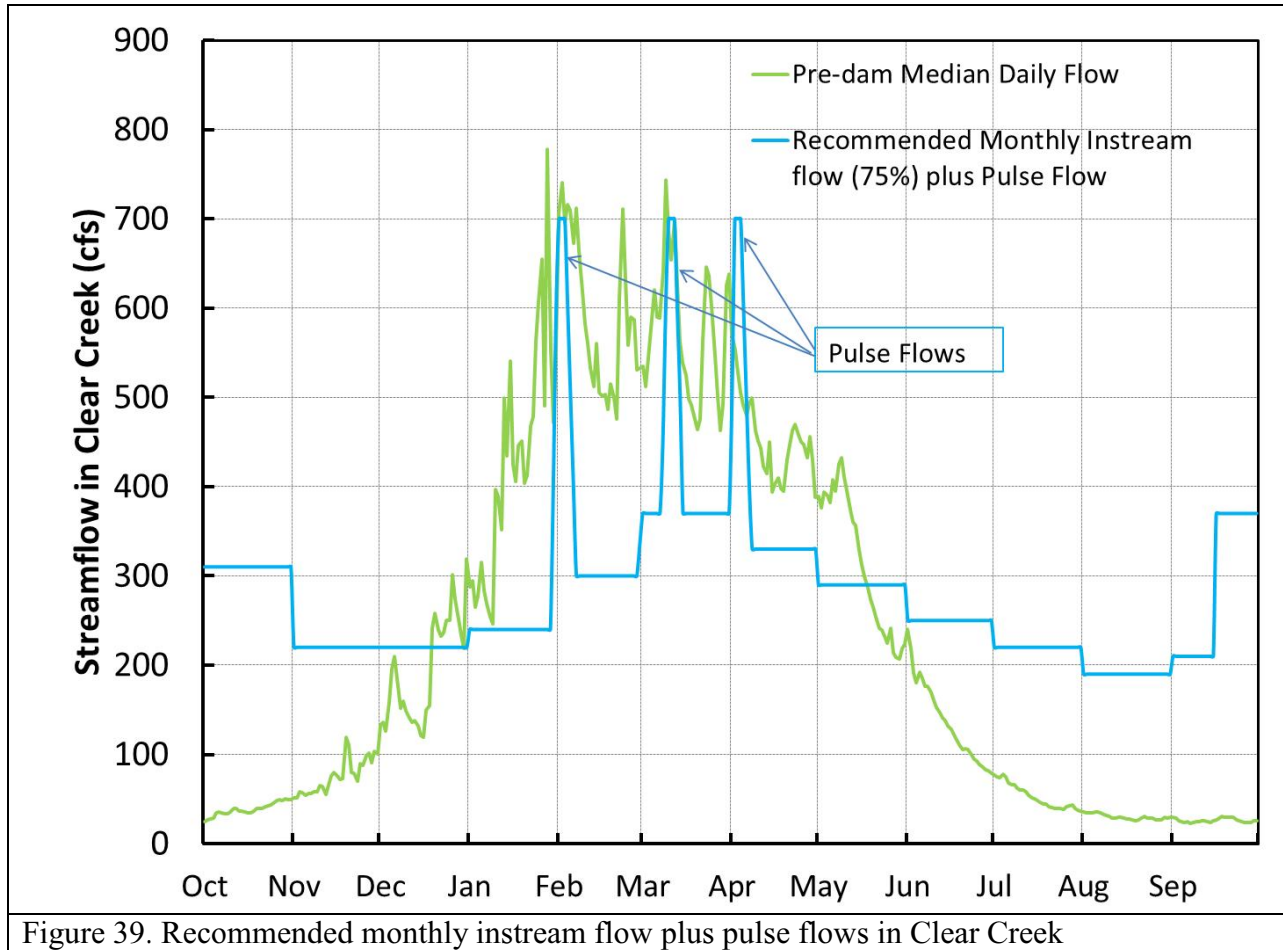


Figure 39. Recommended monthly instream flow plus pulse flows in Clear Creek

9
 10 The recommended flows should be carefully examined for their potential benefits to and adverse
 11 effects on the three anadromous fish species in Clear Creek. The high instream flows from
 12 February to May will provide benefits to juvenile emigration of all three species, adult
 13 immigration of spring-run Chinook, rearing habitat for spring-run Chinook and steelhead
 14 (**Figure 40**).

15
 16 The enhanced flow in September and October will provide benefits to adult immigration of
 17 steelhead and fall-run Chinook and adequate water temperature for spawning of spring-run and
 18 possibly fall-run Chinook (**Figure 40**). The only concern relevant to the enhanced flow is that
 19 some redds might be adversely impacted if those areas where redds exist dry out when flow
 20 decreases from September to October to November. Depending on the degree to which redds are

1 impacted, the enhanced flow could be extended for some time so that eggs in those redds may
 2 develop into fry that can move to lower water when flow decreases.
 3

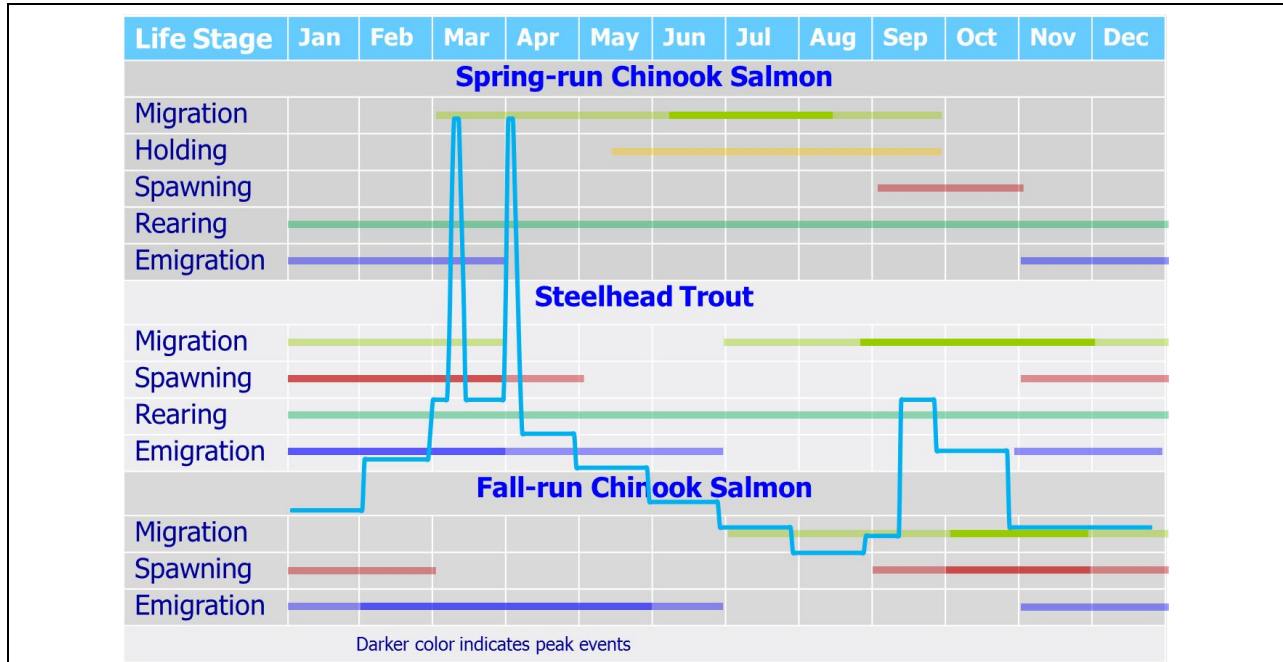


Figure 40. Diagram showing the recommended flows and the life stages of three fish species in Clear Creek

4
 5 The high-flow pulses not only improve access for spring-run adult migration, but also help
 6 remove fine sediments for spawning and facilitate juvenile emigration of all three fish species in
 7 Clear Creek. When the high-flow pulses occur during the peak spawning of steelhead, they may
 8 adversely impact the redds of steelhead in Clear Creek. The adverse impact can be avoided if
 9 pulse flows occur after eggs have developed into fry, for example, in April and May instead of in
 10 March and April.

11
 12 **9.3 Channel Maintenance Flow**

13 Channel maintenance flows usually cover the stream banks. They maintain a long-term sediment
 14 balance, maintain streamside vegetation and structural stability of streambanks, and prevent
 15 vegetation encroachment in the channel (Locke *et al.* 2008). The magnitude of the channel
 16 maintenance flow should be about 6000-7000 cfs with a frequency of once every two or three
 17 years between January and March. The duration of the flow may span 10 days with a rise rate of
 18 1700 cfs/day, and a fall rate of -1000 cfs/day. Restoring the channel maintenance flow will help
 19 to create and maintain several different types of habitats in Clear Creek, including:

- 20
- 21 • Habitat for spawning: Recruit and distribute augmented gravels that are placed on the
 22 banks and floodplains. A flow magnitude of about 6,000 cfs is required to achieve
 23 sediment transport (Stillwater Sciences 2004). Since 1996, local, state, and federal
 24 partners have augmented the creek’s gravel supply. The gravels are placed on the banks
 25 and floodplain and recruited into the channel and distributed by high flow events, rather
 26 than being placed directly in the channel. It was estimated that 103,371 tons of gravel

1 have been injected at specific locations on the creek, resulting in a steady increase in
2 spawning habitat. This added gravel has recharged spawning gravel within about 3 miles
3 of creek below the dam. Securing a long-term gravel supply is critical for reestablishing
4 sediment transport processes that create and maintain fish habitat (USBR and USFWS
5 2008).

- 6
- 7 • Habitat for juvenile rearing: Increase the margin habitat area of low velocity for feeding
8 and rearing, increase the frequency and availability of temporary backwater channels to
9 provide rearing habitat and refuge, increase instream habitat complexity and cover by
10 recruiting large woody debris to provide juvenile rearing habitat, and incorporate
11 complex channel habitats including floodplain ponds and scour channels to support
12 juvenile salmonid rearing.
- 13
- 14 • Habitat for adult holding: Increase and maintain deep, coldwater pools to provide holding
15 habitat for adult spring-run Chinook salmon.
- 16

17 The recommended channel maintenance flow would allow fluvial processes to reshape and
18 maintain a new dynamic river channel and provide favorable water temperature and physical
19 habitat conditions for juvenile and adult salmonids in Clear Creek. There is potential for the
20 channel maintenance flow to scour steelhead redds. This effect can be minimized if the flow is
21 scheduled in April to avoid the peak spawning period of steelhead.

22

23 Reservoir operation for the channel maintenance flow may be a concern because Whiskeytown
24 Dam has a maximum discharge of 1200 cfs to Clear Creek through the Clear Creek outlet.
25 However, the release of 6000-7000 cfs can be achieved through the use of Glory Hole. The
26 Glory Hole discharge depends on a few factors including the rate of inflow and the hydraulic
27 properties of the Glory Hole spillway. The Glory Hole has a crest elevation of 1210 feet and
28 reaches its maximum design discharge capacity of 28,000 cfs at a water surface elevation of
29 1220.5 feet (Stillwater Sciences 2004). Note that the crest of the Whiskeytown Dam itself is
30 1228 feet.

31
32

1 **10 Water Cost Analysis**

2 It is our interest to determine the difference in water use between the recommended flows and
 3 the current flows. The additional water allocated to Clear Creek may be used to generate
 4 hydroelectricity at Spring Creek Powerplant and Keswick Powerplant.
 5

6 The calculation of the current flows was based on the flow data from water year 2001 to 2010.
 7 For this time period, a new flow scheme was implemented: 200 cfs from October through June
 8 and 150 cfs from July through September. These flows were higher than those for the time
 9 period of 1963 to 2000. Monthly low flows from 2001 to 2010 are presented in **Figure 41**. The
 10 median (50th percentile) flow during this time period was higher than 200 cfs from October
 11 through May, about 100 cfs in July and August, and about 150 cfs in September.
 12

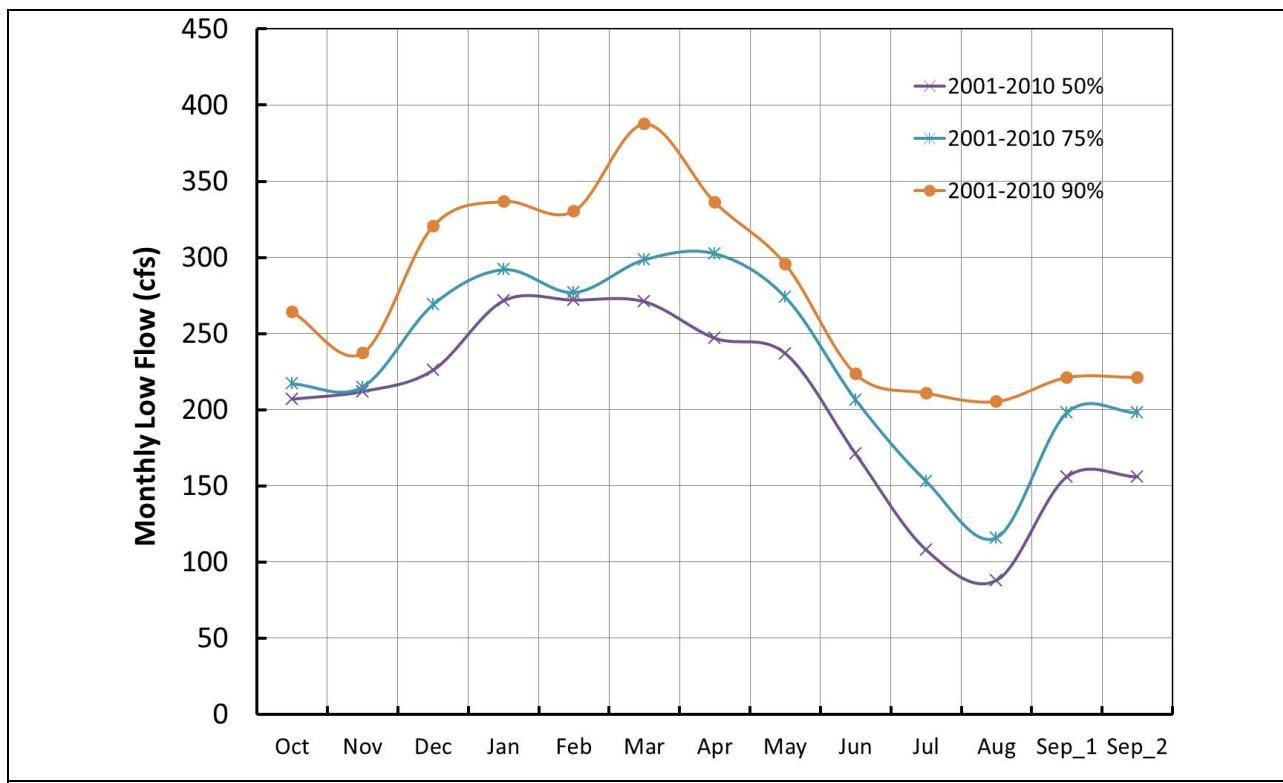


Figure 41. Monthly low flows in Clear Creek from WY 2001 to 2010

13
 14 Implementing the recommended flows requires higher flows than the current flows from March
 15 through October (except for the 50th percentile flow in May), lower flows in December and
 16 January, and lower flows for the 50th percentile and higher flows for the 75th and 90th percentiles
 17 in November and February (**Figure 42**). The highest increases in flow were in the second half of
 18 September and October when a more stringent water temperature criterion (56 °F) was applied,
 19 followed by July and August when air temperatures were high and existing flows were low
 20 (Figure 42). On average, increases from the recommended flows to the current flows were 32.1,
 21 38.7 and 32.2 cfs for 50th, 75th, and 90th percentiles, respectively.
 22

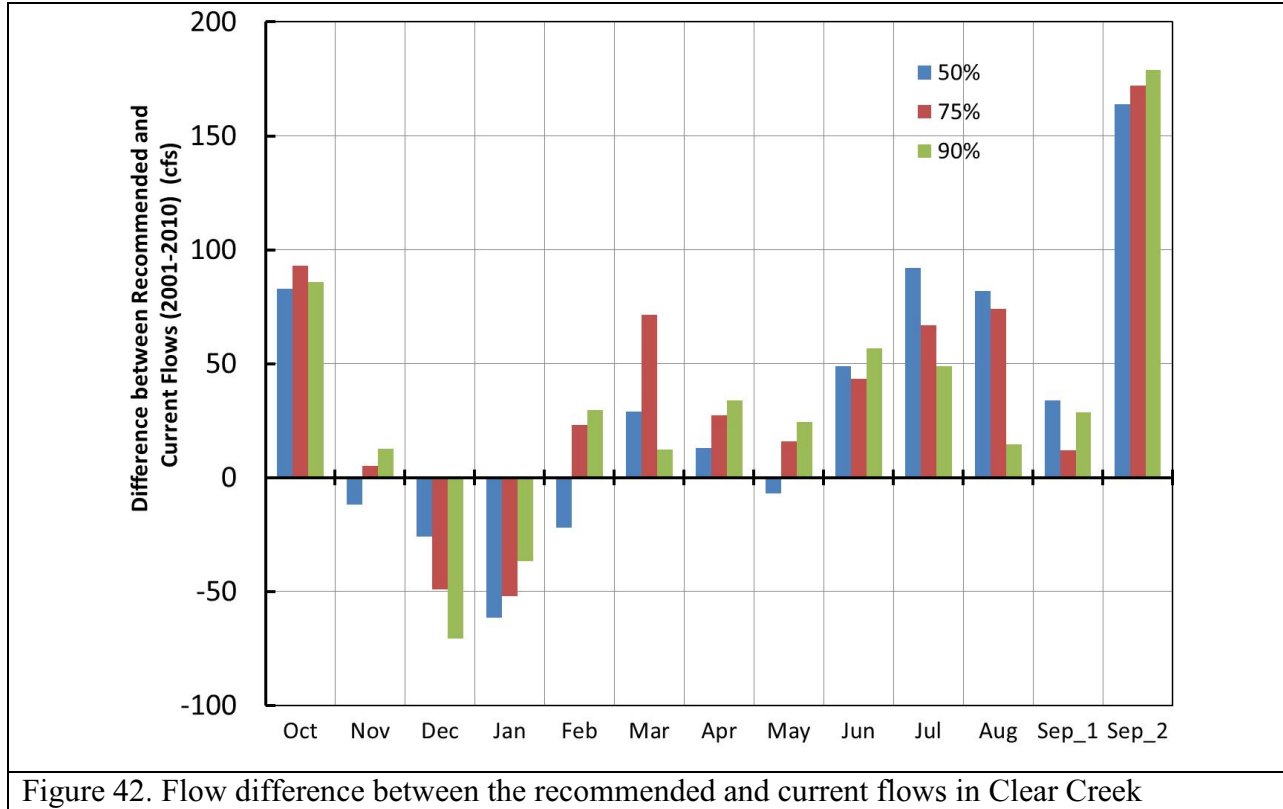


Figure 42. Flow difference between the recommended and current flows in Clear Creek

1
 2 Differences in water use can be readily calculated from a flow and the time period for the flow
 3 and are presented in **Figure 43**. As expected, water use differences follow the same pattern as
 4 flow differences. Higher water uses were required from March through October (except for the
 5 50th percentile flow in May), lower water uses in December and January. The highest increases
 6 in water use were in the second half of September and October, followed by July and August.
 7 The annual additional water use was about 23,000 acre feet for the 50th and 90th percentiles and
 8 28,000 acre feet for the 75th percentile. The higher additional water use for the 75th percentile
 9 than the 90th percentile was attributed to much higher current flows for the 90th percentile than
 10 the 75th percentile (**Figure 43**).
 11

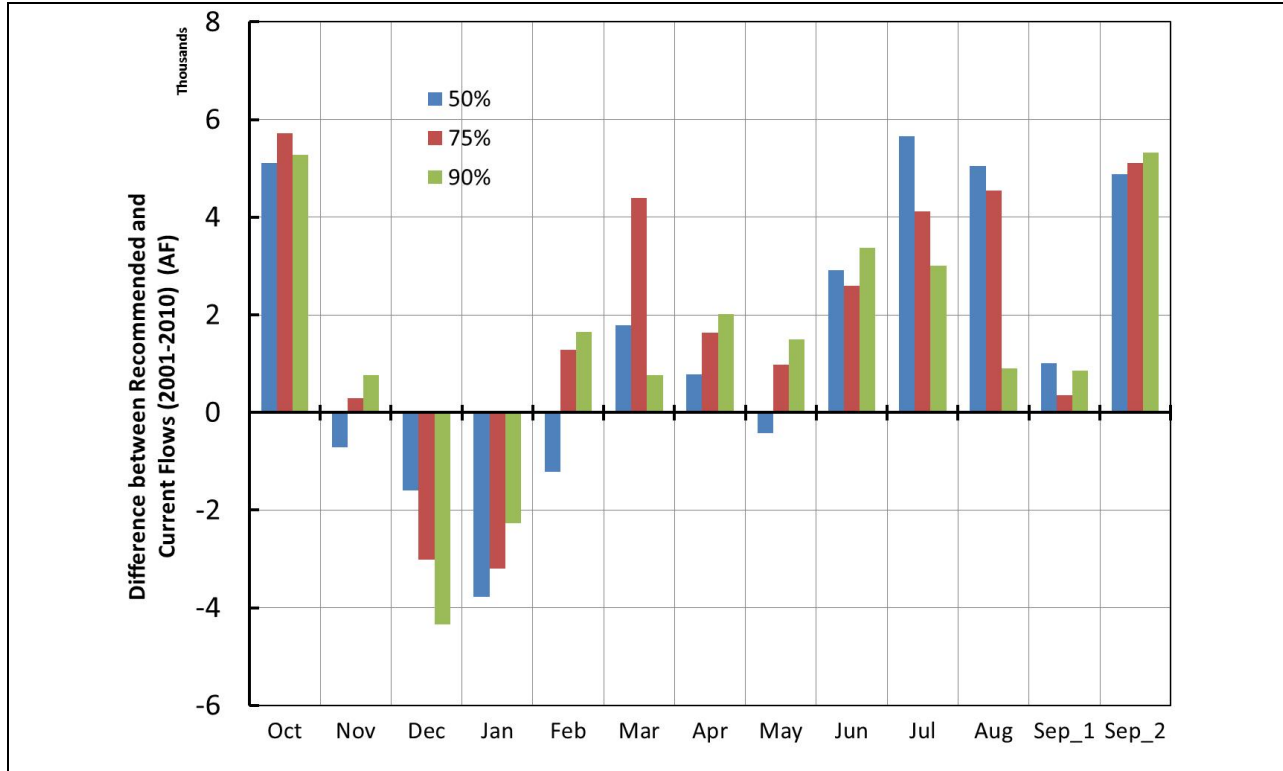


Figure 43. Water use difference between the recommended and current flows in Clear Creek

1
 2 If we assume that the additional water allocated to Clear Creek is equal to the reduction of flows
 3 to Spring Creek Powerplant and then Keswick Powerplant, the hydropower generated from the
 4 powerplants would reduce accordingly. The reduced power generation may be calculated by the
 5 following equation (assuming the efficiency is 100%):

$$P = 10^4 hQ$$

6
 7
 8
 9 where P is power in watt, h is the head of water in meter, and Q is the flow rate in m³/second.

10
 11 The water head is 169.5 meters for Spring Creek Powerplant and 23.8 meters for Keswick
 12 Powerplant. If the additional water allocated to Clear Creek goes directly to the powerplants, it
 13 could generate, on average, hydropower of 1.54 to 1.85 MW (about 1% of the plant capacity of
 14 180 MW) at Springs Creek Powerplant and 0.22 to 0.26 MW (about 0.2% of the plant capacity
 15 of 117 MW) at Keswick Powerplant.

16

1 **11 Implementation and Monitoring**

2 The effectiveness of the recommended flow releases from Whiskeytown Reservoir in achieving
3 the targeted benefits will be realized through implementing the actions and consistent
4 monitoring. Implementation of actions and monitoring programs should occur in parallel.
5 However, before an action is implemented initial conditions should be clearly documented so
6 that a baseline is established. Described in this section is an adaptive management framework,
7 which is derived from the Delta Plan (Delta Stewardship Council 2011)

8
9 **11.1 Establish Goals, Objectives, and Performance Measures**

10 The management goal is to increase the populations of spring-run Chinook and steelhead in
11 Clear Creek to a level that is sustainable, *e.g.*, doubling their populations. Achieving this goal
12 requires taking imperative actions to improve flow, water temperature, and gravel bed for
13 spawning and rearing. To help achieve the doubling goal, the following actions should be taken:

- 14
15 • Operating Whiskeytown Reservoir to provide instream flows with appropriate magnitude,
16 timing, duration, frequency, and rise/fall rates. Specifically, meet the prescribed flow
17 regime within 10% variance and 90% days each year.
- 18
19 • Operating Whiskeytown Reservoir to provide adequate water temperatures for different
20 life stages. Specifically, meet temperature requirements within the variance of 0.25 °C
21 and at least 90% of the days for each prescribed time period.
- 22
23 • Improving physical habitat for spawning and rearing through continuous gravel supply to
24 the streambed.

25
26 **11.2 Develop Implementation and Monitoring Plans**

27 The design of implementation and monitoring should clearly describe specific activities that will
28 occur under those actions, including a plan for both implementation of the actions and
29 monitoring responses from the actions. It is clear that alternative operations of Whiskeytown
30 Reservoir is needed and should be implemented in order to achieve the stated goal and
31 objectives. These alternatives must be described in the implementation plan, which should
32 include specific flows released from the reservoir to Clear Creek.

33
34 A monitoring plan should include the collection and management of data for reservoir release at
35 the dam, streamflow flow and water temperature at Igo, and weather condition in Redding. The
36 monitoring of the parameters has already been in place and make sure they will continue.
37 Monitoring activities must also include fish biology and stream morphology. The FWS, CDFG,
38 and their contractors have been conducting these types of monitoring for the past decade. It is
39 crucial to continue these efforts.

40
41 **11.3 Analyze, Synthesize and Evaluate Actions and Monitoring**

42 Analysis, synthesis, and evaluation of the actions and monitoring are critical for improving
43 current understanding. Analysis and synthesis should be informative of how conditions have
44 changed, both expected and unexpected, as a result of the implementation of the actions. The
45 evaluation should examine whether or not one or more of the performance measures have been

1 met as a result of the implemented actions and why. If a performance measure is not met, an
2 explanation of the potential reasons why this measurement has not been met should be clearly
3 identified and communicated. The following questions should be addressed:

- 4 • Has Whiskeytown Reservoir been operated to meet the prescribed flows within 10%
5 variation and 90% days?
- 6 • Has the reservoir been operated to meet the temperature requirements within 0.25 °C
7 variation and 90% days?
- 8 • Has the reservoir been operated to improve geomorphic processes? (*e.g.*, moving gravels,
9 accessing floodplains, increasing pool depth)
- 10 • Have the changes in water temperature and stream structure had the expected effects on
11 fish habitat? (*e.g.*, have we increased the habitat quantity and quality for adult holding,
12 spawning, and juvenile rearing?)
- 13 • Have the improved flow, water temperature, and physical habitat showed positive
14 biological effects on salmonid adults and juveniles?

15
16 It is apparent that, further down the above list, the questions become more difficult resolving by
17 monitoring. For example, daily flow data or hourly water temperature data within a few years
18 can be used to evaluate to what degree the alternative reservoir releases improved flow and water
19 temperature, while evaluating changes in spring-run and steelhead populations may take decades.
20 In addition, both the uncertainty, with which parameters can be measured, and the impact of
21 confounding factors increases. For practicality, the focus of monitoring will be on short-term
22 effects that may indicate longer-term trends of spring-run and steelhead in Clear Creek.

23
24 As a baseline assessment, monitoring should begin prior to the implementation of the proposed
25 actions. Results from the first year of the implementation will be used to initiate the adaptive
26 management process. For instance, water temperature data at Igo will be used to assess if the
27 alternative releases are sufficient to meet water temperature requirements. Information gained
28 regarding downstream transport of introduced gravels, changes in gravel quality, or changes to
29 channel morphology should help determine the degree of success of that year's flow
30 management and gravel introduction. This information, in combination with other projects, will
31 then be used to better refine flow recommendations for the following season, and also inform
32 recommendations for other management actions such as gravel augmentation.

1 12 References

- 2 Annear, T., I. Chisholm, H. Beacher, A. Locke, P. Aarrestad, C. Coomer, C. Estes, J. Hunt, R.
3 Jacobson, G. Jobsis, J. Kauffman, J. Marshall, K. Mayes, G. Smith, R. Wentworth, and C.
4 Stalnake. 2004. Instream Flows for Riverine Resource Stewardship. Revised Edition.
5 Instream Flow Council, Cheyenne, WY. 268 p.
- 6 Barinaga, M. 1996. A recipe for river recovery? *Science* 273:1648-1650.
- 7 Bovee, K.D., B.L. Lamb, J.M. Bartholow, C.B. Stalnaker, J. Taylor, and J. Henriksen. 1998.
8 Stream habitat analysis using the instream flow incremental methodology: U.S.
9 Geological Survey Information and Technology Report 1998-0004. 130 p.
- 10 Bunn, S.E., and A.H. Arthington. 2002. Basic Principles and Ecological Consequences of
11 Altered Flow Regimes for Aquatic Biodiversity. *Environmental Management* 30:492-
12 507.
- 13 Butte County Association of Governments (BCAG). 2011a. Butte Regional Conservation Plan -
14 Administrative Draft. Appendix A.17 Central Valley
15 Steelhead.http://www.buttehcp.com/documents/1st_Admin_Draft_BRCP_Docs/Appendicies/Appendix_A/A17_Central_Valley_Steelhead.pdf. Accessed July 13, 2011.
- 16
17 Butte County Association of Governments (BCAG). 2011b. Butte Regional Conservation Plan -
18 Administrative Draft. Appendix A.20 Central Valley Fall-/Late Fall-Run Chinook
19 Salmon.
20 http://www.buttehcp.com/documents/1st_Admin_Draft_BRCP_Docs/Appendicies/Appendix_A/A20_CV_Fall-Run_Chinook_Salmon.pdf. Accessed July 13, 2011.
21
22 July 13, 2011.
- 23 Caissie, D. 2006. The thermal regime of rivers: a review. *Freshwater Biology* 51:1389-1406.
- 24 Caissie, D., N. El-Jabi, and M.G. Satish. 2001. Modeling of maximum daily water temperatures
25 in a small stream using air temperatures. *Journal of Hydrology* 251:14-28.
- 26 Caissie, D., M.G. Satish, and N. El-Jabi. 2007. Predicting water temperatures using a
27 deterministic model: Application on Miramichi River catchments (New Brunswick,
28 Canada). *Journal of Hydrology* 336:303-315.
- 29 Carter, K. 2008. Effects of Temperature, Dissolved Oxygen/Total Dissolved Gas, Ammonia, and
30 pH on Salmonids: Implications for California's North Coast TMDLs. California Regional
31 Water Quality Control Board, North Coast Region. January 2008. 47 p.
- 32 CDFG. 1998. A status review of the spring-run Chinook salmon (*Oncorhynchus tshawytscha*) in
33 the Sacramento River drainage. Department of Fish and Game, Sacramento, California.
34 June 1998. .
- 35 CDFG. 2010a. Quantifiable Biological Objectives and Flow Criteria for Aquatic and Terrestrial
36 Species of Concern Dependent on the Delta. Prepared pursuant to the Sacramento-San
37 Joaquin Delta Reform Act of 2009. November 23, 2010. 169 p.
- 38 CDFG. 2010b. Effects of Water Temperature on Anadromous Salmonids in the San Joaquin
39 River Basin. California Department of Fish and Game, Central Region, 1234 E. Shaw
40 Avenue, Fresno, CA 93710. February 2010.
- 41 Chen, Y.D., C.M. Steven, J.N. Douglas, and L.N. Wade. 1998. Stream Temperature Simulation
42 of Forested Riparian Areas: II. Model Application. *Journal of Environmental Engineering*
43 124:316-328.
- 44 Cox, M.M., and J.P. Bolte. 2007. A spatially explicit network-based model for estimating stream
45 temperature distribution. *Environmental Modeling & Software* 22:502-514.

DRAFT

- 1 CVRWQCB. 2009. Clean Water Act Sections 305(b) and 303(d) Integrated Report for the
2 Central Valley Region. Draft Final Staff Report, May 2009. 16 p.
- 3 Danner, E., and A. Pike. 2011. Modeling river water temperatures for salmon: the importance of
4 spatial and temporal scales. PowerPoint presentation to the NMFS Central Valley Office.
5 June 22, 2011.
- 6 Deas, M.L., and C.L. Lowney. 2001. Water Temperature Modeling Review. Central Valley.
7 September 2000. 113 p.
- 8 Delta Environmental Flows Group. 2010. Key Points on Delta Environmental Flows for the State
9 Water Resources Control Board. February 2010. 9 p.
- 10 Delta Stewardship Council. 2011. Fourth Staff Draft Delta Plan. June 13, 2011. 180 p.
- 11 Denton, D.N. 1986. Clear Creek fishery study. Department of Water Resources, 1986. 70 p.
- 12 Earley, J.T., D.J. Colby, and M.R. Brown. 2010. Juvenile salmonid monitoring in Clear Creek,
13 California, from October 2008 through September 2009. U.S. Fish and Wildlife Service,
14 Red Bluff Fish and Wildlife Office, Red Bluff, California. September 2010. 80 p.
- 15 Ferry, M., and P. Miller. 2003. The removal of Saeltzer Dam on Clear Creek: an update.
16 University of California, Berkeley. 21 p.
- 17 Fleenor, W., W. Bennett, P. Moyle, and J. Lund. 2010. On developing prescriptions for
18 freshwater flows to sustain desirable fishes in the Sacramento-San Joaquin Delta.
19 Submitted to the State Water Resources Control Board regarding flow criteria for the
20 Delta necessary to protect public trust resources. 43 p.
- 21 Flint, L.E., and A.L. Flint. 2008. A basin-scale approach to estimating stream temperatures of
22 tributaries to the Lower Klamath River, California. *J. Environ. Qual.* 37:57-68.
- 23 Gard, M. 2009. CVPIA Instream Flow Investigations - Clear Creek Fall-Run Chinook Salmon
24 and Steelhead/Rainbow Trout Spawning. 111 p.
- 25 Giovannetti, S., and M.R. Brown. 2008. Adult Spring Chinook Salmon Monitoring in Clear
26 Creek, California: 2007 Annual Report. USFWS Report. U.S. Fish and Wildlife Service,
27 Red Bluff Fish and Wildlife Office, Red Bluff, California 96080. September 2008. 45 p.
- 28 Giovannetti, S., and M.R. Brown. 2009. Adult Spring Chinook Salmon Monitoring in Clear
29 Creek, California: 2008 Annual Report. USFWS Report. U.S. Fish and Wildlife Service,
30 Red Bluff Fish and Wildlife Office, Red Bluff, California 96080. December 2009. 38 p.
- 31 Giovannetti, S., and M.R. Brown. 2010. Adult steelhead and late-fall Chinook salmon
32 monitoring on Clear Creek, California. 2009 Annual report. U.S. Fish and Wildlife
33 Service, Red Bluff Fish and Wildlife Office, Red Bluff, California. November 2010. 41
34 p.
- 35 Graham Matthews & Associates. 2003. Clear Creek Floodplain Rehabilitation Project, Shasta
36 County, California: WY 2003 Geomorphic Monitoring Report. Prepared for Western
37 Shasta Resource Conservation District, Anderson Clear Creek Floodplain Rehabilitation
38 Project, Shasta County, California: WY 2003 Geomorphic Monitoring Report. Prepared
39 for Western Shasta Resource Conservation District, Anderson CA by Graham Matthews
40 & Associates, Weaverville, CA. July 2003. 124 p.
- 41 Helsel, D.R., and R.M. Hirsch. 2002. Statistical Methods in Water Resources, Techniques of
42 Water Resources Investigations, Book 4, chapter A3. U.S. Geological Survey. 522 p.
- 43 Jean-Francois, C., and C. Daniel. 2008. Stream temperature modeling using artificial neural
44 networks: application on Catamaran Brook, New Brunswick, Canada. *Hydrological
45 Processes* 22:3361-3372.

- 1 Locke, A., C. Stalnaker, S. Zellmer, K. Williams, H. Beecher, T. Richards, C. Robertson, A.
2 Wald, A. Paul, and T. Annear. 2008. Integrated Approaches to Riverine Resource
3 Management: Case Studies, Science, Law, People, and Policy. Instream Flow Council,
4 Cheyenne, WY. 430 p.
- 5 McBain, S., D. Mierau, J. Bair, B. Trush, T. Koehler, F. Meyer, G. Matthews, M. Hampton, and
6 Y. Cui. 2001. Geomorphic Evaluation of Lower Clear Creek Downstream of
7 Whiskeytown Dam, California. Final Report. McBain and Trush, P.O. Box 663, CA
8 95518. November 2001. 257 p.
- 9 McCullough, D.A. 1999. A Review and Synthesis of Effects of Alterations to the Water
10 Temperature Regime on Freshwater Life Stages of Salmonids, With Special Reference to
11 Chinook Salmon. Prepared for the U.S. Environmental Protection Agency Region 10,
12 Seattle, Washington. Published as EPA 910-R-99-010, July 1999. 291 p.
- 13 McCullough, D.A., J.M. Bartholow, H.I. Jager, R.L. Beschta, E.F. Cheslak, M.L. Deas, J.L.
14 Ebersole, J.S. Foott, S.L. Johnson, K.R. Marine, M.G. Mesa, J.H. Petersen, Y. Souchon,
15 K.F. Tiffan, and W.A. Wurtsbaugh. 2009. Research in Thermal Biology: Burning
16 Questions for Coldwater Stream Fishes. *Reviews in Fisheries Science* 17:90-115.
- 17 McEwan, D.R. 2001. Central Valley Steelhead. *Fish Bulletin* 179: Volume One.
- 18 Morrill, J.C., R.C. Bales, and M.H. Conklin. 2005. Estimating stream temperature from air
19 temperature: Implications for future water quality. *Journal of Environmental Engineering*
20 131:139-146.
- 21 Myrick, C.A., and J.J. Cech. 2001. Temperature Effects on Chinook Salmon and Steelhead: a
22 Review Focusing on California's Central Valley Populations. Bay-Delta Modeling
23 Forum. Technical Publication 01-1. 57 p.
- 24 Myrick, C.A., and J.J. Cech. 2004. Temperature effects on juvenile anadromous salmonids in
25 California's central valley: what don't we know? *Reviews in Fish Biology and Fisheries*
26 14:113-123.
- 27 Myrick, C.A., and J.J. Cech. 2005. Effects of temperature on the growth, food consumption, and
28 thermal tolerance of age-0 Nimbus-strain steelhead. *North American Journal of*
29 *Aquaculture* 67:324-330.
- 30 Neumann, D.W., B. Rajagopalan, and E.A. Zagona. 2003. Regression model for daily maximum
31 stream temperature. *Journal of Environmental Engineering* 129.
- 32 Newton, J.M., and M.R. Brown. 2004. Adult spring Chinook salmon monitoring in Clear Creek,
33 California, 1999-2002. US Fish and Wildlife Service, Red Bluff. July 2004. 71 p.
- 34 NMFS. 2009a. Biological opinion and conference opinion on the long-term operations of the
35 Central Valley Project and State Water Project. 844 p.
- 36 NMFS. 2009b. Public Draft Recovery Plan for the Evolutionarily Significant Units of
37 Sacramento River Winter-run Chinook Salmon and Central Valley Spring-run Chinook
38 Salmon and the Distinct Population Segment of Central Valley Steelhead. Sacramento
39 Protected Resources Division. October 2009. 273 p.
- 40 Norton, G.E., and A. Bradford. 2009. Comparison of two stream temperature models and
41 evaluation of potential management alternatives for the Speed River, Southern Ontario.
42 *Journal of Environmental Management* 90:866-878.
- 43 Olden, J.D., and R.J. Naiman. 2010. Incorporating thermal regimes into environmental flows
44 assessments: modifying dam operations to restore freshwater ecosystem integrity.
45 *Freshwater Biology* 55:86-107.

- 1 Orlob, G.T., M. Jensen, X. Wang, and J. Fellos. 1999. Temperature regulation through
 2 Whiskeytown Reservoir. Report 00-5. Water Resources and Environmental Modeling
 3 Group, Center for Water Resources and Environmental Modeling Group, Department of
 4 Civil and Environmental Engineering, University of California, Davis. .
- 5 Parasiewicz, P. 2001. MesoHABSIM: A concept for application of instream flow models in river
 6 restoration planning. *Fisheries* 26:6-13.
- 7 Parasiewicz, P. 2007a. Using MesoHABSIM to develop reference habitat template and
 8 ecological management scenarios. *River Research and Applications* 23:924-932.
- 9 Parasiewicz, P. 2007b. The MesoHABSIM model revisited. *River Research and Applications*
 10 23:893-903.
- 11 Parasiewicz, P. 2008. Application of MesoHABSIM and Target Fish Community approaches to
 12 restoration of the Quinebaug River, Connecticut and Massachusetts, USA. *River*
 13 *Research and Applications* 24:459-471.
- 14 Parasiewicz, P., and J.D. Walker. 2007. Comparison of MesoHABSIM with two microhabitat
 15 models (PHABSIM and HARPFA). *River Research and Applications* 23:904-923.
- 16 Petts, G.E. 2009. Instream Flow Science For Sustainable River Management. *Journal of the*
 17 *American Water Resources Association* 45:1071-1086.
- 18 Poff, N.L., and D.D. Hart. 2002. How dams vary and why it matters for the emerging science of
 19 dam removal. *Bioscience* 52:659-668.
- 20 Poff, N.L., J.D. Olden, D.M. Merritt, and D.M. Pepin. 2007. Homogenization of regional river
 21 dynamics by dams and global biodiversity implications. *Proceedings of the National*
 22 *Academy of Sciences of the United States of America* 104:5732-5737.
- 23 Poff, N.L., J.D. Allan, M.B. Bain, J.R. Karr, K.L. Prestegard, B.D. Richter, R.E. Sparks, and
 24 J.C. Stromberg. 1997. The natural flow regime. *Bioscience* 47:769-784.
- 25 Poff, N.L., B.D. Richter, A.H. Arthington, S.E. Bunn, R.J. Naiman, E. Kendy, M. Acreman, C.
 26 Apse, B.P. Bledsoe, M.C. Freeman, J. Henriksen, R.B. Jacobson, J.G. Kennen, D.M.
 27 Merritt, J.H. O'Keefe, J.D. Olden, K. Rogers, R.E. Tharme, and A. Warner. 2010. The
 28 ecological limits of hydrologic alteration (ELOHA): a new framework for developing
 29 regional environmental flow standards. *Freshwater Biology* 55:147-170.
- 30 Richter, B.D., and G.A. Thomas. 2007. Restoring environmental flows by modifying dam
 31 operations. *Ecology and Society* 12.
- 32 Richter, B.D., J.V. Baumgartner, J. Powell, and D.P. Braun. 1996. A method for assessing
 33 hydrologic alteration within ecosystems. *Conservation Biology* 10:1163-1174.
- 34 Richter, B.D., J.V. Baumgartner, R. Wigington, and D.P. Braun. 1997. How much water does a
 35 river need? *Freshwater Biology* 37:231-249.
- 36 Richter, B.D., J.V. Baumgartner, D.P. Braun, and J. Powell. 1998. A spatial assessment of
 37 hydrologic alteration within a river network. *Regulated Rivers-Research & Management*
 38 14:329-340.
- 39 Risley, J.C., J. Edwin A. Roehl, and P.A. Conrads. 2002. Estimating water temperatures in small
 40 streams in western Oregon using neural network models. WRIR 02-4218. .
- 41 Sahoo, G.B., S.G. Schladow, and J.E. Reuter. 2009. Forecasting stream water temperature using
 42 regression analysis, artificial neural network, and chaotic nonlinear dynamic models.
 43 *Journal of Hydrology* In Press, Accepted Manuscript.
- 44 Stillwater Sciences. 2004. Environmental Water Program - Draft Conceptual Proposal for Flow
 45 Acquisition on Lower Clear Creek. 2855 Telegraph Avenue, Suite 400, Berkeley, CA
 46 94705. May 2004.

DRAFT

1 SWRCB. 2010. Development of Flow Criteria for the Sacramento-San Joaquin Delta Ecosystem.
2 Prepared Pursuant to the Sacramento-San Joaquin Delta Reform Act of 2009. August 3,
3 2010. 190 p.

4 Taylor, R.L. 1998. Simulation of hourly stream temperature and daily dissolved solids for the
5 Truckee River, California and Nevada: U.S. Geological Survey Water-Resources
6 Investigations Report 98-4064, 70 p. .

7 Tetra Tech. 2011. Lower Stanislaus River Water Temperature Model. Final report prepared for
8 NOAA National Marine Fisheries Service. March 2011. 464 p.

9 Tharme, R.E. 2003. A global perspective on environmental flow assessment: Emerging trends in
10 the development and application of environmental flow methodologies for rivers. *River
11 Research and Applications* 19:397-441.

12 The Nature Conservancy. 2009. Indicators of Hydrologic Alteration (version 7.1) User's Manual.

13 US EPA. 2001. Summary of Technical Literature Examining the Physiological Effects of
14 temperature on Salmonids, Issue Paper 5, prepared by Dale McCullough, Shelley
15 Spalding, Debra Sturdevant, and Mark Hicks as Part of EPA Region 10 Temperature
16 Water Quality Criteria Guidance Development Project. EPA-910-D-01-005. May 2001.
17 114 p.

18 US EPA. 2003. EPA Region 10 Guidance for Pacific Northwest State and Tribal Temperature
19 Water Quality Standards. EPA 910-B-03-002. Region 10 Office of Water, Seattle, WA.

20 USBR. 2004. Long-term Central Valley Project Operations Criteria and Plan. Sacramento,
21 California. June 30, 2004. , Sacramento, California.

22 USBR, and USFWS. 2008. Central Valley Project Improvement Act. Public Law 102-575.
23 Annual Report. Fiscal Year 2008.

24 USEPA. 2003. EPA Region 10 Guidance for Pacific Northwest State and Tribal Temperature
25 Water Quality Standards. EPA 910-B-03-002. Region 10 Office of Water, Seattle, WA.

26 USEPA. 2009. Guidance on the Development, Evaluation, and Application of Environmental
27 Models. EPA/100/K-09/003. March 2009. 90 p.

28