Draft Stock Selection Strategy:

Spring-run Chinook salmon Chinook salmon

Draft
May 2010

Table of Contents

Tables

Figures

List of Abbreviations and Acronyms

°C	degrees Celsius
CALFED	CALFED Bay-Delta Program
CVP	Central Valley Project
CVRWQCB	Central Valley Regional Water Quality Control Board
Delta	Sacramento-San Joaquin Delta
DFG	California Department of Fish and Game
DMC	Delta-Mendota Canal
DO	Dissolved oxygen
DPA	Drainage Project Area
DWR	California Department of Water Resources
EDT	Ecosystem Diagnosis and Treatment
EPA	Environmental Protection Agency
°F	degrees Fahrenheit
FGC	California Fish and Game Code
FL	Fork length
FMP	Fisheries Management Plan
FMWG	Fisheries Management Work Group
g/d	grams per day
Growth Population Period	January 1, 2025 through December 31, 2040
IFIM	Instream Flow Incremental Methodology
Interior	U.S. Department of the Interior
m^2	squared meters
MCL	maximum contaminant levels
mg/L	milligrams per liter
µg/L	micrograms per liter
mm	millimeter
MOA	Memorandum of Agreement
Ne	effective population size
Ne/N	mean ratio of the effective population size to total escapement over a 3-year period
NMFS	National Marine Fisheries Service
NOD	Notice of Decision
NPDES	National Pollutant Discharge Elimination System
NRDC	National Resources Defense Council

PMP	Program Management Plan
PTA	Patient-Template Analysis
OP	organophosphate pesticides
RA	Restoration Administrator
Reclamation	U.S. Department of the Interior, Bureau of Reclamation
Restoration Area	San Joaquin River between Friant Dam and the confluence with the Merced River
RKM	river kilometer
ROD	Record of Decision
SAG	Science Advisory Group
Secretary	Secretary of the Department of the Interior
Settlement	San Joaquin River Settlement
SJRRP	San Joaquin River Restoration Program
SNPs	Single nucleotide polymorphism
SR	State Route
Study Area	San Joaquin River upstream from Friant Dam, Restoration Area, San Joaquin River downstream from the Restoration Area, Sacramento-San Joaquin Delta, and the San Francisco Bay
SWRCB	State Water Resources Control Board
TDS	Total dissolved solids
Template	hypothetical potential state
TM	Technical Memorandum
TMDL	Total Maximum Daily Load
USFWS	U.S. Fish and Wildlife Service
Viable population	an independent population that has a negligible risk of extinction due to threats from demographic variation, local environmental variation, and genetic diversity changes that may occur over a 100-year time frame
VSP	Viable Salmonid Population

This page left blank intentionally.

1.0 Introduction

This document is part of a multi-step process to select a stock or stocks of spring-run Chinook salmon Chinook salmon for reintroduction to the San Joaquin River and ultimately determine appropriate methods of reintroduction. The effort is part of the San Joaquin River Restoration Program (SJRRP), whose charge is to execute a legal settlement from the lawsuit, *NRDC et al. v. Kirk Rodgers et al*.; whereby in 1988, a coalition of environmental groups, led by the Natural Resources Defense Council (NRDC), filed a lawsuit challenging the renewal of long-term water service contracts between the United States and California's Central Valley Project Friant Division contractors. After more than 18 years of litigation, the Settling Parties reached a Stipulation of Settlement Agreement (Settlement). The Settling Parties, including NRDC, Friant Water Users Authority, and the U.S. Departments of the Interior and Commerce, agreed on the terms and conditions of the Settlement, which was subsequently approved on October 23, 2006. The Settlement establishes two primary goals:

- **Restoration Goal** – To restore and maintain fish populations in "good condition" in the mainstem San Joaquin River below Friant Dam to the confluence with the Merced River, including naturally reproducing and self-sustaining populations of salmon and other fish.

- **Water Management Goal** – To reduce or avoid adverse water supply impacts to all of the Friant Division long-term contractors that may result from the Interim Flows and Restoration Flows provided for in the Settlement.

Related to the Settlement, President Obama signed the San Joaquin River Restoration Act on March 30, 2009, giving the Department of Interior full authority to implement the SJRRP. The implementing agencies, consisting of the U.S. Department of Interior, Bureau of Reclamation (Reclamation) and U.S. Fish and Wildlife Service (USFWS), National Marine Fisheries Service (NMFS), California Department of Fish and Game (DFG), and California Department of Water Resources (DWR) organized a Program Management Team (PMT) and associated Work Groups to begin work implementing the Settlement. The Fisheries Management Workgroup (FMWG), consisting of representatives of the above agencies, published a draft Fisheries Management Plan (FMP, 2010) to describe the Program's approach to Restoration. The Stock Selection Strategy works to fulfill the stock selection objectives of the FMP with focus on the three largest stocks of spring-run Chinook salmon Chinook salmon in the Central Valley; Feather River, Butte Creek, and the Deer and Mill Creek Complex. A general description of each stock and their river system is provided, as well as an analysis and comparison of each stock's genotypic and phenotypic characteristics and recommendations for stock selection.

1.1 Stock Selection Strategy Development Process

This document is the product of the Genetics Subgroup of the Fisheries Management Work Group (FMWG). The Genetics Subgroup focuses on genetic issues related to protecting the genetic integrity of the reintroduced stock, stock selection, reintroduction strategies, development of the Hatchery and Genetics Management Plan, and other hatchery related issues. This subgroup is composed of State and Federal fisheries scientist and academic researchers. This document is guided by an adaptive management approach as described in the FMP. While extensive analysis and expertise is used to predict stock performance in the restored environment, it is recognized that these predictions are potentially fallible due to the numerous variables associated with the massive scale of this project. A key aspect to this decision making process is the use of adaptive management as described by Williams *et al*. (2009), which recognizes and embraces this uncertainty.

> *"Making a sequence of good management decisions is more difficult in the presence of uncertainty, an inherent and pervasive feature of managing ecological systems (16, 17). Uncertainties arise with incomplete control of management actions, sampling errors, environmental variability, and an incomplete understanding of system dynamics, each affecting the decision making process. An adaptive approach provides a framework for making good decisions in the face of critical uncertainties, and a formal process for reducing uncertainties so that management performance can be improved over time."*

For more information about the adaptive management process use here, refer to Chapter 1 of the Program's 2010 Daft Fisheries Management Plan.

2.0 Donor Stock Selection

As described in SJRRP 2009, spring-run Chinook salmon Chinook salmon once occupied all major river systems in California where there was access to cool reaches that would support over-summering adults. Historically, spring-run Chinook salmon Chinook salmon were widely distributed in streams of the Sacramento-San Joaquin basin, spawning and rearing over extensive areas in the upper and middle reaches (elevations ranging 1,400 to 5,200 feet (450 to 1,600 meters)) of the San Joaquin, American, Yuba, Feather, Sacramento, McCloud, and Pit Rivers (Myers et al. 1998). Spring-run Chinook salmon Chinook salmon populations in the San Joaquin basin were extirpated following basin-wide dam construction between 1894 to 1968 (Yoshiyama et al. 2001, Lindley et al. 2004, Schick and Lindley 2007) and all extant spring-run Chinook salmon Chinook salmon populations are believed to spawn in the Sacramento basin (Moyle 2002). In the upper San Joaquin River, spring-run Chinook salmon Chinook salmon were extirpated by the mid-to late 1940s, following the construction of Friant Dam and diversion of water for agricultural and municipal purposes (e.g. Central Valley Project) to the San Joaquin Valley.

Only two evolutionarily significant units (ESU) of spring-run Chinook salmon Chinook salmon remain in California: the Central Valley spring-run Chinook salmon Chinook Salmon ESU, consisting of four Central Valley spring-run Chinook salmon populations, and the Upper Klamath-Trinity Rivers Chinook salmon ESU, which includes all naturally spawning spring-run Chinook salmon Chinook salmon in the Klamath and Trinity Basins upstream of the confluence of the Klamath and the Trinity Rivers (Moyle et al. 1995). Only Chinook salmon from the Central Valley ESU will be considered for reintroduction. Lindley et al. (2004) used ecogeomorphic principles to identify at least 18 historic spring-run Chinook salmon Chinook salmon populations in the Sacramento – San Joaquin watershed. While the genetic constituency of these historic populations is uncertain, it is possible that each population was sufficiently isolated and maintained some level of genetic distinctiveness in the face of limited gene flow.

Functionally independent populations of spring-run Chinook salmon Chinook salmon remain in Deer, Mill, and Butte creeks and another spring-run Chinook salmon Chinook salmon population is spawned at the Feather River Hatchery and in the river below Oroville Dam. Spring-run Chinook salmon Chinook salmon also occur in numerous smaller northern Central Valley tributaries, though these populations are small and subject to gene flow from the larger independent populations in the California Central valley. Several tributaries within the San Joaquin Valley have spring-run Chinook salmonning Chinook salmon, but their numbers are very small and further monitoring and research is needed to determine if these fish are genotypically spring-run Chinook salmon Chinook salmon, or fall-run Chinook salmon.

Spring-run Chinook salmon Chinook salmon populations are phenotypically similar in their adult behavior patterns. They return to natal rivers sexually immature in the spring, typically ascending farther upstream than later-entering fall-run Chinook salmon, then reside in cool water refugia until spawning starts early in the fall. Life history differences among spring-run Chinook salmon Chinook salmon populations are informative in considering their potential use in reintroduction actions and it is possible this phenology and local adaptation have led to underlying genetic differences among these groups. Research in other salmonids have described the local adaptation of egg incubation temperature optima, yolk conversion efficiencies, development rates, subyearling growth rates, and age at smoltification (Hendry et al. 1998, Obedzinski and Letcher 2004), which may cause differential survival among stocks in environments distinct from the natal streams.

Reintroduction efforts may have the best chance for success when the chosen broodstock have life history characteristics compatible with the anticipated environmental conditions of the reintroduction habitat. Ecoregions closest to the restoration site that contain Chinook salmon populations have the highest likelihood of similar local adaptation of traits and, therefore, only Chinook salmon populations found in California's Central Valley will presently be considered as broodstock.

The primary goal of broodstock selection is to identify the stock(s) with the highest likelihood of establishing a self-sustaining naturally reproducing population in the San Joaquin River restoration area. A key component to identifying the "best" stock(s) is conducting genetic analyses of extant populations to ascertain the genetic integrity of all potential source populations. Measurement indices that are useful for analysis of potential broodstock(s) include, but are not limited to: effective population size (Ne); genetic comparisons to historic population in upper San Joaquin (if feasible); within population genetic diversity and inbreeding levels; among population genetic diversity; and hatchery influence. Optimum characteristics for the chosen donor population sources include:

- Be of local or regional origin (Central Valley)
- Have life history (behavioral and physiological) characteristics that fit conditions expected to occur on the San Joaquin River, thereby maximizing the probability of successful reintroduction
- Large effective population size
- High within population genetic diversity with low inbreeding coefficients
- Adequate representation of overall ESU genetic diversity

The candidate populations for this Program may be limited to those with relatively large effective population size; the independent spring-run Chinook salmon Chinook salmon populations on Deer/Mill and Butte Creeks, and spring-run Chinook salmon population in the Feather River. All potential sources of spring-run Chinook salmon Chinook salmon will by analyzed in this document.

In addition to genetic considerations, the appropriate broodstock(s) for the Project will be selected based on current (census) population size, compatibility of life history characteristics to anticipated restored Restoration Area conditions, and availability of broodstock. This information will be gathered through interactions with biologists for all potential source populations and review of existing literature and databases.

Risks and Uncertainties

- **Selected broodstock(s) will not capture the genetic variation needed to promote a long-term naturally self-sustaining population in the Restoration Area.**

  An assessment of each potential broodstock's genetic diversity (e.g., Ne, heterozygosity) is proposed to ensure that the chosen source population(s) possesses adequate variation in order to adapt to changing environmental conditions. Genetic analyses will be facilitated by genotyping a large number of Single Nucleotide Polymorphism (SNP) markers. Selection of multiple broodstocks could act to reduce risk by increasing overall genetic variation.

- **An overlap in migration run-timing and lack of spatial separation between mature spring-run Chinook salmon and fall-run Chinook salmon in the Restoration Area are expected to result in the genetic introgression of the two populations.**

  To reduce the potential for hybridization it is recommended that a physical barrier (e.g., weir) be installed after the spring-run Chinook salmon Chinook salmon spawning migration is completed to separate upstream spring-run Chinook salmon spawning habitat from the downstream fall-run Chinook salmon spawning habitat. Due to overlap in spring-run Chinook salmon and fall-run Chinook salmon spawning migrations, reestablishment of late fall-run Chinook salmon may be preferable over early fall-run Chinook salmon spawners.

- **Removal of broodstock fishes from source population(s) may increase the risk of extirpation, and reduce the population viability and recovery potential of the source population(s)**.

  To reduce the potential for significant impacts to source population(s), criteria for collection strategies will balance development of reintroduced stocks with minimizing risks to the source population(s)

This page left blank intentionally.

3.0 Stock Descriptions

3.1 Feather River

3.1.1 Introduction

The Feather River is a major tributary to the Sacramento River located at the north end of the western slope Sierra Nevada, with a watershed encompassing 5,900 square miles (FERC 2007, NMFS 2009). The upper Feather River watershed above Oroville Dam, is approximately 3,600 square miles (approximately 68 percent of the Feather River Basin), and has four tributaries, the North, South, Middle and West Forks. Downstream of Oroville Dam, the watershed includes the drainage of the Yuba and Bear rivers, and eventually meets the Sacramento River, contributing 25 percent to its flow (NMFS 2009).

3.1.2 Historic Conditions

The Feather River is renowned as one of the major salmon-producing streams of the Sacramento Valley (Yoshiyama 2001) and once contained over 200 miles of anadromous fish habitat, of which 64 miles remain (NMFS 2009). Prior to the construction of numerous hydroelectric power projects and diversions, spring-run Chinook salmon Chinook ascended high into the watershed (Clark 1929, Yoshiyama et al., 1996, Lindley et al., 2004). The fall-run Chinook salmon spawned primarily in the mainstem, while most of the spring-run Chinook salmon spawned in the Middle Fork, with smaller runs in the North, South and West Forks (Fry 1961, Yoshiyama 2001). Each of the four tributaries above Oroville Dam generally provide suitable habitat for all life stages of Chinook salmon and steelhead (DWR 2005, NMFS 2009) and likely contained independent populations of spring-run Chinook salmon Chinook salmon (Lindley et al., 2004).

Human impacts to the salmon runs of the Feather River began as early as the late 1800's. Hydraulic mining activity and dam construction where established below Oroville and on the West, North, and South Forks occurred in the early 1900's (Clark 1929, Muir 1938, as found in Yoshiyama 2001), and up to 186 million cubic yards of mining debris were produced before 1909 (Gilbert 1917, Yoshiyama 2001).

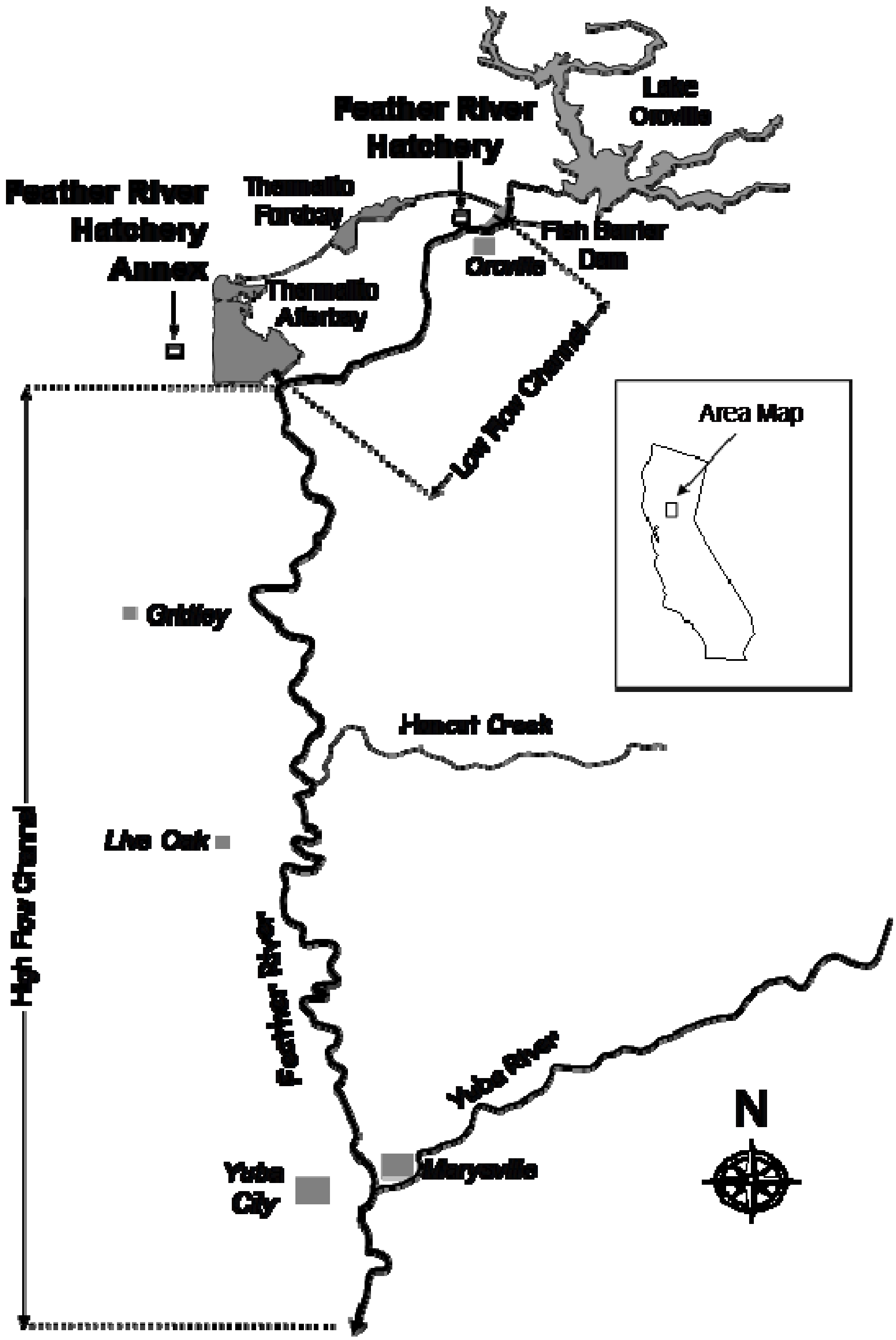
Fry (1961) reported run-size estimates for the fall-run Chinook salmon of 10,000 to 86,000 fish during the period 1940–1959, and about 1,000 to 4,000 spring-run Chinook salmon. Just before the completion of Oroville Dam, a small naturally-spawning spring-run Chinook salmon population still existed in the Feather River (Reynolds et al 1993, Yoshiyama 2001). The number of naturally spawning spring-run Chinook salmon in the Feather River was estimated only periodically in the 1960s and 1970s, with estimates ranging from 2,908 fish in 1964 to two fish in 1978 (NMFS 2009).

3.1.3 Existing Conditions

Flow Regime

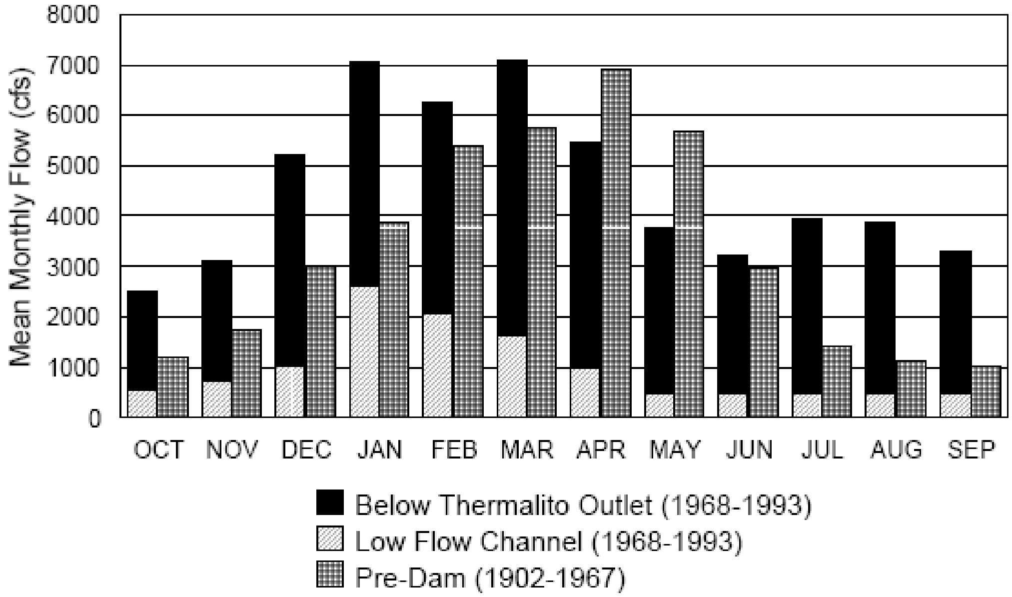
Today, flow in the Feather River is altered by hydroelectric, water storage, and diversion projects (FERC 2007). River flow below the reservoir is regulated by Oroville Dam, Thermalito Diversion Dam, and Thermalito Afterbay Outlet. Oroville Reservoir is the lowermost reservoir on the Feather River and the upstream limit for anadromous fish (USFWS 1995, NMFS 2009).

Under normal operations, the majority of the Feather River is diverted at Thermalito Diversion Dam into Thermalito Forebay. The remainder of the flow, typically 600 cubic feet per second (cfs), flows through the historical river channel, referred to as the “low flow channel” (LFC) (Figure 3-1). Mean monthly flows through the LFC are now 5% to 38% of pre-dam levels (Sommer et al. 2001). Water released by the Thermalito Forebay is used to generate power before discharge into Thermalito Afterbay and enters the “high flow channel” (HFC), then water flows southward through the valley until the confluence with the Sacramento River at Verona (FERC 2007).



Source: DWR

Figure 3-1.
Feather River Low Flow and High Flow Channel system



Source: DWR

Note: Total flow in the post-dam period includes the portion from the low channel and the portion diverted through the Thermalito complex.

Figure 3-2.
Mean Monthly Flows in the Feather River for the pre-Oroville dam (1902-1967) and post-Oroville dam (1968-1993) period

Geology

The North Fork Feather River is in the southern Cascades while the other forks are in the Sierra Nevada ecoregion. The headwaters of the North Fork are fed by rainfall and by snowmelt from Mt Lassen, and rocks are predominately of volcanic origin (Lindley et al. 2004). The bed material in the remaining three tributaries is primarily of granitic origin. As described in NMFS 2009, the most common material in the soils downstream of Oroville Dam is alluvium, with some soils derived from debris deposited during the hydraulic mining period. Channel banks and streambed in the LFC generally consist of armored cobble as a result of periodic flood flows and the absence of gravel recruitment. By far, historic hydraulic mining of gold-bearing gravel deposits has caused the largest impact on the Feather River channel washing massive amounts of erosional debris, including cobbles, gravel, sand, silt, and clay, into the river. Floodplain soils are conducive to agriculture and many areas of riparian floodplain and fluvial terraces have been converted to irrigated crops and orchards (FERC 2007). Human activity over time has resulted in decreased vegetative cover from logging and grazing, channel clearing, levee construction and water diversions. These activities have contributed to the increased sediment load in the Feather River Watershed (FERC 2007).

Temperature and Water Quality

Water is released from Oroville Dam through a multilevel outlet to provide appropriate water temperatures for the operation of the Feather River Hatchery and to protect downstream fisheries (NMFS 2009). Water temperatures downstream of the Fish Barrier Dam vary seasonally and there is a significant temperature difference between the LFC and the HFC. In both channels, temperatures begin to warm in March and peak in July and early August. In the LFC, peak temperatures range from 61°F upstream of the Feather River Fish Hatchery to 69°F upstream of the Thermalito Afterbay Outlet (FERC 2007). Cooling begins in September, with water temperatures dropping to 45°F throughout the reach by February (FERC 2007). Compared to historical levels, mean monthly water temperatures in the LFC at Oroville are 2 to 14 °F cooler during May through October and 2 to 7 °F warmer during November through April (Sommer et al. 2001). Feather River Fish Hatchery water temperatures vary little from temperatures of river water near the hatchery (FERC 2007).

Peak water temperatures in the HFC range from 71 to 77°F. River cooling begins in late August, with minimum temperatures of 44 to 45°F reached by January or February. Releases from the Thermalito Afterbay Outlet as well as flow contributions from Honcut Creek, the Yuba River, and the Bear River influence HFC water temperatures from April through October (FERC 2007). Except during periods of high flow through Thermalito Afterbay, which occur frequently in July and August, releases from Thermalito Afterbay during the warm season generally raise the water temperature of the river. Honcut Creek and Bear River inflows also tend to increase Feather River temperatures downstream of their confluences during this period (FERC 2007). Flows contributed by the Yuba River tend to cool the Feather River during the warmer spring and summer months. DO and pH levels in the Feather River are generally found to comply with the water quality objectives for Chinook salmon. When exceedances occur, they are considered minor (FERC 2007).

3.1.4 Life History/Phenotypic Expression

Holding and Spawning

Upstream migration of Chinook salmon is blocked by Fish Barrier Dam located one kilometer below the Oroville Dam. Adult spring-run Chinook salmon are found holding at the Thermalito Afterbay Outlet and the Fish Barrier Dam as early as April (FERC 2007, NMFS 2009)and begin spawning in September, usually 2-3 weeks earlier than the fall-run Chinook salmon (personal communication, Jason Kindopp). Adult fall-run Chinook salmon typically return to the river to spawn during September through December, with peak returns from mid-October through early December (Sommer et al. 2001).

Spring-run Chinook salmon Chinook salmon are spawned artificially in the Feather River Fish Hatchery (FRFH) and also spawn naturally in the river during late September to late October (Reynolds et al 1993, Yoshiyama 2001) downstream from the Fish Barrier Dam approximately eight miles to the Thermalito Afterbay Outlet (NMFS 2009). Fall-run Chinook salmon and steelhead are also produced by the Feather River Hatchery. Approximately two-thirds of natural Chinook salmon spawning in the Feather River occurs in the Low Flow Channel (LFC) between the Fish Barrier Dam and the Thermalito Afterbay Outlet (NMFS 2009). Spawning occurs primarily in the riffle and glide areas, with the greatest portion crowded in the upper three miles of the LFC (Sommer et al. 2001). The remaining one-third of the spawning occurs between the Thermalito Afterbay Outlet and Honcut Creek (RM 59 to 44) (FERC 2007), where in comparison to the LFC, there is a greater amount of available spawning areas and deeper pools (FERC 2007, NMFS 2009). This represents a marked shift in the spawning distribution of Chinook salmon since the construction of Oroville Dam and FRFH, when less spawning activity occurred in the LFC, which has undoubtedly increased spawning densities in the LFC (Sommer et al. 2001). For both Chinook salmon and steelhead, spawning and embryo incubation is the life stage for which the smallest amount of suitable habitat is available in the upper Feather River (NMFS 2009).

Rearing

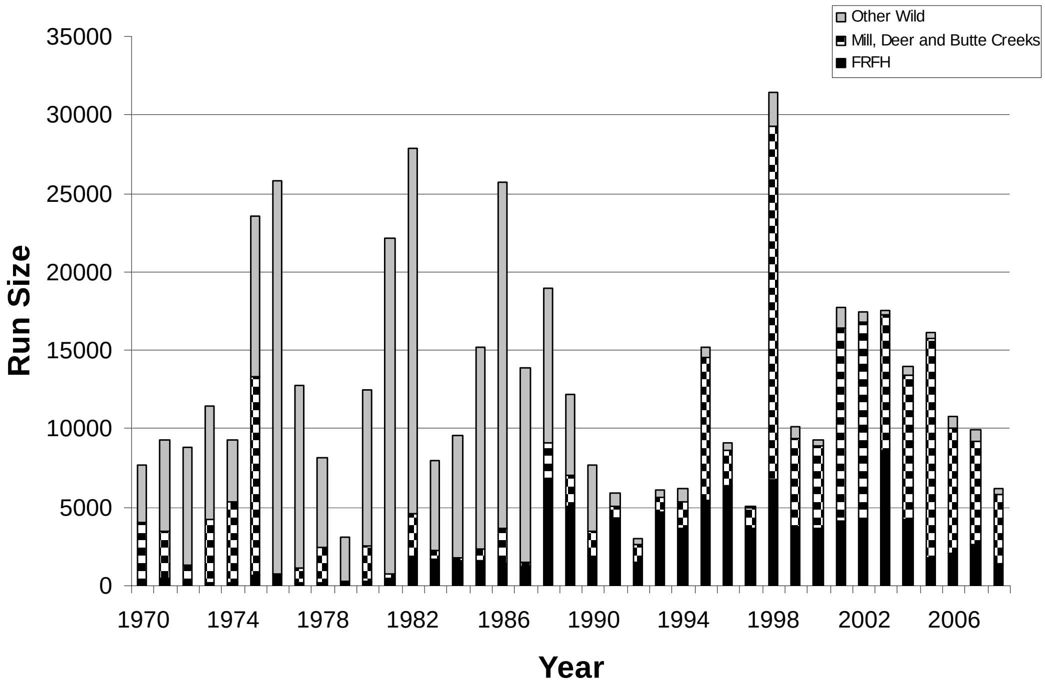
Some spring-run Chinook salmon Chinook juveniles hold over the summer in deep pools within the LFC five miles below Oroville Dam and the downstream Thermalito Afterbay Outlet (Reynolds et al. 1993, (Yoshiyama 2001). The vast majority of spring-run Chinook salmon fish emigrate as fry (DWR unpublished data as found in Sommer et al.), suggesting that rearing habitat is limiting or that conditions later in the season are less suitable (Sommer et al. 2001). The primary location(s) where these fish rear is unknown, however in wetter years it appears that many young salmon rear for weeks to months in the Yolo Bypass floodplain immediately downstream of the Feather River before migrating to the estuary (Sommer et al. 2001).

Outmigration

Fry from both runs of Chinook salmon emerge from spawning gravels as early as November (Painter and others 1977; DWR unpublished data as found in Sommer et al.) and generally rear in the river for at least several weeks. Emigration occurs from December to June, with a typical peak during the February through April period (Sommer et al. 2001), with 95 percent of the juvenile Chinook typically emigrating from the Oroville Facilities project area by the end of May (FERC 2007, NMFS 2009).

3.1.5 Population Size

Between 1967 and 2008, the highest annual hatchery spring-run Chinook salmon Chinook salmon escapement was 8,662, occurring in 2003 (CDFG 2009). Between 1986 and 2007, the average number of spring-run Chinook salmon returning to the FRFH was 3,992, compared to an average of 12,888 spring-run Chinook salmon returning to the entire Sacramento River Basin (NMFS 2009), and an average of 1,700 fish before the construction of Oroville Dam (Reynolds and others 1993, Yoshiyama 2001). More recently, FRFH spring-run Chinook salmon Chinook salmon escapement from 2005 through 2008 was 1,774, 2,061, 2,674, and 1,418, respectively (CDFG 2009) (NMFS 2009). The increase in numbers since the completion of the dam is attributed to the consistent supply of cold water to both the hatchery and the LFC and the contribution of hatchery fish (Reynolds and others 1993, Yoshiyama 2001).



Source: CDFG 2009

Figure 3-3.
Central Valley Spring-run Chinook salmon Chinook Salmon Spawning Run Size Composition (1970-2008)

3.1.6 Hatchery Influence and Interbasin Transfers

The FRFH, was built by DWR to mitigate for the loss of upstream spawning habitat of salmon and steelhead due to the building of Oroville Dam (Reynolds and others 1993, Yoshiyama 2001). The FRFH began operation in 1967, and it is the only source of hatchery produced spring-run Chinook salmon Chinook salmon in the Central Valley (Reynolds et al 1993, Yoshiyama 2001). In the early stages of hatchery operations, FRFH staff attempted to maintain program separation of the two runs by designating the earliest-arriving spawners as spring-run Chinook salmon. Unfortunately, directed and nonintentional incorporation of fall-run Chinook salmon broodstock into the spring-run Chinook salmon program has led to hybridization between the two hatchery stocks over time. Brown and Greene (1994) describe coded-wire-tag studies on the progeny of hatchery fish identified as “fall-run Chinook salmon” and “spring-run Chinook salmon” and found evidence of substantial introgression (Sommer et al. 2001) due to hatchery practices and the overlapping spatial proximity of spawning in the river of the two populations. It has been reported that some proportions of the offspring of each hatchery race return as adults during the wrong period, i.e. spring-run Chinook salmon are returning during months when fall-run Chinook salmon return (Sommer et al. 2001). In an attempt to improve the life-history integrity of the spring-run Chinook salmon hatchery stock, a Settlement Agreement for Licensing of the Oroville Facilities (March 2006) includes measures to improve the short- and long-term genetic management of the FRFH spring-run Chinook salmon program, and measures to physically separate and isolate spring-run Chinook salmon Chinook salmon from fall-run Chinook salmon (NMFS 2009).

Table 3-1.
Feather River Fish Hatchery Temperature Objectives
(±4° F between April 1 and November 30)

Period	Temperature (F)
April – May 15	51
May 16 – 31	55
June 1 - 15	56
June 16 – August 15	60
August 16 – 31	58
September	52
October – November	51
December - March	No greater than 55

Source: DWR 2001

3.2 Deer and Mill Creeks

3.2.1 Introduction

Deer and Mill creeks are eastside tributaries to the upper Sacramento River. Deer Creek enters the Sacramento River at RM 220 and Mill Creek enters at RM 230. Along with Butte Creek, they are recognized as supporting genetically distinct, self sustaining populations of spring-run Chinook salmon Chinook salmon, (CDFG 1998, as cited in CDFG 2008). Mill and Deer creeks appear genetically similar compared to the other extant spring-run Chinook salmon Chinook salmon population in the Central Valley and likely function together demographically as a metapopulation. There is currently no hatchery program supplementing the populations on any of these streams. Between 1902 and 1940, the U.S. Bureau of Fisheries established a hatchery on Mill Creek near Los Molinos. During this time, fall-run Chinook salmon were spawned, with an average of 6-7 million eggs taken annually. Juvenile salmon were reared and released in the spring. Attempts were made to spawn spring-run Chinook salmon Chinook at this site, but were prohibited by warm water temperatures during summer months. (Hanson et. al. 1940)

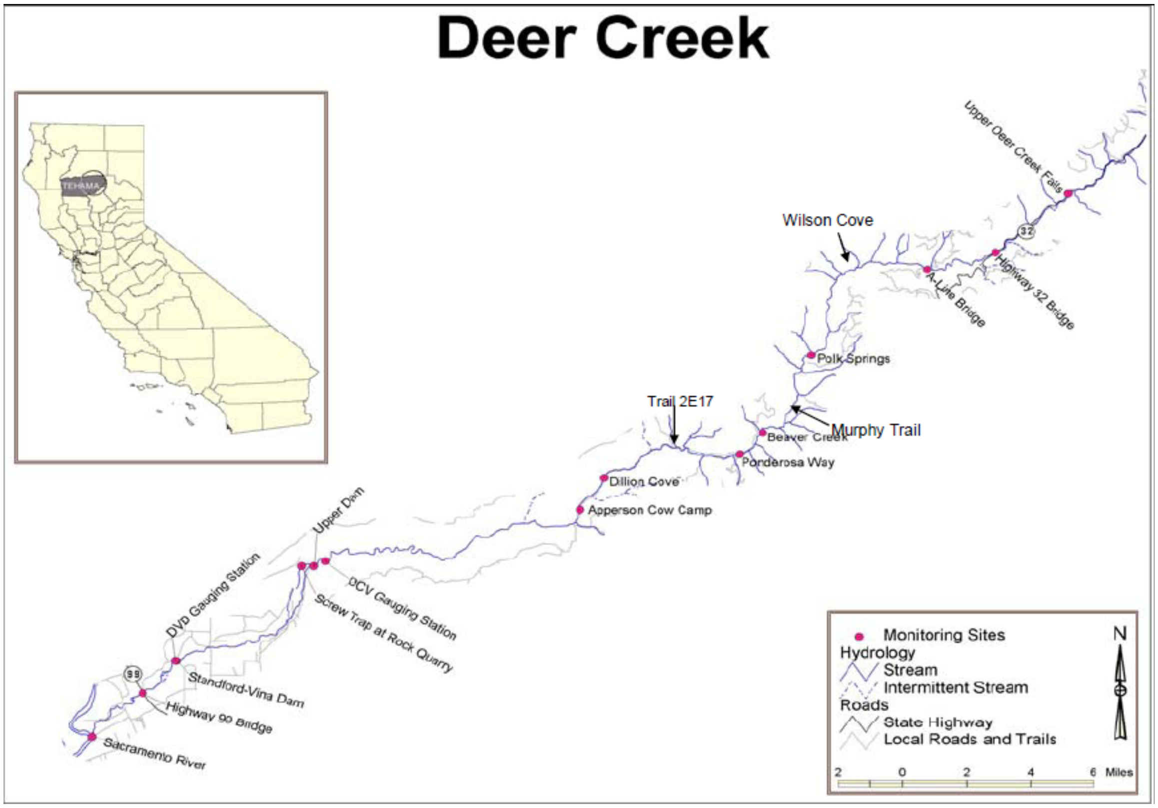
Additionally, during salvage operations resulting from the construction of Keswick Dam between 1941 and 1946 about 13,000 adult spring-run Chinook salmon Chinook from the upper Sacramento River were introduced into Deer Creek (Cramer and Hammack 1952). According to Harvey (1997) some of these may have been winter- and/or fall-run

Chinook salmon. Small numbers of fall-run and/or late fall-run Chinook salmon may also spawn annually in Deer and Mill Creeks (Harvey-Arrison 2007)

3.2.2 Existing Conditions

3.2.2.1 Deer Creek

Deer Creek is 60 miles long and its watershed drains 200 square miles (USFWS 1995). Deer Creek originates on the northern slopes of Butte Mountain at an elevation of approximately 7,320 feet. It initially flows through meadows and dense forests and then descends rapidly through a steep rock canyon into the Sacramento Valley. Deer Creek flows for 11 miles across the Sacramento Valley floor, entering the Sacramento River at approximately 180 feet elevation (DWR 2009) where most of the flow is diverted. In many years, diversions at three dams deplete all of the natural flow from mid-spring to fall. Each of these diversion structures have fish passage structures and screens, so Deer Creek spring-run Chinook salmon Chinook salmon have access to 100% of their historic habitat (Figure 3-4) (NMFS 2009).

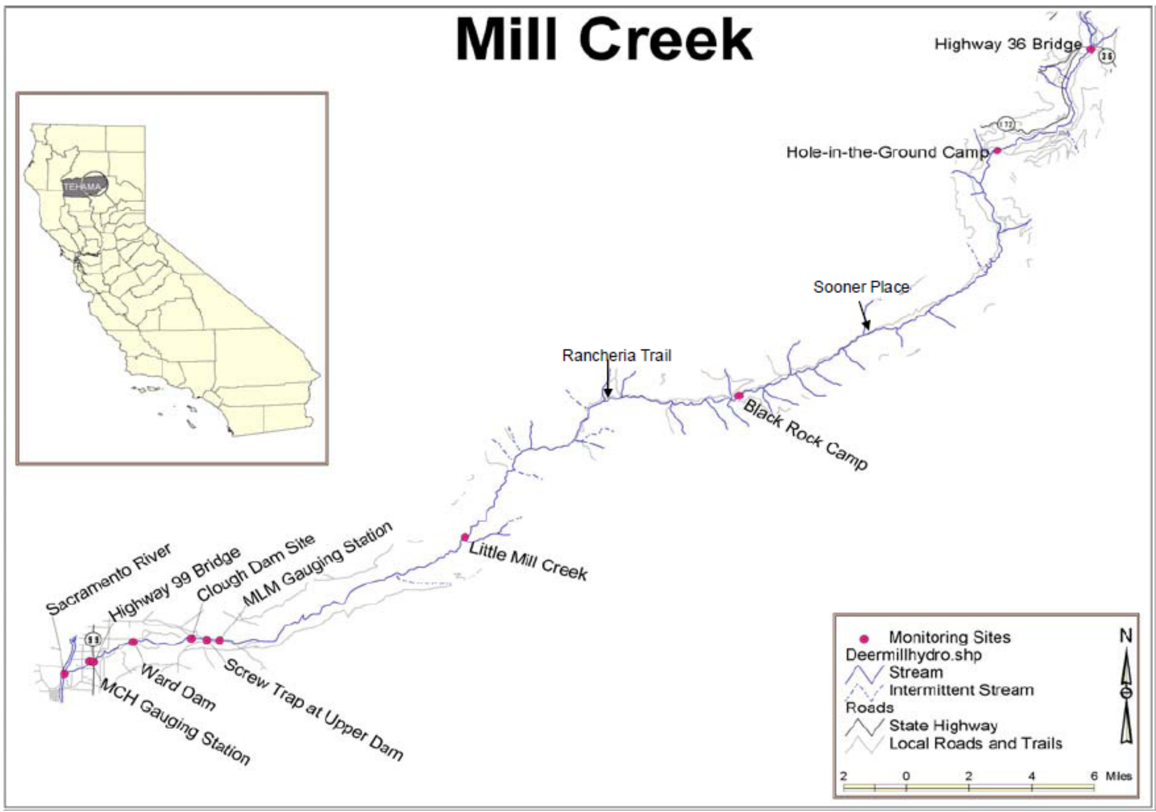


Source: Harvey-Arrison 2008

Figure 3-4.
Spring-run Chinook salmon Chinook salmon holding and spawning habitat in Deer Creek.

3.2.2.2 Mill Creek

Mill Creek is a major tributary of the Sacramento River, flowing from the southern slopes of Mount Lassen and entering the Sacramento River at RM 230. The stream originates at an elevation of approximately 8,200 feet and descends to 200 feet at its confluence with the Sacramento River. Mill Creek originates from springs in Lassen Volcanic National Park (LVNP) and initially flows through meadows and dense forests. It descends rapidly through a steep canyon, flows eight miles across the Sacramento Valley floor, and its total length is approximately 58 miles to its confluence with the Sacramento River. Nearly all of the mainstem habitat is utilized and/or available to spring-run Chinook salmon Chinook salmon (Figure 3-5). The Mill Creek watershed encompasses 134 square miles. During the irrigation season, three dams on the lower eight miles of the stream divert most of the natural flow, particularly during dry years.



Source: Harvey-Arrison 2008

Figure 3-5.

Spring-run Chinook salmon Chinook salmon holding and spawning habitat in Mill Creek

3.2.3 Life History/Phenotypic Expression

3.2.3.1 Deer Creek

Migration

Spring-run Chinook salmon have been documented migrating upstream on Deer Creek from March through early July. Migrations usually end during the peak of the irrigation season when flows are insufficient to pass adults and water temperatures begin to approach lethal limits low in the watershed.

Holding and Spawning

The known range for adult spring-run Chinook salmon holding extends from Upper Falls downstream to near the confluence of Rock Creek, a distance of approximately 25 miles. The upstream limit is a natural waterfall (Upper Falls). Within this area, 30% of the area is represented by all pools. Of 166 total pools, 98 (or 60%) are holding pools (> 6 foot in depth). Because maturing adult spring-run Chinook salmon Chinook salmon enter streams during the spring months and spend the summer holding in deep pools (prior to fall spawning), they are present in the stream system when temperatures are at their peak (generally July and August). In Deer Creek above the canyon mouth, Needham et. al. (1943) observed salmon holding in deep pools when surface water temperatures measured 23^{o}C (73^{o} F). Based on adult spring-run Chinook salmon mortalities reported in lower Deer Creek (below the canyon mouth) in the 1940's, Cramer and Hammack (1952) reported temperatures greater than 27^{o}C (81 ^{o} F) were lethal to migrating salmon.

The known range for adult spring-run Chinook salmon spawning extends from Upper Falls downstream to near the mouth of the canyon, a distance of approximately 30 miles. It appears that in wet years, more spawning takes place lower in the watersheds. Spawning habitat utilization has been known to shift between years at some sites with changes in bed composition resulting from high flow events. Visual observations of spring-run Chinook salmon spawning in Deer Creek indicates spawning substrate is in good condition with the percent fines being low in the areas utilized. Deposition of fines in areas utilized for spawning is virtually absent year round.

Emergence and Rearing

In 2007 CDFG initiated bimonthly rearing surveys to assess relative growth of known spring-run Chinook salmon juveniles with mixed stock juveniles captured in rotary screw trap. In 2007, surveys were initiated in January and juveniles were first detected in February. In 2008, surveys could not begin until March due to snow conditions, and juveniles were detected on the first survey of the season. Monitoring data indicates that emergence of juvenile Chinook begins in November, peaks around February and ends in April. These data are derived from an egg-temperature model to predict emergence based on redd placement and also from direct observation of newly emerged juveniles. (Harvey-Arrison 2007)

Outmigration

Based on annual surveys by the CDFG, outmigration of yearling spring-run Chinook salmon typically occurs from October or November through March or April depending on the year. Fry out migration occurs from February through June, but since traps are located within fall-run Chinook salmon spawning area, these fry migrations are a mix of fall-run and spring-run Chinook salmon progeny. In Deer and Mill Creeks both, many juveniles emigrate during the wet season more than a year after being spawned (Big Chico Creek Watershed Alliance 2000).

3.2.3.1 Mill Creek

Migration

While adult spring-run Chinook salmon have been observed migrating in Mill Creek as early as February, a 10-year study from 1953 to 1964 (CDFG 1966) has documented the majority of upstream migration as occurring between mid-April and the end of June.

Based on observations of spring-run Chinook salmon adults holding and/or spawning, the known range of this habitat extends a distance of approximately 48 miles from near the Little Mill Creek confluence (C. Harvey 1996, personal communications) upstream to within one-half mile of the LVNP boundary (personal observation of adult holding). Suitable spawning habitat on the mainstem of Mill Creek extends to near Morgan Hot Springs (approximately three miles downstream of LVNP), although salmon have been reported spawning in "Middle Creek" (1990 communication with Luke Mason, former caretaker at Hanna Ranch), a small tributary located approximately two miles downstream of the park boundary.

Holding and Spawning

There are two geographically important sections of holding habitat available on Mill Creek, Upper Mill Creek and Lower Mill Creek (Canyon). Upper Mill Creek, defined as the upper 7.6 miles of Mill Creek between the Lassen Volcanic National Park (LVNP) boundary and Mill Creek campground, and Lower Mill Creek (canyon reach), defined as the area downstream of the Mill Creek campground (Figure 3-5).

In Upper Mill Creek, the availability of spring-run Chinook salmon holding habitat appears to be limited. Based on stream survey data collected in 1990, 5% of the area was represented by all pools. Of all 88 pools noted in 1990, none were classified as holding pools.

Downstream of the Mill Creek campground, in the Lower Mill Creek (Canyon) reach, available holding habitat is more abundant. In 1990 and 1994, a survey was conducted over 13 miles of approximately 20 miles of stream extending from the campground to two miles downstream of Black Rock. Within the surveyed segments, 13% of the area was represented by all pools. Of all 86 pools documented, 20 (or 23% of the total) were holding pools.

Little quantifiable data is available on the distribution of holding habitat from approximately two miles downstream of Big Bend to approximately two miles upstream of Black Rock due to the difficulty in accessing the area. In a 1988 holding survey (CDFG file map, T. Healey 1988), over 200 adult salmon were noted within most of the seven miles of stream which had not been previously habitat typed, indicating additional suitable holding habitat is present. Given similar channel characteristics such as substrate composition, gradient, etc., holding habitat distribution and abundance would not likely differ greatly from other areas of Mill Creek surveyed in the lower canyon reaches.

Above the canyon mouth, in the upper alluvial reach of Mill Creek, is an area of possible temperature-related impacts on adults. Adult mortalities have been reported during mid-summer in a single drought year (M. McFarland, 1990, memo to the files). The area where the mortalities occurred contained natural hot springs and lacked deep holding pools. The stream channel was mostly open with little riparian shading and overhead cover, the mortalities may have been attributed to a prolonged exposure to elevated stream temperatures.

Mill Creek spring-run Chinook salmon are unique for spawning at an elevation of more than 5,000 feet, the highest elevation known for salmon spawning in North America (Armentrout et al 1998. In Mill Creek, sediment loading is greater than in Deer Creek and fines are notable especially in areas of deposition. High gravel embeddedness has been observed in some areas of spawning use (M. McFarland 1990, memo to the files). The conditions observed, however, do not appear to limit salmon from spawning.

Size distribution of Mill Creek spring-run Chinook salmon spawners has ranged from 41 cm to 102 cm from carcass survey data from 1990-2000. The majority are in the 60-80 cm fork length range.

Emergence and Rearing

In 2007 CDFG initiated bimonthly rearing surveys to assess relative growth of known spring-run Chinook salmon juveniles with mixed stock juveniles captured in rotary screw trap. In 2007, surveys were initiated in January and juveniles were first detected in February. In 2008, surveys could not begin until March due to snow conditions, and juveniles were detected on the first survey of the season. Monitoring data indicates that emergence of juvenile Chinook begins in November, peaks around February and ends in April. These data are derived from an egg-temperature model to predict emergence based on redd placement and also from direct observation of newly emerged juveniles (Harvey-Arrison 2007).

Outmigration

Based on annual surveys by the CDFG, outmigration of yearling spring-run Chinook salmon typically occurs from October or November through March or April depending on the year. Fry out migration occurs from February through June, but since traps are located within fall-run Chinook salmon spawning area, these fry migrations are a mix of fall-run and spring-run Chinook salmon progeny. In Deer and Mill Creeks both, many juveniles emigrate during the wet season more than a year after being spawned (Big Chico Creek Watershed Alliance 2000).

3.2.4 Population Size

3.2.4.1 Deer Creek

The Table 3-2 shows annual escapement estimates for Deer Creek spring-run Chinook salmon. For the CVPIA doubling period 1967-1991, the average spawning escapement of spring-run Chinook salmon in Deer Creek was 1,300 (USFWS 1995) From 1991 to 2008 present the average is only 1,152.

Table 3-2
Annual Escapement Estimates for Deer Creek

Year	Count	Year	Count	Year	Count
1963	2,302	1979	-	1995	1,295
1964	2,874	1980	1,500	1996	614
1965	-	1981	-	1997	466
1966	-	1982	1,500	1998	1,879
1967	-	1983	500	1999	1,591
1968	-	1984	0	2000	637
1969	-	1985	301	2001	1,622
1970	2,000	1986	543	2002	2,185
1971	1,500	1987	200	2003	2,759
1972	400	1988	371	2004	804
1973	2,000	1989	84	2005	2,239
1974	3,500	1990	496	2006	2,432
1975	8,500	1991	479	2007	644
1976	-	1992	209	2008	144
1977	340	1993	259		
1978	1,200	1994	485		

Source: CDFG 2009

3.2.4.2 Mill Creek

The Table 3-3 shows annual escapement estimates for Mill Creek spring-run Chinook salmon. For the CVPIA doubling period 1967-1991, the average spawning escapement of spring-run Chinook salmon in Mill Creek was 800 (USFWS 1995) From 1991 to present the average is only 646.

Table 3-3
Annual Escapement Estimates for Mill Creek

Year	Count	Year	Count	Year	Count
1960	2,368	1977	460	1994	723
1961	1,245	1978	925	1995	320
1962	1,692	1979		1996	253
1963	1,315	1980	500	1997	202
1964	1,539	1981		1998	424
1965		1982	700	1999	560
1966	-	1983	-	2000	544
1967	-	1984	191	2001	1,100
1968	-	1985	121	2002	1,594
1969	-	1986	291	2003	1,426
1970	1,500	1987	90	2004	998
1971	1,000	1988	572	2005	1,150
1972	500	1989	563	2006	1,002
1973	1,700	1990	844	2007	920
1974	1,500	1991	319	2008	306
1975	3,500	1992	237		
1976	-	1993	61		

Source: CDFG 2009

3.2.5 Hatchery Influence and Interbasin Transfers

There is currently no hatchery program supporting fish populations on either of these streams. Between 1902 and 1940, the U.S. Bureau of Fisheries established a hatchery on Mill Creek near Los Molinos. During this time, fall-run Chinook salmon were spawned, with an average of 6-7 million eggs taken annually. Juvenile salmon were reared and released in the spring. Attempts were made to spawn spring-run Chinook salmon at this site, but were prohibited by hatchery warm water temperatures during the summer months (Hanson et. al. 1940).

3.3 Butte Creek

3.3.1 Introduction

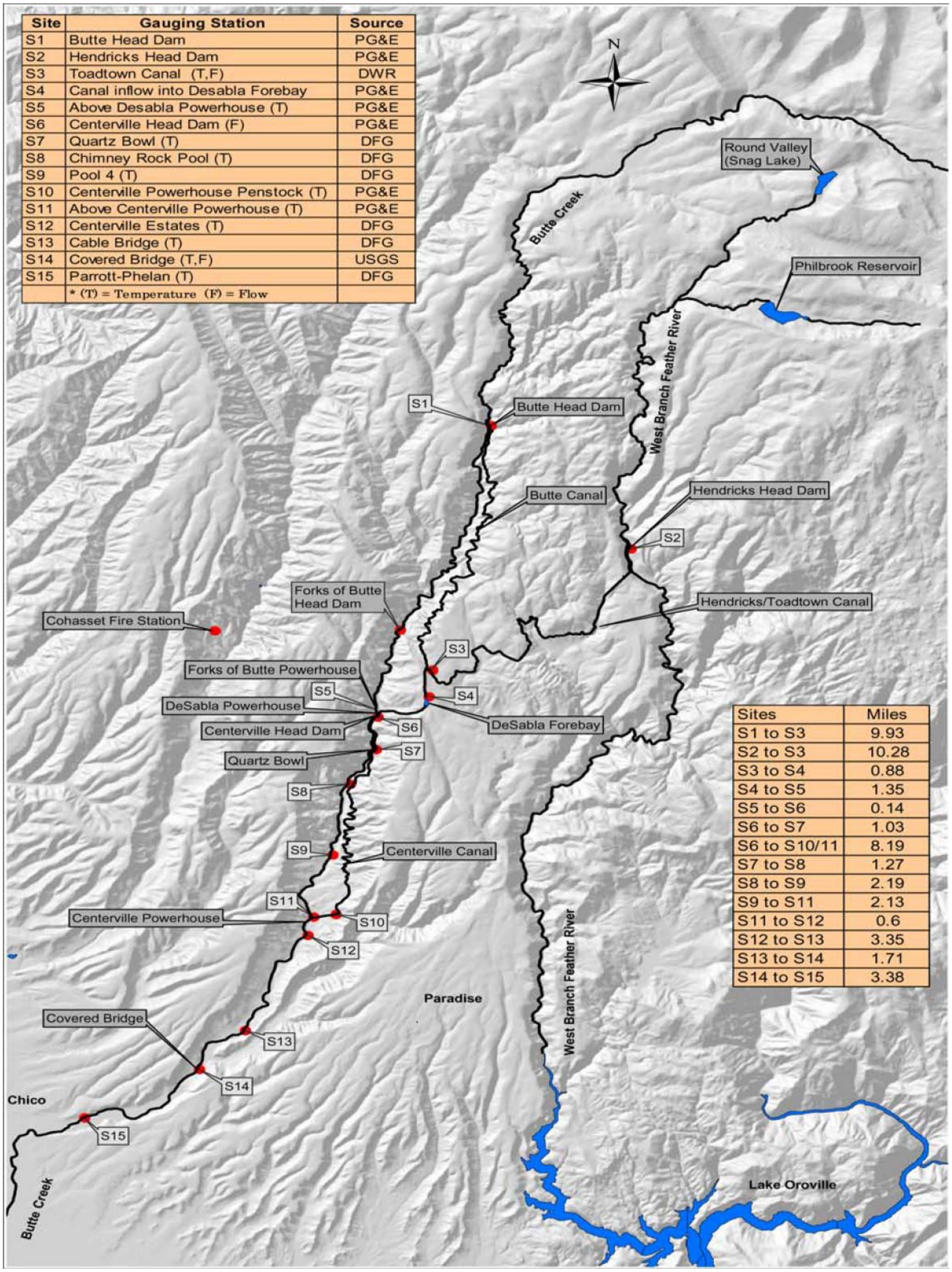
Butte Creek is one of only three streams to sustain a genetically distinct and viably independent population of spring-run Chinook salmon (NMFS 2009). The spring-run Chinook salmon in Butte Creek are considered persistent and viable and is one of the most productive spring-run Chinook salmon streams in the California Central Valley (NMFS 2009). Lindley et al., (2007) indicated that the Butte Creek population is at a low risk of extinction due to the population size, general increases in production, and low hatchery influence. According to Moyle et al., (2008) there is a high likelihood of spring-run Chinook salmon going extinct in the next 50-100 years due to the vulnerability of catastrophic event and due to the narrow physiological tolerances in the summer, where an increase in temperature due to climate change may drastically reduce survival. Population numbers have increased within the last two decades, and large pre-spawn mortalities have occurred on a few years (Williams 2006). The pre-spawn mortalities were due to a high number of fish concentrated in limited holding pools with high water temperatures, resulting in an outbreak of diseases.

3.3.2 Existing Conditions

Flow Regime

The flow regime of the adult holding and spawning habitat in Butte Creek is directly affected by the Pacific Gas and Electric (PG&E) DeSabla-Centerville Project (Figure 3-6) (FERC-083). The entire holding and spawning habitat for spring-run Chinook salmon is located downstream of the Centerville Head Dam. The water at this location comes from two water sources, Butte Creek and water from the west branch of the Feather River. From July through September, the west branch of the Feather River provides approximately 40% of the flows downstream of the Centerville Head Dam in the anadromous reach of Butte Creek. The water from the Feather River is diverted at the Hendricks Head Dam and flows through the Hendricks/Toadtown Canal where it merges with Butte Creek water from the Butte Canal that is diverted at the Butte Head Dam. The water continues through the DeSabla Forebay then reconnects to Butte Creek. Water also flows through the mainstem of Butte Creek between the Butte Head Dam and the DeSabla Forebay confluence. The water is again diverted at the Centerville Head Dam, where a majority of the water is sent down the Centerville Canal, and reconnects to Butte Creek at the Centerville Powerhouse. PG&E is required to maintain a minimum flow of

40 cfs in the mainstem of Butte Creek between the Centerville Head Dam and the Centerville Powerhouse from June 1 through September 14. In recent years, PG&E has voluntarily increased the minimum flow to 60 cfs during the onset of spawning, in late September. PG&E also has a contingency plan for when air temperatures exceed 105°F (typically in the middle of the summer), in which they alter the flow regime to provide colder water to the reach where spring-run Chinook salmon are over-summering above the Centerville Powerhouse.



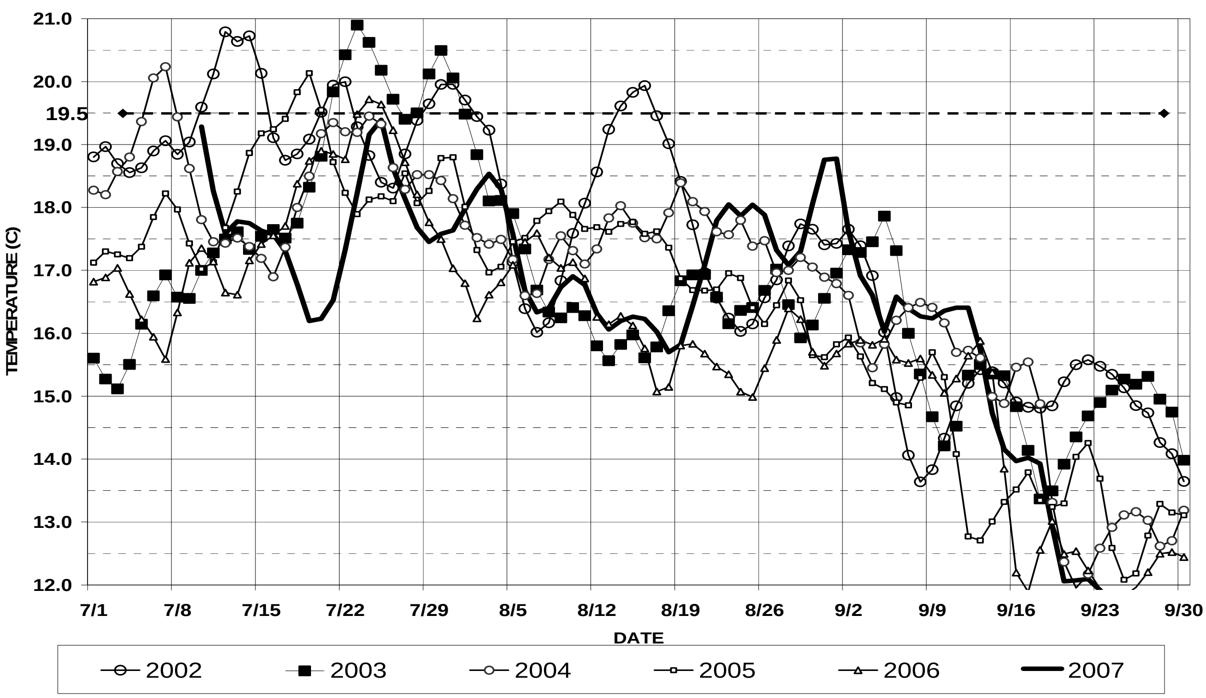
Site	Gauging Station	Source
S1	Butte Head Dam	PG&E
S2	Hendricks Head Dam	PG&E
S3	Toadtown Canal (T,F)	DWR
S4	Canal inflow into Desabla Forebay	PG&E
S5	Above Desabla Powerhouse (T)	PG&E
S6	Centerville Head Dam (F)	PG&E
S7	Quartz Bowl (T)	DFG
S8	Chimney Rock Pool (T)	DFG
S9	Pool 4 (T)	DFG
S10	Centerville Powerhouse Penstock (T)	PG&E
S11	Above Centerville Powerhouse (T)	PG&E
S12	Centerville Estates (T)	DFG
S13	Cable Bridge (T)	DFG
S14	Covered Bridge (T,F)	USGS
S15	Parrott-Phelan (T)	DFG
	* (T) = Temperature (F) = Flow	

Sites	Miles
S1 to S3	9.93
S2 to S3	10.28
S3 to S4	0.88
S4 to S5	1.35
S5 to S6	0.14
S6 to S7	1.03
S6 to S10/11	8.19
S7 to S8	1.27
S8 to S9	2.19
S9 to S11	2.13
S11 to S12	0.6
S12 to S13	3.35
S13 to S14	1.71
S14 to S15	3.38

Figure 3-6.
Reaches of Butte Creek and West Branch of the Feather River controlled by Pacific Gas and Electric Company affecting Butte Creek spring-run Chinook salmon, including temperature and flow gage locations and distances

Water temperature

Water temperatures are regularly monitored seasonally from June through September throughout the PG&E DeSabla-Centerville Project. PG&E in consultation with CDFG, NOAA, and USFWS, has developed a Project Operations and Management Plan that includes a contingency for extreme heat events (beginning in 2004). PG&E prepares weekly weather forecasts, based on USFS weather stations, for the DeSabla-Centerville Project Area, which encompasses the Butte Creek spring-run Chinook salmon's holding and spawning area. If air temperatures will exceed 105°F for two or more days then, in consultation with the Resource Agencies, PG&E changes the flow regime by altering the flow amount and location of release in order to reduce the water temperatures within the DeSabla-Centerville Project Area. The water temperature in the holding and spawning habitat frequently exceeds 15°C (59°F) from July through September (Figure 3-7). PG&E is required to maintain a minimum flow of 40 cfs in Butte Creek between the Centerville Head Dam and the Centerville Powerhouse, from June 1 through September. Since 2004 PG&E has voluntarily increased the minimum flow in Butte Creek to 60 cfs during the onset of spring-run Chinook salmon spawning. This increase has reduced water temperatures in this section of river and has increase the amount of usable spawning gravel by approximately 26%.



Source: McReynolds et al. 2008

Figure 3-7.
Mean Daily Water Temperature (°C) at Quartz Bowl Pool for Period July through September 2002-2007

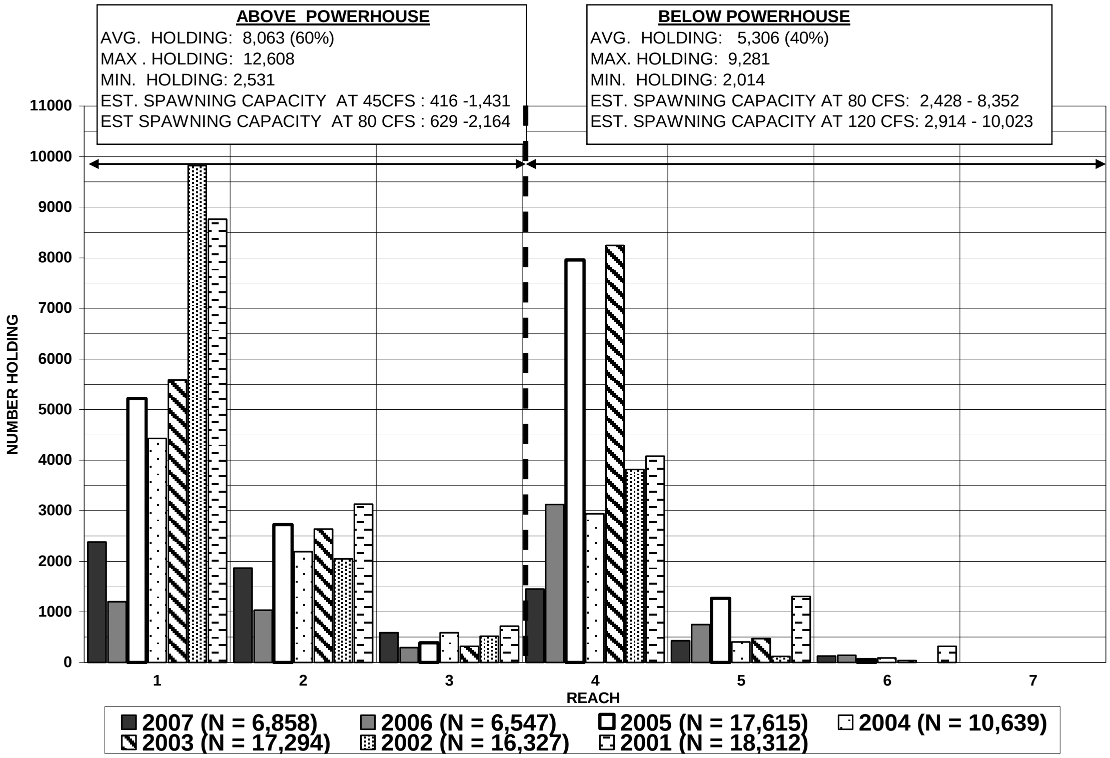
Observed disease outbreaks within the Butte Creek spring-run Chinook salmon population have generally occurred during the summer holding period. In 2002 there were approximately 3,431 pre-spawn mortalities out of an estimated population of 16,328, in 2003 there were approximately 11,231 pre-spawn mortalities out of an estimate population of 17,294, and during 2004 there were approximately 418 pre-spawn mortalities out of an estimated population of 10,639 (Ward et al. 2007). In 2003, fish mortality was attributed to the high number of fish concentrated in limited holding pools with high water temperatures, and an outbreak of two diseases *Flavobacterium columnare* (Columnaris) and the protozoan *Ichthyophthirius multiphilis* (Ich) (Williams 2006). The mortalities during 2002 and 2003 coincided with significant daily average water temperatures above 19.5°C (67 °F). The pre-spawn mortalities during 2004 were concluded to be the normal attrition for salmon holding in fresh water since early spring. During the 2004 summer months, the average air and water temperatures were generally lower than in 2002 and 2003, and Butte Creek flows were slightly higher. The pre-spawn mortalities in subsequent years (2005-2007) were also concluded to be due to normal attrition.

3.3.3 Life History/Phenotypic Expression

Upstream Migration and Holding

The entire available holding and spawning area for Butte Creek spring-run Chinook salmon is below 931 feet elevation, due to a 15-foot waterfall barrier known as the Quartz Bowl Falls. The best holding and spawning habitat for the spring-run Chinook salmon is within approximately 11 miles of the river, from Quartz Pool downstream to the Centerville Covered Bridge (Ward et al. 2004). The highest quality and quantity of holding habitat is within the uppermost three miles (from Quartz Pool to Whiskey Flat). Another good holding location is directly below the Centerville Powerhouse, due to the cooler water found there. The diversion at the Centerville Head Dam, which sends water down the Centerville Canal to the Centerville Powerhouse, which significantly reduces water temperatures directly below the powerhouse due to reduced transition time and shading.

Butte Creek spring-run Chinook salmon adults migrate from February through June, with the peak in mid-April. Adult migration is frequently impaired by low flows and high water temperatures in June, and adult Chinook that have not migrated above State Highway 99 by mid-June have a lower likelihood of surviving to spawn. CDFG biologists also regularly observe large numbers of spring-run Chinook salmon holding directly below the Centerville Powerhouse. During the seven-year period, 2001-2007 approximately 60% of the fish held above the Centerville Powerhouse and 40% held below it (Figure 3-8) (McReynolds et al. 2008).



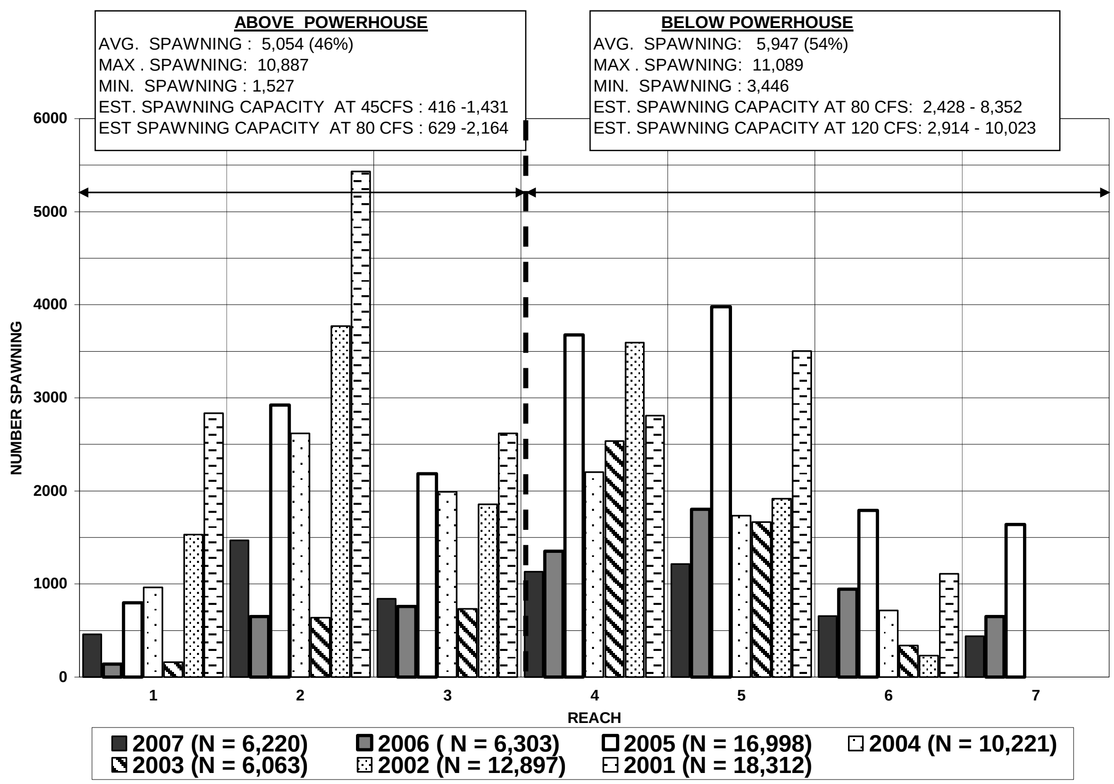
Source: McReynolds et al. 2008

Figure 3-8.
Distribution By Reach of the Number of Butte Creek SRCS Holding, During 2001-2007

Spawning

The highest quality and quantity spawning gravel is within the first five miles directly below the Centerville Powerhouse. Estimates of available spawning habitat based on maximum suitable flows (130 cfs) concluded that approximately 18% of the suitable spawning gravel is located above the Centerville Powerhouse and 82% below (Ward et al. 2004). The maximum number of spawners at these locations are 152 to 1,316 at 40 cfs above Centerville Powerhouse, and 270 to 2,352 at 40 cfs and 1,262 to 10,976 at 130 cfs below (Ward et al. 2004).

The spring-run Chinook salmon generally spawn between late-September through early-November, with the peak in early-October. During the seven-year period 2001-2007 approximately 45% of the fish spawned above the Centerville Powerhouse and 55% below (Figure 3-9) (McReynolds et al. 2008). During 2004, PG&E increased the flow above the Centerville Powerhouse from 40 cfs to 60 cfs to provide additional habitat for the spawning spring-run Chinook salmon. The increase in flow increased the amount of usable spawning gravel by approximately 26% (Ward et al. 2004).



Source: McReynolds et al. 2008

Figure 3-9.
Distribution By Reach of the Number of Butte Creek SRCS Spawning, During 2001-2007

Outmigration

Butte Creek spring-run Chinook salmon generally outmigrate as fry from November through February, and rear below the Parrott-Phelan Diversion Dam. The outmigration movements are heavily influenced by flow. Most spring-run Chinook salmon rear in the Sutter Bypass from February through May, and then migrate into the Sacramento River and continue to the Delta. Some fish will rear above the Parrott-Phelan Diversion Dam, in the mainstem of Butte Creek. These fish will generally rear for 12 or more months before outmigrating.

Rearing

The highest quality and quantity of juvenile rearing habitat is located in the Sutter Bypass, due to the connection to the floodplain (Williams 2006). Butte Creek spring-run Chinook salmon generally rear in the Sutter Bypass. Floodplain productivity increases with spring temperatures and residence times provide advantageous resources for outmigrating juveniles. Juvenile Chinook salmon that rear in the floodplain have significantly higher growth rates than fish that rear in riverine habitats (Moyle et al. 2008). In fact, spring-run Chinook salmon were captured and tagged at the Parrott-Phelam Diversion Dam and recaptured in the Sutter Bypass, CDFG biologist have calculated the average growth rate of juvenile spring-run Chinook salmon for the Sutter Bypass recaptures to be 0.52 mm/day during 1999, 0.66 mm/day during 2000, and 0.38 mm/day during 2002 (Ward et al. 2004b).

Every year there are generally a handful of yearlings observed during spring-run Chinook salmon surveys. These salmon rear above Parrott-Phelan Diversion Dam, in the mainstem of Butte Creek. These fish grow to approximately 150 mm fork-length and remain in Butte Creek above the Parrott-Phelan Diversion Dam for 12 months or more before leaving Butte Creek and outmigrating to the Delta as yearlings (Ward et al. 2004b).

3.3.4 Population Size

The data below is based on DFG escapement estimates for the years 1954 – 2006. The approximate averages for the last thirty, twenty, and ten years are 3,000, 4,400, and 7,400, respectively.

Table 3-4.
Butte Creek SRCS Spawning Escapement Estimates for the Period 1954 Through 2008

Source: McReynolds 2008 and CDFG 2009

Year	Run Size	Year	Run Size	Year	Run Size	Year	Run Size		
1954	830	1969	830	1984	23	1999	3679*		
1955	400	1970	285	1985	254	2000	4118*		
1956	3000	1971	470	1986	1371		Snorkel	Prespawn Mortality	Spawn
1957	2195	1972	150	1987	14	2001	9605	193	18312**
1958	1100	1973	300	1988	1300	2002	8785	3431	12597
1959	500	1974	150	1989	1300*	2003	4398	11231	6063
1960	8700	1975	650	1990	100*	2004	7390	418	10221
1961	3100	1976	46	1991	100*	2005	10625	617	16998

1962	1750	1977	100	1992	730*	2006	4579	244	6303
1963	6100	1978	128	1993	650*	2007	4943	638	6220
1964	600	1979	10	1994	474*	2008	3935		
1965	1000	1980	226	1995	7500*				
1966	80	1981	250	1996	1413*				
1967	180	1982	534	1997	635*				
1968	280	1983	50	1998	20212*				

* Surveys prior to 1989 used various methods with varying precision. Snorkel surveys implemented since 1989 are thought to significantly underestimate the actual population size and should only be used as an index. Spawning surveys results for 2001 – 2006 were generated by a modified Schaefer Model carcass survey.

** Number as reported for 2001 (22,744) in error (Ward et al. 2004).

During a seven-year period 2001-2007, the average size of females was 762 mm and the average size of males was 793 mm. The average size of both males and females were significantly higher in 2007, 2006 and 2003, with males averaging 833 mm and females averaging 775 mm, compared with 2001, 2002, 2004, and 2005, with males averaging 762 mm and females averaging 711 mm. This size distribution is likely due to the percentage of different age classes. Spring-run Chinook salmon generally return at age-3 or age-4, and the compositions of the two age classes vary each year. Between 2001 to 2007 age-4 dominated the adult composition in years 2006 and 2003, 75% and 69% respectively. Whereas in the 2001, 2002, 2004, and 2005 the adult composition was dominantly age-3, 89%, 86%, 89%, and 97.5%. In 2007 the adult composition was approximately evenly distributed, 53% of the population was age-3 and 47% age-4.

3.3.5 Hatchery Influence

There is little hatchery influence on the Butte Creek spring-run Chinook salmon population. No hatcheries exist on Butte Creek and the stream has not historically and is not currently planted with hatchery fish. The only exception was in 1986, when 200,000 juvenile Feather River spring-run Chinook salmon hatchery fish were planted into Butte Creek due to the extreme low levels of returns of Butte Creek spring-run Chinook salmon (Moyle et al. 2009). However, it is not believed that this plant had any genetic effect on the Butte Creek population (Garza et al. 2008). Hatchery Chinook salmon occasionally stray into Butte Creek, but in very low numbers.

3.4 Other Central Valley Phenotypic Spring-run Chinook salmon Populations

Introduction

In addition to the recognized stocks listed above, evidence exists in other Central Valley watersheds of the occurrence of Chinook salmon displaying the spring-run Chinook salmon phenotype. These small localized occurrences warrant consideration because they occur in watersheds in closer proximity to the San Joaquin River geographically, and thus may be more adapted to the local conditions that will occur in the San Joaquin River.

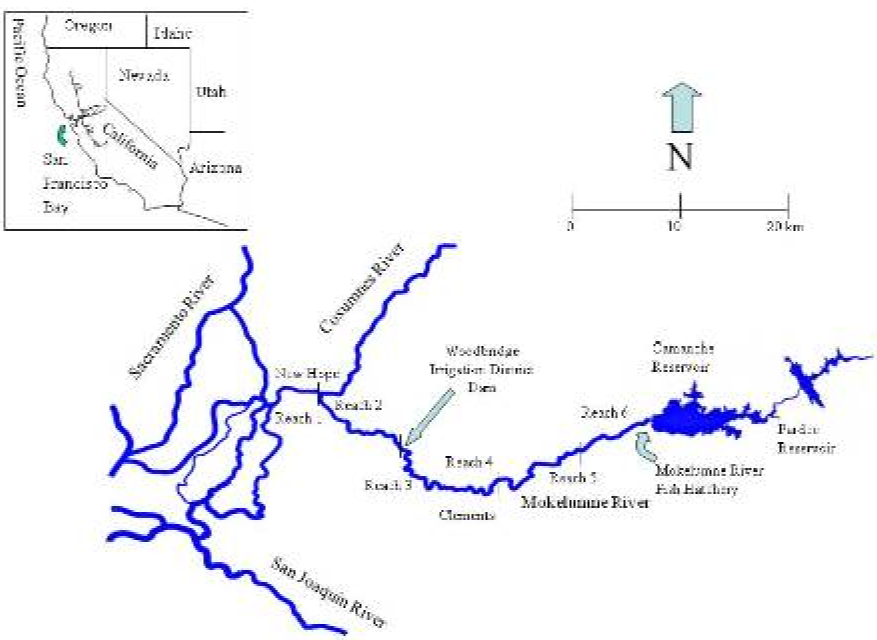
Two such watersheds in which data exists on phenotypic spring-run Chinook salmon are the Mokelumne River, an eastside tributary to the Sacramento San Joaquin Delta, and the Stanislaus River, a tributary to the San Joaquin River.

3.4.1 Existing Conditions

3.4.1.1 Mokelumne River

The lower Mokelumne River is considered an Eastside Tributary to the Sacramento-San Joaquin River Delta. Its confluence with the San Joaquin River is within the Delta proper boundaries. Flows in the Mokelumne are regulated by a Joint Settlement Agreement (JSA 1998) under Federal Energy Regulatory Commission License. As such, the Mokelumne flow is based on water year types derived from both precipitation, snow pack and available storage in Camanche and Pardee reservoirs. Flow varies for the five water year types; wet, normal and above, below normal, dry and critically dry. Minimum flow schedules are based on fall-run Chinook salmon life history and separated into fall (migration/spawning flows), Winter (incubation flows), spring (emigration flows) and summer base flows. Minimum summer base flows range from 80cfs in wet years to 20 cfs in dry and critically dry. Few holding pools are available for oversummering spring-run Chinook salmon type Chinook on the Mokelumne, and summer temperatures typically reach 18^{o}C

Camanche Dam is on river kilometer (RKM) 103 and is the upper limit to anadromy on the Mokelumne River (Figure 3-10). Camanche blocks approximately 80% of historical Chinook spawning habitat (CDFG 1991). There is approximately 16 km of spawning habitat downstream of Camanche Dam available for salmonid spawning, and holding habitat is limited to a few large pools in the first river mile below Camanche Dam.

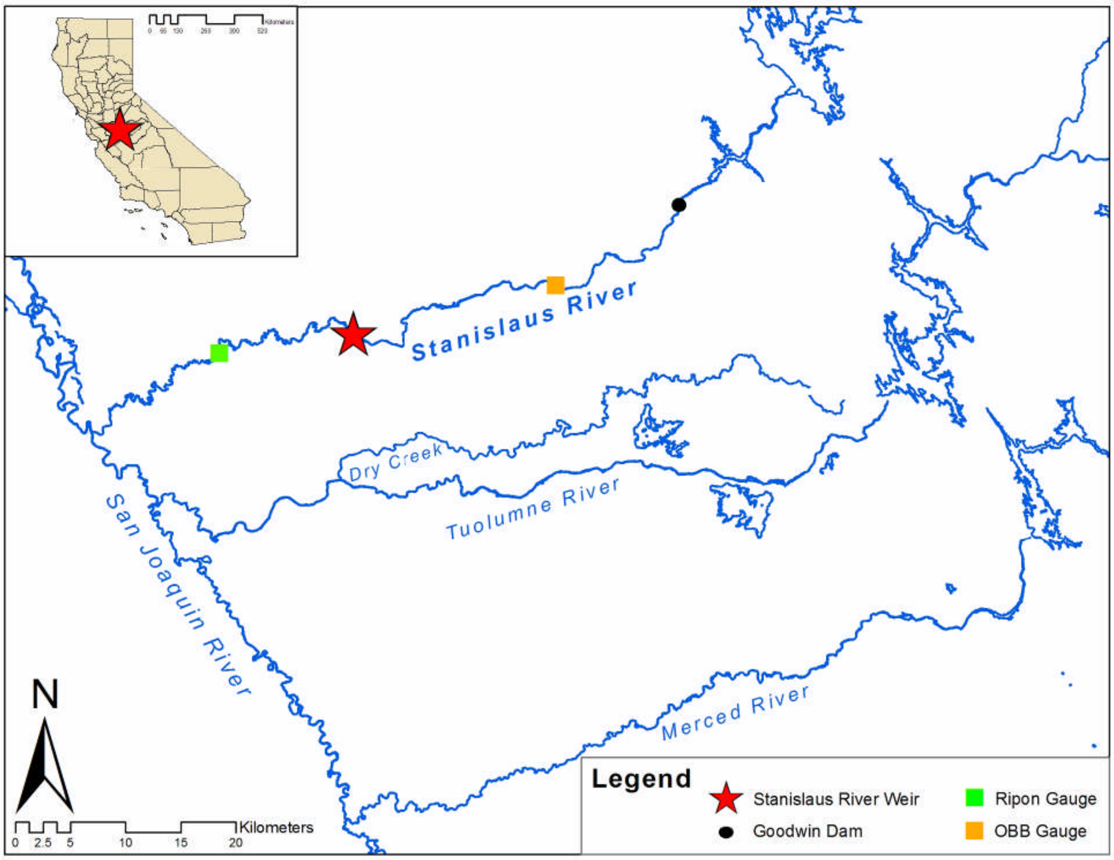


Source: East Bay Municipal Utility District

Figure 3-10.
Mokelumen River

3.4.1.2 Stanislaus River

The Stanislaus River is one of three major tributaries to the San Joaquin River (Figure 3-11). It is snow fed and its headwaters begin at an elevation of approximately 3,675 m. Like all San Joaquin River tributaries, multiple dams are located on the upper Stanislaus River. Historically, various life history types of Chinook salmon inhabited the Stanislaus River, including fall-, late fall-, and spring-run Chinook salmons (Reynolds et al. 1993). Currently, upstream migration for anadromous fishes ends at Goodwin Dam, RKM 94. Historically, upstream migration and spawning occurred well into the Stanislaus River's three forks, but miles of spawning and rearing habitat were lost due to dam construction (Fry 1961).



Source: Anderson et al. 2007

Figure 3-11.
Stanislaus River

3.4.2 Life History/Phenotypic Expression

3.4.2.1 Mokelumne River

Year round video monitoring on the Mokelumne River began in 2001, since that time it has become clear that adult Chinook salmon are ascending the Mokelumne from April through June on an irregular basis, in addition to the well established population of fall-run Chinook salmon (escapement from August/September through January).

Migration

Phenotypic spring-run Chinook salmon observed on the Mokelumne River have passed video monitoring between April and June in low numbers.

Holding and Spawning

Limited holding opportunities exist on the Mokelumne River. There are few large pools in the uppermost reach just below Camanche Dam. No assessments of holding or spawning have been conducted.

Rearing

No assessment of spring-run Chinook salmon rearing has been conducted due to the confounding effects of spatial and temporal overlap with fall-run Chinook salmon, and the relatively small population size of phenotypic spring-run Chinook salmon spawners.

Outmigration

Yearling size juvenile Chinook (>100mm FL) have been observed in rotary screw trapping in low numbers in December and January of some years (Workman 2006a, Workman 2002a). Rotary screw traps are typically installed in mid-December and operated until June or July depending on water year type.

3.4.2.2 Stanislaus River

In 2002 a resistance boar weir was installed on the Stanislaus River to assess escapement numbers and timing of Chinook salmon and steelhead trout (O. mykiss). In 2003 the weir was improved with the addition of an infrared camera.

Migration

Phenotypic spring-run Chinook salmon have been observed passing the weir on the Stanislaus River in May and June (Anderson et al 2007).

Holding and Spawning

Chinook salmon have been reported in the Stanislaus River during the summer months. Snorkel surveys (Kennedy T. and T. Cannon 2005) conducted between October 2002 to October 2004 identified adults in June 2003 and June 2004 between Goodwin and Lovers Lead. Snorkel surveys also observed Chinook fry in December 2003 at Goodwin Dam, Two Mile Bar, and Knights Ferry, which indicates spawning occurring in September. In 2000 CDFG (unpublished data) seined a deep pool at Bottonbush Recreation Area on five occasions, between June 29 to August 25, and captured 28 fish. Of these, eight were adipose fin-clipped and five had coded wire tags. All CWT fish originated from the Feather River Fish Hatchery.

Rearing

No assessment of spring-run Chinook salmon rearing has been conducted due to the confounding effects of spatial and temporal overlap with fall-run Chinook salmon, and the relatively small population size of phenotypic spring-run Chinook salmon spawners.

Outmigration

Rotary screw traps have captured low numbers of yearling smolts (defined as >110mm) on the Stanislaus River from February to April (Watry et al 2007).

3.4.3 Existing Population Size

3.4.2.1 Mokelumne River

Phenotypic spring-run Chinook salmon on the Mokelumne River have numbered as high as 114 in the spring of 2002 between April and July, with 4 adipose clipped fish (i.e. hatchery origin fish) observed (Workman 2002). Ninety-seven were observed in 2003 between March and July, with 21 adipose clipped fish observed (Workman 2003). None were observed in 2004, and in 2005, 2006, and 2007 limitations in video monitoring due to construction led to carcass survey data for escapement estimates, and no estimate of phenotypic spring-run Chinook salmon were attempted (Workman 2004, 2005, 2006, Workman and Rible 2007, Workman et al. 2008).

3.4.2.2 Stanislaus River

In 2007, 11 phenotypic spring-run Chinook salmon were observed passing the weir between May and June. Future monitoring will determine if these fish are a typical occurrence or an anomaly (Anderson et al 2007).

3.4.4 Hatchery Influence and Interbasin Transfers

3.4.2.1 Mokelumne River

The Mokelumne River has a CDFG fall-run Chinook salmon production hatchery at the base of Camanche Dam. Historically, the hatchery has imported eggs and fry from both the Nimbus Fish hatchery and the Feather River Fish Hatchery in order to meet production goals.

3.4.2.2 Stanislaus River

There is no hatchery on the Stanislaus River. Hatchery stock, identified by adipose fin clips, have been detected during weir operations denoting a small portion of hatchery influence is occurring in the watershed (Anderson et al 2007). During carcass surveys in 2009, 11% of Chinook adults were adipose clipped (CDFG unpublished data).

3.4.5 Genetics

Genetics work on these populations to determine if they are spring-run Chinook salmon has not been conducted, and although these populations exhibit the spring-run Chinook salmon phenotype, genetic analysis needs to be conducted to determine whether these fish are genetically or just phenotypically spring-run Chinook salmon.

This page left blank intentionally.

4.0 Population Genetics

There are only three stocks of spring-run Chinook salmon ESU Chinook salmon in the Central Valley that are possible donors for the reintroduction project in the San Joaquin River. These are the Butte Creek stock, the Mill Creek/Deer Creek stock and the Feather River stock. Banks et al. (2000) and Garza et al. (2008) have shown that these three stocks are genetically distinct, and that the Mill Creek and Deer Creek populations are essentially the same stock. There are additional small populations of spring-run Chinook salmon in the Central Valley (e.g. Big Chico, Antelope and Clear Creeks, Mokelumne River, and Stanislaus River), but none of these, other than that on the Yuba River (Garza, unpublished data), have been confirmed to be from the Central Valley spring-run Chinook salmon ESU genetic lineage and may be early returning fall-run Chinook salmon. Even if these small populations were of Central Valley spring-run Chinook salmon ESU stocks these runs are not appropriate as “sole donor” stocks for the SJRRP because they are too small and inconsistent to provide adequate numbers and diversity on which to base reintroduction. Only the three stocks mentioned above were, therefore, carefully evaluated as a potential primary or “sole donor” stock for the San Joaquin River reintroduction project.

The three remaining spring-run Chinook salmon lineages are all in the northern part of the Central Valley in the Sacramento River sub-basin. The San Joaquin River sub-basin has, unfortunately, either completely or almost completely lost its spring-run Chinook salmon populations, although there are persistent reports of a small number of spring-running Chinook salmon returning to the Stanislaus River (M. Workman & J. Merz, pers. comms.). The Mill/Deer Creek population is the northernmost of these and therefore the furthest from the San Joaquin River, with the Butte Creek population just to the south and the Feather River the geographically most proximate of these three potential donor stocks.

The Mill/Deer Creek population also has the lowest current abundance, with escapement estimates of about 3389, 1564 and 502 in 2006, 2007 and 2008 respectively. Butte Creek has a larger census population size, with current escapement estimates of 4579, 4943 and 3935 in 2006, 2007 and 2008 respectively. However, these escapement estimates use different methodology (carcass counts vs. snorkel survey), so they are not directly comparable, and the Butte Creek estimates are likely more comprehensive than those for Mill/Deer Creek. Furthermore, it is important to note that, over the last 20-30 years the mean census size estimates of the two stocks have been similar, and both historical and current population sizes are important in determining levels of genetic variation.

Escapement estimates for the Feather River spring-run Chinook salmon populations are not complete, since the Feather River stock escapement estimates use a different methodology and only attempt to enumerate hatchery fish. The escapement estimates for the hatchery component only in 2006, 2007 and 2008, were 2061, 2674 and 1418 fish, respectively. Since the non-counted naturally-spawning component of this stock is typically large, the census size of the Feather River stock is likely the largest of the three spring-run Chinook salmon stocks (CDFG 2009).

There are three datasets available to evaluate the relative genetic diversity of the three potential spring-run Chinook salmon donor stocks for the San Joaquin River reintroduction project. The first of these is published in Banks et al. (2000) and consists of microsatellite data for the Mill/Deer Creek and Butte Creek stocks. While a substantial number of fish were sampled for this study, this dataset unfortunately does not include fish from the Feather River spring-run Chinook salmon stock. It also includes data from only a small number of microsatellite loci, with an average of only about 7 loci per fish genotyped. As such, the two primary measures of genetic diversity are significantly affected by sampling variance. The first measure, observed heterozygosity, is essentially identical in the two stocks – 0.61 vs. 0.62 in the Mill/Deer and Butte Creek stocks, respectively). Allelic diversity, as measured by the average number of alleles observed per locus, is about 7% higher in the Mill/Deer Creek stock than in the Butte Creek stock (6.60 vs. 6.18 respectively). It is worth noting that, for microsatellite loci, the number of alleles is a more sensitive indicator of recent effective population size than heterozygosity (Garza and Williamson 2001), so these data are indicative of higher effective population size and consequent greater genetic diversity in Mill/Deer Creek than in Butte Creek spring-run Chinook salmon .

The second dataset available for evaluation is that of Garza et al. (2008) and consists of data for 20 microsatellite loci from Chinook salmon sampled in 2002 & 2003 throughout the Central Valley, including all three of the known, extant spring-run Chinook salmon ESU stocks. In this analysis, the Deer and Mill Creek spring-run Chinook salmon populations were considered separately and differences in the sample sizes for the different spring-run Chinook salmon stocks necessitated the use of allelic richness, a measure of the number of alleles that takes into account such differences (Petit et al. 1998). With this large microsatellite dataset, the mean allelic richness per locus of the Mill Creek, Deer Creek, Butte Creek and Feather River stocks were 11.09, 10.85, 9.76 and 11.25, respectively. The observed heterozygosities were 0.77, 0.77, 0.74 and 0.78, respectively. It is worth noting that, aside from the Sacramento River winter-run Chinook salmon, the Butte Creek spring-run Chinook salmon stock had the lowest values of these two measures of genetic diversity of any Central Valley (or Klamath River) salmon population examined. It is also worth noting that, the Feather River spring-run Chinook salmon stock has been affected by hybridization with fall-run Chinook salmon, and at least some of the additional genetic diversity seen is likely due to the addition of fall-run Chinook salmon genes (Garza et al. 2008).

The third dataset consists of recent unpublished data from 169 single nucleotide polymorphism (SNP) loci. These SNP loci were developed by the Genetic Analysis of Pacific Salmonids (GAPS) consortium and by the Molecular Ecology and Genetic Analysis Team of the Southwest Fisheries Science Center, (Garza unpublished). These loci were developed with the dual objectives of developing intergenerational genetic tags for parentage-based tagging (PBT) and as markers for genetic stock identification (GSI) in fishery and ecological investigations.

For these 169 SNP loci, data were available for the Deer/Mill Creek (N=71), Butte Creek (N=54) and Feather River (N=94) spring-run Chinook salmon stocks. Since SNP loci generally only have two alleles, smaller numbers of fish are necessary to estimate per locus measures of genetic diversity for SNPs than for microsatellite loci. However, these SNP loci were discovered using a panel of fish that included Central Valley spring-run Chinook salmon, so ascertainment bias will affect measures of allelic diversity and they are expected to be less informative than the corresponding measures for microsatellites. This is because they represent the proportion of polymorphic loci, with the mean number of alleles equals two when all loci are polymorphic and equals one when all loci are monomorphic, but only SNPs that were variable in the Central Valley were included in this set of genetic markers. The SNP dataset found similar measures of the mean number of alleles, with 1.91, 1.88 and 1.91 in the Mill/Deer Creek, Butte Creek and Feather River stocks, respectively. Observed heterozygosity was more variable, with values of 0.29, 0.26 and 0.31 in the Mill/Deer Creek, Butte Creek and Feather River stocks, respectively.

In summary, all of the measures of genetic diversity in all of the datasets were the lowest for Butte Creek, intermediate for Mill/Deer Creek and the highest for Feather River spring-run Chinook salmon fish. The effective population size of the Butte Creek spring-run Chinook salmon is, therefore, also the smallest of the three, since effective size determines the amount of genetic variation that is maintained in a population. The Butte Creek spring-run Chinook salmon stock then also has the highest risk of inbreeding in a reintroduction project. In contrast, the Feather River spring-run Chinook salmon stock has the highest genetic diversity of the three. However, this stock is known to have been affected by hybridization with fall-run Chinook salmon at the Feather River Hatchery (Garza et al. 2008) and hybridization is ongoing (M. Lacy, pers. comm.). It is also likely that hybridization occurs in the spawning grounds of the lower Feather River. At least some of the additional genetic diversity seen in the Feather River stock is likely due to the addition of fall-run Chinook salmon genes. The Feather River spring-run Chinook salmon population is more genetically similar to fall-run Chinook salmon in the Feather River than to the spring-run Chinook salmon fish in the Mill/Deer Creek and Butte Creek populations, raising the potential for outbreeding depression during an introduction. This is unfavorable for the maintenance of phenotypic differentiation (i.e. spring-run Chinook salmon offspring returning as fall-run Chinook salmon), however, it also reduces the risk of inbreeding in a reintroduction project and the consequent reduction in fitness from inbreeding depression. Conversely, tagging studies have found that some offspring from Feather River spring-run Chinook salmon return as fall-run Chinook salmon, and vice versa (CDFG 1998)

Another aspect of the genetic/demographic history of the three spring-run Chinook salmon stocks that needs to be considered is the relative influence of hatchery-produced fish on the naturally spawning stock. The Feather River Hatchery, which began operation in 1967, has produced and released millions of juvenile salmon, both spring- and fall-run Chinook salmon, annually for over 40 years. These fish have extensively introgressed with naturally spawning populations in the Feather River and elsewhere. In contrast, the Mill/Deer Creek and Butte Creek spring-run Chinook salmon stocks appear to be largely free of introgression from hatchery-produced fish. There is accumulating evidence that salmon from hatchery stocks are less fit than natural origin fish (Berejikian & Ford 2004;

Myers et al. 2004), and that this is at least partly due to hatchery domestication selection, which often causes maladaptation to environmental conditions in natural areas. However, domestication selection from hatchery fish can be counteracted relatively quickly by crossing with natural origin fish and subsequent selection in natural areas (Quinn et al. 2000; Unwin et al. 2000), as long as the artificial selection is not coincident with a loss of genetic variation and increase in inbreeding.

5.0 Lower San Joaquin River Existing Conditions

The Restoration Area, approximately 153 miles long, extends from Friant Dam at the upstream end near the town of Friant, downstream to the confluence of the Merced River, and includes an extensive flood control bypass system (bypass system) (Figure 2-2). The Restoration Area has been significantly altered by changes in land and water use over the past century.

Five river reaches have been defined to address the great variation in river characteristics throughout the Restoration Area. The reaches are differentiated by their geomorphology and resulting channel morphology, and by the infrastructure along the river. Hence, flow characteristics, geomorphology, and channel morphology are similar within each of the reaches. The characteristics of these Reaches are described in further detail in Chapter 2 of the Draft Fisheries Management Plan (SJRRP 2010).

6.0 Stock Comparison

6.1 Population Census

Impacts to the source population must be considered and evaluated prior to taking any fish for reintroduction. CDFG maintains a database that contains estimates of Chinook adult returns. Table 6-1 only includes census information for the three candidate stocks, beginning in 1960. Monitoring techniques and adult census estimates have changed over the last 50 years; stocks are monitored differently now so direct comparisons are difficult, but the overall population trends can be viewed. It should also be noted that certain monitoring techniques, such as snorkel surveys or only relying on hatchery counts, may significantly underestimate the actual population size. In river spawners may be of either hatchery or natural origin.

Table 6-1.
Population census size from the three candidate stocks.

	Mill/Deer Creeks		Butte Creek^	Feather River		Year	Mill/Deer Creeks		Butte Creek	Feather River	
	Mill*	Deer*		In River	Hatchery		Mill	Deer		In River	Hatchery
1960	2,368		8,700			**1986**	291	543	1,371		1,433
1961	1,245		3,082			**1987**	90	200	14		1,213
1962	1,692		1,750			**1988**	572	371	1,290		6,833
1963	1,315	2,302	6,100	600		**1989[a]**	563	84	1,300		5,078
1964	1,539	2,874	600	2,908		**1990**	844	496	250		1,893
1965			1,000	738		**1991**	319	479			4,303
1966			80	297		**1992**	237	209	730		1,497
1967			180		146	**1993**	61	259	650		4,672
1968			280		208	**1994**	723	485	474		3,641
1969			830		348	**1995**	320	1,295	7,500		5,414
1970	1,500	2,000	285		235	**1996**	253	614	1,413		6,381
1971	1,000	1,500	470		481	**1997**	202	466	635		3,653
1972	500	400	150		256	**1998**	424	1,879	20,259		6,746
1973	1,700	2,000	300		205	**1999**	560	1,591	3,679		3,731
1974	1,500	3,500	150		198	**2000**	544	637	4,118		3,657
1975	3,500	8,500	650		691	**2001[aa]**	1,100	1,622	9,605		4,135
1976			46		699	**2002**	1,594	2,185	8,785		4,189
1977	460	340	100		185	**2003**	1,426	2,759	4,398		8,662
1978	925	1,200	128	2	202	**2004**	998	804	7,390		4,212
1979			10		250	**2005**	1,150	2,239	10,625		1,771
1980	500	1,500	226	400	269	**2006**	2,432	1,002	4,579		2,061
1981			250	531	469	**2007**	644	920	4,943		2,674
1982	700	1,500	534	90	1,910	**2008**	140	362	3,935		1,418
1983		500	50		1,702						
1984	191		23		1,562						
1985	121	301	254		1,632						

** For the CVPIA doubling period 1967-1991, the average spawning escapement of spring-run Chinook salmon in Deer Creek was 1,300 (USFWS 1995). From 1991 to present the average is 1,152.*

*** For the CVPIA doubling period 1967-1991, the average spawning escapement of spring-run Chinook salmon in Mill Creek was 800 (USFWS 1995). From 1991 to present the average is 646.*

^ The Butte creek approximate population averages for the last thirty, twenty, and ten years are 3,000, 4,400, and 7,400, respectively.

[a] Surveys prior to 1989 used various methods with varying precision. For the non-Feather River populations, snorkel surveys implemented since 1989 are thought to significantly underestimate the actual population size and should only be used as an index. For the non-Feather River populations, Spawning surveys results for 2001 – 2006 were generated by a modified Schaefer Model carcass survey. Feather river estimates since _____ are based on the fish entering the fish ladder during the spring-run period.

[aa] Butte Creek number previously reported for 2001 (22,744) in error (Ward et al. 2004).

Source: CDFG 2009

6.2 Life History/Phenotypic Characteristics

Source stock(s), which have behavioral and physiological characteristics that best fit conditions, expected to occur on the restored San Joaquin River have a higher likelihood for success. Table 6-2 summarizes the most frequently expressed life history characteristics.

Table 6-2.
General Life History Characteristics for the three candidate stocks.

Life History Characteristics	Feather River	Butte Creek	Deer/Mill Creeks
Adult Run Timing	April - May	February – June, peaking in mid-April.	March – early July
Spawning Timing	September	Late-September to early-November, peaking in early-October .	September
Spawning adult age class structure*	Age 2: 10.9%	Age 2: 0%	Age 2: Unknown
	Age 3: 46.9%	Age 3: 53%	Age 3: Unknown
	Age 4: 41.2%	Age 4: 47%	Age 4: Unknown
	Age 5: 0.68%	Age 5: 0%	Age 5: Unknown
Sex Ratio**	1.2:1	1:1.18	Unknown
Size Range (FL)	Females^ - 782 mm Males^ - 829 mm	Females*** - 762 mm. Males*** - 793 mm.	410 mm to 1002 cm with the majority 600-800 mm.
Outmigration Timing (all three population show two primary life histories for young, fry emigrating within weeks of emergence and juveniles remaining in the river for roughly one year before emigrating)	Emergence: Nov. – Apr., peaking in Jan. Outmigration of yearlings: Unk. Outmigration of fry: Dec. – June, peaking Feb. to Apr.	Emergence: Nov. – Apr., peaking in Jan. Outmigration of yearlings to the Delta: Nov. – Apr. Initial outmigration of fry to Sutter Bypass – Nov. to Feb. Final outmigration of fry from Sutter Bypass to the Sac. River and Delta – Feb. to May.	Emergence: Nov.- Apr. peaking around Feb. Outmigration of yearlings: Oct. – Apr. Outmigration of fry: Feb. – June
Straying Rate	High	Unknown	Unknown

* Feather River data is average percent by age of spring and fall spawning run returning to hatchery, 2000-2004. Butte Creek data based on tag recoveries in 2007, although age varied widely in the Butte Creek population. Age 3 fish were a much higher percentage in 2002, '02, '04, and '05, and Age 4 were much higher in 2003 and '06.

** Males:Females. Feather River data is averaged over 1997 through 2007. Butte Creek data averaged 2001-2006, from carcass surveys.

*** 2001-2007 Averages.

^ Based on 2006-2008 spring-run Chinook salmon broodstock. Personal communication from Ryon Kurth.

6.3 Environmental Conditions

It is presumed that Chinook salmon that currently experience selective pressures similar to that of the restored San Joaquin River will have a higher likelihood for success. Based on this evaluation, the Feather River and Butte Creek are more similar to the expected environmental conditions of the restored San Joaquin River than the Deer/Mill Creek complex (Table 6-3). Further, Chinook in both Butte Creek and Feather River experience higher water temperatures (Figure 6-1 and 6-2) than those in the Deer/Mill Creek complex. Figure 6-1 provides temperatures for the highest elevation locations in Butte, Deer, and Mill creeks for which consistent temperature data was available over the period of interest. Figure 6-2 provides temperatures for the lowest elevation locations in Butte, Deer, and Mill creeks for which consistent temperature data was available over the period of interest. Both figures include Feather River Hatchery water temperatures, and temperatures from the bottom of the Low Flow Channel (LFC) of the Feather River, where two-thirds of spring run spawning takes place.

Table 6-3: Population census size from the three candidate stocks.

Environment	Anticipated Restored San Joaquin River	Feather River	Butte Creek	Deer/Mill Creek
Elevation of holding	Approx. 300 ft	Approx. 200 ft	Approx. 931 ft	Approx. 5,000 ft
Temperature	Restoration flow water temperatures are unavailable at this time	See Figure 6-1 & 6-2	See Figure 6-1 & 6-2	See Figure 6-1 & 6-2
Hydrology	Highly regulated	Highly Regulated	Highly Regulated	

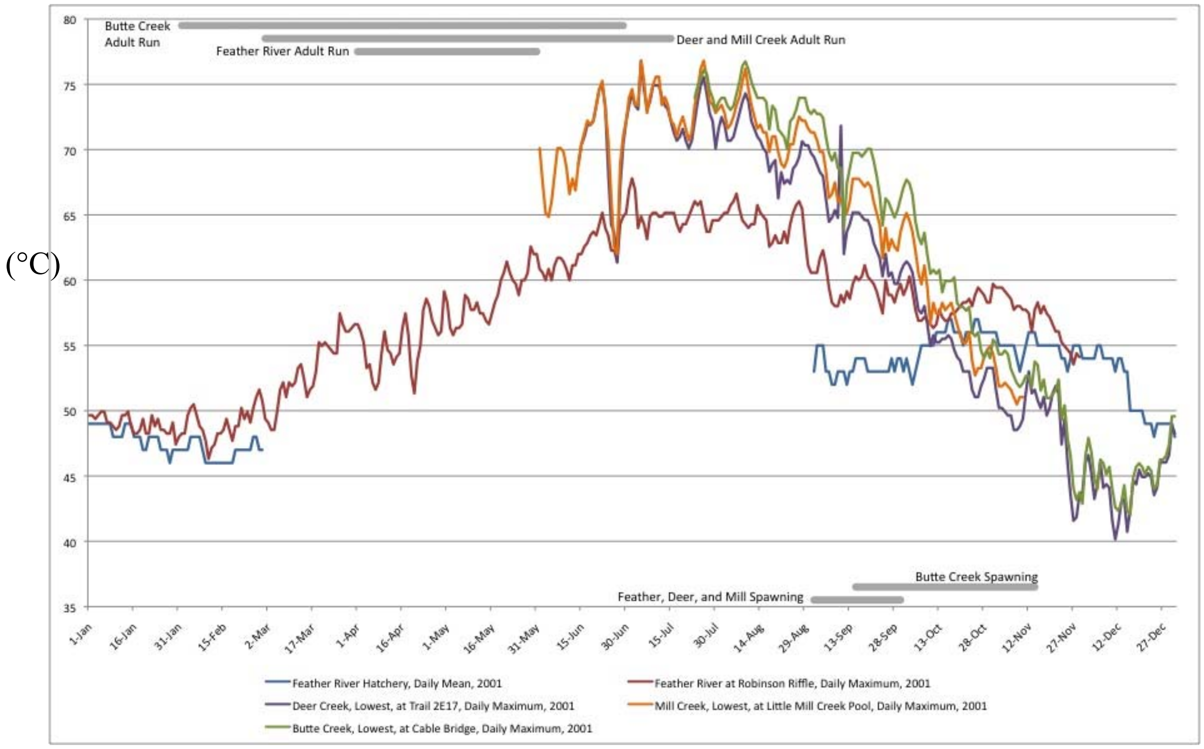


Figure 6-1
Lower Elevation Water Temperature (°C) for Butte, Mill and Deer creeks, Feather River, and Feather River Hatchery.

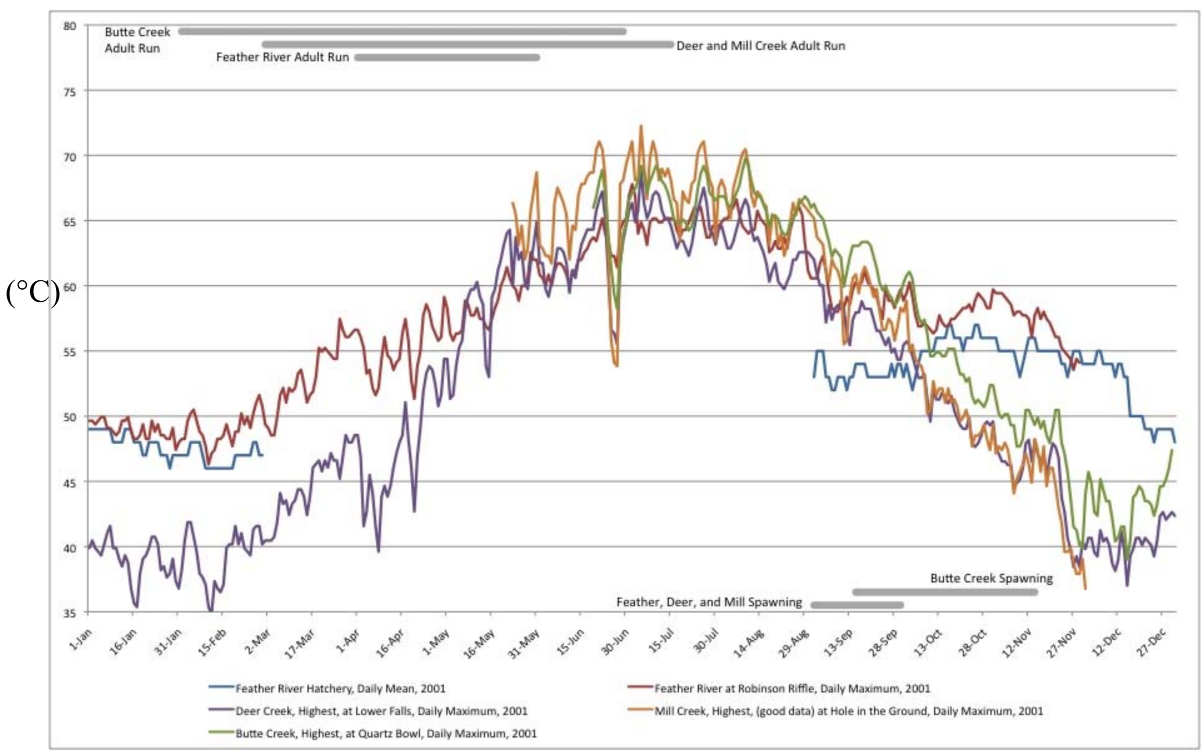


Figure 6-2
Higher Elevation Water Temperature (°C) for Butte, Mill, and Deer creeks, Feather River, and Feather River Hatchery.

6.4 Population Genetics

Table 6-4 below summarizes the Population Genetic discussion from Chapter 4. The Population Viability Classification is from Lindley et al. (2004), where Chinook populations were classified as independent for dependent. Lindley et al (2004) used McElhany el al (2000) independent definition: *An independent population is any collection of one or more local breeding units whose population dynamics or extinction risk over a 100-year period is not substantially altered by exchanges of individuals with other populations*. The Risk of Extinction comes from Lindley et al (2007) where five quantitative criteria (Figure 6-3) were analyzed to determine the population's risk of extinction.

Table 6-4
Genetic Characteristic Comparison

Genetics	Desired Restored San Joaquin River	Feather River	Butte Creek	Deer/Mill Creek
Effective Population Size	Large	Highest	Lowest	Moderate
Hatchery Influence	Little to none	High	None	None
Genetic Diversity	High	Highest	Lowest	Moderate
Natural Origin Spawners	High	Moderate	High	High
Population Viability Classification (Lindley et al. 2004)	Independent	Dependent	Independent	Independent
Risk of Extinction (Lindley et al. 2007)	Low	Data Deficient*	Low	Low - Moderate

** Insufficient data is available to assess status (Lindley et al. 2007)*

	Risk of Extinction		
Criterion	High	Moderate	Low
Extinction risk from PVA	$> 20\%$ within 20 years	$> 5\%$ within 100 years	$< 5\%$ within 100 years
	– or any ONE of –	– or any ONE of –	– or ALL of –
Population size[a]	$N_e \leq 50$	$50 < N_e \leq 500$	$N_e > 500$
	–or–	–or–	–or–
	$N \leq 250$	$250 < N \leq 2500$	$N > 2500$
Population decline	Precipitous decline[b]	Chronic decline or depression[c]	No decline apparent or probable
Catastrophe, rate and effect[d]	Order of magnitude decline within one generation	Smaller but significant decline[e]	not apparent
Hatchery influence[f]	High	Moderate	Low

[a] Census size N can be used if direct estimates of effective size N_e are not available, assuming $N_e/N = 0.2$.

[b] Decline within last two generations to annual run size ≤ 500 spawners, or run size > 500 but declining at $\geq 10\%$ per year. Historically small but stable population not included.

[c] Run size has declined to ≤ 500, but now stable.

[d] Catastrophes occuring within the last 10 years.

[e] Decline $< 90\%$ but biologically significant.

[f] See Figure 1 for assessing hatchery impacts.

Source: Lindley et al 2007

Figure 6-3

Taken from Framework for Assessing Viability of Threatened and Endangered Chinook Salmon and Steelhead in the Sacramento-San Joaquin Basin

This page left blank intentionally.

7.0 Assessment and Prediction of Stock Success for Restoration

7.1 Feather River

The observed introgression between the two (fall- and spring-run Chinook salmon) ESUs in the Feather River poses unique challenges for broodstock selection from this system. While the extent of this effect in unclear, these factors have the capability of reducing reproductive fitness and may influence the efficacy of recolonization. Research increasingly indicates that hatchery-reared anadromous salmonids exhibit reduced reproductive fitness compared to wild fish. This effect has been found to increase with each subsequent hatchery-reared generation (Araki *et al*. 2007b) and may persist over multiple generations after return to the wild (Araki *et al*. 2009). Introgression has also influenced run timing, where some spring-run Chinook salmon express the fall-run Chinook salmon phenotype and visa versa. If these spring-run Chinook salmon are reintroduced into the Restoration Area there is a likelihood that a subset of fish, and/or their progeny, will return in the fall and mate with fall-run Chinook salmon. The use of Feather River fish may bring the introgression problems into the San Joaquin River, however, a separation weir and multi-run management plan may reduced these impacts. Nonetheless, the effect of introgression with fall-run Chinook salmon enriches the phenotypic diversity of adult fish in the Feather River. This effect has been observed in the fall-run Chinook salmon population where known fall-running fish have been observed returning in the spring (J. Kindopp, pers. comm.). The introgression necessitates genetic methods to discriminate run-origin of individuals, as phenotypic distinction between these two runs is unreliable. These factors have prompted the Technical Advisory Committee of the SJRRP to recommend against the use of the Feather River Hatchery stock or any other hatchery origin stock for use in reintroduction (Meade 2007). The negative aspects of using broodstock from the Feather River Hatchery, however, should also be weighed alongside the potential benefits of (1) possibly recovering a phenotypically spring-run Chinook salmon-type fish from Feather River Hatchery, (2) the potential for distinct run timings to emerge when discrete spawning habitats are available, and (3) the potential to minimize impacts to natural spring-run Chinook salmon broodstock source populations.

In spite of these negative factors, several other characteristics of the Feather River stock may prove beneficial for reintroduction. Of the three major candidate stocks (Feather River, Butte Creek and Deer/Mill Creek Complex), the Feather River stock historically had the largest population size and greater extent of habitat, and exhibits the most genetic diversity. While introgression has certainly influenced the breadth of genetic diversity, the Feather River stock may possess remnant alleles from the four presumably independent populations that once existed in the four Feather River tributaries above Oroville Dam. In addition, Lindley et al. (2004) indicated that of all 18 historic independent populations of spring-run Chinook salmon in the Central Valley ESU, the historic environmental conditions in the Feather River most resembled historic conditions in the San Joaquin River. In addition, over the past 40+ years the presence of Oroville Dam has most certainly exerted significant selection pressure on the existing stock due to the dam's effects on temperature, distance and elevation of holding and spawning areas, loss of the natural flow regime, impact to aquatic biodiversity and distribution, and impact to habitat composition and quality (Bunn and Arthington 2002, Angilleta *et al.* 2008). This selection pressure could potentially benefit the Feather River stock, which would experience similar conditions in the Restoration Area.

The importance of ease of accessing the Feather River stock must also be considered. Multiple life stages of wild and hatchery fish are readily accessible from the hatchery, existing screw traps and easily accessible and seinable beaches. This is crucial for capturing enough unrelated individuals to provide the sufficient genetic diversity required to initiate a progenitor population with a reasonable effective population size. Therefore, the positive and negative consequences of selecting Feather River Hatchery Chinook salmon to serve as broodstock should be given thorough and careful consideration.

7.2 Deer and Mill Creeks

Risks include lower survival potential in the San Joaquin drainage due to local adaptation to higher elevation holding areas and cooler stream temperatures. Currently these stocks have adapted growth rates to cold water and a larger proportion of them stay in their natal watersheds until emigrating as yearlings due to suitable temperatures. There are also risks to the parent stocks from collection for the Restoration effort on the San Joaquin. Population sizes in the past few years on these Sacramento River tributaries has been very low, and the populations may not support our harvest of adult individuals for the San Joaquin. Benefits of using these stocks for the San Joaquin are that the stocks are untouched by hatchery influence to this point so have not experienced any decreased fitness due to hatchery practices. All of the available holding habitat in the Restoration Area is in low elevation areas, and these stocks are accustomed to holding in high elevation bedrock reaches in Deer and Mill Creek.

For the past 2 years the Deer and Mill Creek adult escapement estimates have been below the 250 threshold that puts them at a high risk of extinction (Lindley et al 2007). Through the reintroduction period for the SJRRP (2012-2017) is expected that the population will not even reach a moderate risk of extinction. (Harvey-Arrison pers comm). The risks to the existing populations may be too great to allow for collection of these fish during the reintroduction period

7.3 Butte Creek

The Butte Creek spring-run Chinook salmon stock has several characteristics that would be beneficial for reintroduction into the upper San Joaquin River. The stock is a genetically distinct Central Valley spring-run Chinook salmon (Lindley et al. 2004). The Butte Creek population is not dependent nor is stocked with hatchery fish, which have lower reproductive fitness than wild fish (Araki *et al.* 2009), and the population is considered sustaining, persistent, and viable. Out of the three major spring-run Chinook salmon stocks under consideration, Butte Creek has had the largest census size for the last 9 out of 10 years (CDFG 2009). The high pre-spawn mortalities experienced during years of high returns may indicate a density-dependent mortality (Williams 2006), and based on the estimated available spawning habitat Butte Creek may not have enough suitable habitat for the number of adult returns in those years. Therefore, taking fish from this population in years with high returns, as seen in 2002 and 2003, may have little impact on the population.

Genetically, the spring-run Chinook salmon from Butte Creek are "true" spring-run Chinook salmon, but have the lowest genetic diversity out of the three major source populations under consideration (Garza et al 2008). This may increase the risk of inbreeding depression in the reintroduced population if only Butte Creek fish are used for reintroduction. The lower diversity also indicates that Butte Creek may have the lowest effective population size of the three stocks under consideration. Having a large census size in combination with a lower effective population size indicates that there is a lower risk of removing unique individuals from the source population. Therefore, having the lowest diversity out of the three stocks under consideration may be a benefit since genetic impacts to the source population must be considered.

In addition, the salmon in Butte Creek experience selective pressures that may be similar to those of the restored upper San Joaquin River. These include: (1) low elevation of holding and spawning habitats, (2) highly regulated hydrology, (3) warmer water temperatures, and (4) high air temperatures during the summer months. In addition, collection of all life stages for the purposes of reintroduction may be accomplished.

This page left blank intentionally

8.0 Recommendations

Introduction

The Genetics Subgroup considered a number of types of data comparisons and potential scoring and ranking systems to prioritize the three potential source stocks. In addition, the Genetics Subgroup took into consideration the Technical Advisory Committee's recommendations on restoring spring-run Chinook salmon in developing this analysis. During these discussions, the Genetics Subgroup debated stock selection criteria to be used, scoring/ranking systems, and the reliability of these methods. It was noted that there is a dearth of information and data that could be used in a predictive framework, as was a set of somewhat contradictory indicators of status. It was also noted that scoring/ranking systems are inherently bias, and may give us a number, that in the end, means very little. As a consequence, the Genetics Subgroup spent a significant amount of time evaluating an experimental multiple stock reintroduction strategy.

8.1 Preferred Recommendation

Following several discussions, the majority, if not all, of the Genetic Subgroup members concurred that it would be nearly impossible to accurately predict the likelihood of success of the three spring-run Chinook salmon stocks in a San Joaquin River reintroduction project. There is a large amount of genetic data available to evaluate the genetic status of the different stocks, but even if more data were collected, genetic and otherwise, the consensus was that prospects for predicting fitness and success of the stocks would not improve.

Each of the three remaining spring-run Chinook salmon lineages has biological characteristics that might be favorable for a successful reintroduction project and each also has unfavorable characteristics. Spring-run Chinook salmon vary in a number of important traits like distinctive use of diverse aquatic habitats, timing of spawning migration and breeding, and natal fidelity. There is likely significant potential for evolution of traits to occur as a result of the strong, novel selective pressures being placed on the fish in the upper San Joaquin River. We suggest that a simultaneous multiple stock reintroduction experiment be pursued as an adaptive management program. Genetic evaluation and other methods would be used to evaluate the relative fitness and success of fish from the different stocks at various life stages following the reintroduction.

The multi-stock approach would include all available Central Valley spring-run Chinook salmon stocks, including the Feather River stock. There has been much debate on the use of Feather River fish for the reintroduction efforts. Spring-run Chinook salmon Feather River are introgressed with fall-run Chinook salmon, and are "clustered" with fall-run Chinook salmon in population clustering analyses (refer to Section 4.0). However, the Feather River spring-run Chinook salmon stock retains valuable genetic and phenotypic diversity worth conserving (refer to Section 4.0 and 7.1). Therefore, our preferred recommendation would be to reintroduce spring-run Chinook salmon from all three potential source population, the two independent populations of Central Valley spring-run Chinook salmon from Deer/Mill complex and Butte Creek, and the Feather River population.

- Benefits: increase in overall genetic diversity and reduction in inbreeding levels, Program flexibility, and availability of diverse reintroduction methods.
- Risks: outbreeding depression, fall-run Chinook salmon phenotype being expressed, monitoring the independent success of each source population's establishment in the Restoration Area would be an added challenge due to the high likelihood of introgression.

The Genetics Subgroup will work diligently to determine a range of appropriate collection, reintroduction and monitoring strategies. These will be carefully evaluated to determine availability of source stocks at various life stages. It is currently unknown what criteria and population thresholds the regulatory fisheries agencies (NOAA and CDFG) will use to determine if the Program is able to mine fish from the three source populations and the number of fish that may be taken. If it is determined that the risks to the source stock(s) is too high, it is likely the SJRRP will limit the source stock to the utilization of two stocks, or in the worst case scenario, one stock, since spring-run Chinook salmon must be reintroduced by December 31, 2012.

\This page left blank intentionally.

9.0 References

Allendorf, F.W., D. Bayles, D. Bottom, K.P. Currens, C.A. Frissell, D. Hankin, J.A. Lichatowich, W. Nehlsen, P.C. Trotter, T.H. Williams. 1997. Prioritizing Pacific Salmon Stocks for Conservation. Conservation Biology. 11(1):140-152.

Anderson, J.T, C.B. Watry and A. Gray. 2007. Upstream Fish Passage at a Resistance Board Weir Using Infrared and Digital Technology in the Lower Stanislaus River, California 2006−2007 Annual Data Report. 40pp.

Angilletta M. J., E. A. Steel, K. K. Bartz, J. G. Kingsolver, M. D. Scheuerell, B. R. Beckman and L. G. Crozier. 2008. Big dams and salmon evolution: changes in thermal regimes and their potential evolutionary consequences. Evolutionary Applications ISSN 1752-4571. pp 286-299

Araki H., B. Cooper and M. S. Blouin. 2007. Genetic effects of captive breeding cause a rapid cumulative fitness decline in the wild. Science. 318(5847): 100-103. October 2007

Araki, H., B. Cooper and M.S. Blouin. 2009. Carry-over effect of captive breeding reduces reproductive fitness of wild-born descendents n the wild. Biology Letters: 5(5): 621-624. October 2009.

Armentrout, S., H. Brown, S. Chappell, M. Everett-Brown, J. Fites, J. Forbes, M. McFarland, J.Riley, K. Roby, A. Villalovos, R. Walden, D. Watts, and M. R. Williams, 1998. Watershed Analysis for Mill, Deer and Antelope Creeks. Almanor Ranger District Lassen National Forest.

Berejikian, B., and M.J. Ford. 2004. Review of relative fitness of hatchery and natural salmon. National Oceanic and Atmospheric Administration technical memorandum NMFS-NWFSC-61. Northwest Fisheries Science Center, Seattle. Available from http://www.nwfsc.noaa.gov/publications/displayallinfo.cfm?docmetadataid=6011 .

Big Chico Creek Watershed Alliance 2000

Brown R, Greene, S. 1994. And evaluation of the Feather River Hatchery as mitigation for the State Water Project's Oroville Dam. In: Environmental enhancement of water projects. Denver (CO): USCID. P 111-23. As found in Sommer et al. "Factors affecting Chinook salmon spawn on the lower Feather River.

Bunn S. E., and A.H. Arthington. 2002. Basic principles and ecological consequences of altered flow regimes for aquatic biodiversity. Environmental Management 30 (1).

CDFG. YEAR. file map,

CDFG. 1966. Department of Water Resources Bulletin No. 137. Sacramento Valley East Side Investigation. Appendix C, Fish and Wildlife.

CDFG. 1998, A Status Review of the spring-run Chinook salmon (*Oncorhynchus tshawytscha*) in the Sacramento River Drainage. Candidate Species Status Report 98-01. Sacramento, CA: Department of Fish and Game. (as cited in CDFG 2008)

CDFG 1991

CDFG. 2001. Spring-run Chinook salmon – Annual Report Prepared for the Fish and Game Commission.

CDFG. 2009 . Grandtab Chinook Census Database.

CDFG. 2008. Review of Present Steelhead Monitoring Programs in the California Central Valley. Prepared by the Pacific States Marine Fisheries Commission for the California Department of Fish and Game Central Valley Steelhead Monitoring Plan Agreement No. P0685619 May 2008.

California Department of Water Resources (DWR). 2005. Bulletin 250 Fish PassageImprovement 2005. An Element of CALFED's Ecosystem Restoration Program.

Clark GH. 1930. Salmon spawning in drainage canals in the San Joaquin Valley. California Fish and Game 16(3):270

Cramer, F.K., and D.F. Hammack. 1952. Salmon research at Deer Creek, California, U.S.Fish and Wildlife Service. Special Scientific Report. Fisheries No. 67.

DWR 2009

FERC 2007. FERC Project 2100, May 2007 Draft Environmental Impact Report Oroville Facilities Relicensing—FERC Project No. 2100

Fry DH, Jr. 1961. King salmon spawning stocks of the California Central Valley, 1940-1959. California Fish and Game 47 (1): 55-71

Garza, J.C, S.M. Blankenship, C. Lemaire, and G. Charrier. 2008. Genetic population structure of Chinook salmon (Oncorhynchus tshawytscha) in California's Central Valley. Final report for Calfed project "Comprehensive evaluation of population structure and diversity for Central valley Chinook Salmon." 40pp.

Gilbert GK. 1917. Hydraulic-mining debris in the Sierra Nevada. US Geological Survey professional paper nr. 105. Washington, DC.

Hanson, H.A., O.R. Smith and P.R. Needham. 1940. An investigation of fish-salvage problems in relation to Shasta Dam. U.S. Fish and Wildlife Service. Special Scientific Report No.10.

Harvey, C. D. 1996, personal communications

Harvey, C.D. 1997. Juvenile spring-run Chinook salmon emergence, rearing, and outmigration patterns in Deer and Mill Creeks, Tehama County, for the 1995 brood year. Sport Fish Restoration Annual Report. September 1997.

Harvey-Arrison, C. 2007. Chinook salmon population and physical habitat monitoring in Clear, Antelope, Mill and Deer Creeks for 2007. Sacramento River salmon and steelhead assessment project. Sport Fish Restoration Annual Progress Report.

Harvey-Arrison, C. 2008. Summary of Mill and Deer Creek Juvenile Salmonid Emigration Monitoring from October 2007 thru June 2008. Memorandum. Department of Fish and Game, Northern Region. September 3, 2008.

T. Healey 1988

Hendry, A. P., J. E. Hensleigh, and R. R. Reisenbichler. 1998. Incubation temperature, developmental biology, and the divergence of sockeye salmon (Oncorhynchus nerka) within Lake Washington. Canadian Journal of Fisheries and Aquatic Sciences 55:1387–1394.

Kennedy, T. and T. Cannon. 2005. Stanislaus River salmonid density and distribution survey report (2002-2004). Prepared for the U.S. Bureau of Reclamation Central Valley Project Improvement Act. Fishery Foundation of California. October 2005.

Lindley, S. T., Schick, R.S., May, B.P., Anderson, J. J., Greene, S., Hanson, C., Low, A., McEwan, D., MacFarlane, R.B., Swanson, C., J. G. Williams. 2004. Population structure of threatened and endangered Chinook salmon ESUs in California's Central Valley basin. NOAA Technical Memorandum NMFS-SWFSC-360, April 2004.

Lindley, S.T., Schick, R.S., May, B.P., Anderson, J. J., Greene, S., Hanson, C., Low, A., McEwan, D., MacFarlane, R.B., Swanson, C., J. G. Williams 2006. Historical population structure of Central Valley steelhead and its alteration by dams. San Francisco Estuary & Watershed Science 4(1): article 3. February 2006.

Lindley, S.T., Schick, R.S., Mora, E., Adams, P.B., Anderson, J.J., Grene, S., Hanson, C., May, B.P., McEwan, D., MacFalane, R.B., Swanson, C., and J.G. Williams. 2007. Framework for Assessing Viability of Threatened and Endangered Chinook Salmon and Steelhead in The Sacramento-San Joaquin Basin. San Francisco Estuary and Watershed Science 5(1): article 4. February 2007.

Lindley, S. T., et al. March, 2009. What caused the decline of the Central Valley fall Chinook Stock Collapse. Prepublication report to the Pacific Fisheries Management Council.

McElhany, P., M. H. Ruckelshaus, M. J. Ford, T. C. Wainwright, E. P. Bjorkstedt. 2000. Viable salmon populations and the recovery of evolutionarily significant units. U.S. Dept. of Commerce, NOAA Tech. Memo., NMFS-NWFSC-42, 156 p.

McFarland M., 1990, memo to the files

McReynolds T.R. and C.E. Garman. 2008. Butte Creek spring-run Chinook salmon , Oncoryhnchus Tshawytscha pre-spawn mortality evaluation 2007. Inland Fisheries Report No. 2008-2.

Meade, R. J. 2007. Recommendations on restoring spring-run Chinook salmon to the upper San Joaquin River. Prepared for San Joaquin River Restoration Program Restoration Administrator Roderick J. Meade Consulting, Inc. Prepared by San Joaquin River Restoration Program Technical Advisory Committee. October 2007.

Meyers, J.M., R.G. Kope, G.J. Bryant, D. Teel, L.J. Lierheimer, T.C. Wainwright, W.S. Grant, F.W. Waknitz, K. Neely, S.T. Lindley, and R.S. Waples. 1998. Status review of Chinook salmon from Washington, Idaho, Oregon, and California. United States Department of Commerce, NOAA Technical Memorandum. NMFS-NWFSC-35, 443p.

Moyle, P. B., R. M. Yoshiyama, J. E. Williams, and E. D. Wikramanayake. 1995. Fish Species of Special Concern in California. Second Edition. Prepared for California Department of Fish and Game, Rancho Cordova. Contract No. 2128IF.

Moyle, P.B. 2002. Inland fishes of California. Revised and expanded. University of California Press, Berkeley.

Moyle, P.B., J.A. Israel, and S.E. Purdy. 2008. Salmon, steelhead, and trout in California. Status of an emblematic fauna, a report commissioned by the California Trout. Center for watershed sciences. 316pp

Muir J. 1938. John of the Mountains. In:Wolfe LM, editor. The unpublished journals of John Muir. Boston (MA): Houghton Mifflin. 459 p.

Myers, R.A., S.A. Levin, R. Lande, F.C. James, W.W. Murdoch, and R.T. Paine. 2004. Ecology. Hatcheries and endangered salmon. *Science* 303:1980.

NMFS. 2009. National Marine Fisheries Service. Public Draft Central Valley Recovery Plan. Appendix A: Watershed Profiles.

NOAA Marine Fisheries Southwest Region Sacramento Office. 2007 Federal Recovery Outline for the Evolutionary Significant Units of Sacramento River Winter-run Chinook and Central Valley spring-run Chinook salmon Chinook Salmon and the Distinct Population Segment of the California Central Valley Steelhead.

Needham, P.R., and H.A. Hanson, and L.P. Parker. 1943. Supplementary report on investigations of fish-salvage problems in relation to Shasta Dam. U.S. Fish and Wildlife Service. Special Scientific Report No. 26.Needham et. al. (1943)

Obedzinski, M., and Letcher, B.H. 2004. Variation in freshwater growth and development among five New England Atlantic salmon (*Salmo salar*) populations reared in a common environment. Can. J. Fish. Aquat. Sci. 61: 2314–2328.

Painter R.E., L.H. Wixom, and S.N. Taylor. 1977. An Evaluation of Fish Populations and Fisheries in the Post-Oroville Project Feather River. Department of Fish and Game, Anadromous Fisheries Branch. Report submitted to the Department of Water Resources in accourdance with Federal Power Commission License No. 2100. Interagency Agreement No. 456705. Sacramento (CA): California Department of Fish and Game. 56p.

Petit R.J., A. El Mousadik, and O. Pons (1998) Identifying populations for conservation on the basis of genetic markers. *Conservation Biology* 12:844-855.

Quinn, T.P., M.J. Unwin and M.T. Kinnison. 2000. Evolution of temporal isolation in the wild: genetic divergence in timing of migration and breeding by introduced Chinook salmon populations. *Evolution* 54:1372 -1385.

Reynolds FL, Mills TJ, Benthin R, Low A. 1993. Restoring Central Valley stream; a plan for action. Sacramento (CA): California Department of Fish and Game. 129 p.

San Joaquin River Restoration Program (SJRRP) Fisheries Management Work Group (FMWG). 2009. Draft Fisheries Management Plan: A Framework for Adaptive Management for the San Joaquin River Restoration Program.

Schick, R.S. and S. T. Lindley. 2007. Directed connectivity among fish populations in a riverine network. Journal of Applied Ecology 44(6): 1116-1126. December 2007.

Sommer, Ted, Debbie McEwan, and Randall Brown, 2001. Factors Affecting Chinook Salmon Spawning in the Lower Feather River. Found in: Contributions to the Biology of Central Valley Salmonids. Fish Bulletin 179. Volume 2. Sacramento (CA): California Department of Fish and Game.

Ward P.D., T.R. McReynolds, and C.E. Garman. 2007. Butte Creek spring-run Chinook salmon Chinook salmon, Oncoryhnchus Tshawytscha pre-spawn mortality evaluation 2004. Inland Fisheries Administrative Report No. 2006-1. 2004. 49 pp.

Ward P.D., T.R. McReynolds, and C.E. Garman. 2004. Butte Creek spring-run Chinook salmon Chinook salmon, Oncoryhnchus Tshawytscha pre-spawn mortality evaluation 2004. Inland Fisheries Administrative Report No. 2004-5. 2004. 91 pp.

Ward P.D. and T.R. McReynolds. 2004b. Butte and Big Chico Creeks spring-run Chinook salmon Chinook salmon, Oncoryhnchus Tshawytscha, life history investigation 1998-2000. Inland Fisheries Administrative Report No. 2004-2. 59 pp.

Watry, C.B., A. Gray, R. Cuthbert, B. Pyper, and K. Arendt. 2007. Out-migrant Abundance Estimates and Coded Wire Tagging Pilot Study for Juvenile Chinook Salmon at Caswell Memorial State Park in the Lower Stanislaus River, California 2007 Annual Data Report. 50pp.

Williams, J. G. 2006. Central Valley salmon, a perspective on the Chinook and Steelhead in the Central Valley of California.. San Francisco Estuary & Watershed Science 4(3): article 2. December 2006.

Williams, J.G., Anderson, J.J., Greene, S., Hanson, C., Lindley, S.T., Low, A., May, B.P., McEwan, D., Mohr, M.S., MacFarlane, R.B., and C. Swanson. 2007. Monitoring and research needed to manage the recovery of threatened and endangered Chinook and steelhead in the Sacramento-San Joaquin basin. NOAA Technical Memorandum NMFS-SWFSC-399, 2007.

Williams, B. K., R. C. Szaro, and C. D. Shapiro. 2009 Adaptive Management: The U.S. Department of the Interior Technical Guide. Adaptive Management Working Group, U.S. Department of the Interior, Washington, DC.

Workman, M.L. 2002a. Downstream Migration Monitoring at Woodbridge Dam on the Lower Mokelumne River, Ca.December 2001 through July 2002. 35pp.

Workman, M.L. 2002. Lower Mokelumne River Upstream Fish Migration Monitoring Conducted at Woodbridge Irrigation District Dam. August 2001 through July 2002. 19pp. + appendices.

Workman, M.L. 2003. Lower Mokelumne River Upstream Fish Migration Monitoring Conducted at Woodbridge Irrigation District Dam. August 2002 through July 2003. 18pp. + appendices.

Workman, M.L. 2004. Lower Mokelumne River Upstream Fish Migration Monitoring Conducted at Woodbridge Irrigation District Dam. August 2001 through July 2002. 19pp. + appendices.

Workman, M.L. 2005. Lower Mokelumne River Upstream Fish Migration Monitoring Conducted at Woodbridge Irrigation District Dam. August 2001 through July 2002. 13pp. + appendices.

Workman, M.L. 2006a. Downstream Migration Monitoring at Woodbridge Dam on the Lower Mokelumne River, Ca.December 2005 through July 2006. 26pp.

Workman, M.L. 2006. Lower Mokelumne River Fall-run Chinook Salmon Escapement Report October through December 2005. 12pp.

Workman, M.L. and E. Rible. 2007. Lower Mokelumne River Fall-run Chinook Salmon Escapement Report October 2006 through January 2007. 15pp.

Workman, M.L, E. Rible and J. Shillam. 2008. Lower Mokelumne River Fall-run Chinook Salmon Escapement Report. 10pp.

USFWS. 1995. Working Paper on restoration needs: habitat restoration actions to double natural production of anadromous fish in the Central Valley of California. Volumes 1 & 2. May 9, 1995. Prepared for the U.S. Fish and Wildlife Services under the direction of the Anadromous Fish Restoration Program Core Group. Stockton, CA

Unwin, M.J., T.P.Quinn, M.T. Kinnison, and N.C. Boustead. 2000. Divergence in juvenile growth and life history in two recently colonised and partially isolated chinook salmon populations. *Journal of Fish Biology* 57:943-960.

Yoshiyama RM, Gerstung ER, Fisher FW, Moyle PB. 1996. Historical and present distribution of Chinook salmon in the Central Valley drainage of California. Sierra Nevada Ecosystem Project: Final report to US Congress. Volume III, assessments, commissioned report, and background information. P 309-62

Yoshiyama, R., E. Gerstung, F. Fisher and P. Moyle. 2001. Historical and present distribution of Chinook salmon in the Central Valley drainage of California. Found in: Contributions to the Biology of Central Valley Salmonids. Fish Bulletin 179. Volume 2. Sacramento (CA): California Department of Fish and Game.

This page left blank intentionally.