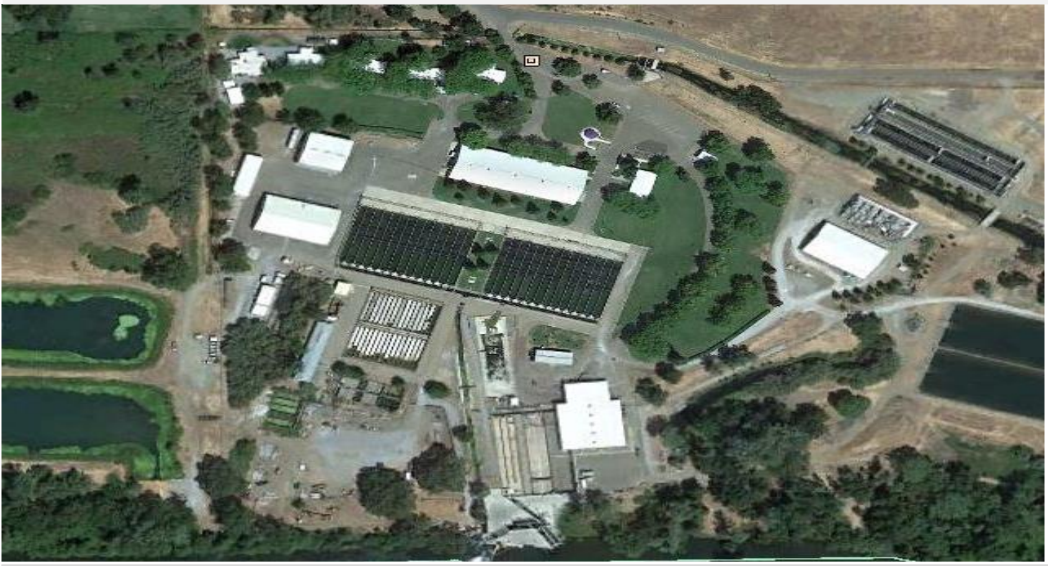
RECLAMATION

Managing Water in the West



Coleman National Fish Hatchery Adaptive Management Plan

U.S. Department of the Interior
Bureau of Reclamation

Coleman National Fish Hatchery Adaptive Management Plan

Public Review Draft
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Prepared for
U.S. Department of the Interior, Bureau of Reclamation
Mid-Pacific Region, 2800 Cottage Way, Sacramento, CA 95825

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Acknowledgments

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Public Involvement

An open and inclusive process was used to develop the Coleman National Fish Hatchery Adaptive Management Plan. Two public meetings were held, one early on to aid in scoping the plan, and a second meeting during the public comment period for the draft plan. Public comments and responses to those comments are separately available in a comment log. Members of the public are encouraged to stay engaged as this adaptive management plan is implemented by attending the Greater Battle Creek Watershed Working Group (GBCWWG) meetings. More information about the group is available at http://www.battle-creek.net/, or by writing the Battle Creek Watershed Conservancy, P.O. Box 606, Manton, CA 96059.

Executive Summary

The Battle Creek watershed, like many in the west, is a complex environment, providing important opportunities for both the natural and man-made environments. Agency and stakeholder representatives with interests in the Battle Creek watershed have worked over the last two decades to reconcile the conflicts between ecological functions and human services. These efforts have mainly focused on conserving and restoring aquatic habitats for native salmonid reproduction and growth, while preserving the use of water resources for hydropower production and water diversions. Mandated fish hatchery operations at the Coleman National Fish Hatchery (CNFH) is another longstanding use that increases the complexity of these reconciliation efforts.

Restoration of the upper Battle Creek watershed, motivated through FERC relicensing of PG&E hydropower facilities, focuses on providing fish access to historical habitat for the re-establishment of naturally occurring salmonid populations. The Battle Creek watershed is considered a highly important watershed that historically supported large numbers and a broad diversity of anadromous salmonids. Infrastructure modifications associated with the Battle Creek Salmon and Steelhead Restoration Project (BCRP) began in early 2010. The goal of the BCRP is to provide high quality habitat and improve fish passage throughout 48 miles of stream habitat. Once completed, the BCRP will be adaptively managed as described in a project-specific adaptive management plan (BCRP-AMP).

The CNFH is located on the north bank of Battle Creek, approximately three miles east of the Sacramento River. The hatchery barrier weir and fish ladder system is the first substantial man-made structure immigrating anadromous fish encounter when returning to Battle Creek. The CNFH is unique among hatcheries in California, in that it is not located immediately downstream from the reservoir dam it is intended to mitigate. Since its establishment in 1942, the CNFH has served as an important mitigation component of the Federal Central Valley Project (CVP), partially compensating for lost natural salmonid production resulting from construction of Shasta and Keswick dams. The hatchery is considered a positive contributor to regional socioeconomics.

To provide for better hatchery operations and outcomes, and to partially mitigate for potential impacts to restoration efforts in the watershed, substantial modifications to the CNFH have occurred over the last decade to address long-standing concerns about: (1) the hatchery's potential to amplify the transmission of fish diseases; (2) adult fish passage through the hatchery's barrier weir and fish ladder system; and (3) entrainment of natural origin juvenile salmonids emigrating from upper Battle Creek. However concerns remain about the continuing impacts the CNFH may have on the timely restoration of impaired salmonid populations in the upper Battle Creek watershed. In 2004 an independent technical panel examined the compatibility of CNFH operations and restoration of salmonid populations in Battle Creek. This panel recommended development of an adaptive management for the CNFH. This document describes a plan that supports adaptive management of the CNFH, and to the extent possible, integrated adaptive management of the CNFH and BCRP. The overall aim is to maximize compatibility of the CNFH with the BCRP, thereby contributing to the further reconciliation of ecological functions and human services in the Battle Creek watershed.

Coleman National Fish Hatchery Adaptive Management Plan

Adaptive management provides a rational approach for addressing issues where competing but uncertain solutions exist, and for which management cannot be delayed until the issues and solutions are fully understood. It is often considered for use in ecological systems where:

1. Conflicts exist
2. The stakes are high
3. There is uncertainty about the best way to proceed

Adaptive management is an iterative process that allows for the formal analysis of data and information as a means of framing new choices, providing understanding, and making decisions. The adaptive management cycle used in development of the CNFH-AMP closely follows the cycle developed through the CALFED Ecosystem Restoration Program, which is the cycle used in the BCRP-AMP (Figure ES.1).

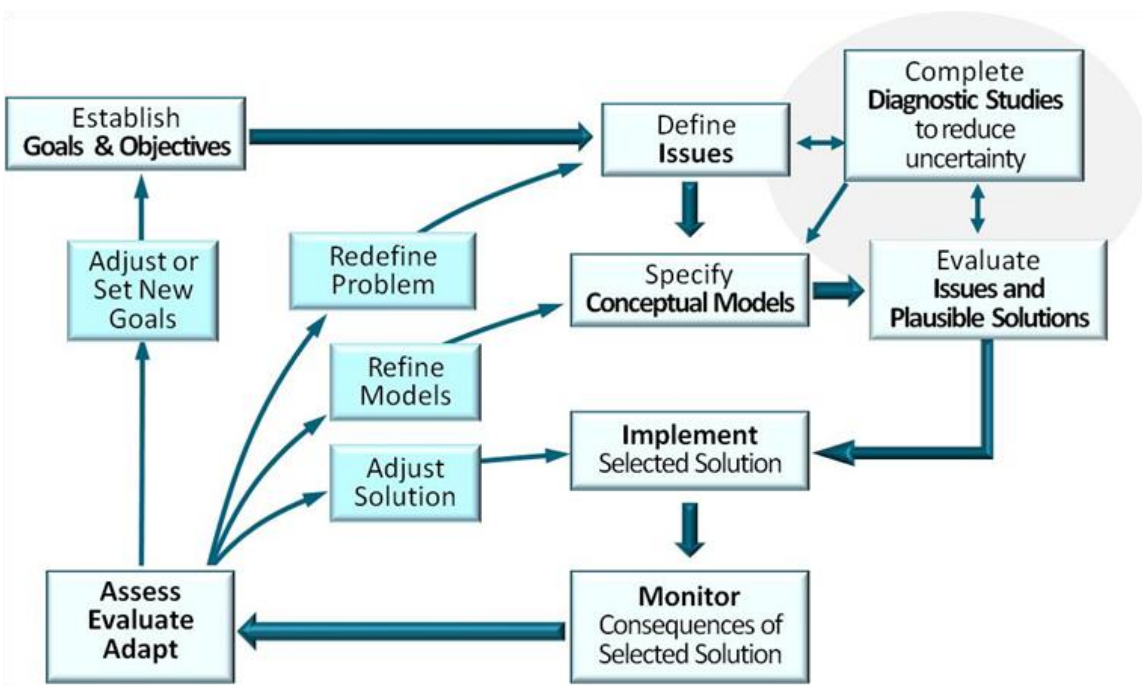

Figure ES.1. Diagram of the adaptive management cycle developed for the CNFH-AMP. (Adapted from Healey et al. 2008). The route with thicker arrows generally follows the passive adaptive management cycle used in the BCRP-AMP. The shaded area (upper right) indicates where active adaptive management can occur within the cycle.

To develop the CNFH-AMP, a Technical Advisory Committee (TAC) comprising the major agency, restoration, and utility stakeholders in the Battle Creek watershed, was consulted on every major element of the AMP. TAC guidance included the following:

- Establish the purpose, goal, and objectives.
- Comment on plan development and organization.
- Define the Issue/Problem statements.
- Provide data (and identify data gaps), and more importantly assess the quality of the data available for analysis.
- Provide technical colleague review of two quantitative life-cycle models, developed to support issue analysis.
- Provide advice on conceptual life cycle models for the fish species in question.
- Identify a governance structure to coordinate the implementation of the CNFH-AMP with restoration efforts in the BCRP-AMP.

The TAC also identified three critical principals that would guide CNFH-AMP development and implementation:

- The CNFH will continue to operate to partially mitigate for the loss of anadromous salmonid production associated with the construction of Shasta Dam.
- The CNFH-AMP assumes restoration of the Battle Creek watershed will occur as described.
- Implementation of the CNFH-AMP will be closely coordinated with BCRP-AMP implementation, but the two projects will remain separate efforts that operate under different authorities.

The CNFH-AMP provides a structure to support future operations of the CNFH in a watershed that has undergone substantial restoration. To the extent possible, the document provides for the coordinated implementation of the CNFH and the BCRP under an integrated adaptive management framework. In order to increase the plan's ease of use and utility, the main document provides focused information about the need for adaptive management, issue identification and evaluation, and key factors affecting implementation (i.e., funding sources, governance, and decision making). Documents providing relevant technical details and directly supporting information are included as appendixes:

- Description of the CNFH, its setting and information about the scope of this project
- Description of a coordinated governance structure for the CNFH and BCRP adaptive management plans
- Conceptual models and detailed analyses of identified issues
- Documentation for the Chinook and steelhead life cycle models
- An integrated monitoring plan

Table of Contents

List of Figures

List of Tables

List of Appendixes

List of Acronyms

ACL	Annual Catch Limit
AFRP	Anadromous Fish Restoration Program
AMPT	Adaptive Management Policy Team
AMTT	Adaptive Management Technical Team
BA	Biological Assessment
BCRP	Battle Creek Salmon and Steelhead Restoration Project
BCRP-AMP	Battle Creek Salmon and Steelhead Restoration Project Adaptive Management Plan
BCWC	Battle Creek Watershed Conservancy
BKD	Bacterial Kidney Disease
CDFG	California Department of Fish and Game
CDFW	California Department of Fish and Wildlife
CFM	Constant Fractional Marking
CFS	Cubic Feet per Second
CNFH	Coleman National Fish Hatchery
CNFH-AMP	Coleman National Fish Hatchery Adaptive Management Plan
CNFH-AMP TAC	Coleman National Fish Hatchery Adaptive Management Plan Technical Advisory Committee
CVI	Central Valley Index
CVPIA	Central Valley Project Improvement Act
CVRWQCB	Central Valley Regional Water Quality Control Board
CWT	Coded Wire Tag
ERM	Enteric Red Mouth
ESA	Endangered Species Act
ESU	Evolutionary Significant Unit
FGC	Fish and Game Commission
FMWT	Fall Mid-water Trawl
FPP	Fish per Pound
GPM	Gallons per Minute
GBCWWG	Greater Battle Creek Watershed Working Group

HMT......................................Hatchery Management Team
IHNV....................................Infectious Hematopoietic Necrosis Virus
IPNV ....Infectious Pancreatic Necrosis Virus
IS..Issue Statements
LCM......................................Life Cycle Model
LSNFH..................................Livingston Stone National Fish Hatchery
MOU ....Memorandum of Understanding
NMFS ....National Marine Fisheries Service
OFL.......................................Overfishing Limit
OSP......................................Ocean Salmon Project
PBT.......................................Parental Based Tagging
PFMC ....Pacific Fisheries Management Council
PG&E...................................Pacific Gas and Electric Company
pHOS...................................Proportion of Hatchery Origin Spawners
PNI.......................................Proportionate Natural Influence
PSMFC ....Pacific States Marine Fisheries Commission
RMPC..................................Regional Mark Processing Center
RST ....Rotary Screw Trap
SAR ....Smolt-to-Adult Return
SDFPF.................................Skinner Delta Fish Protective Facility
SI ....Sacramento Index
SRFC....................................Sacramento River Fall Chinook
TAC ....Technical Advisory Committee
USFWS................................United State Fish and Wildlife Service
VIE.......................................Visible Implant Elastomer
VSP ....Viable Salmonid Population
WD.......................................Whirling Disease

Chapter 1: Introduction

Agency and stakeholder representatives with interests in the Battle Creek watershed have worked over the last two decades to reconcile the conflicts between ecological functions and human services. Reconciliation efforts have mainly focused on conserving and restoring aquatic habitats for native salmonid reproduction and growth, while preserving the use of water resources for hydropower production and water diversions. Mandated fish hatchery operations is another longstanding use that adds to the complexity of these reconciliation efforts. Formal protection of three salmonids stocks under the California and Federal endangered species acts (ESA), and the subsequent identification of the Battle Creek watershed as important recovery habitat (NMFS 2014), provided further motivation to improve ecological functions, while striving to optimize existing human services.

A major outcome of the reconciliation efforts is substantial restoration of the upper Battle Creek watershed, which focuses on providing naturally occurring salmonids access to historical habitat. The Battle Creek watershed is considered a highly important and unique watershed that historically supported large numbers and a broad diversity of anadromous salmonids (Jones and Stokes 2005a, Terraqua 2004). The watershed is part of the Basalt and Porous Lava diversity group, one of four geographic regions in the Central valley considered important to the formulation of Evolutionary Significant Units (ESU) for Chinook salmon and Central Valley steelhead (NMFS 2014). The majority of habitat for this diversity group occurs above Shasta Dam; thus, the Battle Creek watershed is considered highly important in the context of endangered and threatened species recovery planning for winter and spring Chinook salmon, and Central Valley steelhead (NMFS 2014).

Although highly unique and historically important to several salmonids stocks, the Battle Creek watershed has been substantially modified to support hydropower production (Jones and Stokes 2005a). Initiated in early 2010, the Battle Creek Salmon and Steelhead Restoration Project (BCRP) focuses on restoring in-stream flows and improving fish passage through modification of existing hydropower infrastructure (Figure 1.1). The goal is to provide high quality habitat and improve fish passage throughout 48 miles of stream habitat, which together support self-sustaining populations of several Chinook salmon stocks, and Central Valley steelhead (Terraqua 2004). Once completed, the BCRP will be adaptively managed as described in a project-specific adaptive management plan (Terraqua 2004).

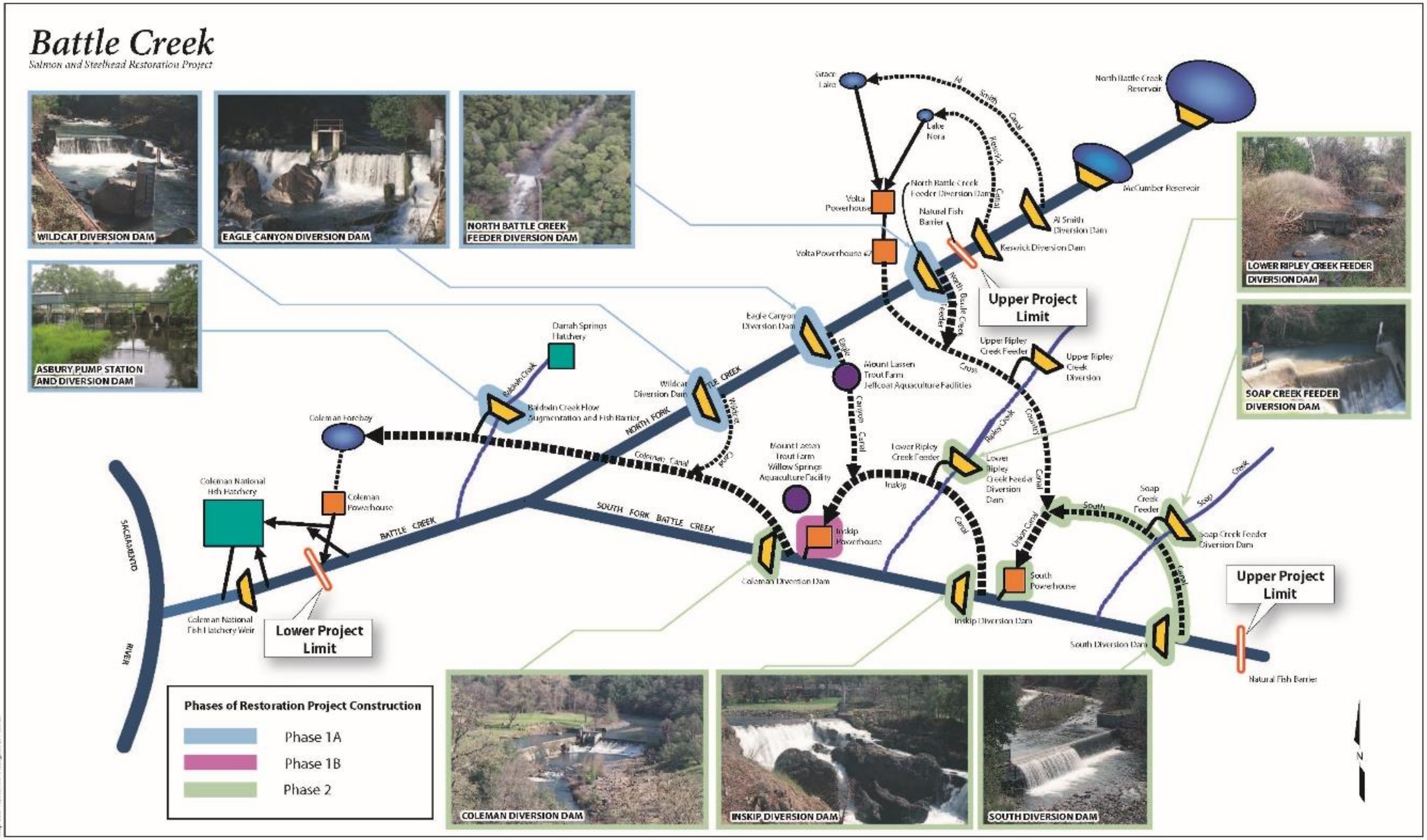

Figure 1.1. Schematic diagram of the Battle Creek watershed identifying the modifications to hydropower infrastructure to be completed through the course of the restoration project. See Jones and Stokes (2005a) for more details on the restoration project.

Since its establishment in 1942, the Coleman National Fish Hatchery (CNFH) has served as an important mitigation component of the Federal Central Valley Project (CVP), partially compensating for lost natural salmonid production resulting from construction of Shasta and Keswick dams (Richardson 1987). The hatchery is considered highly successful, and is a positive contributor to regional socioeconomics (USFWS 2011). Yet the physical infrastructure and operations of the CNFH have the potential to adversely affect the attainment of BCRP goals and objectives.

The CNFH is located on the north bank of Battle Creek, approximately three miles east of the Sacramento River (Figure 1.2). The CNFH is unique among anadromous salmonid mitigation hatcheries in California, in that it is not located immediately downstream from the reservoir dam it is intended to mitigate.

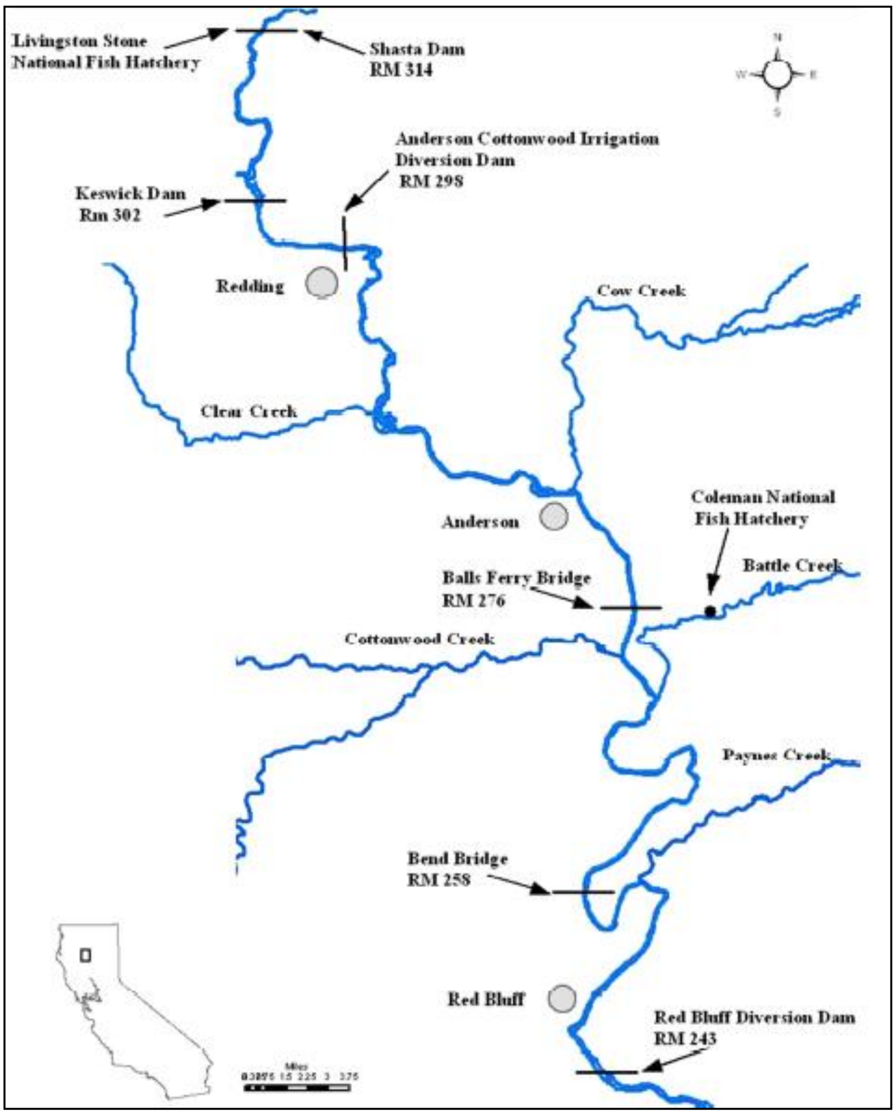

Figure 1.2. Location of Coleman National Fish Hatchery and other notable features of the Sacramento River system between Shasta Dam and Red Bluff Diversion Dam (Figure from USFWS 2011).

Substantial modifications to the CNFH have occurred over the last decade to address what many considered the major adverse impacts of the hatchery on the watershed and its living resources. These modifications addressed long-standing concerns about: (1) the hatchery's potential to amplify the transmission of fish diseases; (2) adult fish passage through the hatchery's barrier weir and fish ladder system; and (3) entrainment of natural origin juvenile salmonids emigrating from upper Battle Creek (USFWS 2011). Yet concerns remain about the continuing impacts the CNFH may have on the timely restoration of impaired salmonid populations in the upper Battle Creek watershed. In 2004 an independent technical panel examined the compatibility of CNFH operations and restoration of salmonid populations in Battle Creek (Technical Review Panel 2004). A major conclusion of this panel stated,

> *The success of the Battle Creek restoration project will depend a great deal on CNFH and possibly Livingston Stone National Hatchery operations. Project planners and USFWS staff need to develop a detailed plan to ensure that hatchery operations are compatible with the recovery goals for Battle Creek.*

The expectation is that development of an adaptive management plan for the CNFH will provide: (1) objective assessment of the importance and understanding of currently identified hatchery issues that may adversely affect the restoration of salmonid populations in upper Battle Creek; and (2) decision support processes to identify, evaluate, and address existing and future concerns.

The adaptive management plan developed to guide ongoing management of the BCRP (Terraqua 2004) does not include the CNFH because the two programs operate under different authorities and responsibilities (Jones and Stokes 2005a). Thus, this document describes a plan that supports adaptive management of the CNFH, and to the extent possible, integrated adaptive management of the CNFH and BCRP. The overall aim is to maximize compatibility of the CNFH with the BCRP, thereby contributing to the further reconciliation of ecological functions and human services in the Battle Creek watershed.

1.1 Coleman National Fish Hatchery Adaptive Management Plan Purpose Goal and Objectives

Clear statements of the purpose, goal, and objectives are foundational elements of any adaptive management plan. The purpose describes what the plan is intended to do, while the goal and objectives describe what the plan is expected to achieve. A technical advisory committee (TAC or CNFH-AMP TAC; see Section 1.2 below) was closely consulted during development of the purpose, goal, and objectives for the Coleman National Fish Hatchery Adaptive Management Plan (CNFH-AMP). Key parameters and several important assumptions that directly influence the stated purpose, goal, and objectives also were identified during TAC consultation:

- The CNFH will continue to operate to partially mitigate for the loss of anadromous salmonid production associated with the construction of Shasta Dam (Jones and Stokes 2005a). Thus, the CNFH-AMP goal assumes the continued coexistence of the CNFH and the BCRP.

- The CNFH-AMP assumes restoration of the Battle Creek watershed will occur as described in Jones and Stokes (2005a), and implementation of the Battle Creek Salmon and Steelhead Restoration Project Adaptive Management Plan (BCRP-AMP) will occur as described in Terraqua (2004).
- The CNFH-AMP will be closely coordinated with the BCRP-AMP. Together the two adaptive management plans will form a single integrated framework for adaptive management in Battle Creek. However, the goals and objectives of the BCRP-AMP are not the same as the goal and objectives of the CNFH-AMP (Table 1.1). To maximize the chances of successful outcomes from the integrated adaptive management framework, it is assumed that the goal for the CNFH-AMP will seek to achieve compatibility with the BCRP by acknowledging that adjustment and adaptations can occur in: (1) CNFH programs and operations; (2) the BCRP (including Pacific Gas and Electric Company (PG&E) facilities within the Federal Energy Regulatory Commission's Battle Creek Hydroelectric Project boundaries); or (3) areas of overlapping interest, such as lower Battle Creek.
- The goal and objectives of the CNFH-AMP are not the same as the goal and objectives of the CNFH (Table 1.1). It is assumed that responsibilities described in the 1993 agreement between USFWS and Reclamation will continue. Specifically, the agreement stipulates that USFWS will continue to operate, maintain, and evaluate the facility for the salvage, protection, and preservation of fish spawned in the upper Sacramento River Basin prior to the construction of Shasta and Keswick dams. Reclamation will assume financial responsibility for the facility and arrange for recovery costs from project beneficiaries in accordance with Federal reclamation law (Jones and Stokes 2005a). Establishing a goal and objectives for the CNFH-AMP that differ from the goal and objectives established for the hatchery creates a circumstance requiring special treatment in the application of adaptive management. This is discussed further in Chapter 2.

The **purpose** of the CNFH-AMP is to acknowledge, identify, study, and evaluate uncertainties regarding the operation of a large scale fish hatchery in a watershed being restored for natural salmonid populations. The CNFH-AMP is intended to closely coordinate with the BCRP-AMP, so that together the two adaptive management plans form a single integrated framework for adaptive management in Battle Creek.

The **goal** of the CNFH-AMP is to provide solutions and processes to support optimization of CNFH programs, operations, and infrastructure so that the hatchery mitigation goals and objectives are achieved, while maximizing its compatibility with the BCRP.

The **objectives** of the CNFH-AMP are as follows:

- Describe and evaluate ten issues related to the CNFH identified by the TAC, and identify solutions to those issues considered of most importance. Develop cost and resource estimates to implement the Tier 1 (i.e., top priority) solutions by 2021.
- Describe and evaluate four key issues of direct relevance to Battle Creek restoration, and determine their importance in achieving BCRP goals.

- Provide an integrated monitoring plan and quantitative life-cycle models to support the coordinated assessment of the CNFH and BCRP.
- Identify and describe diagnostic studies that address the greatest areas of uncertainty related to the CNFH. Provide cost and resource estimates to complete the Tier 1 diagnostic studies by 2021.
- Describe a governance structure that provides for ongoing communication and coordinated decision-making between the CNFH and BCRP projects throughout their implementation.
- Describe the steps and processes for adaptive management in sufficient detail so that the CNFH-AMP remains a durable plan with ongoing utility.

These objectives are structured to support the aim of having two adaptive management plans that form a single integrated framework for adaptive management in Battle Creek.

Table 1.1. Purpose, goals, and objectives of the BCRP-AMP (from Terraqua 2004), CNFH (from USFWS 2011), and the CNFH-AMP.

BCRP-AMP	CNFH	CNFH-AMP
Purpose		
Restore anadromous fish habitat in Battle Creek and its tributaries while minimizing the loss of clean and renewable energy produced by the Hydroelectric Project.	The CNFH provides partial mitigation for the loss of fish habitat due to the construction of Shasta and Keswick dams.	The CNFH-AMP will acknowledge, identify, study, and evaluate uncertainties regarding the operation of a large scale fish hatchery in a watershed being restored for natural salmonid populations.
Goals		
Restore and enhance approximately 42 miles of anadromous fish habitat in Battle Creek and an additional 6 miles of habitat in its tributaries while minimizing the loss of renewable energy produced by the Battle Creek Hydroelectric Project (FERC Project No. 1121). The additional 48 miles of anadromous fish habitat is being restored to support an assemblage of fish species including four separate runs (races) of Chinook salmon and steelhead. Winter-run Chinook, spring-run Chinook, and steelhead have been identified as the priority species for recovery because they are listed under the state or federal ESA.	<u>Fall & Late-fall Chinook salmo</u>n Contribute to ocean harvest. Contribute to the commercial fishery, ocean sport fishery, and freshwater sport fishery. Provide adequate escapement to the hatchery for broodstock. Minimizing negative impacts to natural populations. Provide fish for future recovery efforts, if needed. <u>Steelhead</u> Mitigate for fishery losses resulting from the construction of Shasta and Keswick dams. Contribute to the sport fishery in the Sacramento River and Delta. Provide adequate broodstock to the hatchery. Minimize risks to natural populations.	The goal of the CNFH-AMP is to provide solutions and processes to support optimization of CNFH programs, operations, and infrastructure so that the hatchery mitigation goals and objectives are achieved, while maximizing its compatibility with the BCRP.

Table 1.1 continued. Purpose, goals, and objectives of the BCRP-AMP (from Terraqua 2004), CNFH (from USFWS 2011), and the CNFH-AMP.

BCRP-AMP	CNFH	CNFH-AMP
Objectives		
Restoration of self-sustaining populations of four races of Chinook salmon and steelhead, and their habitats in the Battle Creek watershed through a voluntary partnership with state and federal agencies, a third party donor(s), and PG&E. <u>Natural spawner escapement objectives</u>[/1]: Winter-run = 2,500 Spring-run = 2,500 Fall-run = 4,500 Late-fall run = 4,500 Steelhead = 5,700	CNFH objectives are to attain the following numerical targets[/2] <u>Fall Chinook</u>: Number of broodstock = 5,200 Annual juvenile release = 12,000,000 (@ 90 fish/pound (fish/lb)) <u>Late-fall Chinook</u>: Number of broodstock = 540 Annual juvenile release = 1,000,000 (@ 13 fish/lb) <u>Steelhead</u>: Number of broodstock = 400 Annual juvenile release = 600,000 (@ 4 fish/lb)	Describe and evaluate ten issues related to the CNFH identified by the TAC, and identify solutions to those issues considered of most importance. Develop cost and resource estimates to implement the Tier 1 (i.e., top priority) solutions by 2021. Describe and evaluate four key issues of direct relevance to Battle Creek restoration and determine their importance in achieving BCRP goals.
Up-front certainty regarding specific restoration components, including Resource Agency prescribed in-stream flow releases, selected decommissioning of dams at key locations in the watershed, dedication of water diversion rights for instream purposes at decommissioned sites, construction of tailrace connectors, and installation of fish ladders and fail-safe fish screens.		Provide an integrated monitoring plan and quantitative life-cycle models to support the coordinated assessment of the CNFH and BCRP.
Timely implementation and completion of restoration activities.		Identify and describe diagnostic studies that address the greatest areas of uncertainty. Provide cost and resource estimates to complete the Tier 1 diagnostic studies by 2021.
Joint development and implementation of a long-term adaptive management plan with dedicated funding sources to ensure the continued success of restoration efforts under this partnership.		Describe a governance structure that provides for ongoing communication and coordinated decision-making between the CNFH and BCRP projects throughout their implementation. Describe the steps and processes for adaptive management in sufficient detail so that the CNFH-AMP remains a durable plan with ongoing utility.

/1. Escapement numbers are predicted population sizes following restoration based on USFWS (1995) as cited in Terraqua (2004).

/2. The number of broodstock listed for fall and late-fall Chinook and steelhead is the minimum number of adult fish needed to meet the production target. However, in practice the CNFH will increase the number of broodstock to increase the representation of individuals throughout the run and maintain genetic variability. The increased numbers are approximately 8,000 for fall Chinook; 1,000 late-fall Chinook; and 800 steelhead.

1.2 Plan Development and Organization

An open and inclusive process was used to develop the CNFH-AMP. The consultant team engaged and received input from the TAC throughout plan conception, development, and revision (Table 1.2). Many parts of the plan are a result of TAC discussions and input. Two public meetings were held, one early on to aid in scoping the plan, and a second meeting during the public comment period for the draft plan. An independent science panel was commissioned to evaluate the technical merits of the draft plan. The science panel was provided with a specific review charge, and its comments were used to revise the plan. Finally, Federal and State agency review occurred to maximize the veracity and utility of the plan to those agencies with direct involvement in the BCRP and the CNFH.

Table 1.2. Members and affiliation of the CNFH-AMP Technical Advisory Committee (TAC).

Technical Advisory Committee Members	Affiliation
Naseem Alston	NOAA, National Marine Fisheries Service
Mike Berry	CA Department of Fish and Wildlife
Matt Brown	U.S. Fish & Wildlife Service
Amanda Cranford	NOAA, National Marine Fisheries Service
Laurie Earley	U.S. Fish & Wildlife Service
Brett Galyean	U.S. Fish & Wildlife Service
Gene Geary	Pacific Gas & Electric Company
Scott Hamelberg	U.S. Fish & Wildlife Service
Doug Killam	CA Department of Fish & Wildlife
Mary Marshall	U.S. Bureau of Reclamation
Kevin Niemela	U.S. Fish & Wildlife Service
Robert Null	U.S. Fish & Wildlife Service
Trang Nguyen	U.S. Bureau of Reclamation
Steve Tussing	Battle Creek Watershed Conservancy
Jonathan Walsh	Pacific Gas & Electric Company

1.2.1 Document Organization

This document provides an adaptive management plan to support future operations of the CNFH in a watershed that has undergone substantial restoration. To the extent possible, the document provides for the coordinated implementation of the CNFH and the BCRP under an integrated adaptive management framework. In order to increase the plan's ease of use and utility, the main document provides focused information, while documents providing relevant technical details and directly supporting information are included as appendixes. This adaptive management plan is based on the CNFH facilities and operations as described in the 2011 biological assessment for the hatchery (USFWS 2011). Appendix A provides a description of the CNFH, its setting, and information about the scope of this project.

Adaptive management is defined in this document as a set of tools and processes that can provide information to learn about the system, and if needed, change the system (Hollings 1978). The CNFH-AMP relies on an adaptive management cycle developed for use in the CALFED Ecosystem Restoration Program (see CALFED 2000, and Healey et al. 2008 for more details). This same adaptive management cycle is used in the BCRP-AMP, and thus serves as a central component of the integrated framework under which both plans will be implemented. The adaptive management cycle and its component steps are described in Chapter 2.

A functional governance structure is essential to successful implementation of an adaptive management plan. Appendix B provides a detailed description of the coordinated governance structure that will be used to support information communication and assessment, conflict resolution, and decision-making throughout implementation of the CNFH and BCRP adaptive management plans.

The issues that have the potential to adversely affect the CNFH's compatibility with the BCRP, and a summary of their evaluations are presented in Chapter 3. Summary evaluations of four key BCRP issues also are presented in Chapter 3. All of these issues were evaluated in the context of four conceptual models. These conceptual models along with detailed analyses of the issues are presented in Appendix C. Two quantitative life-cycle models were developed to estimate the effects many of the identified issues may have on Chinook salmon and Central Valley steelhead populations in Battle Creek. Documentation for these models is presented in Appendixes D and E.

Chapter 4 provides details on the identification and prioritization of actions or studies to address issues determined to be of importance, or with incomplete understanding. Further, an integrated monitoring plan is provided (Appendix F) to guide the coordinated collection and analysis of data used to assess both the CNFH and the BCRP, based on pre-determined performance measures. This plan also identifies monitoring efforts to inform long-term status and trends metrics for target fish stocks, as well as the data collection efforts to support the quantitative life-cycle models.

A wealth of information is available on the Battle Creek watershed, the CNFH, and the BCRP (see for example, the Battle Creek Watershed Conservancy web site (http://www.battle-creek.net) or Jones and Stokes 2005a). However, this document is not intended to provide an extensive review of this information. Salient facts and information are included where appropriate, with references to source materials that provide detailed information.

1.3 Literature Cited

CALFED. 2000. Ecosystem Restoration Program Plan: Strategic Plan for Ecosystem Restoration. Technical appendix in: CALFED Bay-Delta Program Final EIS/EIR.

Healey, M.C., M.D. Dettinger, and R.B. Norgaard, eds. 2008. The State of Bay-Delta Science, 2008. Sacramento,CA: CALFED Science Program. 174 pp.

Hollings, C.S. 1978. Adaptive environmental assessment and management. New York: Wiley Publisher. 377 p.

Jones and Stokes. 2005a. Battle Creek salmon and steelhead restoration project final environmental impact statement/environmental impact report. Volume I, Report. Sacramento, CA.

NMFS (National Marine Fisheries Service). 2014. Final Recovery Plan for the Evolutionarily Significant Units of Sacramento River Winter run Chinook Salmon and Central Valley Spring run Chinook Salmon and the Distinct Population Segment of Central Valley Steelhead. Sacramento Protected Resources Division, CA. 273p.

Richardson, T.H. 1987. An analysis of the effectiveness of the mitigation plan for Shasta and Keswick dams. U.S. Department of Interior, Fish and Wildlife Service, Division of Ecological Services. Sacramento, CA. 84 p.

Technical Review Panel. 2004. CALFED Bay-Delta Program, Report of the Technical Review Panel - Compatibility of Coleman National Fish Hatchery Operations and Restoration of Anadromous Salmonids in Battle Creek. 68 p.

Terraqua. 2004. Draft Battle Creek salmon and steelhead restoration project adaptive management plan, prepared for the U.S. Bureau of Reclamation, Pacific Gas and Electric Company, National Marine Fisheries Service, U.S. Fish and Wildlife Service, and California Department of Fish and Game. Wauconda, Washington. 238 p.

USFWS (United States Fish and Wildlife Service). 2011. Biological assessment of artificial propagation at Coleman National Fish Hatchery and Livingston Stone National Fish Hatchery: program description and incidental take of Chinook salmon and steelhead. U.S. Fish and Wildlife Service, Red Bluff and Coleman National Fish Hatchery Complex, CA. 406 p.

Chapter 2: Framework and Processes for Adaptive Management of the Coleman National Fish Hatchery

> *We do not learn from a system that is constant. This is not serious if the system is known, is static, and presents no surprises. But resource systems are exactly the opposite. They are known only very partially, which will always be so; they are dynamic and they produce endless surprises –from the collapse of fisheries to the reemergence of other ecosystems. And the act of management and harvesting changes the fundamental structure of the resource itself. Walters (1986).*

A variety of processes and techniques have been advanced to guide those who seek to plan and implement a project or program through adaptive management (see Stankey et al. 2005 for a thoughtful review). At the project level, an adaptive management framework typically involves a cyclical process that makes explicit linkages among the steps of issue identification, information acquisition, management decisions, and management action. Adaptive management provides a rational approach for addressing issues where competing but uncertain solutions exist, and for which management cannot be delayed until the issues and solutions are fully understood (Walters 1986). It is often considered for use in ecological systems where:

4. <u>Conflicts exist</u>. The overarching issue for the CNFH-AMP concerns the potential conflicts between the existence of the hatchery, and the effects its ongoing operations may have on the timely restoration of anadromous salmonid populations in Battle Creek.

5. <u>The stakes are high</u>. The CNFH provides partial mitigation for impacts associated with Shasta Dam, which created the largest reservoir in California’s Central Valley. The completion of Shasta dam is estimated to have blocked “approximately 50% of the Chinook salmon spawning beds in the Sacramento River system” (Skinner 1958). The CNFH is considered highly successful, contributing substantially to the multi-million dollar ocean and in-land fisheries, and it has become an important part of the local community (USFWS 2011). Yet Battle Creek is a unique watershed that is considered highly important in the context of endangered and threatened species recovery planning for winter and spring Chinook salmon, and Central Valley steelhead (NMFS 2014). Approximately $150 million will be spent to restore the upper Battle Creek watershed, with the expectation that the restored area will support self-sustaining populations of threatened and endangered anadromous salmonids (Jones and Stokes 2005a, Terraqua 2004).

6. <u>There is uncertainty about the best way to proceed</u>. A fundamental premise of adaptive management is that knowledge of ecological systems is not only incomplete but elusive (Walters and Holling 1990). The CNFH-AMP TAC identified ten issues

associated with the hatchery and its operations that may adversely impact the BCRP. Further, four key issues related to the BCRP were identified, and their impacts also were evaluated. However, uncertainties exist regarding the importance and understanding of these issues, as well as the most appropriate course of action to address each issue. Thus, the purpose of the CNFH-AMP is to acknowledge, identify, study, and evaluate uncertainties regarding the operation of a large-scale fish hatchery in a watershed being restored for natural salmonid populations.

2.1 Adaptive Management Cycle

The adaptive management cycle used in this plan is based on the approach developed for the CALFED Ecosystem Restoration Program (Figure 2.1). This adaptive management cycle also is used in the BCRP-AMP (Terraqua 2004).

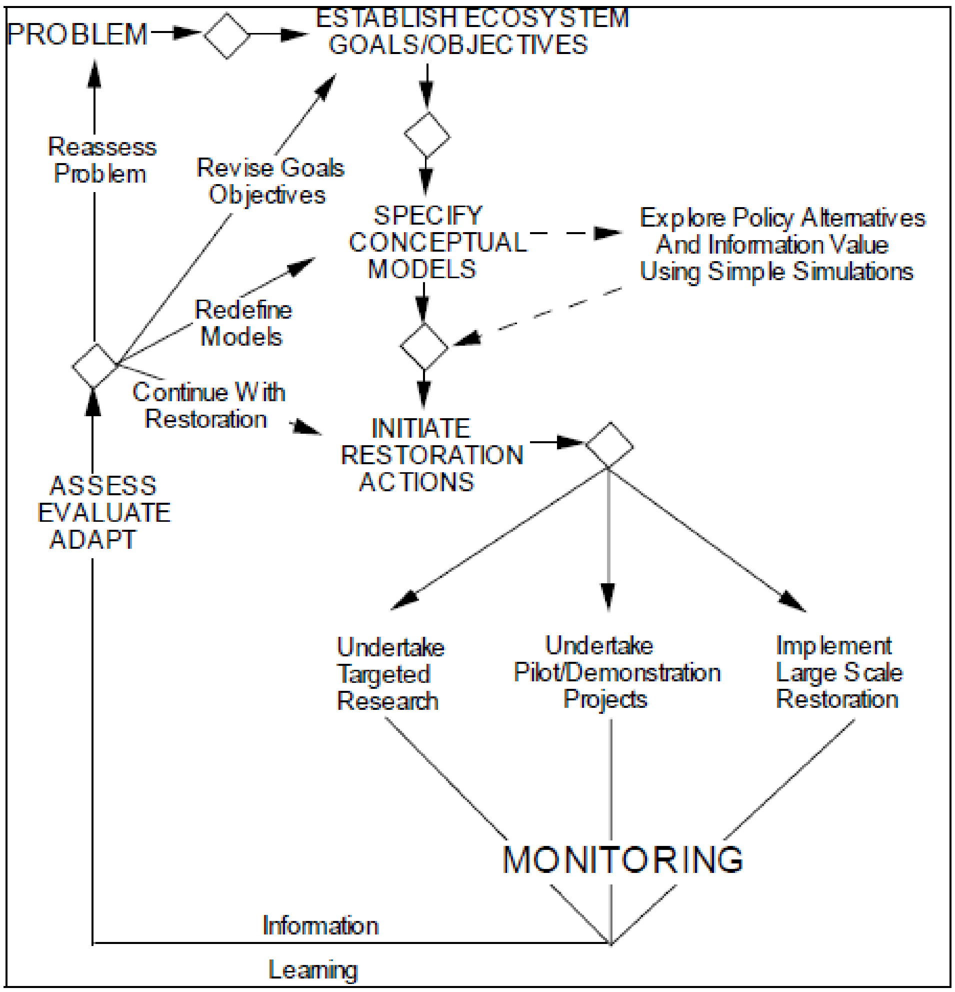

Figure 2.1. Diagram of the adaptive management cycle developed for use in the CALFED Ecosystem Restoration Program, and used in the BCRP-AMP (from Healey 2001, as cited in Terraqua 2004).

The BCRP-AMP identified six steps of passive adaptive management in its processes to identify and evaluate problems, and to develop solutions:

1. Review the available information so as to define the problem as precisely as possible.

2. Think of plausible solutions to the management problem. Describe these solutions in terms of conceptual models of system behavior, and its response to possible management interventions.

3. Subject these solutions to some form of structured analysis to determine which solution offers the greatest promise of success.

4. Specify criteria (indicators or measures) of success or failure of the most promising solution.

5. Implement the most promising solution, and monitor the system response according to the criteria developed in step 4.

6. Adjust the design of the solution from time to time according to the results of monitoring in an attempt to make it work better.

The CNFH-AMP employs an adaptive management cycle similar to that used in the BCRP-AMP (Figure 2.2), although some important changes were incorporated to more accurately reflect the order of the steps and process used to develop the CNFH-AMP, and to address the unique relationship among the CNFH, the BCRP-AMP, and this adaptive management plan.

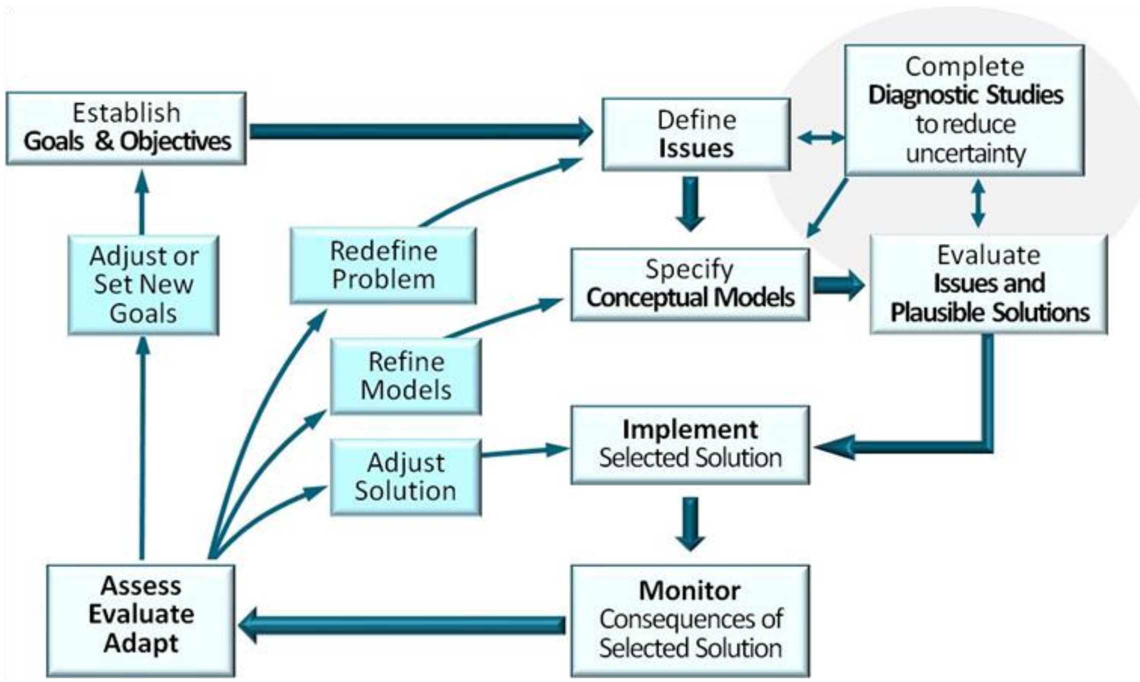

Figure 2.2. Diagram of the adaptive management cycle developed for the CNFH-AMP. (Adapted from Healey et al. 2008). The route with thicker arrows generally follows the passive adaptive management cycle used in the BCRP-AMP. The shaded area (upper right) indicates where active adaptive management can occur within the cycle.

The CNFH-AMP adaptive management cycle generally relies on a passive adaptive management approach. In passive adaptive management historical information is used to frame a single best approach along a linear path assumed to be correct (i.e., it is based on the belief that past assumptions and antecedent conditions still apply; Stankey et al. 2005). This approach applies a formal, rigorous, albeit retrospective analysis to data and information as a means of framing new choices, providing understanding, and making decisions. The routes in the CNFH-AMP adaptive management cycle involving diagnostic studies and their input into other steps in the cycle is considered the active adaptive management loop (Figure 2.2). Active adaptive management allows for the purposeful integration of experimentation into policy and management design and implementation (Kusel et al. 1996 as cited in Stankey et al. 2005). However, the application of active adaptive management in the CNFH-AMP focuses on the use of experimentation to reduce uncertainty associated with defining/clarifying issues, evaluating issue importance, and evaluating alternative solutions.

The following steps were completed to develop the CNFH-AMP using the adaptive management cycle shown in Figure 2.2. Long-term implementation of the CNFH-AMP will require revisiting each of the steps in this adaptive management cycle, and critically evaluate the outputs from each step based on incorporation of new data and information.

1. Establish goals and objectives. Goals and objectives for the CNFH-AMP were developed in collaboration with the TAC. As noted in Chapter 1, the CNFH-AMP goal and objectives are not the same as the goal and objectives for the hatchery or the BCRP-AMP (see Table 1.1). Solutions selected to address important issues are intended to maximize the compatibility of the CNFH and its operations with the BCRP; however, overall assessment of CNFH-AMP performance will be based on how well the plan achieves its unique goal and objectives, not the goal and objectives of the CNFH or the BCRP. This is an unusual situation. It is more common for a project's adaptive management plan to have the same goals and objectives as the project (e.g., as was done for the BCRP-AMP). Further, it is more common for two projects that co-occur in the same watershed, and with interest in the same species, to establish shared goals and objectives. However, this was not possible in this case due to the differing authorities and responsibilities underlying the two projects (Appendix B).

   Establishing separate goals and objectives for the project and its adaptive management plan has both pros and cons. Separate goals and objectives provide greater flexibility to those implementing the CNFH-AMP in responding to changing conditions at the CNFH, including changes to its goal and objectives. However, establishing separate goals and objectives also creates the possibility for greater divergence between the CNFH and the CNFH-AMP over time. Moreover, maintaining separate goals and objectives among the CNFH, the CNFH-AMP, and the BCRP-AMP creates the need for the governance structure established to oversee implementation to include processes and authorities that deal with conflicts, which may arise due to differing goals and objectives. The operating premise is that collaborative implementation of both adaptive management plans by the responsible agencies and stakeholders will result in the achievement of all identified goals (Appendix B).

2. Define the Issues. Issues (i.e., problems in Figure 2.1) were defined as precisely as possible using available information, and in collaboration with the TAC (see Chapter 3). Issues for both the CNFH and the BCRP were identified for evaluation. The CNFH issues are based on the most recent hatchery project description (USFWS 2011, Appendix A). The BCRP issues are based on the BCRP-AMP (Terraqua 2004). The issues do not consider possible future CNFH operations or programs, but they do

assume implementation of the BCRP will result in some number of fish from each target stock reproducing and rearing in upper Battle Creek. The CNFH issues statements were developed within the context of the CNFH-AMP goal of meeting CNFH mitigation obligations, while maximizing its compatibility with the BCRP.

3. Specify conceptual models. Simple conceptual models were developed to describe the interactions among CNFH issues and BCRP restoration actions targeting four life-stage events of anadromous salmonids: (a) adult immigration; (b) spawning and egg incubation; (c) juvenile rearing and emigration from Battle Creek; and (d) rearing in the Sacramento River, San Francisco Estuary, and Pacific Ocean. The conceptual models were developed in this way to ensure connectivity and consistency with the conceptual models used in the BCRP-AMP (Terraqua 2004). This connectivity is another tangible aspect of the integrated framework for adaptive management developed to support coordinated implementation of the CNFH-AMP and the BCRP-AMP. Further, this connectivity will help promote future coordinated efforts to update and revise the conceptual models used in this plan, and in the BCRP-AMP. Appendix C provides the conceptual models used in this adaptive management plan.

4. Evaluate the issues and plausible solutions. The identified issue were analyzed to assess their importance and understanding (Appendix C). In many cases, results from quantitative life-cycle models (Appendixes D and E) also were used to inform the issue evaluation, although some issues were outside the scope of the models. Solutions were identified and evaluated as part of the issue analysis. Solutions generally consisted of one or more potential actions that could reduce or avoid the adverse effects of the issue, and a tiered solution set was then developed using objective criteria. Factors considered in selecting solutions included feasibility, expected benefits to the BCRP versus expected impacts to CNFH operations, potential for collateral impacts, and durability. Diagnostic studies were identified to address issues estimated to have moderate or low understanding, or where no preferred solutions could be confidently identified due to a lack of understanding.

5. Implement selected solution. Implementation of this adaptive management plan and the BCRP-AMP are expected to begin after completion of the BCRP. Successful implementation of the CNFH-AMP requires an effective governance structure, and functional decision-making processes (Section 3.2). Additional funding also is necessary (Section 3.4).

6. Monitor consequences of the selected solution. Monitoring is necessary to determine the effects of solutions selected for implementation. Appendix F describes the monitoring efforts necessary to assess the performance of preferred solutions. Chapter 4 provides: (1) specifications of performance measures designed to gauge success or failure; (2) data analysis procedures; and (3) reporting protocols.

7. Assess, evaluate, adapt. This step also occurs during implementation of the CNFH-AMP, and is critical to completing the adaptive management cycle. This is the step where information is evaluated and assessed, and recommendations for change (adaptations) are determined. The governance structure and decision-making

processes developed for the CNFH-AMP provide a coordinated framework, and assign responsibilities for completing the activities associated with this step (see Section 2.2 and Appendix B). Further, Section 2.3 describes tools and processes that support the completion of this step.

2.2 Governance and decision-making

Clear and effective project governance and decision-making processes are essential to the success of any adaptive management plan. Project governance is defined as the management framework within which project information is assimilated and converted into knowledge, and project decisions are made. The role of project governance is to provide a decision-making framework that is durable, transparent, and credible. Decision-making processes more specifically define the steps and responsibilities necessary to assimilate information and arrive at a decision. These processes also describe how a decision is made (e.g., by consensus, majority rule, or individual authority).

In the context of the CNFH-AMP, project governance and decision-making processes are central to accomplishing the tasks of assessment, evaluation, and adaptation (Figure 2.2). Project governance outcomes include decisions that can result in a variety of adaptations (i.e., redefine problems, adjust existing goals, set new goals, refine models, or adjust solutions). Outcomes also include decisions and recommendations having other programmatic implications (e.g., new funding requests or allocations, modifications to monitoring efforts, or requests for new studies). Thus, effective project governance and decision-making processes are crucial to determining whether an adaptive management plan becomes fully functional or not.

Providing a governance structure and decision making processes that are compatible with both the BCRP-AMP, and the existing CNFH management is essential to the integrated implementation of the CNFH and BCRP adaptive management plans. To that end, Federal and State agencies, and Pacific Gas and Electric Company collaborated in the development of a charter agreement to support coordinated governance and decision-making throughout implementation of the CNFH-AMP and the BCRP-AMP (Figure 2.3, Appendix B). Implementation of the charter will ensure ongoing interactions and effective communications occur between the existing governing bodies with primary responsibilities for the CNFH-AMP and the BCRP-AMP, so that together the two adaptive management plans form a single integrated framework for adaptive management in Battle Creek as described in Jones and Stokes (2005a).

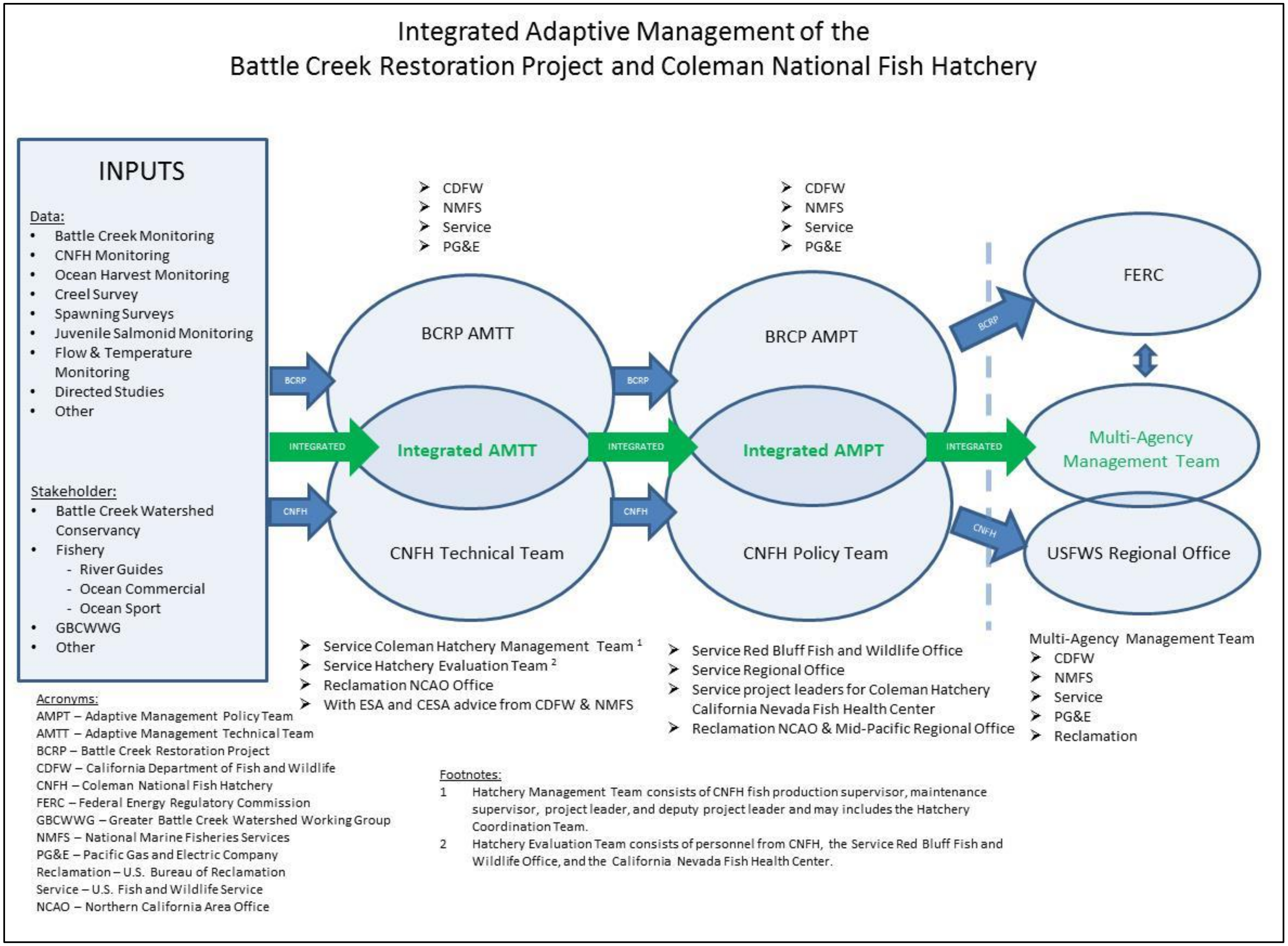

Figure 2.3. Diagram of the proposed decision-making structure to support coordinated implementation of the CNFH-AMP and BCRP-AMP. See Appendix B for more details.

2.3 Tools and processes to optimize CNFH-AMP Implementation

Merely producing an adaptive management plan for the CNFH is not enough to ensure the sustained commitments of all parties to ensure successful implementation, especially in dealing with adaptations requiring substantive funding or resource augmentation. An explicit assumption is that all responsible agencies and stakeholders will work collaboratively to establish the funding, resources, and infrastructure necessary for sustained implementation of this plan. The USFWS and Reclamation have demonstrated this level of commitment in the past with construction of the hatchery water treatment plant, the redesign and screening of two CNFH water intake structures, and the completion of substantial upgrades to the fish barrier weir and ladder system. In the future, however, a larger suite of agencies and entities with a direct stake in the CNFH and the BCRP will need to work together to obtain the goal of maximizing compatibility of the CNFH with the BCRP, while meeting the hatchery's mitigation goals.

This section describes tools and processes that can help to optimize the future implementation of the CNFH-AMP and the BCRP-AMP, and help to achieve a single integrated framework for adaptive management in Battle Creek. These tools and processes also should help in identifying and contending with future issues.

2.3.1 Future issue identification and assessment

It is reasonable to expect new issues will emerge that affect the compatibility of the CNFH with the BCRP, or affect the ability of these projects to separately achieve their goals. These issues may be the result of managed drivers (i.e., physical, chemical, or biological forces under direct management control or influence) or uncontrolled drivers (i.e., drivers outside the direct control of project managers, such as climate change). All of the issues identified and evaluated in Appendix C are considered managed drivers, and there is no doubt new issues will emerge in the future.

Critical examination and regular revision of the conceptual models developed for this plan and for the BCRP-AMP provides an objective and structured framework for identification and assessment of future issues. These efforts would incorporate new information and findings from monitoring and research to identify emerging issues and support their evaluation. Monitoring and research results also would be used to: (1) reduce uncertainty among existing drivers, linkages, and outcomes; (2) identify and evaluate new drivers and linkages; and (3) focus efforts to update and expand the quantitative life-cycle models (Appendixes D and E).

A commitment to ongoing communication and coordination also is vital to the early identification and assessment of new issues. The governance structure presented in Appendix B describes the interactions and pathways for ongoing communication and coordination among the entities responsible for implementation of the CNFH-AMP and the BCRP-AMP. Ideally, the staff engaged in the two projects would work together to critically examine and revise the conceptual models, evaluate new information, and describe new issues.

2.3.2 Tools and Processes for assessment evaluation and adaptation

The concept of learning is central to adaptive management and is grounded in the recognition that learning derives from action, and in turn, informs subsequent actions (Stankey et al. 2005). Tools and processes for assessment, evaluation, and adaptation are intended to result in learning, and incorporate the activities of data management, analysis, and reporting in order to accomplish the following objectives: (1) manage data and information in ways that ensure their quality and availability; (2) complete analyses, which convert data into information that can directly inform and guide adaptive management; and (3) share that information with others to promote transparency. These activities are essential to a functional adaptive management program, because they provide research and monitoring results in forms that managers and decision-makers can use in their evaluations, and subsequent development of adaptations.

Implementation of a structured data management, analysis, and reporting system is considered the best way to ensure that data are translated into information, and information is converted into knowledge and learning as efficiently as possible. Ideally, this system works within existing institutional arrangements and policies to meet agency communication and coordination needs, while allowing for the integration of data and information among a wide variety of entities working in the Battle Creek watershed, which supports transparency.

A dedicated source of funds and resources is required for long-term implementation of a data management, analysis, and reporting system to support the CNFH-AMP. It is recommended that implementation of this system become a shared responsibility, given the expectation that the CNFH and BCRP adaptive management plans will form a single integrated framework for adaptive management in Battle Creek.

According to Terraqua (2004) reporting will be an important component of BCRP adaptive management, which includes emergency reporting procedures, regular periodic reporting, and final long-term reporting. Integrating these efforts with the reporting the USFWS completes for the CNFH is considered highly beneficial to achieving a single integrated framework for adaptive management. Furthermore, other entities (e.g., NMFS, CDFW, or PG&E) may also consider contributing to maintenance and operation of a data management, analysis and reporting system, given the benefits this system would provide to these entities, and given the enhanced watershed-wide understanding that would result. The identification of responsible entities and their contributions to fulfilling the requisite functions in this regard is critical to achieving success, and to minimizing overall costs by eliminating redundant efforts among the entities.

At a minimum, the data management, analysis, and reporting system would support two essential activities:

- <u>Establishment and maintenance of a centralized database</u>. A centralized database would promote the organization and management of both research and monitoring data in a manner that ensures their quality, utility, and accessibility. Web-based infrastructure could be developed and maintained so that basic data and summary information is stored, integrated, and readily accessible to a diversity of users.

- Completion of an annual assessment report. This report would be completed under the direction of the integrated Adaptive Management Technical Team (AMTT, Appendix B). The report would communicate an assessment from implementing both the CNFH-AMP and the BCRP-AMP, including
  - Provide basic information on Battle Creek habitat and resource status, and trends directly related to salmonid ecology.
  - Provide basic information on hatchery operations and outputs.
  - Provide assessments of CNFH-AMP and BCRP-AMP implementation actions using established performance measures.
  - Summarize information from the results of diagnostic studies and other science projects completed during the previous year. This information would aim to improve understanding and address information gaps.
  - Identify new research needs that have emerged as a result of monitoring results, new environmental conditions, or emerging issues.
  - Present the evaluations and resulting adjustments and adaptations made to the CNFH and BCRP. Both interannual (i.e., mid-course) adjustments and more substantive adaptations would be described.

The suggested timeline for report preparation is as follows:

October – provide a 'data draft' that includes the relevant data and analyses to be presented that year;

January – provide a complete draft including all relevant data and analyses, as well as recommended adjustments and adaptations;

March provide the final report.

The information in this annual report could serve as the basis for an annual public meeting to allow the integrated AMTT to: (1) share information about the progress and challenges in implementing the CNFH-AMP and the BCRP-AMP; (2) describe next steps, including adjustments or adpatations; and (3) obtain input from stakeholders and the general public.

2.4 Funding for Implementation of the Coleman National Fish Hatchery Adaptive Management Plan

A 1993 interagency agreement between USFWS and Reclamation establishes general principles, and describes responsibilities of both agencies concerning the custody, operation, and funding for the CNFH. This agreement states

> *Reclamation (a) shall pay all applicable Hatchery costs including the costs of the appropriate rehabilitation of existing Hatchery facilities and equipment, and the costs of any appropriate mitigation facilities; and (b) arrange for the recovery of such costs from Project beneficiaries in accordance with Federal Reclamation law.*

Reclamation annually provides the USFWS approximately $5 million to support CNFH, Livingston Stone National Fish Hatchery (LSNFH), and associated field facilities. Hatchery-related evaluations, biological studies and investigations are recognized as essential components of the CNFH mitigation programs (S. Hamelberg, pers. comm.). Annual appropriations to support the two hatcheries come from Reclamation's 'Water and Related Resources' fund. In Fiscal Year 2012 (October 2011-September 2012) the funds provided by Reclamation were allocated as detailed in Table 2.1.

Table 2.1. Fiscal year 2012 allocations of Reclamation funding provided to support the USFWS programs at CNFH and LSNFH and associated field facilities (Data from S. Hamelberg USFWS, pers. comm.).

Facility (activities)	Funding Provided
CNFH (propagation of fall and late-fall Chinook salmon, and steelhead)	$2,677,456
LSNFH (propagation of winter Chinook salmon)	$250,000[1/]
CA/NV Fish Health Center (fish health monitoring and pathogen diagnostic support)	$338,866
Red Bluff Fish and Wildlife Service Office (hatchery-related ESA compliance, monitoring, research, and other activities conducted by the Hatchery Evaluation Program (see Appendix A for more information on many of these activities)	$693,313
Abernathy Fish Technology Center (genetic technical support associated with the endangered winter Chinook salmon propagation program, and to provide fish feed quality control for all propagation programs)	$54,883
Total funding provided to field facilities in FY 2012	**$4,014,518**
USFWS national overhead	$732,163
USFWS Regional Fisheries Office	$292,319
Grand total funding provided in FY 2012	**$5,039,000**

1/ Amount of funding provided to LSNFH is an estimate.

Additional funding above that provided by Reclamation is currently needed to fully fund some ongoing hatchery monitoring activities, such as

- The constant fractional tagging and marking of fall Chinook salmon.
- The 100% tagging and marking of late-fall Chinook salmon.
- The subsequent tag recovery efforts for fall Chinook salmon.
- The winter Chinook salmon carcass survey.

Implementation of the BCRP-AMP and designated funding are described in Terraqua 2004. Implementation of the CNFH-AMP is expected to consist of the following types of activities:

1. Implementation of preferred solutions. Preferred solutions (i.e., implementation actions) may include additions or changes to hatchery infrastructure (e.g., screening water intakes), changes to existing operations (e.g., methods of handling and sorting adult fish during broodstock collection), or changes to existing programmatic policies (e.g., timing and location of juvenile fish releases).

2. Monitoring to assess the performance of implemented actions and issue status. Monitoring includes the regular collection and analysis of data and reporting of results. Monitoring will be needed to: (a) evaluate the performance of implementation actions relative to established indicators of program success; and (b) provide data for the quantitative life-cycle models, when completing subsequent evaluation of the issue statements to confirm the level of importance through time, and to aid in the identification of new issues. Monitoring results also are expected to inform the development of recommendations for adaptations in cases where the actions are not meeting expectations, or for the development of new actions.

3. Diagnostic studies to reduce uncertainties regarding the importance of issues affecting CNFH compatibility with the BCRP or to evaluate potential solutions. The information on diagnostic studies provided in this plan (see Chapter 4) includes identification of the first priority (Tier 1) studies, and further details associated with those studies.

New funding will be needed to implement CNFH-AMP preferred solutions, complete associated additional monitoring, and to complete all diagnostic studies identified in the CNFH-AMP. Members of the Integrated Adaptive Management Policy Team (AMPT, Appendix B) will jointly work together to seek funding and develop funding recommendations to assist USFWS in implementation of the CNFH-AMP. For integrated CNFH and BCRP activities, the Integrated Adaptive Management Technical Team and Integrated AMPT will work together to identify funding needs and to secure available funding to support these needs.

2.5 Literature Cited

Jones and Stokes. 2005a. Battle Creek salmon and steelhead restoration project final environmental impact statement/environmental impact report. Volume I, Report. Sacramento, CA.

NMFS (National Marine Fisheries Service). 2014. Final Recovery Plan for the Evolutionarily Significant Units of Sacramento River Winter run Chinook Salmon and Central Valley Spring run Chinook Salmon and the Distinct Population Segment of Central Valley Steelhead. Sacramento Protected Resources Division, CA. 273p.

Skinner, J.E. 1958. Some observations regarding the king salmon runs of the Central Valley.Water Projects Miscellaneous Report 1. California Department of Fish and Game.

Stankey, George H.; Clark, Roger N.; Bormann, Bernard T. 2005. Adaptive management of natural resources: theory, concepts, and management institutions. Gen. Tech. Rep. PNW-GTR-654. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 73 p.

Terraqua. 2004. Draft Battle Creek salmon and steelhead restoration project adaptive management plan, prepared for the U.S. Bureau of Reclamation, Pacific Gas and Electric Company, National Marine Fisheries Service, U.S. Fish and Wildlife Service, and California Department of Fish and Game. Wauconda, Washington. 238 p.

USFWS (United States Fish and Wildlife Service). 2011. Biological assessment of artificial propagation at Coleman National Fish Hatchery and Livingston Stone National Fish Hatchery:

program description and incidental take of Chinook salmon and steelhead. U.S. Fish and Wildlife Service, Red Bluff and Coleman National Fish Hatchery Complex, CA. 406 p.

Walters, C.J. 1986. Adaptive management of renewable resources. MacMillan Pub. Co, New York, USA. 374 p.

Walters, C.J. and C.S. Holling. 1990. Large scale management experiments and learning by doing. Ecology. 71(6): 2060-2068.

Personal Communications

Hamelberg, Scott. U.S. Fish and Wildlife Service, Coleman National Fish Hatchery. Personal communications on August 29, 2012, October 24, 2012, December 5, 2012, and March 5, 2013.

Chapter 3: Issue Identification and Evaluation

Outcomes from the identification and evaluation of issues are used to determine the need and scope of plausible solutions. The solutions, in turn, are used to guide implementation of the CNFH-AMP, under the direction of specific teams (Appendix B). Four conceptual models were developed to structure the evaluation of ten CNFH and four BCRP issues that may affect the timely and successful restoration of target anadromous salmonid populations in upper Battle Creek. The issues were developed in consultation with the CNFH-AMP Technical Advisory Committee (TAC), with the aim of describing all potential problems as specifically as possible. The issues were then evaluated in the context of the relevant conceptual model. Evaluation of each issue involved a detailed analysis of existing data and information, and where appropriate, examination of quantitative Chinook and steelhead life cycle model (LCM) results (presented in Appendixes D and E, respectively). The results of these analyses were used to determine issue importance and understanding[1]. These determinations serve as the basis for the identification of potential actions (i.e., plausible solutions) that could be pursued to address an issue (Chapter 4). Potential actions for initial execution are categorized as: (1) implementation measures that would result in changes to CNFH infrastructure, operations, or programs; (2) monitoring to better understand conditions over the long-term and address gaps in knowledge; or (3) focused diagnostic studies to increase understanding.

3.1 Issue Statements

The adaptive management cycle used in this plan generally follows the adaptive management cycle used in the BCRP-AMP (Terraqua 2004). (See Chapter 2 for more details about this adaptive management cycle.) Describing the issues (i.e., problem statements) as specifically as possible is a critical step in this adaptive management cycle, and is the main purpose of this section.

3.1.1 CNFH Issues Statements

Unlike most other anadromous fish hatcheries in California, the CNFH is not situated immediately downstream of the dam and reservoir it is intended to mitigate. Instead, the CNFH was established in the lower reach of a unique watershed that is presently undergoing restoration to support self-sustaining populations of anadromous salmonids (Jones and Stokes 2005a). Thus, the overarching issue is the existence of the hatchery and the effects its ongoing operations may have on the restoration of anadromous salmonid populations in Battle Creek. This overarching issue can be parsed into ten specific issues, which are described in the statements below.

<u>CNFH Issue Statement 1 (IS-1)</u> – An unscreened water diversion used at times to deliver water to the CNFH may result in the entrainment of Battle Creek juvenile salmonids.

<u>CNFH Issue Statement 2 (IS-2)</u> – The current CNFH steelhead program excludes naturally produced (unmarked) fish from the broodstock. This practice leads to continued

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[1] Detailed definitions of 'importance' and 'understanding' are provided in Section 3 of Appendix C.

domestication, and the potential for reduced fitness when hatchery fish spawn in the restoration area.

CNFH Issue Statement 3 (IS-3) – Current operations at CNFH and at the fish barrier weir cannot always identify and prevent passage of (1) hatchery origin salmonids, and (2) non-target runs of Chinook salmon.

CNFH Issue Statement 4 (IS-4) – Fall Chinook (hatchery or wild), hatchery late-fall Chinook, and hatchery-origin steelhead may reach the restoration area during high flow events where they may have adverse effects on Battle Creek steelhead, late-fall, spring, and winter Chinook salmon.

CNFH Issue Statement 5 (IS-5) – Trapping, handling, and sorting, of salmonids within CNFH and at the CNFH fish ladder results in migratory delay, and may result in direct mortality or sub-lethal effects to natural origin winter Chinook, late-fall Chinook, spring Chinook, and steelhead trying to access the restoration area.

CNFH Issue Statement 6 (IS-6) – Pathogens resulting from CNFH operations may be transmitted to and expressed among wild fish in the restoration area.

CNFH Issue Statement 7 (IS-7) – In-stream flows in upper Battle Creek are reduced by CNFH water diversion(s) between the diversion site(s) downstream to the return effluent site (distance of 1.2 to 1.6 miles, depending on location of the water intake). These diversions may result in inadequate in-stream flows or increased water temperatures in this segment of the river during drought conditions, and in association with operations at upstream hydropower facilities.

CNFH Issue Statement 8 (IS-8) – High abundance of hatchery-origin adult salmon in lower Battle Creek may create adverse effects including: (1) reduction of in-stream spawning success due to the physical destruction of redds; (2) interbreeding between natural and hatchery origin Chinook salmon; and (3) increased mortality of juvenile salmonids emigrating from upper Battle Creek.

CNFH Issue Statement 9 (IS-9) – Releases of hatchery produced juvenile Chinook salmon and steelhead from CNFH may result in predation on, and behavior modifications to natural origin fish produced in the restoration area.

CNFH Issue Statement 10 (IS-10) – Current production releases of CNFH juvenile fall Chinook salmon may contribute to exceeding the carrying capacity for Chinook salmon in the Sacramento River, San Francisco Estuary, or the Pacific Ocean leading to reduced success of Battle Creek origin salmonids.

3.1.2 BCRP Issues Statements

The BCRP-AMP (Terraqua 2004) identified eleven objectives related to population, habitat and passage within Battle Creek. Terraqua (2004) generated hypotheses, suggested monitoring, and identified triggers associated with each of the eleven objectives. These eleven objectives were consolidated into four key issues, in order to facilitate linkage and comparison with CNFH issues. The four BCRP issues are:

BCRP Issue Statement A (IS-A) – Habitat quality and quantity may be insufficient to support BCRP population objectives.

BCRP Issue Statement B (IS-B) – Battle Creek water temperatures may not be suitable to support salmonid populations consistent with BCRP population objectives.

BCRP Issue Statement C (IS-C) – Natural and man-made barriers may not be sufficiently passable to support BCRP salmonid population objectives.

BCRP Issue Statement D (IS-D) – Redd scouring and related egg mortality may limit BCRP salmonid populations.

3.2 Summary of Issue Statement Evaluations

This section presents a summary of the issue ratings of importance and understanding for each of the stocks targeted for restoration in upper Battle Creek (Tables 3.1 – 3.5)[2]. These ratings are based on the detailed analyses of life-stage specific effects presented in Appendix C. For CNFH issues, this summary also identifies the hatchery program most closely linked with the issue. An overall examination of the results in Tables 3.1 – 3.5 is presented below.

- CNFH Issue 1 (unscreened diversions) will influence the juvenile emigrant life-stage, but is estimated to be of low importance for all BCRP target stocks.
- CNFH Issue 2 (segregated steelhead hatchery program) is not expected to influence BCRP target stocks, but is estimated to be of moderate importance to the steelhead hatchery program.
- CNFH Issue 3 (non-target fish passage) would most influence spawning and egg incubation (via introgression that could occur at this life stage). This issue was estimated to have medium importance for steelhead and spring Chinook, but low importance for all other stocks.
- CNFH Issue 4 (high flow fish passage) would most influence spawning and egg incubation (via introgression that could occur at this life stage), and was estimated to have low importance for all BCRP target stocks.
- CNFH Issue 5 (fish handling effects) would most influence adult immigrants. This issue was estimated to have high importance for late-fall Chinook, medium importance for winter Chinook and steelhead, and low importance for spring Chinook.
- CNFH Issue 6 (Transmission of pathogens) would most influence adult immigrants, but was estimated to have low importance for all BCRP target stocks.
- CNFH Issue 7 (Diversion effects on stream flow and temperature) was estimated to be of low importance to all BCRP target stocks.
- CNFH Issue 8 (Abundance of hatchery Chinook in lower Battle Creek) would most influence spawning and egg incubation. This issue was estimated be of high

[2] Importance and understanding and their associated ratings are described in Appendix C in detail.

importance to fall Chinook in lower Battle Creek, and of low importance to all BCRP target stocks.

- CNFH Issue 9 (In-river release of hatchery fish) would most influence juvenile emigrants, and was estimated to have medium importance for spring, late-fall, and winter Chinook.
- CNFH Issue 10 (Hatchery production influence on carrying capacity) was estimated to be of low importance to all BCRP target stocks, although understanding also is low.
- BCRP issues related to habitat suitability and productivity (issues A and B) were estimated to be of high importance for all BCRP target stocks.
- Adult immigrants having access beyond natural barriers (BCRP Issue C) was estimated to be of high importance to winter Chinook, spring Chinook and steelhead.
- Redd scour (BCRP Issue D) due to high flow events was estimated to be of high importance to steelhead and late-fall Chinook.
- With the exception of CNFH Issues 6 and 7, understanding for most issues (both CNFH and BCRP issues) was considered low or moderate. This suggests the continued need for diagnostic studies and targeted monitoring.

The quantitative life cycle models considered two hypothetical scenarios instructive for assessing cumulative effects on the fulfillment of BCRP population objectives: (1) CNFH least effects, and (2) natural barriers in the BCRP. As explained in Appendixes D and E, the “CNFH least effects” scenario turns off or minimizes all adverse effects on natural origin fish associated with CNFH operations. CNFH least effects produced the largest improvement for fall Chinook salmon (>100% equilibrium abundance for natural origin fall Chinook), 31% equilibrium abundance improvement for late-fall Chinook, a 16% improvement for spring Chinook, a 13% improvement for winter Chinook, and a 12% improvement for steelhead. If existing natural barriers to adult immigration were assumed to remain in the BCRP, fall and late-fall Chinook were not affected, but equilibrium abundance for spring Chinook, winter Chinook and steelhead were reduced by 74%, 79%, and 76%, respectively.

Although the quantitative life cycle models do not represent all possible effects, they do suggest that cumulatively, both CNFH and BCRP issues have the potential to substantially influence the population performance of BCRP target stocks. The evaluation of specific issues (Appendix C) provides a prioritized and structured approach for selecting and implementing management actions, which can help to address important issues. This approach also can help to resolve uncertainties in the current or future performance of the CNFH and BCRP.

Table 3.1. Steelhead - Overall summary for levels of importance and understanding estimated from the analysis of CNFH and BCRP issues that potentially affect natural-origin steelhead in Battle Creek. Detailed analyses and rationales for the estimates of importance and understanding can be found in Appendix C. For each issue considered, Affecting Hatchery Program indicates the CNFH hatchery propagation program thought to affect natural-origin steelhead. Abbreviations for hatchery propagation programs: FC: fall Chinook salmon program; LFC: late-fall Chinook salmon program; SH: Central Valley steelhead program.

Issue	Evaluation Method/1	Importance	Understanding	Potentially Most Affected Life Stage Event	Affecting Hatchery Program		
					FC	LFC	SH
CNFH 1. Unscreened CNFH water diversion	Model & Qualitative	L	M	Juvenile rearing and emigration	X	X	X
CNFH 2. Exclusion of unmarked steelhead from the CNFH broodstock	Model & Qualitative	M	H	Spawning and egg incubation			X
CNFH 3. Limited ability to identify and prevent passage of: (1) all hatchery-produced salmonids, and (2) non-target runs of Chinook salmon	Model & Qualitative	M	M	Spawning and egg incubation	X	X	
CNFH 4. Hatchery fish may reach the BCRP area during high flow events	Model & Qualitative	L	L	Spawning and egg incubation	X	X	X
CNFH 5. Hatchery handling, sorting, and migratory delay may result in sub-lethal effects or mortality	Model & Qualitative	M	L	Adult immigration		X	X
CNFH 6. Transmission of pathogens from CNFH production to wild fish	Qualitative	L	H	Adult immigration	X	X	X
CNFH 7. Diversions reduce flows and increase water temperatures.	Qualitative	L	H	Juvenile rearing and emigration & Adult immigration		X	X
CNFH 8. High abundance of hatchery adults in lower Battle Creek	Model & Qualitative	L	M	Juvenile rearing and emigration	X		
CNFH 9. Release of hatchery fish may result in predation and behavior modifications of natural origin fish	Model & Qualitative	L	H	Juvenile rearing and emigration			X
CNFH 10. Hatchery production may contribute to exceeding the carrying capacity in the river, delta, or ocean	Qualitative	L	L	Rearing in river, estuary, and ocean	X		
BCRP A. Availability of suitable habitat for wild-origin adult and juvenile salmonids	Model & Qualitative	H	M	Adult immigration and juvenile rearing and emigration	None		
BCRP B. Water temperature effects on salmonid mortality	Model & Qualitative	H	M	Juvenile rearing and emigration	None		
BCRP C. Natural and man-made barrier effects on adult salmonid access	Model & Qualitative	H	M	Adult immigration	None		
BCRP D. Redd scouring and egg mortality due to extreme flow events	Qualitative	H	M	Spawning and egg incubation	None		

/1 Model: Quantitative life-cycle model. Qualitative: narrative evaluation of existing data and information

Table 3.2. Spring Chinook - Overall summary for levels of importance and understanding estimated from the analysis of CNFH and BCRP program issues that potentially affect natural-origin spring Chinook salmon in Battle Creek. Detailed analyses and rationales for the estimates of importance and understanding can be found in Appendix C. For each issue considered, Affecting Hatchery Program indicates the CNFH hatchery propagation program thought to affect natural-origin spring Chinook. Abbreviations for hatchery propagation programs: FC: fall Chinook salmon program; LFC: late-fall Chinook salmon program; SH: Central Valley steelhead program.

Issue	Evaluation Method	Importance	Understanding	Potentially Most Affected Life Stage Event	Affecting Hatchery Program		
					FC	LFC	SH
CNFH 1. Unscreened CNFH water diversion	Model & Qualitative	L	M	Juvenile rearing and emigration	X	X	X
CNFH 2. Exclusion of unmarked steelhead from the CNFH broodstock	NA	NA	NA	NA			
CNFH 3. Limited ability to identify and prevent passage of: (1) all hatchery-produced salmonids, and (2) non-target runs of Chinook salmon	Model & Qualitative	M	M	Spawning and egg incubation	X	X	
CNFH 4. Hatchery fish may reach the BCRP area during high flow events	Model & Qualitative	L	L	Spawning and egg incubation	X	X	
CNFH 5. Hatchery handling, sorting, and migratory delay may result in sub-lethal effects or mortality	Model & Qualitative	L	L	Adult immigration		X	X
CNFH 6. Transmission of pathogens from CNFH production to wild fish	Qualitative	L	H	Adult immigration	X	X	X
CNFH 7. Diversions reduce flows and increase water temperatures.	Qualitative	L	H	Juvenile rearing and emigration & Adult immigration		X	X
CNFH 8. High abundance of hatchery adults in lower Battle Creek	Model & Qualitative	L	M	Juvenile rearing and emigration	X		
CNFH 9. Release of hatchery fish may result in predation and behavior modifications of natural origin fish	Model & Qualitative	M	M	Juvenile rearing and emigration			X
CNFH 10. Hatchery production may contribute to exceeding the carrying capacity in the river, delta, or ocean	Qualitative	L	L	Rearing in river, estuary, and ocean	X		
BCRP A. Availability of suitable habitat for wild-origin adult and juvenile salmonids	Model & Qualitative	H	M	Adult immigration and juvenile rearing and emigration	None		
BCRP B. Water temperature effects on salmonid mortality	Model & Qualitative	H	M	Spawning and egg incubation	None		
BCRP C. Natural and man-made barrier effects on adult salmonid access	Model & Qualitative	H	M	Adult immigration	None		
BCRP D. Redd scouring and egg mortality due to extreme flow events	Model & Qualitative	L	M	Spawning and egg incubation	None		

/1 Model: Quantitative life-cycle model. Qualitative: narrative evaluation of existing data and information

Table 3.3. Fall Chinook - Overall summary for levels of importance and understanding estimated from the analysis of CNFH program issues that potentially affect natural-origin fall Chinook salmon in Battle Creek. Detailed analyses and rationales for the estimates of importance and understanding can be found in Appendix C. For each issue considered, Affecting Hatchery Program indicates the CNFH hatchery propagation program thought to affect natural-origin species targeted in the Battle Creek restoration project. Abbreviations for hatchery propagation programs: FC: fall Chinook salmon program; LFC: late-fall Chinook salmon program; SH: Central Valley steelhead program.

				Potentially Most Affected Life Stage Event	Affecting Hatchery Program		
Issue	Evaluation Method[/1]	Importance	Understanding		FC	LFC	SH
CNFH 1. Unscreened CNFH water diversion	NA	NA	NA	NA			
CNFH 2. Exclusion of unmarked steelhead from the CNFH broodstock	NA	NA	NA	NA			
CNFH 3. Limited ability to identify and prevent passage of: (1) all hatchery-produced salmonids, and (2) non-target runs of Chinook salmon	NA	NA	NA	NA			
CNFH 4. Hatchery fish may reach the BCRP area during high flow events	NA	NA	NA	NA			
CNFH 5. Hatchery handling, sorting, and migratory delay may result in sub-lethal effects or mortality	NA	NA	NA	NA			
CNFH 6. Transmission of pathogens from CNFH production to wild fish	Qualitative	L	H	Adult immigration	X	X	X
CNFH 7. Diversions reduce flows and increase water temperatures.	Qualitative	L	H	Juvenile rearing and emigration & Adult immigration	X	X	X
CNFH 8. High abundance of hatchery adults in lower Battle Creek	Model & Qualitative	H	H	Spawning and egg incubation	X		
CNFH 9. Release of hatchery fish may result in predation and behavior modifications of natural origin fish	Model & Qualitative	L	M	Juvenile rearing and emigration			X
CNFH 10. Hatchery production may contribute to exceeding the carrying capacity in the river, delta, or ocean	Qualitative	L	L	Rearing in river, estuary, and ocean	X		
BCRP A. Availability of suitable habitat for wild-origin adult and juvenile salmonids	NA	NA	NA	NA	None		
BCRP B. Water temperature effects on salmonid mortality	NA	NA	NA	NA	None		
BCRP C. Natural and man-made barrier effects on adult salmonid access	NA	NA	NA	NA	None		
BCRP D. Redd scouring and egg mortality due to extreme flow events	NA	NA	NA	NA	None		

/1 Model: Quantitative life-cycle model. Qualitative: narrative evaluation of existing data and information

Table 3.4. Late-fall Chinook - Overall summary for levels of importance and understanding estimated from the analysis of CNFH program issues that potentially affect natural-origin late-fall Chinook salmon in Battle Creek. Detailed analyses and rationales for the estimates of importance and understanding can be found in Appendix C. For each issue considered, Affecting Hatchery Program indicates the CNFH hatchery propagation program thought to affect natural-origin late-fall Chinook. Abbreviations for hatchery propagation programs: FC: fall Chinook salmon program; LFC: late-fall Chinook salmon program; SH: Central Valley steelhead program.

				Potentially Most Affected Life Stage Event	Affecting Hatchery Program		
Issue	**Evaluation Method**/1	**Importance**	**Understanding**		**FC**	**LFC**	**SH**
CNFH 1. Unscreened CNFH water diversion	Model & Qualitative	L	M	Juvenile rearing and emigration	X	X	X
CNFH 2. Exclusion of unmarked steelhead from the CNFH broodstock	NA	NA	NA	NA			
CNFH 3. Limited ability to identify and prevent passage of: (1) all hatchery-produced salmonids, and (2) non-target runs of Chinook salmon	Model & Qualitative	L	M	Spawning and egg incubation	X	X	
CNFH 4. Hatchery fish may reach the BCRP area during high flow events	Model & Qualitative	L	L	Spawning and egg incubation	X	X	
CNFH 5. Hatchery handling, sorting, and migratory delay may result in sub-lethal effects or mortality	Model & Qualitative	H	L	Adult immigration		X	X
CNFH 6. Transmission of pathogens from CNFH production to wild fish	Qualitative	L	H	Adult immigration	X	X	X
CNFH 7. Diversions reduce flows and increase water temperatures.	Qualitative	L	H	Juvenile rearing and emigration & Adult immigration		X	X
CNFH 8. High abundance of hatchery adults in lower Battle Creek	Model & Qualitative	L	M	Juvenile rearing and emigration	X		
CNFH 9. Release of hatchery fish may result in predation and behavior modifications of natural origin fish	Model & Qualitative	M	M	Juvenile rearing and emigration			X
CNFH 10. Hatchery production may contribute to exceeding the carrying capacity in the river, delta, or ocean	Qualitative	L	L	Rearing in river, estuary, and ocean	X		
BCRP A. Availability of suitable habitat for wild-origin adult and juvenile salmonids	Model & Qualitative	H	M	Adult immigration and juvenile rearing and emigration	None		
BCRP B. Water temperature effects on salmonid mortality	Model & Qualitative	H	M	Juvenile rearing and emigration	None		
BCRP C. Natural and man-made barrier effects on adult salmonid access	Model & Qualitative	L	M	Adult immigration	None		
BCRP D. Redd scouring and egg mortality due to extreme flow events	Qualitative	H	M	Spawning and egg incubation	None		

/1 Model: Quantitative life-cycle model. Qualitative: narrative evaluation of existing data and information

Table 3.5. Winter Chinook - Overall summary for levels of importance and understanding estimated from the analysis of CNFH program issues that potentially affect natural-origin winter Chinook salmon in Battle Creek. Detailed analyses and rationales for the estimates of importance and understanding can be found in Appendix C. For each issue considered, Affecting Hatchery Program indicates the CNFH hatchery propagation program thought to affect natural-origin winter Chinook, upon reintroduction. Abbreviations for hatchery propagation programs: FC: fall Chinook salmon program; LFC: late-fall Chinook salmon program; SH: Central Valley steelhead program.

				Potentially Most Affected Life Stage Event	Affecting Hatchery Program		
Issue	Evaluation Method[/1]	Importance	Understanding		FC	LFC	SH
CNFH 1. Unscreened CNFH water diversion	Model & Qualitative	L	M	Juvenile rearing and emigration	X	X	X
CNFH 2. Exclusion of unmarked steelhead from the CNFH broodstock	NA	NA	NA	NA			
CNFH 3. Limited ability to identify and prevent passage of: (1) all hatchery-produced salmonids, and (2) non-target runs of Chinook salmon	Model & Qualitative	L	H	Spawning and egg incubation	X	X	
CNFH 4. Hatchery fish may reach the BCRP area during high flow events	Model & Qualitative	L	H	Spawning and egg incubation	X	X	
CNFH 5. Hatchery handling, sorting, and migratory delay may result in sub-lethal effects or mortality	Model & Qualitative	M	L	Adult immigration		X	X
CNFH 6. Transmission of pathogens from CNFH production to wild fish	Qualitative	L	H	Adult immigration	X	X	X
CNFH 7. Diversions reduce flows and increase water temperatures.	Qualitative	L	H	Juvenile rearing and emigration & Adult immigration	X	X	X
CNFH 8. High abundance of hatchery adults in lower Battle Creek	Model & Qualitative	L	M	Juvenile rearing and emigration	X		
CNFH 9. Release of hatchery fish may result in predation and behavior modifications of natural origin fish	Model & Qualitative	M	M	Juvenile rearing and emigration			X
CNFH 10. Hatchery production may contribute to exceeding the carrying capacity in the river, delta, or ocean	Qualitative	L	L	Rearing in river, estuary, and ocean	X		
BCRP A. Availability of suitable habitat for wild-origin adult and juvenile salmonids	Model & Qualitative	H	M	Adult immigration and juvenile rearing and emigration	None		
BCRP B. Water temperature effects on salmonid mortality	Model & Qualitative	H	M	Spawning and egg incubation	None		
BCRP C. Natural and man-made barrier effects on adult salmonid access	Model & Qualitative	H	M	Adult immigration	None		
BCRP D. Redd scouring and egg mortality due to extreme flow events	Qualitative	L	M	Spawning and egg incubation	None		

/1 Model: Quantitative life-cycle model. Qualitative: narrative evaluation of existing data and information

3.3 Literature Cited

Terraqua. 2004. Draft Battle Creek salmon and steelhead restoration project adaptive management plan, prepared for the U.S. Bureau of Reclamation, Pacific Gas and Electric Company, National Marine Fisheries Service, U.S. Fish and Wildlife Service, and California Department of Fish and Game. Wauconda, Washington. 238 p.

Chapter 4: Issue Synthesis and Action Evaluation

Several steps were completed in the process of providing a structured and transparent adaptive management framework for CNFH and the BCRP. Building on the work completed for the BCRP-AMP (Terraqua 2004), the TAC was consulted to specify program goals and objectives (Chapter 1), and to formulate issue (i.e., problem) statements (Chapter 3). Appendix C present conceptual models, which schematically depict how issues associated with the CNFH, and issues inherent to the BCRP affect salmonid stocks targeted for restoration. Appendix C also provides a critical evaluation of available data, analyses, and quantitative model results related to each of the identified issue statements. These evaluations are used to estimate the importance and understanding of each issue.

In this Chapter, the issues and related analytical results are considered in order to propose and prioritize management actions. Candidate management actions for CNFH issues were developed in collaboration with the TAC. Management actions considered include implementation actions, monitoring, and diagnostic studies. The selection of management actions, however, is not an endpoint in the adaptive management process. In particular, the pursuit of selected implementation actions should be coupled with the initiation of data collection (monitoring) necessary to allow for action assessment and, if necessary, adjustment of the selected management action. Similarly, the outcomes of any monitoring or diagnostic studies must be analyzed and reported, so that this information can be considered in the 'assess, evaluate, and adapt' step in the adaptive management process.

4.1 Issue Synthesis

The BCRP AMP (Terraqua 2004) identified eleven objectives related to population, habitat and fish passage. Terraqua (2004) generated hypotheses, suggested monitoring and identified triggers associated with each of the eleven objectives. We simplified these eleven objectives into four issues in order to facilitate linkages to the CNFH-AMP. These issues were presented in Chapter 3, and detailed evaluations are presented in Appendix C.

Terraqua (2004) did not attempt to prioritize the relative importance or understanding of the eleven objectives. Rather the BCRP-AMP described how these objectives could be evaluated in the future as the program was implemented. Terraqua (2004) explained:

> *"Central to the [BCRP] AMP focus on management of habitat is an implicit expectation that salmon and steelhead populations will respond affirmatively to positive changes in their habitat. During the term of the AMP, Restoration Project elements will change fish habitat with the intention of improving that habitat for Chinook salmon and steelhead. The AMTT expects to be able to measure significant responses to these habitat changes from the larger populations of salmonids like steelhead and fall-run Chinook salmon."*

Collectively, life cycle model results suggest that challenges (e.g., natural barrier passage, water temperatures, and redd scour) and uncertainties (e.g., habitat productivity) intrinsic to the BCRP can exert a substantial influence on population trajectories. Analysis of CNFH issues suggests challenges and uncertainties also exist with hatchery operations and facilities. The effect of introgression and superimposition (CNFH IS-8) from hatchery origin fall Chinook on natural origin fall Chinook in lower Battle Creek was estimated to be of high importance. The effect of handling late-fall Chinook at CNFH (IS-5) also was determined to be of high importance. Several CNFH issues were found to be of medium importance (CNFH IS-2: exclusion of natural origin steelhead from broodstock; CNFH IS-3: accidental passage for spring Chinook and steelhead; CNFH IS-5: fish handling for winter Chinook and steelhead; and CNFH IS-9: predation from hatchery releases for late fall Chinook, winter Chinook, and spring Chinook). Other issues were estimated to be of low importance (Tables 3.1 – 3.5).

In addition to importance, it is also critical to consider the level of understanding associated with each issue. For example, CNFH IS-5 (fish handling mortality) was found to be of medium importance to winter Chinook based only upon direct mortality as it is currently understood. However, the medium importance for CNFH IS-5 does not reflect an analysis of sub-lethal stress or more accurate direct mortality measures, which may emerge as part of improved monitoring and diagnostic studies. Overall, understanding of CNFH IS-5 is estimated as low. Assessments of importance for CNFH IS-4, IS-9 and IS-10 are similarly handicapped by low levels of understanding.

In all cases, the same data and information were used to assess understanding and importance, but estimates of each factor were made independently. Thus, it is possible to estimate importance as high, medium, or low, and estimate understanding as low, as described in the paragraph above. Both understanding and importance were considered for each issue to identify recommended implementation actions. In most but not all cases, diagnostic studies are recommended in cases where understanding is moderate or low. Implementation actions were not recommended for issues with low importance except where effective and necessary studies could not be identified.

The tables presented in this section provide a tabular synthesis of determinations, data needs, and actions associated with both CNFH and BCRP issues. Further explanation and definition for terms listed in the tables are first provided below.

Determination synthesis: briefly describes the importance and understanding for the issue and the species-life stages most effected.

Required monitoring and data assessment: data and information required to continue assessing the issue in the adaptive management framework. Monitoring details are presented in Appendix F.

Success standards: data, analyses results or other outcomes, which need to be observed in order to drive next steps (decisions) in the adaptive management process. Success standards are often based upon performance measures (defined below) observed over several years, or utilized as new inputs to the quantitative life cycle model.

Implementation actions: Identifies the actions (if any) that should be taken given alternative outcomes from monitoring, studies, or modeling. In most cases, only Tier 1 actions are identified because contingencies that might necessitate implementing Tier 2 actions are difficult to anticipate at this point. (Tier 1 and Tier 2 actions are described further below.)

Performance measures: Key population metrics derived from the integrated monitoring program, which will contribute to evaluating the issue and re-evaluating action alternatives.

Table 4.1. Summary of issue determinations, resulting evaluation standards, and related actions.

CNFH Issue #1: Unscreened CNFH water diversion

Determination Synthesis: Potentially effects juvenile salmonids of all BCRP target stocks while emigrating from Battle Creek. Based principally upon life cycle model analyses, low importance and medium understanding for all BCRP target species.

Required monitoring and data assessment

- Frequency, duration, rate, and proportion of flow through the unscreened diversion (see CNFH Biological Opinion (BiOp) 2014)
- Fish salvage operations during diversion (see CNFH BiOp 2014)

Success standards

- Multi-year: Update diversion and fish salvage data incorporated into the life cycle model (LCM), which indicates equilibrium abundance for BCRP stocks is reduced by less than 5%, OR satisfaction of other LCM-based quantitative standards approved by the TAC.

Implementation Action:

- If success standard continues to be met, no action is required for this issue.
- If success standards are not met, implement IA14: Screen Intake 2 (Tier 2 Action).

Performance measures:

- Annual: Diversion data and fish salvage data associated with diversions [CNFH Monitoring as described in 2014 CNFH BiOp]

CNFH Issue #2: Exclusion of unmarked steelhead from the CNFH broodstock

Determination Synthesis: Both importance and understanding are medium for this issue. The most important effect (introgression) occurs at spawning and egg incubation, but has consequences for subsequent life stages. Applies to both CNFH and natural origin steelhead in Battle Creek. Does not apply to Chinook stocks.

Required monitoring and data assessment

- Spawning escapement monitoring (M-SE1)
- Juvenile production monitoring (M-JP)
- Incidence of hatchery strays determined by monitoring (M-PM)
- Incidence of genetic introgression as determined by monitoring (M-PM)
- Relative reproductive success for hatchery and natural origin steelhead (M-PM)

Success standards

- Multi-year: New monitoring data incorporated into the LCM indicates equilibrium abundance for BCRP steelhead is reduced by less than 5%, OR satisfaction of other LCM-based quantitative standards approved by the TAC.

Implementation Actions:

- Implement DS2: Steelhead Integration diagnostic study (Tier 1 Action)

Performance measures:

- Annual: steelhead spawning escapement (M-SE1); steelhead smolt production (M-JP)
- Multi-year: Smolt-to-adult rate (M-PM); cohort replacement rate (M-PM); straying incidence rate (M-PM); Relative reproductive success (M-PM)

CNFH Issue #3: Limited ability to identify and prevent passage of: (1) all hatchery-produced salmonids, and (2) non-target runs of Chinook salmon

Determination Synthesis: Medium importance for spring Chinook and steelhead. The most important effect (introgression) occurs at spawning and egg incubation, but has consequences for subsequent life stages. Medium understanding for spring Chinook due to incomplete fall Chinook tagging (particularly at Feather River Hatchery), and limited coded wire tag recoveries from the BCRP area. Low importance for other BCRP target stocks. Medium understanding for other species due to insufficient data on the incidence and effect of non-target salmonids reaching the BCRP area. Does not apply to fall Chinook, which are restricted to lower Battle Creek.

Required monitoring and data assessment

- Spawning escapement monitoring (M-SE1)
- Juvenile production monitoring (M-JP)
- Incidence of non-target strays determined by monitoring (M-PM)
- Incidence of genetic introgression as determined by monitoring (M-PM)

Success standards

- Multi-year: New monitoring data related to this issue incorporated in the LCM indicates an equilibrium abundance for BCRP target species that is reduced by less than 5%, OR satisfaction of other LCM-based quantitative standards approved by the TAC.

Implementation Actions:

- Implement DS1: Fish Handling Research (Tier 1 Action) and IA11: Provide 100% marking/tagging of fall run Chinook (Tier 2 Action)

Performance measures:

- Annual: Spawning escapement (M-SE1); Smolt production (M-JP)
- Multi-year: Smolt-to-adult rate (M-PM); cohort replacement rate (M-PM); Straying incidence rate (M-PM); Relative reproductive success (M-PM)

CNFH Issue #4: Hatchery fish may reach the BCRP area during high flow events

Determination Synthesis: Low importance for all BCRP target stocks because incidence appears to be low, but low understanding for all stocks except winter Chinook due to insufficient data on the incidence of hatchery fish reaching the BCRP area during high flow events. The most important effect (introgression) occurs at spawning and egg incubation, but has consequences for subsequent life stages. Understanding is high for winter Chinook because LSNFH winter Chinook reaching the BCRP area is not considered a problem. Does not apply to natural origin fall Chinook which are restricted to lower Battle Creek.

Required monitoring and data assessment

- Spawning escapement monitoring (M-SE1)
- Juvenile production monitoring (M-JP)
- Incidence of non-target strays determined by monitoring (M-PM)
- Incidence of genetic introgression as determined by monitoring (M-PM)

Success standards

- Multi-year: New monitoring data related to this issue incorporated in the LCM indicates an equilibrium abundance for BCRP target species that is reduced by less than 5%, OR satisfaction of other LCM-based quantitative standards approved by the TAC.

Implementation Actions:

- Implement DS4: fish barrier weir diagnostic study (Tier 1 Action)

Performance measures:

- Annual: Spawning escapement (M-SE1); Smolt production (M-JP)
- Multi-year: Smolt-to-adult rate (M-PM); cohort replacement rate (M-PM); Straying incidence rate (M-PM); Relative reproductive success (M-PM)

CNFH Issue #5: Hatchery handling, sorting, and migratory delay may result in sub-lethal effects or mortality

Determination Synthesis: The effect occurs at adult immigration, but may also adversely affect spawning success. Low importance and medium understanding for spring Chinook; current operations allow most spring Chinook to avoid any handling. High importance for late-fall Chinook, medium importance for all other BCRP target stocks. Low understanding for stocks other than spring Chinook due to insufficient data on delayed mortality or sub-lethal stress, which may be associated with handling. Does not apply to natural origin fall Chinook, which are restricted to lower Battle Creek.

Required monitoring and data assessment

- Spawning escapement monitoring (M-SE1)
- Juvenile production monitoring (M-JP)
- Relative reproductive success for fish with different handling exposure (M-PM)

Success standards:

- Multi-year: New monitoring data related to this issue incorporated into the LCM indicates an equilibrium abundance for BCRP target stocks that is reduced by less than 5%, OR satisfaction of other LCM-based quantitative standards approved by the TAC.

Implementation Actions:

- Implement DS1: fish handling research (Tier 1).

Performance measures:

- Annual: Spawning escapement (M-SE1); Smolt production (M-JP)
- Multi-year: Smolt-to-adult rate (M-PM); cohort replacement rate (M-PM); Straying incidence rate (M-PM); Relative reproductive success (M-PM)

CNFH Issue #6: Transmission of pathogens from CNFH production to wild fish

Determination Synthesis: Low importance and high understanding for all BCRP target stocks and for fall Chinook in lower Battle Creek.

Required monitoring and data assessment

- Results of fish actions and investigations as described in California Hatchery Scientific Review Group (HSRG 2012)

Success standards

- Short-term: Consistency with fish health recommendations from HSRG (2012).
- Multi-year: Consistency with fish health recommendations from HSRG (2012), OR satisfaction of other LCM-based quantitative standards approved by the TAC.

Implementation Actions:

- Implement (IA13) minimize risk of disease transmission and expression action (Tier 1 Action).

Performance measures:

- Annual: Spawning escapement (M-SE1); Smolt production (M-JP)
- Multi-year: Smolt-to-adult rate (M-PM); cohort replacement rate (M-PM); Relative reproductive success (M-PM)

CNFH Issue #7: Diversions reduce flows and increase water temperatures

Determination Synthesis: Low importance and high understanding for all BCRP target stocks. Could affect both adults or juvenile rearing and emigration. Does not apply to natural origin fall Chinook, which are restricted to lower Battle Creek.

Required monitoring and data assessment

- Temperature and flow monitoring for mainstem Battle Creek

Success standards

- Multi-year: Temperature data related to this issue incorporated into the LCM indicates an equilibrium abundance for BCRP target species that is reduced by less than 5%, OR satisfaction of other LCM-based quantitative standards approved by the TAC.

Implementation Actions:

- None recommended

Performance measures:

- Annual: Spawning escapement (M-SE1); Smolt production (M-JP)
- Multi-year: Smolt-to-adult rate (M-PM); cohort replacement rate (M-PM)

CNFH Issue #8: High abundance of hatchery adults in lower Battle Creek

Determination Synthesis: Low importance and medium understanding for BCRP target species where only juvenile emigrants could be appreciably affected. High importance and high understanding for fall Chinook where the most important effect (introgression) occurs at spawning and egg incubation, but has consequences for subsequent life stages.

Required monitoring and data assessment

- Adult escapement monitoring

Success standards

- Annual: pHOS consistent with HSRG (2012) recommendations
- Multi-year: New monitoring data related to this issue incorporated in the LCM indicates an equilibrium abundance for natural origin fall Chinook that is reduced by less than 5%, OR satisfaction of other LCM-based quantitative standards approved by the TAC.

Implementation Actions:

- Implement IA11: 100% marking/tagging (Tier 2 Action)
- If success standards are not met, implement IA12: Reduce excess returns of CNFH fall Chinook to Battle Creek (Tier 2 Action).

Performance measures:

- Annual: fall Chinook spawning escapement and proportion of hatchery fall Chinook fish on the spawning grounds (M-SE2)
- Multi-year: cohort replacement rate (CRR) for natural origin fall Chinook

CNFH Issue #9: Release of hatchery fish may result in predation and behavior modifications of natural origin fish

Determination Synthesis: The issue effects juvenile emigrants. Medium importance and medium understanding for spring, winter, and late-fall Chinook, which emigrate at a time and size making them potentially vulnerable to predation. Low importance and medium understanding for fall Chinook, which are expected to emigrate quickly from lower Battle Creek. Low importance and high understanding for steelhead, which are large enough as emigrating smolts to avoid predation.

Required monitoring and data assessment

- Spawning escapement monitoring (M-SE1)
- Juvenile production monitoring (M-JP)

Success standards

- Multi-year: New study data related to this issue incorporated into the LCM indicates an equilibrium abundance for spring, winter or late-fall Chinook that is reduced by less than 5%, OR satisfaction of other LCM-based quantitative standards approved by the TAC.

Implementation Actions:

- Implement DS10 *O. mykiss* predation studies (Tier 1 Action).

Performance measures:

- Annual: Spawning escapement (M-SE1); Smolt production (M-JP)
- Multi-year: Smolt-to-adult rate (M-PM); cohort replacement rate (M-PM)

CNFH Issue #10: Hatchery production may contribute to exceeding the carrying capacity in the river, delta or ocean.

Determination Synthesis: Effects juvenile rearing outside Battle Creek. Low importance, but also low understanding for BCRP target species and fall Chinook.

Required monitoring and data assessment

- Spawning escapement monitoring (M-SE1)
- Juvenile production monitoring (M-JP)

Success standards

- Multi-year: New study data related to this issue incorporated into the LCM indicates an equilibrium abundance for spring, winter or late-fall Chinook that is reduced by less than 5%, OR satisfaction of other LCM-based quantitative standards approved by the TAC.

Implementation Actions:

- None recommended

Performance measures:

- Annual: Spawning escapement (M-SE1); Smolt production (M-JP)
- Multi-year: Smolt-to-adult rate (M-PM); cohort replacement rate (M-PM)

BCRP Issue A: Availability of suitable habitat for natural-origin adult and juvenile salmonids
Determination Synthesis: High importance and medium understanding for BCRP target species. Not applicable to fall Chinook, which are restricted to lower Battle Creek.
Required monitoring and data assessment • Spawning escapement monitoring (M-SE1) • Spawning distribution and passage (M-SD) • Juvenile production monitoring (M-JP) • Reach specific reproductive success (M-PM)
Success standards • Annual: Reach specific spawning and juvenile production estimates consistent with expectations. • Multi-year: New monitoring data related to this issue incorporated into the LCM indicates BCRP population goals can still be met.
Implementation Actions: • See Terraqua (2004)
Performance measures: • Annual: Spawning escapement (M-SE); Smolt production (M-JP) • Multi-year: Reach specific spawning escapement (M-PM); Reach specific juvenile production (M-PM); Smolt-to-adult rate (M-PM); cohort replacement rate (M-PM)

BCRP Issue B: Water temperature effects on salmonid mortality
Determination Synthesis: High importance and medium understanding for BCRP target species. Could affect spawning and egg incubation, and/or juvenile rearing depending on the stock. Not applicable to fall Chinook, which are restricted to lower Battle Creek.
Required monitoring and data assessment • Spawning escapement monitoring (M-SE1) • Spawning distribution and passage (M-SD) • Juvenile production monitoring (M-JP) • Reach specific reproductive success (M-PM)
Success standards • Annual: Water temperature monitoring consistent with expectations; Reach specific spawning and juvenile production estimates consistent with expectations. • Multi-year: New monitoring data related to this issue incorporated into the LCM indicates BCRP population goals can still be met.
Implementation Actions: • See Terraqua (2004)
Performance measures: • Annual: Spawning escapement (M-SE); Smolt production (M-JP) • Multi-year: Reach specific spawning escapement (M-PM); Reach specific juvenile production (M-PM); Smolt-to-adult rate (M-PM); cohort replacement rate (M-PM)

BCRP Issue C: Natural and man-made barrier effects on adult salmonid access

Determination Synthesis: High importance and medium understanding for BCRP target species. Principally effects adult immigrants. Not applicable to fall Chinook, which are restricted to lower Battle Creek.

Required monitoring and data assessment

- Spawning escapement monitoring (M-SE1)
- Spawning distribution and passage (M-SD)
- Juvenile production monitoring (M-JP)
- Reach specific reproductive success (M-PM)

Success standards

- <u>Annual</u>: Spawning distribution consistent with expectations.
- <u>Multi-year</u>: New monitoring data related to this issue incorporated into the LCM indicates BCRP population goals can still be met.

Implementation Actions:

- See Terraqua (2004)

Performance measures:

- <u>Annual</u>: Spawning distribution (M-SD)
- <u>Multi-year</u>: Reach specific spawning escapement (M-PM); Reach specific juvenile production (M-PM); Smolt-to-adult rate (M-PM); cohort replacement rate (M-PM)

BCRP Issue D: Redd scouring and egg mortality due to extreme flow events

Determination Synthesis: Effects spawning and egg incubation life stage. High importance and medium understanding for late-fall Chinook and steelhead, which spawn during months most likely to experience bed-mobilizing flows. Low importance and medium understanding for spring and winter Chinook. Not applicable to fall Chinook, which are restricted to lower Battle Creek.

Required monitoring and data assessment

- Spawning escapement monitoring (M-SE1)
- Spawning distribution and passage (M-SD)
- Juvenile production monitoring (M-JP)
- Reach specific reproductive success (M-PM)

Success standards

- <u>Annual</u>: Spawning distribution and juvenile production consistent with BCRP expectations.
- <u>Multi-year</u>: New monitoring data related to this issue incorporated into the LCM indicates BCRP population goals can still be met.

Implementation Actions:

- See Terraqua (2004)

Performance measures:

- <u>Annual</u>: Spawning distribution (M-SD) and reach specific juvenile production (M-PM)
- <u>Multi-year</u>: Reach specific spawning escapement (M-SE); Reach specific juvenile production (M-JP)

4.2 Tier I Action Identification and Routing

Section 4.1 provides an overview of issue determinations, data needs, and actions associated with both CNFH and BCRP issues as they are currently understood. However, to be successful, implementation of actions under an adaptive management framework must occur in a step-wise, structured fashion that allows new scientific information to influence future decision-making and adjustments. The quantitative life cycle models (Appendixes D and E) and the conceptual models (Appendix C), provide the foundation for a structured and transparent process where pertinent scientific data and information is incorporated and critically assessed. The results can then be integrated into the decision-making process. Figure 4.1 graphically depicts these steps for any identified issue.

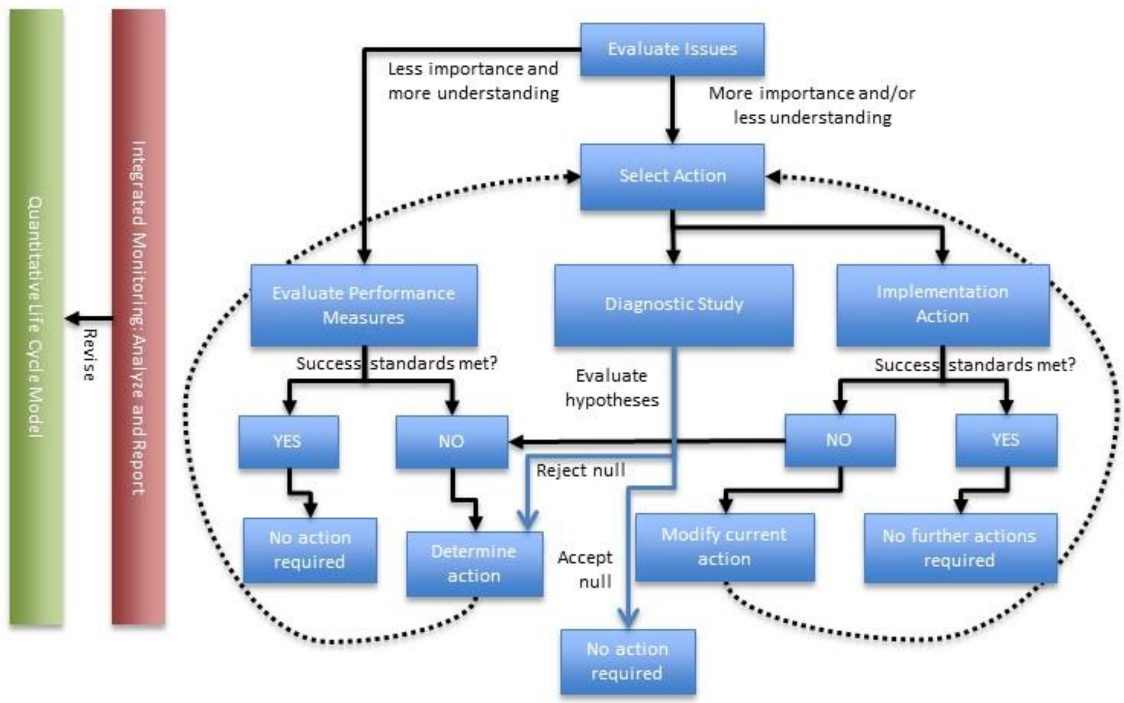

Figure 4.1. Diagram illustrating steps in the CNFH and BCRP adaptive management cycle related to action selection, implementation, and evaluation of performance. The process begins with the identification and evaluation of an issue.

Two tiers were defined to facilitate the prioritization and recommended selection of implementation actions, monitoring, and diagnostic studies:

Tier 1: High or medium importance issues where priority actions can be clearly identified and where actions do not require changes to existing goals or objectives for the CNFH or the BCRP. Tier 1 actions address issues related to BCRP winter Chinook, spring Chinook, and steelhead (*Oncorhynchus mykiss)*. Tier 1 actions (implementation, monitoring or diagnostic studies) should be implemented as soon as possible. Understanding ratings within this tier will vary. However, Tier 1 actions for issues with low understanding will tend to require study before, or as part of the implementation action.

Tier 2: Actions that address lower importance issues where available actions are known and relatively well understood, but where implementation requires additional information. Most

Tier 2 implementation actions will be contingent upon results of studies (Tier 1 and Tier 2), or implementation actions recommended in Tier 1. Tier 2 monitoring and diagnostic studies are less urgent than Tier 1. Tier 2 actions are described further in Section 4.4.

Informed by importance and understanding ratings, each issue falls into one of three action processes. Issues with less importance and more understanding, call for ongoing evaluation of performance metrics provided by monitoring plan implementation. If monitoring data indicate success standards will be met despite the issue, then no implementation actions are required. If monitoring data indicate success standards will not be met because of an issue, then implementation actions should be considered.

For issues with more importance and/or less understanding, two pathways are available. The first involves diagnostic studies. Diagnostic studies are called for where more information about an issue is required before implementation actions can be considered. Diagnostic studies specify testable hypotheses. Whether hypotheses are accepted or rejected determines the next steps. Specific hypotheses and resulting alternative actions for Tier 1 diagnostic studies are provided in Table 4.2.

Table 4.2. Null hypothesis, approach, and result actions for Tier 1 diagnostic studies.

Diagnostic Study: Fish handling research (DS1)
Description: Addresses CNFH IS-5. Research and evaluate new methods for processing, sorting and collecting tissues from fish, while causing minimal stress and mortality. Note: DS1 targets new methodologies and equipment whereas IA9 emphasizes changes made with existing operations and facilities.
Null Hypothesis: Expected mortality and stress associated with sorting and processing fish in CNFH and at the fish barrier weir, when incorporated into the LCM, indicates equilibrium abundance for BCRP target species is not reduced by more than 5%, OR satisfaction of other LCM-based quantitative standards approved by the TAC.
Approach: Collect data on baseline stress, mortality (direct and delayed), and relative reproductive success of adult fish handled at CNFH, the barrier weir fish ladder trap, and at other comparable facilities. Evaluate approaches, technology and facility features that can be effective in reducing stress and mortality. Include evaluation of automatic or remote controlled fish processing.
Result Actions: If null hypothesis is rejected: a. Implement recommendations derived to minimize stress and mortality for fish encountered at CNFH, and encountered in the barrier weir fish ladder. b. Elevated priority for IA8. If null hypothesis is accepted, and there is evidence that the levels of stress and mortality are incompatible with BCRP goals, then elevated priority for IA4, IA6, IA7 and IA12.
Resources Required (excluding existing monitoring and Analytic Methods): • No additional FTE's (full-time equivalent personnel) if contracted • $100,000 to $200,000

Diagnostic Study: Steelhead Integration (DS2)

Description: Addresses CNFH IS-2. Field studies, modeling and/or literature review to assess options for incorporating natural origin *O. mykiss* into CNFH steelhead broodstock

Null Hypotheses:

1. The CNFH steelhead propagation program cannot be integrated due to an inadequate source of natural origin steelhead broodstock.
2. The risk of adverse effects from a segregated CNFH steelhead program to the BCRP steelhead population when incorporated into the LCM, indicates the steelhead equilibrium abundance is not reduced by more than 5%, OR satisfaction of other LCM-based quantitative standards approved by the TAC.

Approach:
Conduct a detailed evaluation of available natural origin steelhead broodstock. Assess changes in benefits/risks relative to the number and source of natural origin steelhead included in the broodstock.

Result Actions:
If null hypothesis (1) is accepted, then elevated priority for DS3, IA4 or IA7.
If null hypothesis (1) is rejected, then elevated priority for IA2 or IA3.
If null hypothesis (2) is accepted, then no further related actions may be necessary.
If null hypothesis (2) is rejected, then elevated priority for IA4 or IA7.

Resources Required (excluding existing monitoring and Analytic Methods):

- No additional FTE's if contracted
- $50,000 to $100,000

Diagnostic Study: Fish barrier weir (DS4)

Description: Addresses CNFH IS-4. Conduct studies to detect the incidence of adult fish defeating the CNFH fish barrier weir during flow events greater than 800 cfs.

Null Hypothesis: CNFH fall Chinook, late-fall Chinook, and steelhead reaching the restoration area during Battle Creek flows >800 cfs do not, when incorporated into the LCM, indicate the equilibrium abundance for BCRP target species is reduced by more than 5%, OR satisfaction of other LCM-based quantitative standards approved by the TAC.

Approach:
Conduct studies to estimate the number of CNFH fish reaching the restoration area during 800cfs+ flow events. Studies will likely include fish tagging, and analysis of genetic data. Assessment may apply the LCM to assess the effect of observed or probable straying rates on BCRP stock recovery goals.

Result Actions:
If null hypothesis is rejected, then elevated priority for IA4, IA5, IA6, IA7 and IA12.
If null hypothesis is accepted, then elevated priority for IA2.

Resources Required (excluding existing monitoring and Analytic Methods):

- No additional FTE's if contracted or if studies completed by existing staff
- $25,000 to $50,000 to analyze available data and report likelihood of passage during high flow events.

Diagnostic Study: Steelhead and late-fall Chinook predation (DS10)

Description: Addresses CNFH IS-9. Study diets of natural and hatchery *O. mykiss* and late-fall Chinook to detect potential predation on BCRP target stocks. For example, evaluate if *O. mykiss* begin consuming more spring and winter Chinook fry due to competition for other food resources upon release of hatchery steelhead production.

Null Hypothesis: Predation by releases of CNFH steelhead and late-fall Chinook juveniles, when incorporated into the LCM, indicates the equilibrium abundance for BCRP target species is not reduced by more than 5%, OR satisfaction of other LCM-based quantitative standards approved by the TAC.

Approach: Conduct studies to determine how long and how many hatchery smolts reside in lower Battle Creek or the adjacent Sacramento River. Estimate likely predation losses of juvenile salmonids emigrating from the BCRP area.

Result Actions:

If null hypothesis is rejected, then elevated priority for IA4, IA5, IA6, or IA7.

If null hypothesis is accepted, then no further action or studies may be required.

Resources Required (excluding existing monitoring and Analytic Methods):

- No additional FTE's if contracted
- $100,000 to $200,000 to conduct related field studies and analyses

The second pathway for issues with more importance and understanding involves pursuit of one or implementation actions. Here the action is implemented and performance metrics are evaluated to determine whether or not success standards related to the issue are being met. If monitoring data indicate success standards will be met, then the implementation action has been successful and further actions are not required. However, if monitoring data indicate success standards will not be met because of the issue, then modified or alternative actions must be considered. Specific alternatives for Tier 1 Implementation Actions are provided in Table 4.3.

Table 4.3. Performance measures, monitoring and data assessment, success standards, contingencies, and resources required for Tier 1 implementation actions.

Implementation Action: Minimize risk of disease transmission and expression (IA13)
Description: Addresses CNFH IS-6. Implement fish health related management recommendations of the California Hatchery Scientific Review Group (HSRG 2012). Help eliminate or further reduce transmission and expression of pathogens outside of CNFH. It is expected that adopting this implementation action would require some modifications to internal hatchery operations. The ease and costs of modifying these operations is unknown.
Rationale: • Consistent with California HSRG recommendation and already in practice at CNFH • Intended to help ensure disease issues continue to be studied and kept from having adverse effects (IS6).
Performance measure responses: • Annual: Consistency with fish health recommendations from HSRG (2012). • Multi-year: Spawning escapement, Cohort Replacement Rate
Required monitoring and data assessment: Results of fish health actions and investigations
Success standards Annual: Consistency with fish health recommendations from HSRG (2012).
Contingency: • If measure is implemented, but does not meet success standards as result of disease transmission and expression, then elevated priority for IA4, IA5, IA6, IA7 and IA12. • If measure is implemented and success standards met, then further actions related to hatchery-mediated fish disease may not be necessary.
Resources Required (excluding existing monitoring and Analytic Methods): • No additional FTE's expected • $10,000 to $100,000

4.3 Making Adjustments: Completing the Adaptive Management Cycle

The selection and implementation of initial management actions (any of the three pathways depicted in Figure 4.1) does not terminate the input of science to the adaptive-management process. Rather, the implementation of initial management actions is paired with initiation of monitoring and studies to allow for assessment of effectiveness of the selected action. It is expected that additional data analysis and its interpretation by experts may lead to changes including:

- Adjustment of existing goals or objectives, or setting new goals or objectives for the CNFH or BCRP.
- Redefining issues (i.e., problem statements), or defining new issues.
- Conceptual model revisions reflecting new or different linkages between issues and species-life stage effect.
- Revisions to a life cycle model, which quantifies and links issues, actions, and ecological interactions.
- New information on environmental conditions needed to support target stocks in the BCRP area, the Sacramento River, the Estuary, or the Ocean.
- New or altered management action opportunities.

Tables presented in Section 4.1 provide advance specification of performance measures, monitoring and data assessment requirements, and success standards for each Issue. Some contingencies associated with Tier 1 implementation actions are identified in Table 4.3, and Table 4.2 for diagnostic studies. These contingencies are meant to provide rational possibilities for next steps based on the suite of identified actions and potential outcomes. However, these contingencies should be considered a starting point for the discussion of adjustments. Other contingencies will undoubtedly become apparent over time as understanding increases and new opportunities emerge.

4.4 Tier 2 Actions

Tier 2 implementation actions and diagnostic studies are described below. Tier 2 actions are considered to be of second priority, and would be triggered for consideration mainly by new information from monitoring, by studies that have not yet been completed, or potentially from the outcome of Tier 1 actions.

Implementation Actions

IA1. **Reduce CNFH water use**.

- Monitoring and analyses suggests flows in affected area are limiting success of BCRP target populations.

Purpose: Temporarily modify CNFH operations to minimize water use during drought periods in order to improve upstream passage of adult spring Chinook salmon.

Risks and Uncertainties: Decreasing water supply to CNFH increases risks to on-station hatchery fish production due to elevated water temperatures and decreased flow, which can cause stress and elevate disease risk.

IA2. **Include natural origin Battle Creek steelhead or *O. mykiss* in CNFH broodstock**.

- Need for implementation informed by DS2

Purpose: Incorporate natural origin *O. mykiss* from Battle Creek into CNFH in order to reduce domestication and genetic divergence of CNFH steelhead broodstock.

Risks and Uncertainties: Would reduce abundance of natural origin Battle Creek *O. mykiss*. Given only hatchery origin fish are currently used in the broodstock, and with an unknown proportion of hatchery origin steelhead in the naturally producing population, it is unclear what proportion of natural origin fish would need to be incorporated to significantly offset domestication effects (e.g. Araki et al. 2006, 2007, 2008, 2009, Chilcote et al. 2011). Abundance of natural origin fish may be insufficient to support integration objectives.

IA3. **Include natural origin *O. mykiss* from outside Battle Creek in CNFH broodstock**.

- Need for implementation informed by DS2

Purpose: Incorporate natural origin *O. mykiss* into CNFH to reduce domestication of CNFH steelhead broodstock without reducing the abundance of the restoration area *O. mykiss* population.

Risks and Uncertainties: Will reduce abundance of natural origin *O. mykiss* from some other Central Valley watershed. Given only hatchery origin fish are currently used in broodstock, it is unclear if a large enough proportion of natural origin fish could be incorporated to significantly offset domestication effects (e.g. Araki et al. 2006, 2007, 2008, 2009, Chilcote et al. 2011). Abundance of natural origin fish in other tributaries may be insufficient to support integration. Adaptations and genetic characteristics unique to restoration area may be lost by relying upon out-of-basin fish.

IA4. **Reevaluate CNFH steelhead program**.

- Need for implementation informed by IA10, IA13, DS1, DS2, DS3, DS4, and DS10

Purpose: Reconsider if and how many steelhead will be produced at CNFH in order to minimize risk of interbreeding between natural origin restoration area *O. mykiss* and CNFH program *O. mykiss*. Potentially expands the period of unimpeded access to the restoration area (i.e., provides upstream access without sorting at CNFH, or without trapping in the upstream fish ladder).

Risks and Uncertainties: May be difficult to implement due to mitigation function of CNFH steelhead program. Action may only be effective if implemented with IA5 or IA7.

IA5. Reevaluate CNFH late-fall Chinook program.

- Need for implementation informed by IA9, IA10, IA13, DS1, DS3, and DS4

Purpose: Reconsider if and how many late-fall Chinook will be produced at CNFH in order to further minimize the risk of interbreeding between natural origin restoration area late-fall Chinook, and CNFH program late-fall Chinook. Potentially expands period of unimpeded access to the restoration area (i.e., provides upstream access without sorting at CNFH, or without trapping in the upstream fish ladder).

Risks and Uncertainties: May be difficult to implement due to mitigation function of CNFH late-fall Chinook program. Action may only be effective if implemented with IA4 or IA7. A decision to terminate the late-fall Chinook production program would eliminate the availability of late-fall hatchery juveniles for use as spring Chinook salmon surrogates to estimate take at the South Delta pumping plants.

IA6. Reevaluate CNFH/Battle Creek fall Chinook program objectives

- Need for implementation informed by IA11, IA13, DS1, and DS4

Purpose: If other actions are not effective in resolving problems with hatchery fall Chinook, changing management objectives for CNFH or BCRP fall Chinook could offer a solution. For example, those implementing the BCRP-AMP may decide to shift away from the goal of having an independent natural origin fall Chinook population on Battle Creek.

Risks and Uncertainties: May be difficult to implement due to mitigation function of CNFH fall Chinook program.

IA7. Relocate CNFH steelhead and/or late-fall Chinook program.

- Need for implementation informed by, DS2, DS3, and DS4.

Purpose: Relocate CNFH steelhead and/or late-fall Chinook program to another location where strays to the restoration area would be less likely, in order to reduce risk of interbreeding between natural origin restoration area *O. mykiss* and late-fall Chinook, and CNFH produced fish. Potentially expands period of unimpeded access to the restoration area (i.e., provides upstream access without sorting at CNFH, or without trapping in the upstream fish ladder).

Risks and Uncertainties: May relocate adverse impacts related to CNFH steelhead and late-fall Chinook programs to some other Central Valley watershed. Difficult to implement due to mitigation function of CNFH steelhead and late-fall programs. Action may only be effective if implemented for both steelhead and late-fall Chinook programs, or with IA4 or IA5.

IA8. **Expand selective passage at fish barrier weir**.

- Need for implementation informed by DS1 and by incidence of straying and introgression within the BCRP.

Purpose: Modify current upstream fish ladder operations to expand the period during which hatchery origin salmonids can be trapped and prevented from entering the restoration area. This would reduce the number of hatchery origin Chinook and hatchery origin steelhead reaching the restoration area. This action also might provide the means to collect additional data (e.g., tissues samples) from a larger portion of fish immigrating into the restoration area, which would support monitoring data needs (see Appendix F).

Risks and Uncertainties: Current operations are designed to minimize handling stress, especially at water temperatures warmer than 60^0 F. If this action increases stress and mortality, then it may result in net harm to restoration area salmonid populations.

IA9. **Improve CNFH fish processing**.

- Monitoring and analysis indicate fish passage and handling through CNFH is limiting success of BCRP target populations.

Purpose: Improve survival and reproductive success of natural origin winter Chinook, late-fall Chinook and *O. mykiss* passing through CNFH. This would be accomplished by taking actions to decrease migratory delay, sorting and pre-sorting stress, and mortality resulting from CNFH broodstock collection. This may entail more frequent sorting events, or different sorting methods. For example, fish arriving at CNFH could be processed near continuously using video to notify staff when fish arrive in the holding tanks. Note: IA9 emphasizes changes that can be made immediately with existing operations and facilities, whereas DS1 targets new methodologies and equipment which may take time to research and implement.

Risks and Uncertainties: Efforts to minimize delay (i.e., more rapid processing) could have the unintended consequence of increasing stress and mortality. Actions implemented would need to support established CNFH production objectives.

IA10. Improve barrier weir fish processing.

- Monitoring and analyses indicate fish passage and handling at the barrier weir fish ladder is limiting success of BCRP target populations.

Purpose: Improve survival and reproductive success for natural late-fall Chinook, spring Chinook and *O. mykiss* subject to selective passage through the upstream fish ladder. This would be accomplished by modifying fish monitoring operations in the upstream fish ladder to minimize delay and reduce handling stress during trap operation. For example, fish could be processed continuously (using video to notify staff when fish arrive at the trap), and/or implement automatic fish processing or other related methods to minimize time out of water, and avoid collisions with hard objects. Related to IA8.

Risks and Uncertainties: Efforts to minimize delay (i.e., more rapid processing) could have the unintended consequence of increasing stress and mortality. Unknown if the action will be effective in improving survival and reducing stress.

IA11. Provide 100% marking/tagging of CNFH Production

- Monitoring and analyses indicate absence of this action for CNFH fall Chinook is limiting success of BCRP target populations, or if it is necessary to provide for improved management of fall Chinook.

Purpose: Begin marking and/or tagging all (100%) of fall Chinook smolts produced by CNFH in order to allow CNFH origin fall Chinook to be identified when encountered. The ability to identify hatchery origin fall Chinook would enhance CNFH broodstock management, and might also improve monitoring and selective passage at the fish barrier weir. The ability to identify hatchery origin fall Chinook would enhance efforts to identify and protect BCRP target salmonids encountered in downstream monitoring programs. However, available data indicates fall Chinook straying from other hatcheries, particularly Feather River Hatchery, are much more problematic than unmarked fall Chinook produced by CNFH. This action is consistent with HSRG (2012) recommendation.

Risks and Uncertainties: This action would be most effective if coordinated and implemented among all Central Valley fall Chinook hatcheries, rather than only at CNFH.

IA12. Reduce excess returns of CNFH fall Chinook to Battle Creek.

- Need for implementation informed by observed pHOS and spawning escapement of natural origin fall Chinook in lower Battle Creek.

Purpose: Alter fall Chinook salmon CNFH propagation program and/or work with harvest managers to reduce numbers of adult fish returning to Battle Creek. Such actions might include: (1) in-river releases and/or reduced production levels (HSRG 2012), (2) use of a weir for selective passage into lower Battle Creek, (3) directed harvest of hatchery fall Chinook (e.g., HSRG 2009, HSRG 2012), and/or (4) off-site rearing with associated terminal fisheries targeting hatchery origin fall Chinook (HSRG 2009). Some of these actions would require dialogue and coordination with other Central Valley fall Chinook hatcheries, with fishermen, and with harvest managers. This action is intended to reduce adverse effects of excess hatchery fall Chinook in lower Battle Creek, and reduce the risk of hatchery strays entering the restoration area.

Risks and Uncertainties: Need to seek coordination with other Central Valley hatcheries, and with harvest managers.

IA14. Screen Intake 2.

- Need for implementation informed by diversion monitoring data incorporated into LCM.

Purpose: Install a permanent screen at the current unscreened diversion (Intake 2) to eliminate entrainment of restoration area juvenile salmonids, which can occur during outages at other intakes.

Risks and Uncertainties: None identified.

Diagnostic Studies

DS3. Relocate or Discontinue Steelhead and/or late fall Chinook programs.

Evaluate risks, costs, and benefits of discontinuing or relocating these CNFH hatchery propagation programs.

4.4 Literature Cited

Araki, H., W.R. Ardren, E. Olsen, B. Cooper, and M.S. Blouin. 2006. Reproductive success of captive-bred steelhead trout in the wild: Evaluation of three hatchery programs in the Hood River. Conserv. Biol. 21(1): 181-190.

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

Araki, H. B., B. A. Berejikian, M. J. Ford, and M.S. Blouin. 2008. Fitness of hatchery-reared salmonids in the wild. Evol. Appl. 1:342-355.

Araki, H. B. Cooper, and M. S. Blouin. 2009. Carry-over effects of captive breeding reduce reproductive fitness of wild-born descendants in the wild. Biology Letters, Conservation Biology. 10 June 2009.

Chilcote, M.W., K.W. Goodson, and M.R. Falcy. 2011. Reduced recruitment performance in natural populations of anadromous salmonids associated with hatchery-reared fish Can. J. Fish. Aquat. Sci. 68: 511–522.

HSRG (Hatchery Scientific Review Group). 2009. Columbia River hatchery reform system-wide report. Bonneville Power Administration and NOAA Fisheries. 32 p.

HSRG (California Hatchery Scientific Review Group). 2012. California Hatchery Review Group report. Prepared for the US Fish and Wildlife Service, Sacramento, CA. 102 p.

Terraqua. 2004. Draft Battle Creek salmon and steelhead restoration project adaptive management plan, prepared for the U.S. Bureau of Reclamation, Pacific Gas and Electric Company, National Marine Fisheries Service, U.S. Fish and Wildlife Service, and California Department of Fish and Game. Wauconda, Washington. 238 p.

Appendix A: Coleman National Fish Hatchery Setting and Description

Prepared for:

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CRAMER FISH SCIENCES
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Table of Contents

1. Introduction

Construction of Coleman National Fish Hatchery (CNFH) was completed in 1942, and fish culture operations began in 1943. CNFH is the principle remaining feature of the original Shasta Salvage Plan, and it provides partial mitigation for the loss of salmonid habitat resulting from the construction of Shasta and Keswick dams (USFWS 2011). Currently, CNFH annually propagates three salmonid stocks: fall Chinook salmon, late-fall Chinook salmon, and Central Valley steelhead. Fish produced at the CNFH contribute substantially to the multi-million dollar commercial and recreational fishing industry in California, and the hatchery is considered a benefit to the region's social, cultural, and economic well-being (USFWS 2011). However, ongoing hatchery operations may affect the timely restoration of self-sustaining populations of natural origin salmon and steelhead in upper Battle Creek (Terraqua 2004, Technical Review Panel 2004).

2. Coleman National Fish Hatchery Setting and the Battle Creek Watershed

CNFH is situated in the upper Sacramento River basin of northern California. More specifically, the hatchery is located on the north bank of Battle Creek, an east-side tributary to the Sacramento River, approximately three miles east of the Sacramento River and twenty miles southeast of the city of Redding (Figure 1).

The CNFH is unique among anadromous salmonid mitigation hatcheries in California in that it is not located immediately downstream from the reservoir dam it is intended to mitigate. Further, the hatchery is located in the lower section of a watershed that is not directly affected by Shasta Dam (Figures 1 and 2). The Battle Creek watershed is considered a highly important and unique watershed, which historically supported large numbers and a broad diversity of anadromous salmonids (Jones and Stokes 2005, Terraqua 2004).

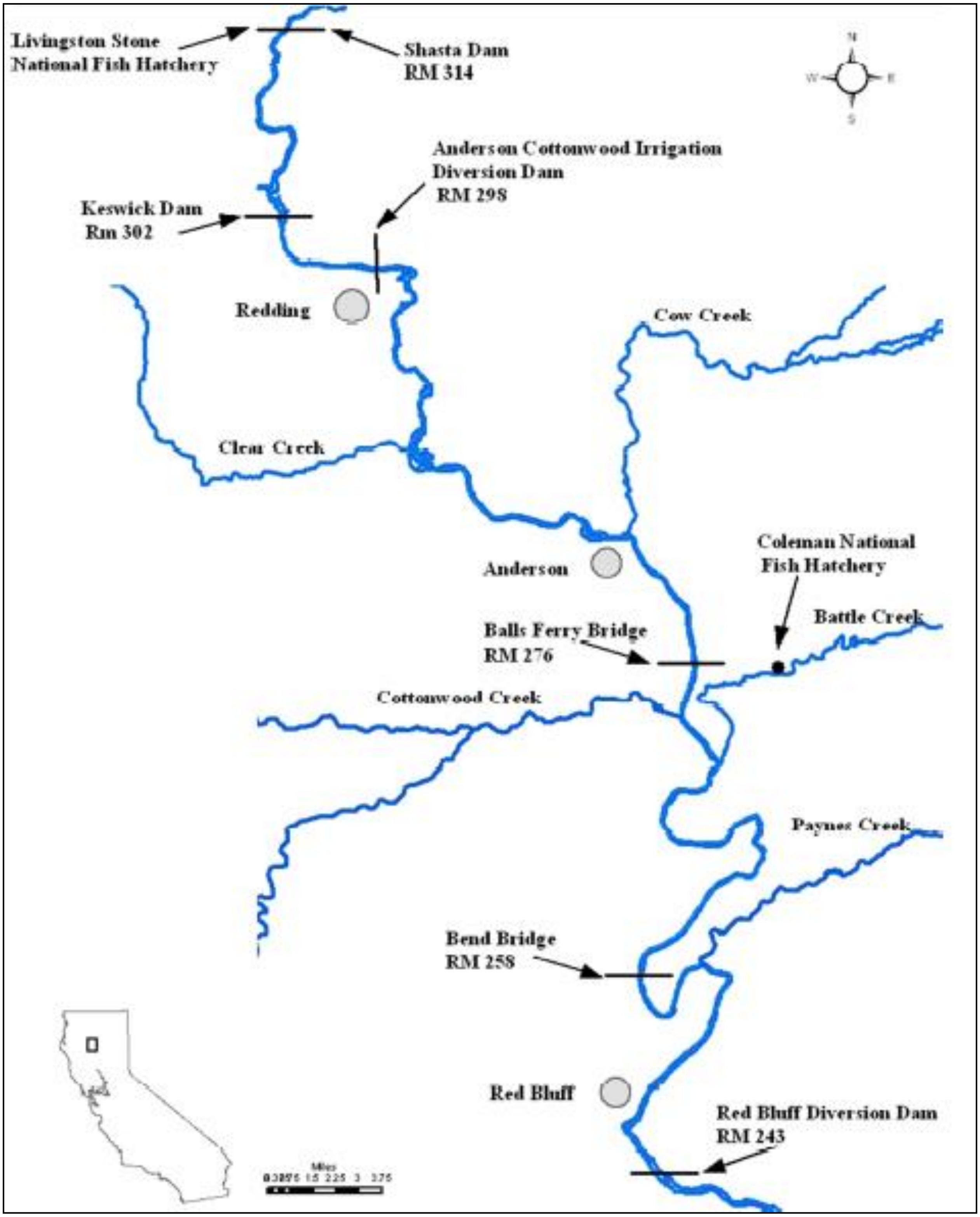


Figure 1. Location of Coleman National Fish Hatchery and other notable features of the Sacramento River system between Shasta Dam and Red Bluff Diversion Dam (Figure from USFWS 2011).

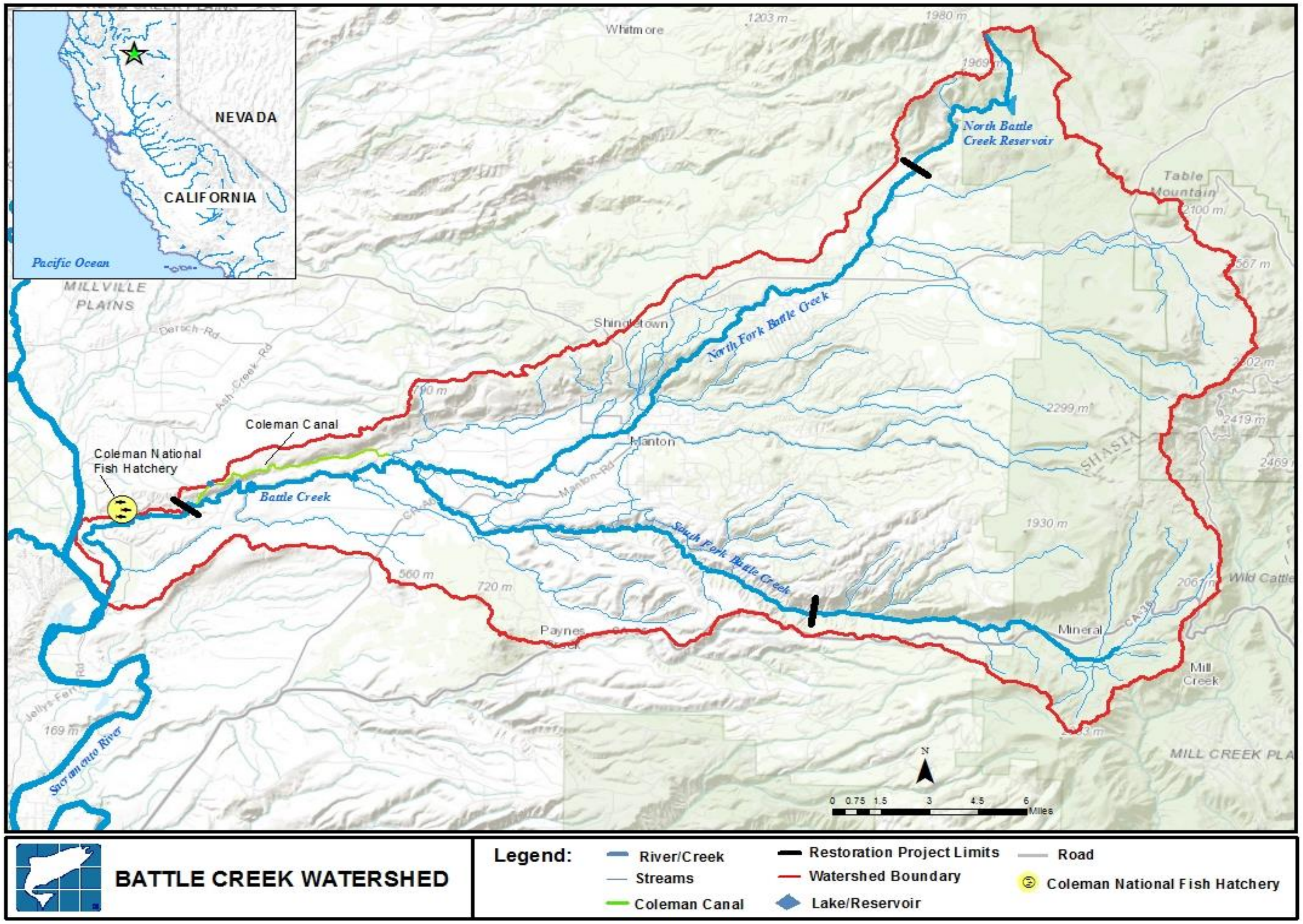


Figure 2. Water courses in the Battle Creek watershed. Upstream and downstream boundaries of the Battle Creek Restoration Project also are indicated. The Coleman National Fish Hatchery fish barrier weir (located adjacent to the hatchery) is the first substantial man-made structure encountered by anadromous fish returning to Battle Creek.

The Battle Creek watershed also is recognized as belonging to the Basalt and Porous Lava diversity group, one of four geographic regions in the Central Valley considered important to the formulation of Evolutionarily Significant Units (ESU) for Chinook salmon and Central Valley steelhead (NMFS 2014). The majority of habitat for this diversity group occurs above Shasta Dam; thus, the Battle Creek watershed is considered highly important in the context of endangered and threatened species recovery planning for winter and spring Chinook salmon, and Central Valley steelhead (NMFS 2014).

Substantial restoration of the upper Battle Creek watershed is underway. Restoration efforts focus on improving fish passage through: (1) modifications to existing hydropower infrastructure and operations; (2) modifications of natural barriers; and (3) improvements to in-stream flows (Jones and Stokes 2005). The ultimate goal is to restore and enhance approximately 42 miles of anadromous fish habitat in Battle Creek and an additional 6 miles of habitat in its tributaries, while minimizing the loss of renewable energy produced by the Battle Creek Hydroelectric Project. Restoration project proponents aim to re-establish self-sustaining populations of all anadromous salmonids stocks, although restoration of steelhead, spring Chinook, and winter Chinook populations are the top priority. (Basic life history information for each stock is provided in Section 7 below.)

3. Project Scope

The scope of the CNFH-AMP is primarily focused on the CNFH and the Battle Creek watershed. However, the scope of this project also considers other regions that anadromous central valley salmonids utilize throughout their life cycle, including the main-stem Sacramento River, the San Francisco Estuary, and the Pacific Ocean. An expanded geographic scope is necessary given the complex life cycle of the species of interest, and given the important role these regions have in their life cycle. Additionally, consideration of a broader geographic scope is warranted because the possible actions identified in the CNFH-AMP include some actions that could change the geographic scope and magnitude of the hatchery's influence beyond those resulting from current operations. The Sacramento River, Estuary, and Ocean rearing and survival conceptual model presented in Appendix C specifically considers the broader project scope. The information provided in this appendix, however, focuses on the CNFH and Battle Creek watershed. More information about the physical setting and ecology of the main stem Sacramento River, the San Francisco Estuary, and the coastal Pacific Ocean is available in Hollibaugh (1996), CALFED (2000), and Brown (2001).

4. Coleman National Fish Hatchery Goals Objectives and Performance Standards

CNFH was constructed to provide partial mitigation for the loss of salmonid spawning and rearing habitat resulting from the construction of Shasta and Keswick dams (USFWS 2011). Shasta Dam blocked approximately 50% of the Chinook salmon spawning and rearing habitats in the Sacramento River watershed (Skinner 1958), although the effects of habitat losses varied substantially among species and races. The federal government created the Shasta Salvage Plan, which included the construction and operation of a fish hatchery to mitigate for habitat lost upstream of Shasta Dam (Moffett 1949). (See Black 1999 for more details about the development of the Shasta Salvage Plan. Also, see Section 2.2 in USFWS 2011 for additional information on the original authorization of CNFH.)

The CNFH maintains propagation programs for fall and late-fall Chinook salmon, and Central Valley steelhead. Numerical objectives have been established for each propagation program (Table 1).

Table 1. Annual juvenile salmonid production release objectives for Coleman National Fish Hatchery (From USFWS 2011).

Species or race	Annual minimum objectives for broodstock/Battle Creek escapement[1/]	Annual production release objective	Life-stage at release
Fall Chinook salmon	5,200/10,000	12,000,000 at 90 fish/lb	Subyearling smolt
Late-fall Chinook salmon	540/1,000	1,000,000 at 13 fish/lb	Yearling smolt
Central Valley steelhead	800/1,500	650,000 at 4 fish/lb	Yearling smolt

1/ Increased levels of escapement (i.e., above broodstock targets) are necessary to account for fish not entering the hatchery, prespawning mortality, unequal gender ratios, and synchronization of spawn timing.

The primary goal of the CNFH fall and late-fall Chinook propagation programs is to mitigate for the Central Valley Project (CVP), which includes the loss of salmonid spawning and rearing habitat above Shasta and Keswick dams, and the consequent reduction in the population size of these salmon stocks. Fall and late-fall Chinook are produced to contribute to harvest in the ocean commercial fishery, ocean sport fishery, and freshwater sport fishery. The fall Chinook propagation program annually releases approximately 12 million juvenile fish in April at a size of 90 fish/lb, which are expected to contribute a total of 120,000 fish to harvest and escapement over the life of the brood (60-75% for harvest; HSRG 2012). The late-fall Chinook propagation program annually releases approximately 1 million yearling fish in December at a size of 13 fish/lb, which are expected to contribute a total of 10,000 fish to harvest and escapement over the life of the brood (50% for harvest; HSRG 2012).

The primary goal of the CNFH Central Valley steelhead propagation program is to mitigate for the Central Valley Project (CVP), which includes the loss of steelhead spawning and rearing habitat above Shasta Dam. Steelhead returning from the CNFH program are intended to contribute to the sport fishery in the Sacramento-San Joaquin Delta and Sacramento River, and to CNFH broodstock. More specifically, HSRG (2012) indicates that the CNFH steelhead propagation program is expected to contribute 3,000 fish to the annual run: 1,000 fish (33%) for harvest in the sport fishery, with the balance (2,000 fish) contributing to adult escapement.

The 2011 Biological Assessment of the CNFH and its operations identifies a number of performance standards (USFWS 2011). The performance standards are designed to document the benefits and risks of fish propagation at CNFH. Performance standards categorized as “benefits” describe the expected benefits resulting from the artificial propagation program (Table

2). Performance standards categorized as "risks" document the possible risks the artificial propagation program may pose to natural salmonid populations (Table 3).

Table 2. CNFH Performance standards to ACHIEVE BENEFITS, associated strategies to address the performance standard, and associated monitoring and analysis to assess performance over time. Notations in parentheses, e.g., (Ongoing), indicate the status of the strategy, monitoring effort, or analysis as provided by K. Niemela, pers. comm. The following abbreviations are used to indicate the specific propagation program at CNFH to which the performance standard applies: FCS - fall Chinook salmon; LFCS - late-fall Chinook salmon; SH - Central Valley steelhead.

Optimize abundance of anadromous salmonids in Battle Creek by integrating CNFH with the Battle Creek Restoration Project (FCS, LFCS, SH).
Strategies proposed to address the performance standard: • Manage adult fish passage at the fish barrier weir (Ongoing). • Manage the number of adult fall Chinook in lower Battle Creek (Ongoing). • Return hatchery carcasses to Battle Creek (Being considered as a possible future action).
Monitoring and analysis undertaken to evaluate performance: • Enumerate hatchery- and natural-origin adults encountered at the hatchery during spawning operations (Ongoing). • Enumerate passage of hatchery- and natural-origin adults at the fish Barrier Weir (Ongoing). • Enumerate abundance of fall Chinook salmon in Battle Creek (Ongoing; cooperative project with CDFW).
Comments: • Incomplete (i.e., <100%) marking of fall Chinook salmon inhibits management strategies that require differentiation of hatchery and natural origin fall Chinook. • Improvements to the CNFH barrier weir and fish ladder have allowed improved passage to upper Battle Creek for natural origin salmonids and improved control of fish passage into upper Battle Creek by decreasing numbers of hatchery origin salmonids escaping above the barrier weir. • CNFH ozone water treatment system reduces concerns of passing potentially disease-carrying fish into upper Battle Creek. • CNFH has largely implemented a long-term solution to the hatchery water intake structures to minimize natural origin juvenile salmonids entrainment, although additional funding is needed to complete planned improvements to hatchery intake number 2.
Increase or maintain harvest opportunities for commercial and sport fisheries (FCS, LFCS, SH).
Strategies proposed to address the performance standard: • Use fish culture and release practices at CNFH that are intended to maximize survival of hatchery fish, while minimizing negative effects on natural salmonid stocks in the Sacramento River and Battle Creek (Ongoing).

Monitoring and analysis undertaken to evaluate performance:
Estimate contribution (rates and total numbers) of CNFH fall and late-fall Chinook salmon to Pacific Ocean commercial and sport fisheries and the Sacramento River sport fishery (Ongoing). Monitor CNFH-origin fall and late-fall Chinook salmon contributions to fisheries as a proportion of the Central Valley Abundance Index (ocean harvest plus river escapement) as reported by Pacific Fishery Management Council (Ongoing). Estimate sport harvest of CNFH fall and late-fall Chinook salmon in the Sacramento River (Ongoing; using data from CDFW creel surveys). Conduct on-site bio-sampling of returning adults for mark identification and CWT retrieval to develop indices of harvest and escapement constraints (Ongoing).
Comments: Propagation of fish at CNFH increases harvest *opportunity*; however, the total number of fish *actually* harvested in the mixed-stock ocean fishery has been restricted to protect ESA listed stocks or depressed stocks. Over-escapement of hatchery-origin Chinook caused in part by reduction in harvest opportunities and due to more stringent fishing regulations to protect depressed stocks, can result in large escapement of fall Chinook to Battle Creek.
Maintain stock integrity and conserve genetic and life history diversity (FCS, LFCS, SH).
Strategies proposed to address the performance standard: • Use locally-collected, natural-origin adults for broodstock (FCS, LFCS) (Ongoing). • Spawn the number of adults necessary to minimize genetic drift and inbreeding, and conserve genetic variability of the stock (FCS, LFCS, SH) (Ongoing). • Collect and spawn adults throughout the duration of run/spawn timing, modeling the spawning schedule after a normal (bell-shaped) distribution (FCS, LFCS, SH) (Ongoing). • Use a paired mating strategy (i.e., 1 male to fertilize 1 female) (FCS, LFCS, SH) (Ongoing). • Use phenotype and mark status to effectively identify and spawn only the target population (FCS, LFCS, SH) (Ongoing). • Use natal stream water at ambient temperature to reinforce genetic compatibility with local environments and promote homing (FCS, LFCS, SH) (Ongoing).
Monitoring and analysis undertaken to evaluate performance: • At the conclusion of each spawning season, analyze CWT's from spawned fish to verify selection of target broodstock (Ongoing). • Analyze trends in fecundity, return rates, return timing, spawn timing, adult size and age composition, survival for different life stages, and other parameters as surrogates for measures of "fitness" of the hatchery stock (Ongoing).
Comments: • Current practice of marking less than 100% of hatchery production of fall Chinook salmon does not enable complete differentiation of hatchery- and natural-origin stocks based on mark status, and hinders absolute differentiation between different hatchery- and natural-origin fish based on mark status.

Provide fish for experimental purposes (FCS, LFCS, SH).

Strategies proposed to address the performance standard:

- Spawn and rear fish in a manner that will support the needs of researchers (Ongoing).
- Mark and CWT experimental fish prior to release (Ongoing).

Monitoring and analysis undertaken to evaluate performance:

- No specific monitoring identified. Specific evaluations developed based on experimental design.

Comments:

- The size and configuration of rearing units limits flexibility of lot sizes.
- Potential exists for increased interaction with natural-origin fish, including ESA listed and candidate stocks, associated with experimental releases.
- Potential exists for reduced contribution of experimental groups.

Conduct research to monitor and evaluate hatchery operations and practices (FCS, LFCS, SH).

Strategies proposed to address the performance standard:

- Evaluate contribution of fall and late-fall Chinook salmon to ocean fisheries (Ongoing – using data from the Pacific Fisheries Management Council).
- Continue mark screening and mark/tag recovery efforts on adults returning to the CNFH and Keswick Dam Fish Trap (river mile 302) (Ongoing).
- Continue to collect and analyze information obtained through adult trapping and video monitoring in Battle Creek (Ongoing; video monitoring is conducted cooperatively with CDFW).
- Summarize and analyze ocean harvest data (PSFMC) (Ongoing; ocean harvest data is generated by Pacific Fisheries Management Council).
- Summarize and analyze information collected during Battle Creek and mainstem Sacramento River adult carcass surveys (Ongoing – Battle Creek carcass surveys have been replaced in favor of video monitoring, which is conducted cooperatively with CDFW).
- Develop and implement a study to examine reproductive success of hatchery-origin steelhead that were released into upper Battle Creek to spawn naturally (Draft report available from K. Niemela, USFWS)).
- The USFWS will support and participate in the hatchery adaptive management process to integrate the hatchery with the Battle Creek Restoration process (Ongoing).

Monitoring and analysis undertaken to evaluate performance:

- See strategies proposed to address the performance standard, listed above.

Comments:

- USFWS lacks funding and a basin-wide agreement on a strategy to mark all hatchery-origin fall Chinook salmon.
- Environmental conditions (e.g., high flows and turbidity) may hinder field research and monitoring efforts.

Improve survival of propagated species/stock using appropriate incubation, rearing, and release strategies (FCS, LFCS, SH).
Strategies proposed to address the performance standard: • Release fish at a time and size to improve survival and minimize potential negative effects on natural stocks in freshwater (Ongoing). • To the extent possible, rear fish at densities favorable for minimizing stress, disease, and mortality during all life stages (Ongoing). • Use proper disease prevention and control techniques to maximize survival (Ongoing). • Conduct studies to investigate effects of the following factors on survival: food types; rearing densities; ponding strategies; natural-type rearing elements; size, time, and location of release; and other factors. Apply knowledge gained through these investigations to modify hatchery practices, when appropriate, and to maximize survival and minimize potential negative effects on natural stocks (Ongoing).
Monitoring and analysis undertaken to evaluate performance: • Analyze trends in survival for different life stages at the hatchery (Ongoing). • Analyze trends in rates of ocean harvest, freshwater harvest, and escapement (Ongoing; Ocean harvest data is generated by the Pacific Fishery Management Council).
Comments: • Rearing densities at CNFH are dictated largely by the size of the production programs, the availability of rearing space, and the availability of water for hatchery use. Ponding of juvenile fishes at CNFH is generally managed to maximize the use of hatchery rearing space, while maintaining rearing densities suitable for fish culture. • Release locations and timing are chosen to maximize survival while minimizing effects on natural stocks. Therefore, upriver release locations are generally used to minimize stray rates and geographic distribution of hatchery-origin strays (although releasing fish lower in the system would improve overall survival to maturity and contribution of adults). Likewise, timing of releases is adjusted to maintain high rates of contribution and reduce potential effects on natural stocks.
Improve survival by preventing disease introduction, spread, or amplification (FCS, LFCS, SH).
Strategies proposed to address the performance standard: • Maintain sanitary conditions for fish rearing including: (1) disinfecting all equipment (e.g., nets, tanks, rain gear, boots, brooms) with iodophor between uses with different fish/egg lots; (2) disinfecting (with iodophor) the surface of all eggs spawned at the facility; and (3) when practicable, disinfecting outside rearing units between use with a portable ozone sprayer (Ongoing). • Continue to operate an ozone water treatment facility to prevent the introduction of pathogens into CNFH through the Battle Creek water supply. (In 2005, Reclamation also provided a new 2,000 kv back-up generator and 5,000 gallon diesel fuel tank which provides greater assurance of maintaining water treatment when grid power is lost.) (Ongoing). • Enclosed rearing ponds with fencing and bird netting to minimize predation and risks of disease transmitted by predators (Ongoing). • Prescribe appropriate treatments (prophylactics, therapeutics, or modified fish culture practices) to alleviate disease-contributing factors using approved methods and chemicals (Ongoing). • Conduct applied research leading to improved control of disease epizootics (Ongoing). • Develop and conduct special release strategies to minimize occurrence of disease in hatchery and natural fish (Ongoing). • Develop and execute disease control protocol for marking and tagging of Chinook salmon and steelhead (Ongoing).

• Routinely perform examinations of live fish to assess health status and detect problems before they progress into clinical disease or mortality (Ongoing). • Routinely remove dead and moribund fish from rearing containers. In cases of increased mortality, perform necropsies of diseased and dead fish to diagnose the cause of death (Ongoing). • Perform routine examinations of collected broodstock for disease organisms (viruses, bacteria, and parasites) (Ongoing).
Monitoring and analysis undertaken to evaluate performance: • Monitor output and efficacy of the ozone water treatment system (Ongoing). • Analyze survival trends for different life stages at the hatcheries (Ongoing). • Examine trends of ocean harvest, freshwater harvest, and hatchery escapement in regards to documented history of disease incidence at CNFH (Ongoing; Ocean harvest data generated by Pacific Fishery Management Council; freshwater harvest data generated by CDFW creel survey). • Examine on-station mortality of Chinook salmon and steelhead as percent of total production (Ongoing).
Comments: • Studies have been conducted to: (1) complete a post-release evaluation of hatchery-origin smolts to examine disease progression during emigration through the Sacramento River system; and (2) complete a survey for Infectious Hematopoietic Necrosis virus (IHNV) in natural-origin fall Chinook salmon from Battle Creek and the upper Sacramento River. • Power outages or water turbidity may affect the efficacy of the water treatment facility. • Disease organisms may be introduced through other vectors (birds, mammals, visitors).
Provide local, state, and regional economic enhancement (FCS, LFCS, SH).
Strategies proposed to address the performance standard: • Release fish at a time and size to improve survival and reduce effects on natural-origin stocks (Ongoing). • To the extent possible, rear fish at densities favorable for minimizing stress, disease, and mortality during all life stages (Ongoing). • Release fish at a location to maximize survival, while reducing straying from the hatchery (Ongoing). • Use disease prevention and control techniques to maximize survival (Ongoing). • Conduct studies to investigate effects of alternative: food types; rearing densities; ponding strategies; natural-type rearing elements; size, time, and location of release; and other factors (Ongoing). • Apply knowledge gained through investigations to modify hatchery practices, when appropriate, to maximize survival and minimize potential negative effects on natural stocks (Ongoing).
Monitoring and analysis undertaken to evaluate performance: • Estimate direct and indirect economic enhancement of local, state, and regional economies resulting from propagation programs at CNFH by calculating input to local economy and commercial and sport value of the fishery attributable to the hatchery (Economic data are utilized when produced or updated).
Comments: • Artificial propagation can increase harvest opportunity; however, ocean harvest in a mixed stock fishery is restricted to protect listed stocks. • Cost/benefit economic analysis provides only a partial valuation of mitigation and restoration/recovery programs for listed stocks.

Table 3. CNFH Performance standards to REDUCE RISKS, associated strategies to address the performance standard, and associated monitoring and analysis to assess performance over time. Notations in parentheses, e.g., (Ongoing), indicate the status of the strategy, monitoring effort, or analysis as provided by K. Niemela, pers. comm. The following abbreviations are used to indicate the specific propagation program at CNFH to which the performance standard applies: FCS - fall Chinook salmon; LFCS - late-fall Chinook salmon; SH - Central Valley steelhead.

Minimize potential negative effects of CNFH on restoration of Battle Creek (FCS, LFCS, SH).
Strategies proposed to address the performance standard: • Screen water intakes for CNFH to prevent entrainment of fish from Battle Creek upstream of the hatchery (Main Intakes-Completed: back-up intake-being considered as future action, contingent upon funding). • Water used for fish propagation at CNFH is non-consumptive and returned to the creek immediately downstream of the hatchery (Ongoing). • Operate pollution abatement pond as appropriate to meet the National Pollution Discharge Elimination System water quality discharge criteria (Ongoing). • Manage fish passage at the CNFH fish barrier weir in a manner compatible with both restoration of Battle Creek and broodstock collection needs at the hatchery. Passage above the barrier weir is blocked and fish are congregated during periods necessary for collection of broodstock for the propagation programs. When broodstock are not being congregated and collected, operation of the barrier weir fish ladder and associated monitoring programs will be coordinated with CDFW and NMFS (Ongoing). • Juvenile release strategies are designed to promote rapid emigration of hatchery origin fish (Ongoing).
Monitoring and analysis undertaken to evaluate performance: • Monitor emigration of hatchery releases to document rates of movement (Ongoing). • Monitor quality of water discharged from CNFH to Battle Creek (Ongoing).
Comments: • CNFH has largely implemented a long-term solution to the hatchery water intake structures to minimize natural origin juvenile salmonids entrainment, although additional funding is needed to complete planned improvements to hatchery intake number 2. • Environmental conditions (e.g., high flows) may decrease the effectiveness of the hatchery barrier weir at blocking the upstream migration of hatchery origin salmon and steelhead. • Over-escapement of hatchery-origin Chinook salmon, caused in part by reduction in harvest opportunities, presents management difficulties in Battle Creek. • Improvements to the CNFH barrier weir and fish ladder have allowed improved passage to upper Battle Creek for natural origin salmonids and improved control of fish passage into upper Battle Creek by decreasing numbers of hatchery origin salmonids escaping above the barrier weir. However, Operation of the CNFH barrier weir for broodstock collection may block or delay migration of natural-origin adults. • CNFH ozone water treatment system reduces concerns of passing potentially disease-carrying fish into upper Battle Creek.

Minimize potentially harmful interactions between hatchery- and natural-origin stocks (FCS, LFCS, SH).

Strategies proposed to address the performance standard:

- Integrate natural-origin fish into the hatchery mating schemes (LFCS-Ongoing and managed rate of integration: FCS-Ongoing but not managed rate of integration: SH-Not currently conducted due to low abundance of natural-origin steelhead in Battle Creek).
- Minimize potential interactions in the freshwater environment by releasing fish at a time, size, physiological condition, and location that promote rapid emigration and minimal straying (Ongoing).
- Control upstream passage of natural- and hatchery-origin adult salmon in Battle Creek using the CNFH fish barrier weir (Ongoing).

Monitoring and analysis undertaken to evaluate performance:

- Analyze stray rates of fall and late-fall Chinook salmon, comparing groups released at different sizes and at different locations (Ongoing).
- Analyze emigration rates and timing of hatchery- and natural-origin Chinook salmon and steelhead (Ongoing).

Comments:

- Environmental conditions limit field monitoring capabilities.
- Lack of a Central Valley-wide total marking program precludes the ability to positively identify and differentiate hatchery and natural origin fall Chinook salmon.
- The practice of releasing excess fry has been terminated.

Do not introduce, spread, or amplify pathogens of natural stocks (FCS, LFCS, SH).

Strategies proposed to address the performance standard:

- Disinfect the hatchery water supply from Battle Creek with an ozone water treatment facility to prevent the introduction of pathogens to CNFH (Ongoing).
- Develop and conduct release strategies to minimize occurrence of disease in hatchery fish and decrease the potential for transmission of diseases to natural fish (Ongoing).
- Develop and conduct a disease control protocol for marking and tagging Chinook salmon and steelhead (Ongoing).
- Maintain sanitary conditions for fish rearing including: (1) disinfecting all equipment (e.g., nets, tanks, rain gear, boots, brooms) with iodophor between uses with different fish/egg lots; (2) disinfecting (with iodophor) the surface of all eggs spawned at the facility; and (3) when practicable, disinfect outside rearing units between use with a portable ozone sprayer (Ongoing).
- Prescribe appropriate treatments (prophylactics, therapeutics, or modified fish culture practices) to alleviate disease-contributing factors using approved methods and chemicals (Ongoing).
- Conduct applied research through the U. S. Food and Drug Administration Investigational New Animal Drug process to control disease epizootics (Ongoing – as needed).
- Routinely remove dead and moribund fish from rearing containers. Perform necropsies of diseased and dead fish to diagnose the cause of death (Ongoing).
- Perform routine examinations of collected broodstock for disease organisms (viruses, bacteria, and parasites) (Ongoing).
- Routinely perform examinations of juveniles to assess health status and detect problems before they progress into clinical disease or mortality (Ongoing).

Monitoring and analysis undertaken to evaluate performance:

- Examine trends of ocean harvest, freshwater harvest, and hatchery escapement in regards to documented history of disease incidence at CNFH and Livingston Stone NFH (Ongoing).
- Examine on-station mortality of Chinook salmon and steelhead as proportion of total production (Ongoing).

Comments:

- Studies have been conducted to: (1) complete a post-release evaluation of hatchery-origin smolts to examine disease progression during emigration through the Sacramento River system; (2) complete a survey for Infectious Hematopoietic Necrosis virus (IHNV) in natural-origin fall Chinook salmon from Battle Creek and the upper Sacramento River; and (3) examine the mode(s) and potential for IHNV transmission between hatchery- and natural-origin Chinook salmon.

Reduce the potential for negative genetic effects of artificial propagation programs on natural stocks (FCS, LFCS, SH).

Strategies proposed to address the performance standard:

- Use phenotype and mark status to effectively identify and spawn only the target population (fall and late-fall Chinook) (Ongoing).
- Manage egg takes to ensure all portions of the run are represented in the spawning distribution (Ongoing).
- Use natal stream water to reinforce genetic compatibility with local environments (Ongoing).
- Incorporate natural-origin fish as hatchery broodstock (LFCS-Ongoing and managed: FCS-Ongoing but not managed: SH-Not currently conducted due to low abundance of natural-origin steelhead in Battle Creek).
- Spawn numbers of adults necessary to minimize genetic drift and inbreeding, and to conserve genetic variability of the stock. Use large numbers (>500) adults (Ongoing).
- Collect and spawn adults throughout the duration of run/spawn timing, modeling the spawning distribution after a normal, bell-shaped curve (Ongoing).
- Use a mating strategy of 1 male to fertilize 1 female (Ongoing).
- Select broodstock randomly from collected adults. Incorporate jacks into the spawning plan (Ongoing).

Monitoring and analysis undertaken to evaluate performance:

- Analyze CWT recoveries of fish spawned at the hatchery to verify selection of target broodstock (Ongoing).
- Monitor and analyze trends in fecundity, survival for different life stages, return rates, return timing, spawn timing, adult size and age composition, and other parameters to indicate potentially deleterious changes occurring in the hatchery stock (Ongoing).

Comments:

- Lack of a Central Valley-wide total marking program precludes the ability to positively identify and differentiate hatchery- and natural-origin fall Chinook.
- Constraints of genetic monitoring (e.g., not “real-time” and expense) inhibit wide-spread use.
- Overlap of run/spawn timing of stocks such as winter/spring, spring/fall, and fall/late-fall may lead to hybridization.
- Studies have been completed to: (1) analyze broodstock history and the level of incorporation of natural stocks; and (2) analyze stray rates of fall and late-fall Chinook salmon, comparing groups released at different sizes and at different locations.

Do not exceed carrying capacity of freshwater habitats (FCS, LFCS, SH).

Strategies proposed to address the performance standard:

- Release juvenile salmon and steelhead at or near the smolt stage to encourage rapid emigration, thereby reducing the potential for competition with natural-origin juvenile fish in the freshwater environment (Ongoing).
- Cull excess fall and late-fall Chinook salmon to reduce competition between hatchery and natural origin fish in spawning areas (Ongoing).
- Retain post-spawn hatchery origin steelhead in the hatchery until after the spawning season is completed to reduce spawning competition with natural-origin steelhead (Ongoing).

Monitoring and analysis undertaken to evaluate performance:

- Evaluate emigration rates of hatchery-origin juveniles to verify rapid emigration (Ongoing; juvenile emigration data collected by existing monitoring projects and new studies).
- Monitor returns of natural- and hatchery-origin adults (Ongoing).

Comments:

- A high level of inter-annual variability in survival rates makes it impossible to predict the number of hatchery fish that will survive to adulthood.
- Carrying capacity has not been determined for freshwater environments.
- During years of high escapement, it may not be possible to remove a sufficient number of hatchery-origin Chinook from lower Battle Creek to promote optimum spawning success.

Conduct research to evaluate potential effects on natural stocks and adaptively manage hatchery operations and activities (FCS, LFCS, SH).

Strategies proposed to address the performance standard:

- Continue existing fish culture practices at CNFH (Ongoing).
- Control, monitor, and evaluate passage of steelhead and Chinook salmon above the CNFH fish barrier weir (Ongoing).
- Changed release strategy for late-fall Chinook to synchronize releases with high flow events in the Sacramento River. This is intended to encourage rapid emigration from the upper Sacramento River (Ongoing).
- Terminated the spawning of natural-origin steelhead from Battle Creek to protect a diminished population (Ongoing).

Monitoring and analysis undertaken to evaluate performance:

- Monitor straying of fall and late-fall Chinook salmon produced at CNFH (Ongoing)
- Conduct monitoring to assess predation by emigrating hatchery origin juvenile late-fall Chinook salmon in the Sacramento River (Completed).

Comments:

- Lack of a Central Valley-wide total marking program precludes the ability to positively identify and differentiate hatchery- and natural-origin fall Chinook salmon.
- Environmental conditions (e.g., flows, turbidity) may limit field monitoring capabilities.
- In 2000, an interagency agreement was reached to extend the duration that salmonids can pass above the CNFH fish barrier weir into upper Battle Creek.
- Studies have been conducted to: (1) complete a post-release evaluation of hatchery-origin smolts to examine disease progression during emigration through the Sacramento River system; (2) complete a survey for Infectious Hematopoietic Necrosis virus (IHNV) in natural-origin fall Chinook salmon from Battle Creek and the upper Sacramento River; and (3) examine the mode(s) and potential for IHNV transmission between hatchery- and natural-origin Chinook salmon.
- Conducted a public re-evaluation of CNFH, where potential effects of the artificial propagation programs were assessed. Solicit alternative management strategies that may decrease potential impacts to natural stocks.

5. Coleman National Fish Hatchery Physical Layout and Facilities

CNFH covers approximately 75 acres of land owned by the USFWS. Easements for pipelines and access exist over an additional 63 acres of land. Facilities at CNFH include: (1) the main hatchery building containing incubation stacks and trays and early-rearing tanks; (2) the administration building; (3) the feed storage building; (4) garage, warehouse and storage buildings; (5) the spawning building; (6) the shop; (7) electrical sub-station and generator buildings; (7) ozone water treatment plant and associated structures; and (8) three residences (Figure 3). Additionally, the USFWS CA-NV Fish Health Center uses three buildings located on the hatchery grounds. Other structures for fish propagation include: (1) twenty-eight 2,250 square feet (ft^2) concrete raceways; (2) thirty 640 ft^2 concrete raceways; (3) a pollution abatement pond, and (4) facilities for congregating, collecting, holding, and spawning broodstock. Details about key hatchery facilities and their operations are provided below.

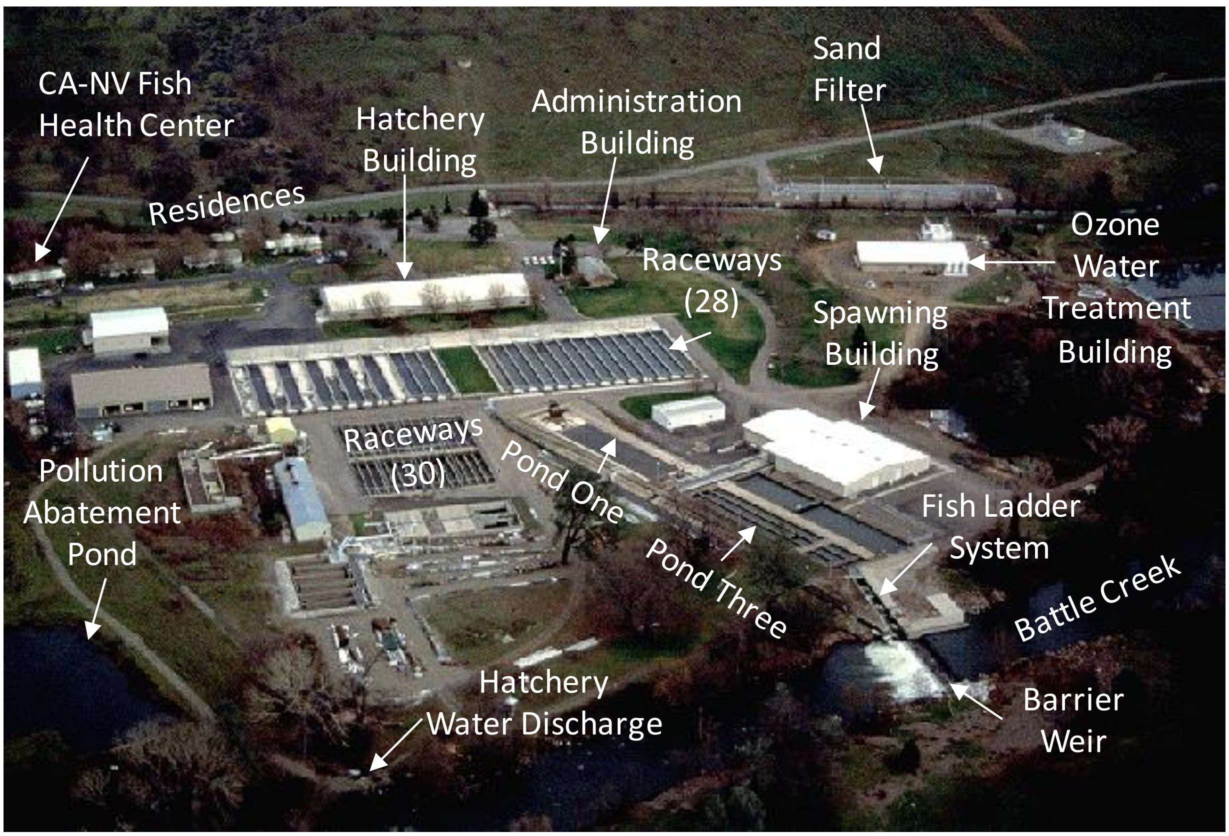


Figure 3. Aerial view showing the facilities and physical layout of the Coleman National Fish Hatchery prior to reconstruction of the fish ladder system and barrier weir (Photograph from S. Hamelberg USFWS).

5.1 Broodstock Collection Facilities

Broodstock congregation and collection facilities at CNFH include a fish barrier weir and a fish ladder system (Figure 4), both located in Battle Creek approximately six river miles upstream of its confluence with the Sacramento River. The weir is a permanent structure, and extends across the full width of Battle Creek (approximately 90 feet). The primary purpose of the fish barrier weir is to inhibit the upstream immigration of adult salmonids and facilitate their diversion into a fish ladder system. Manipulation of gates and flows within the fish ladder system allows the routing of fish into the hatchery adult collection facility and holding ponds during periods of broodstock collection. The ladder system also can allow fish to bypass the hatchery, and proceed into upper Battle Creek through the upstream fish ladder.

The USFWS, in cooperation with Reclamation, completed substantial modifications to the CNFH fish barrier weir and ladder system in October 2008. Modifications to the original barrier weir included the addition of a 2-foot-wide lipped crest cap, and an overshot gate. These modifications are intended to improve the management of adult salmonids immigrating into Battle Creek. The modified weir blocks the passage of immigrating adult salmonids at flows up to 800 cubic feet per second (cfs), and allows selective passage management at least equal to that provided by the ladders planned for upstream hydropower dams at flows up to 3,000 cfs (USFWS 2011). Battle Creek overflows its primary channel banks at flows $\geq$ 3,000 cfs, and fish passage becomes uncontrolled at these flows. Modifications to the barrier weir and fish ladder system were consistent with the Final Restoration Plan for the Anadromous Fish Restoration Program (USFWS 2001), the CALFED Ecosystem Restoration Program Strategic Plan (CALFED 2000), and were supported by the Battle Creek Salmon and Steelhead Restoration Working Group (USFWS 2011).

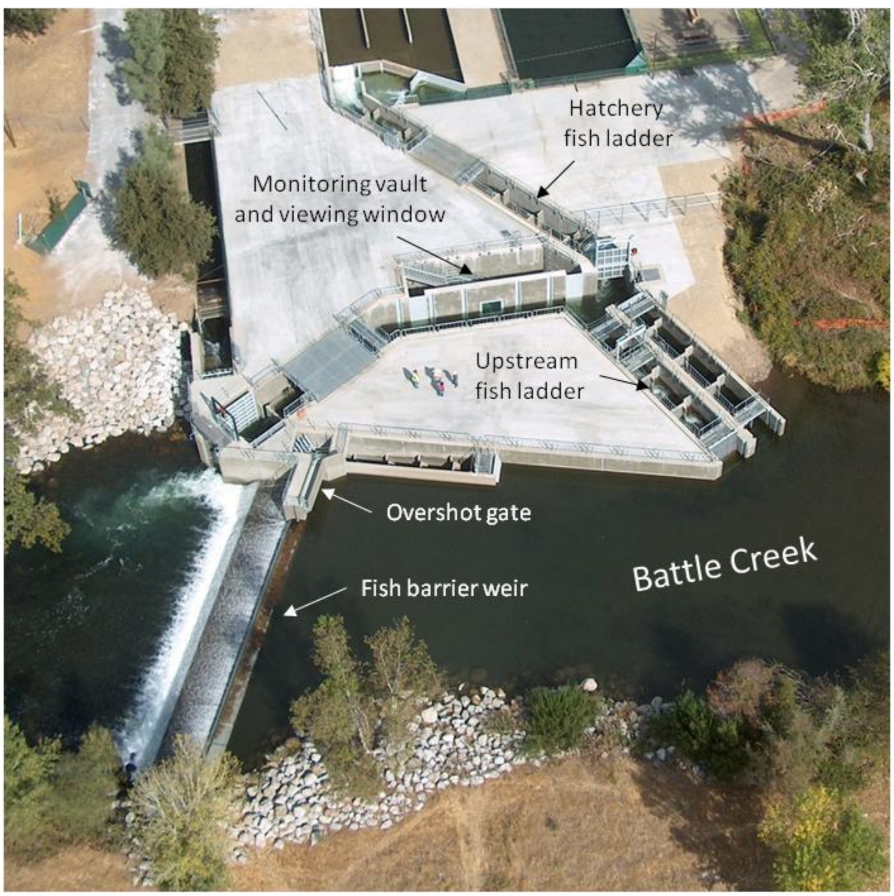
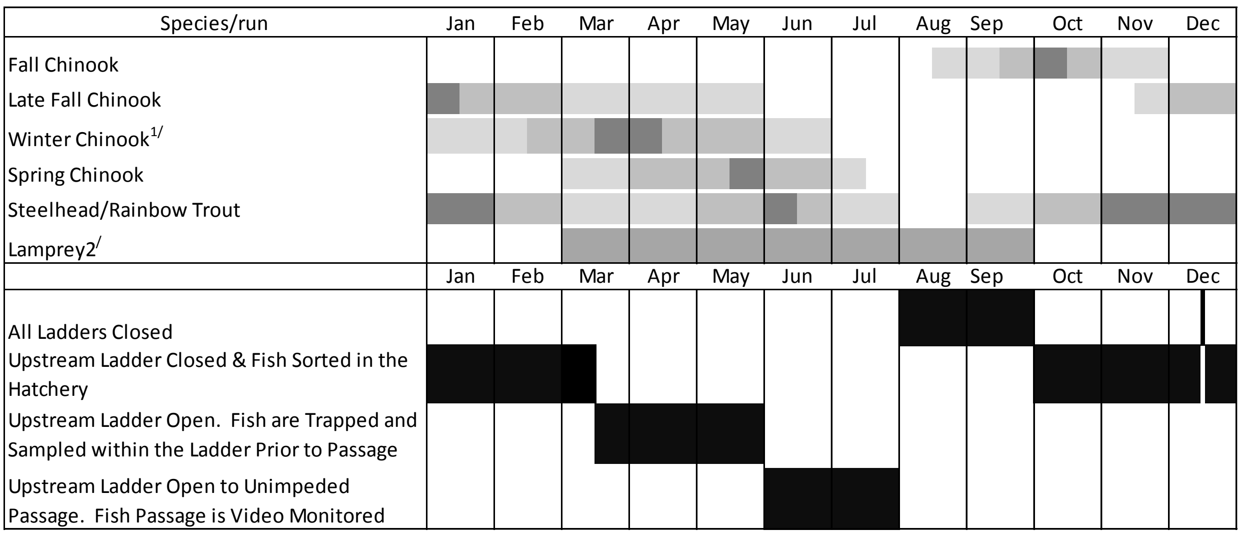


Figure 4. Aerial photo of the fish barrier weir and ladder system at Coleman National Fish Hatchery after the completion of modifications in 2008 (Photograph from S. Hamelberg USFWS).

The new fish ladder system contains two forks, one leading directly to the existing CNFH adult holding ponds (i.e., the hatchery fish ladder) and the other providing access to Battle Creek upstream of the barrier weir (i.e., the upstream fish ladder). Operation of the fish ladder system is based on a prescribed schedule (Table 4). The amount of water flowing through the new fish ladder plus attraction flows is not expected to be less than 10% of Battle Creek flow. Additional modifications were included to enable lamprey (*Lampetra* spp.) to migrate through the upstream fish ladder. A monitoring vault and viewing window were included to support monitoring of fish passing through the ladder system.

Table 4. Probable adult migration period of anadromous salmonids stocks in Battle Creek, and CNFH barrier weir fish ladder operational status over the calendar year. Density of shading indicates intensity of run timing at the barrier weir. Darker shading indicates higher intensity. (Table provided by K. Niemela, USFWS).



1/ Winter Chinook migration timing is speculative in Battle Creek. Information presented is based on historic run timing in the Sacramento River past Red Bluff Diversion Dam.

2/ Bar racks in place to preclude salmonid movement during August and September do not impede lamprey movement through the ladder.

The fish ladder system at the barrier weir and into CNFH is closed during two periods each year. The ladder system is closed between August 1 and October 1 in accordance with a multi-agency Fishery Management Action agreement for Battle Creek (USFWS 2011). The majority of spring Chinook salmon are thought to have ascended Battle Creek past the barrier weir prior to August first. Closure of the fish ladder on August 1 prevents early migrating fall Chinook salmon from accessing upper Battle Creek. This management strategy may result in the blockage of some late migrating spring Chinook salmon after the fish ladder is closed on August 1, although this is considered unlikely (USFWS 2011). The second ladder system closure occurs in December for approximately 10 days. The purpose of the December closure is to provide temporal separation in the broodstock collection of fall Chinook and late-fall Chinook (USFWS 2011).

After all CNFH broodstock collection is completed (approximately March 15th), the hatchery fish ladder is closed and the upstream ladder is opened (Table 4). Adult salmonids passing through the upstream ladder are initially monitored by *in situ* trapping and handling of fish, and later via video monitoring as Battle Creek water temperatures warm (Newton and Stafford 2011). A fish trap is installed within the upstream fish ladder at the onset of spring adult salmonid monitoring. The trap is operated 8-hr/day, 7-days/week. During hours when the trap is not operated, fish are allowed to enter the trap, but the exit is closed, blocking fish passage. To decrease potential passage delays for Chinook salmon, trap operation (including fish sampling and sorting) occurs during two time shifts based on diel movement patterns observed in previous years: (1) 0930-1730 (PST) from March 1 to mid-April; and (2) 0430-1230 (PDT) from mid-April until about May 15, when video surveillance monitoring typically begins. Fish captured in the trap are physically handled for collection of biological data, and Chinook salmon and steelhead are classified as either unmarked or marked[1]. When water temperature exceed 60 degrees Fahrenheit (ºF), trapping is terminated for that day to minimize the stress caused by handling fish at high temperatures. Trapping is terminated for the season when water temperatures exceeded 60ºF for a majority of the daily trap operation period, generally mid-May (Newton and Stafford 2011). Note that since 2011, the fish trap has not been used to capture adult salmonids due primarily to fish avoidance. Instead, fish are allowed to enter CNFH collection facilities where they are identified and sorted.

Newton and Stafford (2011) provided a description of the trapping, handling, and sorting methods associated with *in situ* adult fish monitoring in the upstream fish ladder:

> *The trap was checked every 30 minutes and non-target fish were identified to species, counted, and released. Native fish were released upstream, and non-native fish were released downstream. Salmonids were netted from the trap and immediately transferred to a holding trough where biological data was collected. Water temperature in the holding trough was maintained within 2ºF of Battle Creek water temperatures. All salmonids were measured (fork length) to the nearest 0.5 cm, identified as male or female when possible, and examined for scars and tissue damage. Salmonids also were examined for the presence of a mark such as an adipose-fin clip, Floy tag, or Visible Implant Elastomer (VIE) tag. A tissue sample was taken from unmarked Chinook salmon and rainbow trout for genetic analysis. All marked Chinook salmon were sacrificed and coded-wire tags (CWT) extracted and decoded to determine run designation, hatchery of origin, and age. Since only a fraction of the marked rainbow trout were tagged with a CWT, they were first scanned using a V-detector or a hand-held wand detector. Marked trout with a CWT were sacrificed for tag recovery. Marked trout without a CWT were transported live to a CNFH raceway where they were reconditioned, VIE tagged, and released into lower Battle Creek. Any reconditioned kelts recaptured in the trap were released downstream of the fish barrier weir.*

Video surveillance monitoring is conducted from the termination of *in situ* fish trap monitoring (typically starting in mid-May) until August 1, when the ladder system is completely closed

[1] Throughout this document 'marked' fish or 'externally marked' fish refers to fish externally marked by removal of the adipose fin, unless otherwise specified. Unmarked fish have an adipose fin, i.e., no external mark.

(Table 4). The fish ladder system has an open-air monitoring vault adjacent to the middle ladder, and a viewing window between the vault and middle ladder that allows for observation of fish passage (Figure 4). A fish crowder system in the ladder guides fish to within 18” of the viewing window for video monitoring. Digital video footage is later viewed to enumerate fish, determine species, and determine the presence or absence of an adipose fin.

5.2 Adult Holding and Spawning Facilities

Adult holding and spawning facilities at CNFH consist of five holding ponds of various configurations, as well as a fully mechanized facility for crowding, sorting, and spawning of collected adults. Upon ascending the hatchery fish ladder and the lower part of Pond 2 (approximate volume = 4,800 ft^3), salmonids enter Pond 3 (approximate volume = 30,600 ft^3). From Pond 3, collected fish are routed into the spawning building using mechanical fish crowders. The spawning building includes a spawning and sorting facility, and encloses two additional holding ponds (Ponds 4 and 5; each with an approximate volume = 23,390 ft^3). During spawning operations, a hydraulic lift located in the spawning building raises fish into a carbon dioxide (CO_2) anaesthetization tank. Upon being anaesthetized, target fish are phenotypically sorted into one of three categories: (1) ripe fish to be spawned; (2) fish to be culled (excessed); or (3) unripe fish to be held for possible later spawning. Non-target native fish can be immediately returned to Battle Creek by placing them into a tube that terminates in Battle Creek upstream of the hatchery barrier weir. During late-fall Chinook salmon propagation, Pond 2 is used to hold natural-origin late-fall Chinook collected at the Keswick Dam fish trap, and transferred to the CNFH for use as broodstock. Pond 1, or the pre-release pond (approximate volume = 25,000 ft^3) is used to hold post-spawn steelhead during the recondition of those fish. Pond 1 has concrete sides and a gravel bottom.

5.3 Incubation and Indoor Rearing Facilities

Egg incubation facilities are located in the Hatchery Building. Incubation units consist of 178 sixteen-tray vertical fiberglass incubators (Heath Incubation Trays). Sixty-seven 52-ft^2 fiberglass tanks used for early rearing of steelhead also are located in the Hatchery Building.

5.4 Outdoor Rearing Facilities

Outdoor rearing units include twenty-eight raceways (approximately 5,600 ft^3, each), and thirty raceways (approximately 1,148 ft^3, each). The raceways are constructed of concrete. Both banks of raceways are enclosed with a wire fence and covered with wire mesh to minimize bird predation.

5.5 Fish Transportation Equipment

CNFH has two trucks that are used to transport fish: (1) a 2002 Freightliner (tank capacity of 2,000 gallon); and (2) a 1998 Freightliner (tank capacity of 1,500 gallon). CNFH uses the distribution trucks for transporting steelhead to the Sacramento River at Bend Bridge (RM 258; Figure 1). The fish distribution trucks also are used to transport adult late-fall Chinook salmon from the Keswick Dam fish trap to CNFH, and to transport adult winter Chinook salmon from the Keswick Dam fish trap to the Livingston Stone National Fish Hatchery (LSNFH). The distribution trucks also have been used to transport a portion of the fall Chinook production for release in San Pablo Bay (San Francisco Estuary) or in the Sacramento River near Rio Vista.

Occasionally, the trucks also are used to transport Chinook salmon and steelhead for various research projects.

5.6 Water Intake Facilities

The CNFH has three separate water intakes to support its operations (Figure 5). The primary water intake for the CNFH (Intake 1) is located in the tailrace of PG&E's Coleman Powerhouse. Water in the PG&E Coleman Powerhouse tailrace originates from an area of upper Battle Creek that is currently considered inaccessible to anadromous fish (USFWS 2011). However, this area in upper Battle Creek will become accessible to anadromous fish once the restoration project is complete, and the fish screen at the Coleman Powerhouse becomes operational. Intake 1 also is inaccessible to anadromous salmonids from the downstream direction due to the presence of a juvenile fish barrier and an adult salmonid exclusion weir. Water diverted through Intake 1 is conveyed to the hatchery via a 46-inch diameter pipe, which daylights into an open canal. Water in the PG&E powerhouse tailrace not diverted to the hatchery empties into Battle Creek approximately 1.6 miles upstream of the hatchery.

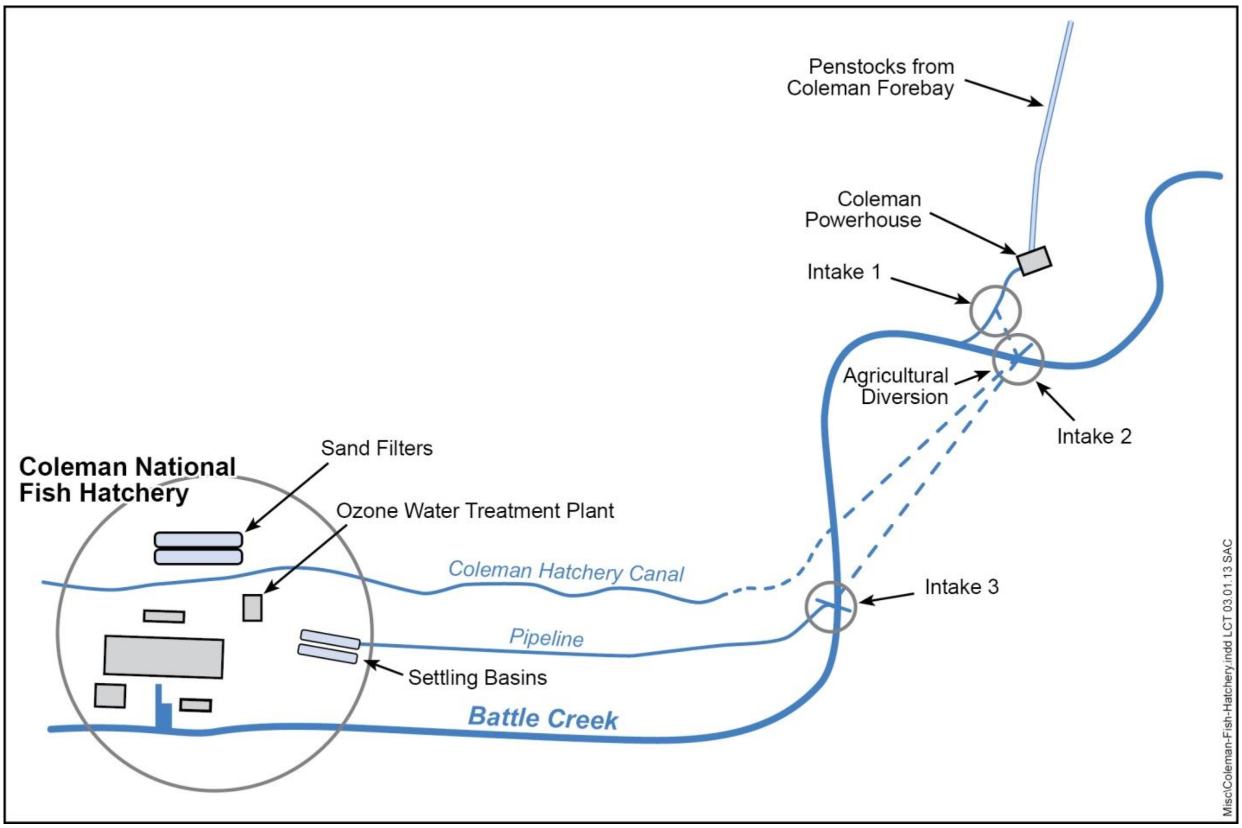


Figure 5. Existing water diversion and delivery system at Coleman National Fish Hatchery, Battle Creek, California (From USFWS 2011).

Anticipating implementation of the Battle Creek Restoration Project (BCRP), USFWS expanded the capacity of Intake 1 in 2009 to provide improved efficiency and operational flexibility. Since the water available in the PG&E Coleman Powerhouse Tailrace is considered devoid of anadromous fish, an independent fish screen was not considered necessary at the Intake 1 diversion site. Instead, modifications were made by adding an adjacent intake orifice at the

Intake 1 site, which supplies a new 36-inch pipeline. This new pipeline ties into the new Intake 3. The expansion of Intake 1 allows the hatchery to use more of the water from the PG&E Coleman powerhouse tailrace (i.e., water that has already been diverted through the PG&E hydroelectric system project), thereby reducing the need for additional diversions directly from Battle Creek.

The hatchery's secondary water intake, Intake 3, is located 1.2 miles upstream of the hatchery (Figure 5). Intake 3 was rebuilt in 2009 to incorporate a state-of-the-art traveling fish screen that meets National Marine Fisheries Service (NMFS) and California Department of Fish and Wildlife (CDFW) fish protection criteria. Water directly diverted from Battle Creek through Intake 3, or delivered to this site via Intake 1 is conveyed to the hatchery through a 48-inch diameter pipeline.

The hatchery backup water intake structure, Intake 2, is unscreened. When in use, this intake may entrain juvenile fish. USFWS (2011) reported that Intake 2 is used only as an emergency backup to Intakes 1 and 3. Also, the design of Intake 2 prevents diversion of water simultaneous with diversion at Intake 1. During normal CNFH operations, water is diverted from either Intake 1 or a combination of Intakes 1 and 3. Occasionally, however, Coleman hydropower diversions are disrupted due to either a planned (e.g., annual maintenance) or an unplanned event (e.g., breakdown of PG&E powerhouse, or water delivery system infrastructure failure). Under these circumstances, the PG&E Coleman Powerhouse tailrace empties, and no water is available for Intake 1. When Intake 1 is not functional, Intake 2 automatically begins diverting water (Intake 3 also may be used), thus maintaining adequate water supply to CNFH.

5.7 Water Treatment Facilities

In 1993, the CNFH initiated construction of a water treatment facility to reduce sediment in the hatchery water supply and to alleviate recurring disease problems. The treatment facility is capable of filtering 45,000 gpm and ozonating 30,000 gpm. Although ozone production capability reached full capacity in 2000, construction and final build-out of the facility did not conclude until 2002. Several alternatives were considered in determining the size of the ozone treatment plant, and its treatment capacity (USFWS 1986, 1987, 1989, 1997a, 1997b). The alternative chosen allows the egg incubation and juvenile rearing facilities to receive 100% treated water, while the broodstock collection and spawning facilities receive a mixture of treated and untreated water. Operation of the ozone water treatment facility has substantially reduced the occurrence of disease in the hatchery production, and has substantially reduced the potential for disease transmission to naturally-produced salmonids (USFWS 2011). Since brood year 1999, juvenile salmonids propagated at the CNFH have been reared and released with no incidence of IHNV (USFWS 2011).

6. Coleman National Fish Hatchery Propagation Programs

CNFH has the highest production targets of any California Central Valley hatchery for the salmonids stocks it propagates (Table 5).

Table 5. Annual production targets for hatcheries producing juvenile anadromous salmonids in the California Central Valley. Coleman and Livingston Stone hatcheries are operated by the USFWS, all other hatcheries are operated by the CDFW. Data from NMFS (2014).

	Juvenile fish production targets				
Fish Hatchery	**Steelhead**	**Spring Chinook salmon**	**Fall Chinook salmon**	**Late-fall Chinook salmon**	**Winter Chinook salmon**
Coleman	600,000	0	12,000,000	1,000,000	0
Feather River	500,000	2,000,000	6,000,000	0	0
Nimbus	430,000	0	4,000,000	0	0
Mokelumne	100,000	0	5,000,000	0	0
Merced River	0	0	1,000,000	0	0
Livingston Stone	0	0	0	0	<250,000
Total	**1,680,000**	**2,000,000**	**26,000,000**	**1,000,000**	**<250,000**

CNFH propagation operations occur year-around, and include broodstock collection, spawning, egg incubation, and juvenile rearing of three salmonids (Figure 6). Further details on each hatchery propagation program are provided below.

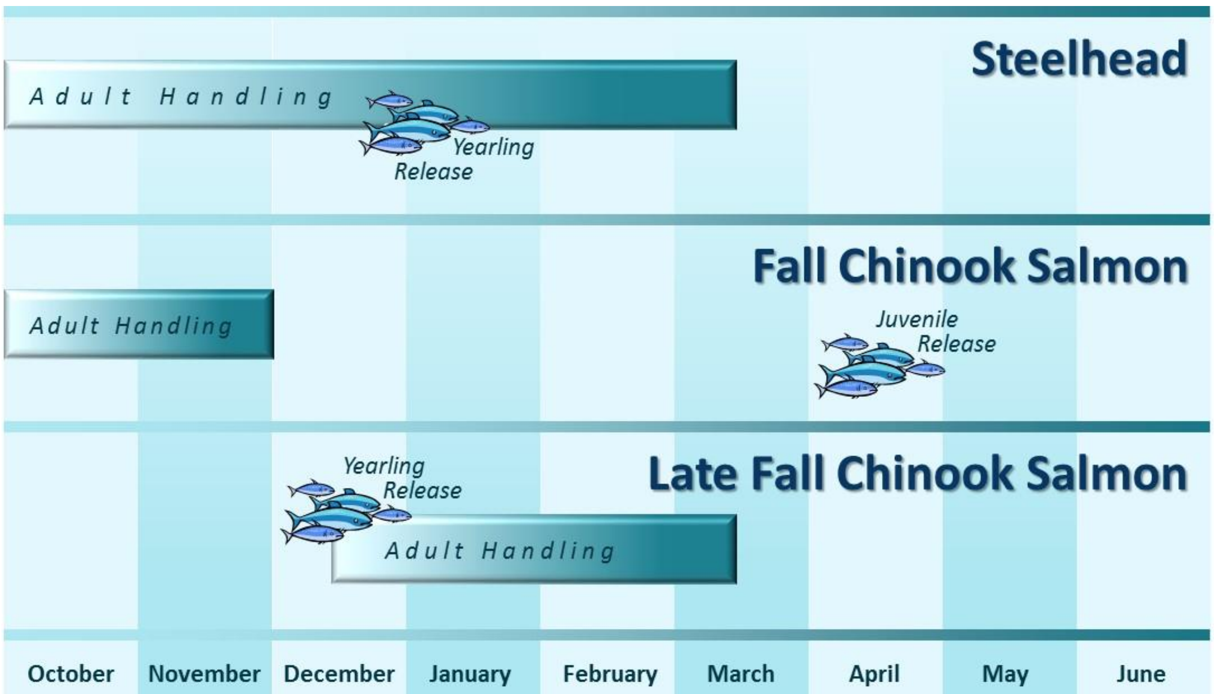


Figure 6. Timing of broodstock collection (i.e., adult handling) and juvenile release of the three salmonids propagated at the Coleman National Fish Hatchery. Steelhead and late-fall Chinook are reared to yearling size, while fall Chinook salmon are reared and released as sub-yearling smolts. Thus, juvenile rearing of steelhead and late-fall Chinook is essentially a year-around activity. Juvenile rearing of fall Chinook occurs from December through April of each year.

6.1 Steelhead Propagation Program

The steelhead propagation program at CNFH is operated as a segregated harvest program. Since 2009, this propagation program has relied entirely on marked adult steelhead for its broodstock (USFWS 2011). Operations at CNFH and selective passage of natural origin fish into upper Battle Creek mean the program could be largely consistent with standards for proportionate natural influence (PNI, HSRG 2009). However, as discussed in Appendix C, there is some uncertainty regarding hatchery steelhead reaching upper Battle Creek during periods of video monitoring or during flow events greater than 800 cfs. Adult steelhead broodstock are spawned in the hatchery. Juveniles are reared in the hatchery and released approximately one year later, at yearling size. Adult broodstock are reconditioned after spawning and released into Battle Creek downstream of the hatchery.

The CNFH steelhead propagation program was historically operated as an integrated harvest program, and an integrated-recovery program (USFWS 2011). This hatchery program has a long history of integrating natural-origin broodstock from the Sacramento River (1947-1986), and from Battle Creek (1952-2008) into the hatchery-origin broodstock. Although natural origin fish may have been included in broodstock during these earlier periods, the degree to which the program was consistent with integrated program standards (e.g., HSRG 2009) is unknown.

Adult steelhead are collected starting in October, and marked steelhead are held until sexually mature. Since 2001, an average of 2,075 marked and unmarked adult steelhead have returned to Battle Creek (Table 6). Since 2009, all unmarked steelhead brought into the hatchery have been released into upper Battle Creek. Presently, all marked steelhead are either spawned, or when numbers of hatchery-origin steelhead exceed broodstock collection requirements, stripped of eggs[2].

2 Stripping the eggs from hatchery steelhead is done to: (1) minimize female spawning behavior in the reconditioning pond, which aggravates competition for space and may adversely affect fish survival. If excess females are not stripped of eggs they will attempt to complete spawning activity in the reconditioning pond, or the eggs would need to be reabsorbed by the female which could result in health complications/impacts (S. Hamelberg and R. Null, pers. comm.). And (2) minimize the proportion of hatchery origin fish that spawn on the natural spawning grounds (see HSRG 2012 for more details).

Table 6. Number of marked and unmarked adult *O. mykiss*[3] returning to Battle Creek for return years 2001 to 2014 (unpublished data from R. Null, USFWS).

Season	Marked	Unmarked	Total [1/]
2001 - 2002	3,075	411	**3,4863**
2002 - 2003	1,887	428	**2,315**
2003 - 2004	1,378	225	**1,603**
2004 - 2005	1,343	312	**1,655**
2005 - 2006	994	282	**1,276**
2006 - 2007	1,391	164	**1,555**
2007 - 2008	2,968	184	**3,152**
2008 - 2009	1,987	196	**2,183**
2009 - 2010	624	266	**890**
2010 - 2011	1,108	200	**1,308**
2011 - 2012	1,524	203	**1,727**
2012 - 2013	2,651	185	**2,836**
2013 - 2014	2,619	365	**2,984**
Total	**23,549**	**3,421**	**26,970**
Mean	**1,811**	**263**	**2,075**

1/ Prior to 2003, it was not possible to completely differentiate all hatchery- and natural-origin steelhead, since all juvenile hatchery steelhead were externally marked beginning in 1998.

After spawning or stripping, steelhead are placed in holding ponds at the hatchery and "reconditioned" until March or April when they are released into lower Battle Creek. As part of studies to evaluate survival and movement, steelhead kelts were implanted with ultrasonic transmitters and released. The fish were subsequently monitored using an array of fixed-site ultrasonic receivers located throughout the Sacramento River basin. Null et al (2012) reported that migratory patterns were variable among individual fish released during both years, and fish demonstrated both anadromous and non-anadromous life histories. However, the majority (90 %) of the kelts demonstrated behavior consistent with anadromy.

USFWS personnel also studied the incidence of repeat spawning of CNFH steelhead using Visible Implant Elastomer (VIE) tags to identify fish. During the period 2005 through 2014, an average of 60 (4%) repeat steelhead spawners were identified at CNFH, and during adult fish monitoring at the fish barrier weir (Table 7)

3 The scientific name *Oncorhynchus mykiss* or *O. mykiss* is generally used throughout this report instead of steelhead or Central Valley steelhead when presenting data or discussing information based on field data and observations, due to the inability to definitively distinguish between anadromous steelhead and resident rainbow trout during all life stages.

Table 7. Number and percentage of repeat spawning steelhead (*O. mykiss*) collected at Coleman National Fish Hatchery and in the fish ladder trap from 2005 to 2014 (unpublished data from R. Null, USFWS).

	Number of repeat spawners			Number of hatchery-origin *O. mykiss*			
Return Year 1/	**Male**	**Female**	**Total**	**Male**	**Female**	**Total**	**Percent of return comprised of repeat spawners**
2004 - 2005	8	16	**24**	717	631	**1,348**	1.8%
2005 - 2006	2	22	**24**	470	528	**998**	2.4%
2006 - 2007	4	35	**39**	686	720	**1,406**	2.8%
2007 - 2008	9	14	**23**	1,670	1,297	**2,967**	0.8%
2008 - 2009	34	121	**155**	964	1,057	**2,021**	7.7%
2009 - 2010	28	126	**154**	288	373	**661**	23.3%
2010 - 2011	12	45	**57**	549	637	**1,186**	4.8%
2011 - 2012	18	69	**87**	1,234	1,256	**2,490**	3.5%
2012 - 2013	20	37	**57**	912	849	**1,761**	3.2%
2013 - 2014	8	64	**72**	1,185	1,340	**2,525**	2.9%
Total	**143**	**549**	**692**	**8,675**	**8,688**	**17,363**	
Mean	**14**	**55**	**69**	**868**	**869**	**1,736**	**4.0%**

1/ Adult steelhead are collected for broodstock at CNFH from October through February, *in situ* adult fish monitoring in the barrier weir fish ladder occurs from March through July.

Juvenile steelhead are reared in the hatchery for approximately one year. All fish are externally marked by removing the adipose fin, before release into the Sacramento River near Bend Bridge during December and January (Figure 1).

The production objective for the steelhead program is the annual release of 600,000 yearlings at a size of 8 inches (200 mm). CNFH steelhead production represents about 36% of the total annual Central Valley hatchery steelhead production (Table 5).

6.2 Fall Chinook salmon Propagation Program

USFWS (2001) identifies the fall Chinook salmon hatchery propagation program as an integrated harvest type program. Boundaries for estimating the PNI for fall Chinook salmon have not been delineated (HSRG 2012). However, estimates of natural origin Chinook from lower Battle Creek, the Sacramento River, and other Central Valley tributaries (Kormos et al. 2012) indicate that, by any boundaries which might be delineated, the Battle Creek fall Chinook propagation program is inconsistent with PNI standards for an integrated hatchery program (HSRG 2009, HSRG 2012).

Adult fall Chinook salmon are collected from early October through mid- to late-November. Between late-November and late-December, the hatchery fish ladder is generally kept open, with the exception of a 10-day closure in December (Table 4). Fall and late-fall Chinook salmon collected between late-November and late-December are euthanized and removed, to promote separation of spawn timing between hatchery stocks of fall and late-fall Chinook salmon, and to reduce the risk of hybridization.

Hatchery personnel estimate that 2,600 pairs of fall Chinook salmon are needed to meet annual production targets. Broodstock are selected from mature adults greater than 27.6 inches (700 mm), and grilse (also known as jacks) are incorporated at a rate of up to 5% of the total number of fish spawned. The annual spawning target is back-calculated based on a release target of 12 million smolt, estimated fecundity of female broodstock (eggs/female), and estimated mortality during incubation and rearing in the hatchery (USFWS 2011). Actual numbers spawned between 2001 and 2008 have averaged 8,352 adults (USFWS 2011).

Since 1987, CNFH personnel have artificially spawned only fall Chinook salmon broodstock selected from fish entering the hatchery fish ladder. During the past 11 seasons (2004-14), an average of 48,217 fall Chinook salmon have been collected at the hatchery annually (Table 8), although not all are used as broodstock. The goals are to leave approximate 20,000 fall Chinook in Battle Creek below the weir to spawn naturally, and to obtain enough adults to meet broodstock needs. Fish in excess of lower the Battle Creek target, and in excess of broodstock needs are taken into the hatchery and euthanized to reduce spawning pressure in lower Battle Creek (S. Hamelberg, pers. comm.). Adult fall Chinook salmon have not been intentionally released above the CNFH fish barrier weir since 1989.

Table 8. Estimated numbers of adult fall Chinook salmon returning to Battle Creek for return years 2004 through 2014 (Data from CDFW Grand Tab, and D. Killam, pers. comm.).

Year	Collected at CNFH	Downstream CNFH fish barrier weir	Upstream CNFH fish barrier weir	Total
2004	69,172	23,861	0	**93,033**
2005	142,673	20,520	0	**163,193**
2006	57,832	19,493	0	**77,325**
2007	11,744	9,904	0	**21,648**
2008	10,639	4,286	0	**14,925**
2009	6,152	3,047	0	**9,199**
2010	17,237	6,633	0	**23,870**
2011	42,092	12,804	0	**54,896**
2012	84,289	32,558	0	**116,847**
2013	70,021	31,116	1	**101,138**
2014[1/]	18,532	27,482	0	**46,014**
Totals	**530,383**	**191,704**	**1**	**722,087**
Means	**48,217**	**17,428**	**0**	**65,645**

1/ 2014 estimated numbers are draft and subject to revision. D. Killam pers. comm.

The annual fall Chinook release target from Coleman Hatchery is 12 million smolts at an average size of 90 fish/lb (Table 1). Of these, 25%, or about three million fish/yr are coded wire-tagged and externally marked as part of a constant fractional marking (CFM) program[4]. Juvenile fish are currently released into Battle Creek downstream of the fish barrier weir in two large groups (approximately 6 million fish in each group) during April, although from 2008

[4] The constant fractional marking program for fall Chinook salmon is distinct from the 100% marking and tagging of all other hatchery-origin salmonids produced in the Central Valley.

through 2011 about 10% of the smolts were transported and released in San Pablo Bay (HSRG 2012). Smolts also were transported and released on the Sacramento River near Rio Vista in 2014 and 2015, due to severe drought conditions and low river flows. However, transport and release of smolts outside of Battle Creek is not standard CNFH operations. These actions are intended to support ocean commercial and recreational fisheries in response to low abundance and/or drought conditions (R. Null, pers. comm.) The standard practice is to release smolts from the hatchery in large groups, as a strategy to decrease predation during emigration, and to decrease concurrent residence time with natural-origin salmonids in the Sacramento River. Monitoring shows rapid emigration of smolts from Battle Creek and through the Sacramento River at a maximum rate of nine miles per day (Snider and Titus 2000).

6.3 Late-fall Chinook salmon Production Program

USFWS (2011) identifies the late-fall Chinook salmon program as an integrated harvest type program. Late-fall Chinook salmon at CNFH are thought to be integrated with the natural population in the upper Sacramento River because:

1. They have similar ancestry with upper Sacramento River late-fall Chinook salmon.
2. Natural-origin adults captured in the Keswick Dam fish trap have been regularly incorporated into hatchery broodstock, comprising as much as 15%.
3. Hatchery-origin adults stray and spawn naturally with natural-origin late-fall Chinook salmon, primarily in the upper Sacramento River.

More detailed examination of the hatchery broodstock composition suggests the late-fall Chinook propagation program has the characteristics of an integrated program: with a proportion of natural origin broodstock (pNOB) of 0.06, and a PNI of 0.53 (R. Null, pers. comm.). Late-fall Chinook PNI is within integration standards defined by the HSRG (2012), but pNOB is somewhat below the minimum recommend value of 0.10. Data available from in-river spawners suggest the proportion of late-fall Chinook hatchery origin spawners (pHOS) spawning in the Sacramento River is 0.06 (R. Null, pers. comm); substantially less than the recommended maximum pHOS of 0.5 (HSRG 2009). Few late-fall Chinook are thought to spawn in lower Battle Creek (K. Neimala, pers. comm); however, the possibility should be explored further in order to fully evaluate pHOS, and the proportion of natural origin spawners (pNOS) in lower Battle Creek.

Broodstock fish for this program are collected from two sources: (1) the Keswick Dam fish trap (Figure 1); and (2) the CNFH fish ladder. The annual broodstock requirement is 270 spawning pairs to achieve the juvenile fish production target, although the actual number of fish collected is higher (Table 1). Broodstock collection begins in Battle Creek in late December, after a brief period of fish ladder closure. Unmarked, presumed natural origin late-fall Chinook salmon are released above the fish barrier weir, while hatchery-origin (i.e., marked) salmon in excess of broodstock needs are euthanized. Since 2004 up to 15% (<100 fish) of the natural-origin adult fish annually trapped at the Keswick trap have been included in the CNFH broodstock, in order to incorporate natural-origin adult fish without affecting the natural population in Battle Creek (USFWS 2011).

Late-fall Chinook salmon broodstock selection criteria include run timing, phenotypic characteristics, and hatchery mark status. Since 1992 all juvenile late-fall Chinook salmon produced and released from CNFH have been marked externally with an adipose fin-clip, and internally with a CWT. Late-fall Chinook salmon are differentiated from early-arriving winter Chinook salmon based on phenotypic characteristics including the degree of maturity and body coloration and morphology. The accuracy of these visual observations was tested in 2003 through 2007 by analyzing fin tissue samples from 112 presumed late-fall Chinook salmon. Microsatellite markers indicated that 111 were late-fall Chinook. One fish could not be assigned to a run.

Mature adult fish ≥23.6 inches (600mm) are randomly selected for artificial spawning and grilse are incorporated at a rate of 5% of the total number of fish spawned. Late-fall Chinook salmon are spawned from late December through mid-March (Figure 6).

Juvenile late-fall Chinook salmon are held in outdoor raceways for about one year until reaching a release size of 13 fish/lb or about 5 inches (135 mm). Fish are released into Battle Creek during a period of one to two days, and coinciding with high flow and turbidity events to promote rapid emigration. In the past, alternate release locations and timing have been used to accommodate research or pond management needs. During the past 15 years (2000 – 2014), approximately one million juvenile late-fall Chinook salmon have been released from CNFH each year, and CNFH is the only Central Valley hatchery propagating this salmon stock (Table 5).

7. Basic Life History Information of Salmonid Stocks in Battle Creek

This section provides basic life history information for the five salmonid stocks targeted for restoration in upper Battle Creek: (1) Central Valley steelhead, (2) spring Chinook salmon, (3) fall Chinook salmon, (4) late-fall Chinook salmon, and (5) winter Chinook salmon.

7.1 Central Valley Steelhead

California Central Valley steelhead Distinct Population Segment (DPS) is listed as a threatened species under the ESA (NMFS 1998). Central Valley steelhead have been identified as a priority species for restoration in Battle Creek (Terraqua 2004), and also are produced at CNFH (see Section 6.1 above). The Battle Creek watershed is thought to have high potential to support a viable independent population of Central Valley steelhead within the Basalt and Porous Lava diversity group (NMFS 2014).

Central Valley Steelhead DPS is not listed under the California Endangered Species Act. However, the California Fish and Wildlife Commission has developed policy objectives for anadromous rainbow trout[4]:

- Anadromous rainbow trout, commonly called steelhead, shall be managed to protect and maintain the populations and genetic integrity of all identifiable stocks. Naturally spawned anadromous rainbow trout shall provide the foundation of the Department's management program.
- Domesticated or non-native fish species will not be planted, or fisheries based on them will not be developed or maintained, in drainages of anadromous rainbow trout waters,

where, in the opinion of the Department, they may adversely affect native anadromous rainbow trout populations by competing with, preying upon, or hybridizing with them. Exceptions to this policy may be made for stocking drainages that are not part of an anadromous rainbow trout restoration or recovery program.

Life history characteristics for natural-origin Central Valley steelhead are variable (Reclamation 2008). *Oncorhynchus mykiss* are observed passing above the CNFH fish barrier weir from October thru April, with peak migration occurring in November and December (Brown and Alston 2007, Alston et al. 2007, Newton et al. 2007a, Newton et al. 2007b, Newton et al. 2008, Stafford and Newton 2010, Bottaro and Brown 2012) (Table 4). Based on redd surveys completed by the USFWS in 2004 and 2005, most spawning appears to occur between January and April (Alston et al 2007, and Newton et al 2007a).

Juvenile *O. mykiss* may emigrate soon after emergence, or spend up to three years in freshwater before immigrating to the ocean (Hallock 1989). Newly emerged *O. mykiss* fry emigrate from the upper Sacramento River in two temporal peaks annually. *O. mykiss* fry (~50 mm) typically begin to pass the Red Bluff Diversion Dam (located on the Sacramento River approximately 35 miles downstream from the mouth of Battle Creek; see Figure 1) in February. Downstream movement continues through July, with a second emigration peak occurring in the late summer and fall (Johnson and Martin 1997, Gaines and Martin 2001, USFWS 2002). USFWS monitoring in Battle Creek suggests peak juvenile emigration occurs between March and May (Colby et al 2012, Whitton et al 2006, 2007a, 2007b, 2007c, 2010, 2011). Larger one and two year old fish migrate downstream primarily in the spring with peak movement occurring during May through mid-June, although some fish migrate at all months of the year (Colby et al 2012, Whitton et al 2006, 2007a, 2007b, 2007c, 2010, 2011).

Hallock et al. (1961) reported that adult steelhead migrate into the upper Sacramento River during most months of the year. In Battle Creek, immigrating adult *O. mykiss* are collected at CNFH starting in October through February. After February, *O. mykiss* trapped and video monitored in the barrier weir upstream fish ladder have generally demonstrated two peaks in movement past the fish barrier weir: the first in March at the end of the fall/winter run; and a second, smaller peak during the mid-May through mid-June period.

7.2 Spring Chinook salmon

The Central Valley spring Chinook salmon ESU was listed as a federally threatened species in 1999; and reaffirmed in 2005; and as a state threatened species in 1999. The ESU includes all natural-origin spring Chinook salmon in the Sacramento River and its tributaries, including the Feather River, as well as the Feather River Hatchery (FRH) spring Chinook propagation program. Spring Chinook are not propagated at the CNFH but are a priority species for restoration in Battle Creek.

Spring Chinook in Battle Creek have been impacted by dams and diversions associated with the Battle Creek hydroelectric project since the early 1900's. According to Clark (1928),

> *Spring Chinook, which run during April, May, and June, is allowed to spawn naturally [in Battle Creek], and did so until the power dams became more or less*

barriers. Now the spring runs amount to almost nothing, only six or seven spring fish having been seen in the creek this year [1928].

Only sporadic counts of spring Chinook salmon are available for Battle Creek between the 1940's and 1994. During this period, incomplete counts of 1,000 or more fish indicated that a relatively large population was present in Battle Creek (CDFG 1998 as cited in NMFS 2014). Current spring Chinook salmon populations in the Central Valley appear to be severely depressed when compared to populations that existed in the 1940's and 1950's (Jones and Stokes 2005). Since 1995, USFWS personnel have estimated the number of adult phenotypic spring Chinook salmon escaping into Battle Creek (Table 9).

Table 9. Estimated adult phenotypic spring Chinook salmon adult escapement to upper Battle Creek between March and August of each year, 1995 – 2014.

	Number of fish[1/]		
Year	**Clipped[2/]**	**Unclipped**	**Total**
1995	0	66	**66**
1996	0	35	**35**
1997	0	107	**107**
1998	0	178	**178**
1999	0	73	**73**
2000	0	78	**78**
2001	0	111	**111**
2002	0	222	**222**
2003	0	221	**221**
2004	0	90	**90**
2005	0	73	**73**
2006	0	221	**221**
2007	0	291	**291**
2008	0	105	**105**
2009	0	194	**194**
2010	50	124	**174**
2011	19	140	**159**
2012	148	651	**799**
2013	27	581	**608**
2014	32	397	**429**
Total	**276**	**3,958**	**4,234**
Mean	**14**	**198**	**212**

1/ Number of fish include all unmarked phenotypic spring Chinook salmon passed during ladder trap and video operation, as well as marked Chinook salmon passed during video operation. Video monitoring began in 1995.

2/ Since 1992, 100% of late-fall Chinook salmon released from CNFH have been marked. 25% marking of fall Chinook began with the 2006 brood year.

Adult Central Valley spring Chinook leave the ocean to begin their immigration in late January and early February (CDFG 1998, as cited in NMFS 2014). Adult spring Chinook salmon immigrate into Battle Creek from March through mid-July (Table 4). However, variability in immigration timing is known to occur among Sacramento River tributaries. In their examination of CDFW adult spring Chinook immigration monitoring data, Lindley et al. (2004) found the primary immigration period is April – June in Mill and Deer creeks. Their examination also found that adult immigration ended in July in Mill and Deer creeks. However, spring Chinook in Butte Creek enter their natal stream roughly six weeks earlier, on average, and exhibit a more protracted immigration period. The fish entering the rivers are generally sexually immature, and will hold in freshwater for up to several months before spawning (Moyle 2002).

By July, most spring Chinook salmon have typically migrated past the Battle Creek fish barrier weir (USFWS 2011). Moyle (2002) reported that spawning normally occurs between mid-August and early October, peaking in September. Fry emerge from the gravel from November to March. However, based on redd surveys by USFWS personnel, the majority of spring Chinook salmon spawning in Battle Creek above the fish barrier weir occurred during late-September and early October (Brown and Newton 2002, Brown et al 2005, Brown and Alston 2007, Alston et al 2007, Newton et al 2007a, Newton et al 2007b, Newton et al 2008, Stafford and Newton 2010, Newton and Stafford 2011, and Bottaro and Brown 2012). Juveniles may reside in freshwater for 12 to 16 months, but most emigrate to the ocean as young-of-the-year in the following winter or spring, within 8 months of hatching (CALFED 2000, as cited in NMFS 2014).

7.3 Fall and Late-fall Chinook salmon

The Central Valley fall and late-fall Chinook salmon Evolutionarily Significant Unit (ESU) was listed as a federal Species of Special Concern in 1999 (NMFS 2010). The ESU includes all natural-origin populations of fall and late-fall Chinook salmon in the Sacramento and San Joaquin river basins and their tributaries, east of Carquinez Strait, California.

Fall and late-fall Chinook salmon are differentiated from other Chinook salmon runs based on timing of entry into freshwater and onto the spawning grounds, and based on spawning habitats. As general characterizations, fall Chinook salmon spawn in lower-elevation rivers and tributaries; late-fall Chinook salmon use main-stem areas; spring Chinook salmon use higher elevation rivers and tributaries; and winter Chinook salmon historically spawned in spring-fed headwater areas (Yoshiyama et al. 2001). The development of dams, water diversions, and hydropower infrastructure has severely limited the potential for spatial separation of Chinook salmon runs in spawning areas.

Late-fall Chinook salmon adults may occur in Battle Creek from mid-November through June (Table 4). Historical estimates of the number of late-fall Chinook salmon in Battle Creek are not available. Moyle (2002) indicated that late-fall Chinook salmon typically hold for one to three months in freshwater before spawning, and juvenile fish rear in main-stem areas of the Sacramento River that remain cold and deep in the summer. USFWS (2011) indicated late-fall Chinook salmon spawning in Battle Creek occurs from late December through early March.

Adult late-fall Chinook salmon are taken into the hatchery for broodstock from late December through mid-March. After that period, the fish ladder to the hatchery is closed, although fish monitoring continues (Table 4). During the past 14 seasons, on average approximately 58 unmarked adult late-fall Chinook were passed upstream of the fish barrier weir each year (Table 10).

Table 10. Number of phenotypic late-fall Chinook salmon returning to Battle Creek from return years 2001 through 2014 (unpublished data from R. Null, USFWS).

Season	Trapped at CNFH [1/]	Released Upstream of CNFH [2/]	Total
2000 - 2001	2,439	98	**2,537**
2001 - 2002	4,186	216	**4,402**
2002 - 2003	3,183	57	**3,240**
2003 - 2004	5,166	40	**5,206**
2004 - 2005	5,562	23	**5,585**
2005 - 2006	4,827	50	**4,877**
2006 - 2007	3,361	72	**3,433**
2007 - 2008	6,334	19	**6,353**
2008 - 2009	6,429	32	**6,461**
2009 - 2010	5,505	27	**5,532**
2010 - 2011	4,536	14	**4,550**
2011 - 2012	3,048	14	**3,062**
2012 - 2013	3,526	38	**3,564**
2013 - 2014	4,668	106	**4,774**
Total	**62,770**	**806**	**63,576**
Mean	**4,484**	**58**	**4,541**

1/ USFWS (2011)

2/ All fish passed were unmarked (Newton and Stafford 2011)

Most juvenile late-fall Chinook salmon emigrate from Battle Creek as young-of-the-year. Peak emigration from Battle Creek based on rotary screw trap data occurs in April through June, although some fish have been collected from November through March, and a few in July (Colby et al 2012, Whitton et al 2006, 2007a, 2007b, 2007c, 2007d, 2007e, 2008, 2010, and 2011). Timing of emigration in the Sacramento River and ocean is difficult to ascertain due to the difficulties in distinguishing among different races of Central Valley Chinook salmon (Cramer and Demko 1997). Since 1992, all juvenile late-fall Chinook salmon released from CNFH have been externally marked allowing identification from unmarked natural-origin fish (USFWS 2011).

Only a portion of the Central Valley hatchery production of fall Chinook salmon can be identified from natural-origin fish. Since 2007 (brood year 2006), 25% of the fall Chinook produced at the CNFH and all other Central Valley hatcheries have been externally marked and coded-wire-tagged, as part of the constant fractional marking program.

Since 2003, a video monitoring weir has been seasonally installed in lower Battle Creek to monitor escapement of fall Chinook salmon (Killam 2006). The weir is operated cooperatively by the CDFW and USFWS, and fall Chinook salmon escapement estimates are made from this monitoring effort. Since 2004, a large annual effort has been made to remove excess fall Chinook from lower Battle Creek, with the objective of leaving approximately 20,000 fish in the lower reach to spawn naturally (R. Null, pers. comm.). During the past 11 years, CNFH has taken in an average of 48,217 adult and grilse fall Chinook salmon annually, while the number of fish in lower Battle Creek has annually averaged 17,428 (Table 8). Efforts are made to prevent the passage of all fall Chinook salmon upstream of the CNFH fish barrier weir, at the request of restoration project proponents.

Improved estimates of the proportion of hatchery- and natural-origin fall Chinook in lower Battle Creek became available in 2009 when age-three adults returned from the first year of the constant fractional marking program. An estimated 13% of the fall Chinook salmon collected at CNFH in 2009 were of natural-origin (USFWS 2011). Kormos et al. (2012) reported that 11 and 7% of the fall Chinook salmon in Battle Creek were natural-origin fish based on recoveries of CWT's during the 2010 and 2011 seasons respectively.

Fall Chinook salmon spawn in Battle Creek from early October through November (USFWS 2011) and juvenile fish begin emigration soon after emergence from the gravel (Table 4). Whitton et al (2006, 2007a, 2007b, 2007c, 2007d, 2007e, and 2008) indicated that fry sized juvenile fish were the most common fall Chinook salmon captured in a rotary screw trap operated by the USFWS near the mouth of Battle Creek. Peak emigration occurred during January and February, although some fish were captured as late as June. Fall Chinook salmon smolts are released from CNFH in April and May and have demonstrated rapid downstream movement (Snider and Titus 2000).

7.4 Winter Chinook salmon

The Sacramento River winter Chinook salmon ESU was listed as a state endangered species in 1989 and a federally listed endangered species in 1994. The federal listing status was reviewed and reaffirmed in 2005 and 2011. The ESU includes all natural-origin winter Chinook salmon in the Sacramento River and its tributaries in California, as well as winter Chinook produced in an artificial propagation program at the LSNFH. Winter Chinook salmon are a priority species for restoration in Battle Creek.

Historically, winter Chinook salmon were abundant and comprised of populations in the upper Sacramento River basin, especially the McCloud and Pit rivers (Moyle 2002, USFWS 2011). Construction of Shasta Dam isolated all of these populations from their historical spawning and rearing habitats. Presently, the ESU is confined to the main-stem Sacramento River below Keswick Dam. Based on passage estimates at Red Bluff Diversion Dam, the Sacramento River winter Chinook salmon population reached its lowest abundance in 1994, when an estimated 189 adults passed above Red Bluff Diversion Dam. From the early 1990's through 2006, the winter Chinook salmon adult population exhibited generally increasing abundance, but thereafter decreased to less than 3,000 adult fish in recent years.

Winter Chinook do not currently inhabit Battle Creek as a self-sustaining population. Although identified for restoration in Battle Creek, only six winter Chinook salmon have been reported to occur in the watershed since 1995, and only one has been observed since 2007 (USFWS 2011; K. Niemela, pers. comm.). Planning is underway to develop a strategy for reintroduction of winter Chinook salmon into upper Battle Creek. The resulting document will serve as a working plan for reintroduction, once funding becomes available, and once Battle Creek is ready to support winter Chinook (D. Killam, pers. comm.).

Immigration of adult winter Chinook salmon occurs from January to July. Adult fish return to freshwater during the winter but delay spawning until the spring and summer. Juveniles spend about 5 to 9 months in the river and estuary systems before entering the ocean (Hallock and Fisher 1985, Vogel et al 1991, CDFG 1989 as cited in Reclamation 2008).

Winter Chinook salmon are not currently propagated at CNFH since high water temperatures result in fish mortality (USFWS 2011). The USFWS operates a conservation hatchery program for winter Chinook at LSNFH, located at the base of Shasta Dam. Adult salmon are trapped at the Keswick Dam fish trap (located on the Sacramento River) and transferred to the LSNFH for holding and spawning. Progeny are reared at LSNFH and released into the Sacramento River downstream from Keswick Dam (Figure 1).

8. Literature Cited

Alston, N. O., J. M. Newton, and M. R. Brown. 2007. Monitoring adult Chinook salmon, rainbow trout, and steelhead in Battle Creek, California, from November 2003 through November 2004. USFWS Report. U.S. Fish and Wildlife Service, Red Bluff Fish and Wildlife Office, Red Bluff, California. 75 p.

Black, M. 1999. Shasta salmon salvage efforts: Coleman National Fish Hatchery on Battle Creek, 1895-1992. Prepared for the Battle Creek Technical Advisory Committee and the Battle Creek Work Group by Kier Associates Sausalito, California: 39p.

Bottaro, RJ, and M. R. Brown. 2012. Monitoring adult Chinook salmon, rainbow trout, and steelhead in Battle Creek, California, from March through November 2011. USFWS Report. U.S. Fish and Wildlife Service, Red Bluff Fish and Wildlife Office, Red Bluff, California.

Brown, M. R., and J. M. Newton. 2002. Monitoring adult Chinook salmon, rainbow trout, and steelhead in Battle Creek, California, from March through October 2001. USFWS Report. U.S. Fish and Wildlife Service, Red Bluff Fish and Wildlife Office, Red Bluff, California.

Brown, M. R., and N. O. Alston. 2007. Monitoring adult Chinook salmon, rainbow trout, and steelhead in Battle Creek, California, from November 2002 through November 2003. USFWS Report. U.S. Fish and Wildlife Service, Red Bluff Fish and Wildlife Office, Red Bluff, California.

Brown, M. R., N. O. Alston, and J. M. Newton. 2005. Monitoring adult Chinook salmon, rainbow trout, and steelhead in Battle Creek, California, from March through November 2002. USFWS Report. U.S. Fish and Wildlife Service, Red Bluff Fish and Wildlife Office, Red Bluff, California.

Brown, R.L., [ed.]. 2001. Contributions to the biology of Central Valley salmonids. Fish Bulletin 179: Volume 2. State of California, the Resources Agency, Department of Fish and Game. Sacramento, CA. 355p.

CALFED. 2000. Ecosystem Restoration Program Plan: Strategic Plan for Ecosystem Restoration. Technical appendix in: CALFED Bay-Delta Program Final EIS/EIR.

CDFW (California Department of Fish and Wildlife). 2015. California Central Valley Chinook Population Database Report. Available at http://www.dfg.ca.gov/fish/Resources/Chinook/CValleyAssessment.asp

Clark, G.H. 1928. Sacramento-San Joaquin Salmon (*Oncorhynchus tshawytscha*) Fishery of California. California Department of Fish and Game Fish Bulletin No. 17. 73 p.

Colby, D.J. and M. R. Brown. 2012. Juvenile salmonid monitoring in Battle Creek, California, November 2010 through June 2011. USFWS Data-Draft Report. U.S. Fish and Wildlife Service, Red Bluff Fish and Wildlife Office, Red Bluff, California.

Cramer, S.P. and D.B. Demko. 1997. The status of late-fall and spring Chinook salmon in the Sacramento River basin regarding the Endangered Species Act. S.P. Cramer & Associates Special Report submitted to Association of California Water Agencies and California Urban Water Agencies, Sacramento, California, 125 pp.

Gaines, P.D. and C.D. Martin. 2001. Abundance and seasonal, spatial and diel distribution patterns of juvenile salmonids passing the Red Bluff Diversion Dam, Sacramento River. Red Bluff Research Pumping Plant Report Series, Volume 14. U.S. Fish and Wildlife Service, Red Bluff, CA.

Hallock, R.J., W.F. Van Woert, and L. Shapovalov. 1961. An evolution of stocking hatchery-reared steelhead rainbow trout (*Salmo gairdnerii gairdnerii*) in the Sacramento River system. California Department of Fish and Game Fish Bulletin No. 114. 83 p.

Hallock, R.J., and F.W. Fisher. 1985. Status of winter-run Chinook salmon, *Oncorhynchus tshawytscha*, in the Sacramento River. State of California, Department of Fish and Game, Anadromous Fisheries Branch, 1985.

Hallock, R.J. 1989. Upper Sacramento River steelhead, Oncorhynchus mykiss, 1952-1988. Report to U.S. Fish and Wildlife Service. 86 pp.

Hollibaugh, J.T., [ed.]. 1996. San Francisco Bay: The Ecosystem. Pacific Division for the American Association for the Advancement of Science. California Academy of Sciences. San Francisco, CA. 542 pgs.

HSRG (Hatchery Scientific Review Group). 2009. Columbia River hatchery reform system - wide report. Bonneville Power Administration and NOAA Fisheries. 32 p.

HSRG (California Hatchery Scientific Review Group). 2012. California Hatchery Review Group report. Prepared for the US Fish and Wildlife Service, Sacramento, CA. 102 p.

Johnson, R.R., and C.D. Martin. 1997. Abundance and seasonal, spatial and diel distribution patterns of juvenile salmonids passing the Red Bluff Diversion Dam, Sacramento River, July 1994 - June 1995. Red Bluff Research Pumping Plant Report Series, Volume 2. U.S. Fish and Wildlife Service, Red Bluff, CA.

Jones and Stokes. 2005. Battle Creek salmon and steelhead restoration project final environmental impact statement/environmental impact report. Volume I, Report. Sacramento, CA.

Killam, D. 2006. Results of the experimental video station for fall-run Chinook salmon escapement into Battle Creek for years 2003-2005. SRSSAP Technical Report No. 06-01.

Kormos B., M. Palmer-Zwahlen, and A. Low. 2012. Recovery of Coded-Wire Tags from Chinook Salmon in California's Central Valley Escapement and Ocean Harvest in 2010. California Department of Fish and Game, Sacramento, CA. Fisheries Branch Administrative Report 2012-02. 44 p.

Lindley, S.T., R. Schick, B.P. May, J.J. Anderson, S.S Greene, C.C. Hanson, A. Low, D. McEwan, R.B. MacFarlane, C. Swanson, J.G. Williams. 2004. Population Structure of Threatened and Endangered Chinook Salmon ESUs in California's Central Valley Basin. NOAA Technical Memorandum.

Moffett, J.W. 1949. The first four years of king salmon maintenance below Shasta Dam, Sacramento River, California. California Fish and Game 35(2):77-102.

Moyle, P.B. 2002. Inland fishes of California revised and expanded. University of California Press. 502 p.

Newton, J. M., and L.A. Stafford. 2011. Monitoring adult Chinook salmon, rainbow trout, and steelhead in Battle Creek, California, from March through November 2009. USFWS Report. U.S. Fish and Wildlife Service, Red Bluff Fish and Wildlife Office, Red Bluff, California. 61 p.

Newton, J. M., L. A. Stafford, and M. R. Brown. 2008. Monitoring adult Chinook salmon, rainbow trout, and steelhead in Battle Creek, California, from March through November 2007. USFWS Report. U.S. Fish and Wildlife Service, Red Bluff Fish and Wildlife Office, Red Bluff, California.

Newton, J. M., N. O. Alston, and M. R. Brown. 2007a. Monitoring adult Chinook salmon, rainbow trout, and steelhead in Battle Creek, California, from November 2004 through November 2005. USFWS Report. U.S. Fish and Wildlife Service, Red Bluff Fish and Wildlife Office, Red Bluff, California.

Newton, J. M., N. O. Alston, and M. R. Brown. 2007b. Monitoring adult Chinook salmon, rainbow trout, and steelhead in Battle Creek, California, from March through November 2006. USFWS Report. U.S. Fish and Wildlife Service, Red Bluff Fish and Wildlife Office, Red Bluff, California.

NMFS (National Marine Fisheries Service). 2010. Species of concern. Chinook salmon *Oncorhynchus tshawytscha*, Central Valley fall, late-fall run ESU. Accessed on August 28, 2015 at www.nmfs.noaa.gov/pr/pdfs/species/chinooksalmon_highlights.pdf.

NMFS (National Marine Fisheries Service). 2014. Final Recovery Plan for the Evolutionarily Significant Units of Sacramento River Winter run Chinook Salmon and Central Valley Spring run Chinook Salmon and the Distinct Population Segment of Central Valley Steelhead. Sacramento Protected Resources Division, CA. 273p.

Null, R. E., K.S. Niemela, and S.F. Hamelburg. 2012. Post-spawn migrations of hatchery-origin Oncorhynchus mykiss kelts in the Central Valley of California. Environmental Biology of Fishes 13 p.

Reclamation (U.S. Bureau of Reclamation). 2008. Operations Criteria and Plan (OCAP) Biological Assessment (BA), for the Central Valley and State Water Projects. Chapter 5 Basic biology, life history and baseline for winter-run and spring-run Chinook salmon and Coho salmon. 48 p.

Skinner, J.E. 1958. Some observations regarding the king salmon runs of the Central Valley.Water Projects Miscellaneous Report 1. California Department of Fish and Game.

Snider, B., and R.G. Titus. 2000. Timing, composition and abundance of juvenile anadromous salmonid emigrations in the Sacramento River near Knights Landing, October 1997-September 1998. California Department of Fish and Game, Environmental Services Division, Stream Evaluation Program. Technical Report No. 00-05.

Stafford, L.A., and J.M. Newton. 2010. Monitoring adult Chinook salmon, rainbow trout, and steelhead in Battle Creek, California, from March through November 2008. USFWS Report. U.S. Fish and Wildlife Service, Red Bluff Fish and Wildlife Office, Red Bluff, California.

Technical Review Panel. 2004. CALFED Bay-Delta Program, Report of the Technical Review Panel - Compatibility of Coleman National Fish Hatchery Operations and Restoration of Anadromous Salmonids in Battle Creek. 68 p

Terraqua. 2004. Draft Battle Creek salmon and steelhead restoration project adaptive management plan, prepared for the U.S. Bureau of Reclamation, Pacific Gas and Electric Company, National Marine Fisheries Service, U.S. Fish and Wildlife Service, and California Department of Fish and Game. Wauconda, Washington. 238 p.

USFWS (U.S. Fish and Wildlife Service). 1986. An Evaluation of Alternative Water Supply Systems for Coleman National Fish Hatchery. Prepared for U.S. Fish and Wildlife Service (Portland, Oregon) by Sverdrup & Parcel and Associates, Inc. Consulting Engineers. September 1986.

USFWS (U.S. Fish and Wildlife Service). 1987. Coleman National Fish Hatchery Station Development Plan. U.S. Fish and Wildlife Service Division of Engineering Region 1. Portland, Oregon.

USFWS (U.S. Fish and Wildlife Service). 1989. Advance Project Planning for Water Supply Distribution, Treatment and Waste Systems at Coleman National Fish Hatchery Near Anderson, California. Prepared for U.S. Fish and Wildlife Service (Portland, Oregon) by Sverdrup & Parcel and Associates, Inc. Consulting Engineers. February 1989.

USFWS (U.S. Fish and Wildlife Service). 1997a. Water treatment system cost study and alternatives analysis. U.S. Fish and Wildlife Service, Sacramento, California.

USFWS (U.S. Fish and Wildlife Service). 1997b. Coleman Fish Hatchery Improvements Environmental Assessment. U.S. Fish and Wildlife Service, Sacramento, California.

USFWS (U.S. Fish and Wildlife Service). 2001. Final Restoration Plan for the Anadromous Fish Restoration Program. Prepared for the Secretary of the Interior. 146p. Accessed on August 15, 2012 at http://www.fws.gov/stockton/afrp/SWRCB/B.finalrestplan.pdf.

USFWS (U.S. Fish and Wildlife Service). 2002. Abundance and seasonal, spatial and diel distribution patterns of juvenile salmonids passing the Red Bluff Diversion Dam, Sacramento River.

USFWS (United States Fish and Wildlife Service). 2011. Biological assessment of artificial propagation at Coleman National Fish Hatchery and Livingston Stone National Fish Hatchery: program description and incidental take of Chinook salmon and steelhead. U.S. Fish and Wildlife Service, Red Bluff and Coleman National Fish Hatchery Complex, CA. 406 p.

Vogel, D.A., and K.R. Marine. 1991. Guide to upper Sacramento River Chinook salmon life history. Report by CH2M Hill to U.S. Bureau of Reclamation, Central Valley Project, Redding, CA.

Whitton, K. S., J. M. Newton, D. J. Colby and M. R. Brown. 2006. Juvenile salmonid monitoring in Battle Creek, California, from September 1998 to February 2001. USFWS Data Summary Report. U.S. Fish and Wildlife Service, Red Bluff Fish and Wildlife Office, Red Bluff, California.

Whitton, K. S., J. M. Newton, and M. R. Brown. 2007a. Juvenile salmonid monitoring in Battle Creek, California, July 2001 through September 2002. USFWS Report. U.S. Fish and Wildlife Service, Red Bluff Fish and Wildlife Office, Red Bluff, California.

Whitton, K. S., J. M. Newton, and M. R. Brown. 2007b. Juvenile salmonid monitoring in Battle Creek, California, October 2002 through September 2003. USFWS Report. U.S. Fish and Wildlife Service, Red Bluff Fish and Wildlife Office, Red Bluff, California.

Whitton, K. S., J. M. Newton, and M. R. Brown. 2007c. Juvenile salmonid monitoring in Battle Creek, California, October 2003 through September 2004. USFWS Report. U.S. Fish and Wildlife Service, Red Bluff Fish and Wildlife Office, Red Bluff, California.

Whitton, K. S., J. M. Newton, and M. R. Brown. 2007d. Juvenile salmonid monitoring in Battle Creek, California, October 2004 through September 2005. USFWS Report. U.S. Fish and Wildlife Service, Red Bluff Fish and Wildlife Office, Red Bluff, California.

Whitton, K. S., J. M. Newton, and M. R. Brown. 2007e. Juvenile salmonid monitoring in Battle Creek, California, October 2005 through September 2006. USFWS Report. U.S. Fish and Wildlife Service, Red Bluff Fish and Wildlife Office, Red Bluff, California.

Whitton, K. S., D. J. Colby, J. M. Newton, and M. R. Brown. 2008. Juvenile salmonid monitoring in Battle Creek, California, November 2007 through June 2008. USFWS Report. U.S. Fish and Wildlife Service, Red Bluff Fish and Wildlife Office, Red Bluff, California.

Whitton, K. S., D. J. Colby, J. M. Newton, and M. R. Brown. 2010. Juvenile salmonid monitoring in Battle Creek, California, November 2008 through June 2009. USFWS Report. U.S. Fish and Wildlife Service, Red Bluff Fish and Wildlife Office, Red Bluff, California.

Whitton, K. S., D. J. Colby, J. M. Newton, and M. R. Brown. 2011. Juvenile salmonid monitoring in Battle Creek, California, November 2009 through July 2010. USFWS Report. U.S. Fish and Wildlife Service, Red Bluff Fish and Wildlife Office, Red Bluff, California. 51 p.

Yoshiyama, R.M., E.R.Gerstung, F.W. Fisher, and P.B. Moyle. 2001. Historical and present distribution of Chinook salmon in the Central Valley drainage of California. Pages 71-176 *in* R. Brown, editor, Contributions to the biology of anadromous salmonids of the Central Valley, Fish Bulletin 179, Volume 1. California Department of Fish and Game, Sacramento.

Personal Communications

Hamelberg, Scott. U.S. Fish and Wildlife Service, Coleman National Fish Hatchery. Personal communications on August 29, 2012, October 24, 2012, December 5, 2012, and March 5, 2013.

Killam, Doug. California Department of Fish and Wildlife. Redding Field Office. Personal communication on March 4, 2013 and November 30, 2015.

Niemela, Kevin. U.S. Fish and Wildlife Service, Red Bluff Field Office. Personal communications on June 6, 2012, December 5, 2012, and August 25, 2015.

Null, Robert. U.S. Fish and Wildlife Service, Red Bluff Field Office. Personal communications on September 9, 2012, December 12, 2012, and September 9, 2015.

Appendix B: Memorandum of Understanding Regarding Integrated Adaptive Management of the Battle Creek Salmon and Steelhead Restoration Project and Coleman National Fish Hatchery

I. Purpose

This Memorandum of Understanding (MOU) creates and describes a process of integrated adaptive management of the Coleman National Fish Hatchery (CNFH) and the Battle Creek Salmon and Steelhead Restoration Project (BCRP). The CNFH and BCRP are located in the Battle Creek watershed, Shasta and Tehama counties, California, and operated through differing management authorities to achieve different goals and objectives. The BCRP is restoring approximately 48 miles of habitat in Battle Creek watershed to support threatened and endangered populations of Chinook salmon and steelhead. The CNFH is operated to produce salmon and steelhead to mitigate for fishery losses resulting from the construction and operation of Shasta Dam. The existence of the CNFH may influence the performance of the restoration project. To optimize the benefits of the CNFH and BCRP, the Bureau of Reclamation (Reclamation), U.S. Fish and Wildlife Service (Service), National Marine Fisheries Service (NMFS), California Department of Fish and Wildlife (CDFW), and Pacific Gas and Electric Company (PG&E) recognize the importance of developing an integrated framework for adaptive management. An adaptive management plan (AMP) for the BCRP has previously been developed to ensure operational decisions for the BCRP are based on the best available information. The CNFH has been adaptively managed through an informal process of adaptive management. This document creates and describes a process of collaboration, information sharing, and decision making that merges the existing management structure of the CNFH with the formal adaptive management process for the BCRP. It is intended that increased information sharing and collaboration will promote that operational decisions for the CNFH and BCRP AMP are made based on the best available information and to bring transparency to the decision making process for the CNFH. This MOU does not change or affect the authorities of agencies responsible for operating CNFH or the BCRP.

II. BCRP

A. Goals

The BCRP is a joint effort between PG&E, NMFS, CDFW, USFWS, and USBR. The primary goal of the BCRP is to restore and enhance about 42 miles of anadromous fish habitat in Battle Creek and an additional 6 miles of habitat in its tributaries while minimizing the loss of renewable energy produced by the Battle Creek Hydroelectric Project. The BCRP has been codified in an MOU between the Service, Reclamation, NMFS, CDFW, and PG&E.

B. Authorization

- The Service is participating in the BCRP pursuant to the Central Valley Project Improvement Act (Public Law 102-575 Section 3401 et seq. (CVPIA)) Anadromous Fish Restoration Program, the Endangered Species Act (16 U.S.C. Sections 1531-1544, as amended (ESA)), Fish and Wildlife Coordination Act (FWCA), Federal Power Act, Fishery Conservation and Management Act (16 U.S.C. Sections 1801-1882).

- NMFS is participating in the BCRP pursuant to the NMFS Central Valley Salmon and Steelhead Recovery Plan, ESA, FWCA, and the amended 1996 Magnuson-Stevens Act to protect Essential Fish Habitat (EFH).

- Reclamation is participating in the BCRP pursuant to the CVPIA and the California Bay-Delta Environmental Enhancement Act (P.L. 104-333).

- CDFW is participating in the BCRP based on its responsibilities as trustee agency for the fish and wildlife resources of California (Fish and Game Code Section 711.7(a)) and its jurisdiction over the conservation, protection, and management of fish, wildlife, native plants, and habitat necessary for biologically sustainable populations of those species (Fish and Game Code Section 1802), and other applicable state and federal laws.

- PG&E is participating in the BCRP as owner and operator of the Battle Creek Hydroelectric Project (FERC Project No. 1121).

III. CNFH

A. Goals

The CNFH was constructed in 1942 to partially mitigate for the negative effects of Shasta Dam (a CVPIA facility) on Central Valley salmonid populations. CNFH is funded by USBR, owned and operated by the USFWS pursuant to the March 1993 Interagency Agreement between Reclamation and the Service. Mitigation policies and objectives of the Service are described in the Mitigation Policy document dated January 23, 1981 (46 FR 7644). Annual fish production targets for the CNFH include 12 million fall Chinook, 1 million late-fall Chinook, and 0.6 million steelhead. Average expected total contribution targets (including ocean and freshwater fisheries plus freshwater escapement) for fishes produced at the CNFH are 120,000 fall Chinook, 10,000 late-fall Chinook, and 3,000 steelhead.

B. Authorization

CNFH roles and responsibilities are contained within the following authorities:

- Fish and Wildlife Coordination Act (March 10, 1934; 48 Stat. 401)
- Fish and Wildlife Act of 1956 (August 8, 1956; 70 Stat. 1119)
- Endangered Species Act of 1973 (December 28, 1973; 87 Stat. 884-903)
- Reclamation Projects Authorization and Adjustment Act of 1992 (CVPIA; October 30, 1992; 106 Stat. 4714-4731).

C. CNFH Management and Decision Making

This MOU does not change the Service's authority and responsibility to make decisions regarding the operation of the CNFH. On-station decisions, such as hatchery day-to-day operational activities and programmatic decisions; design and implementation of hatchery evaluation; research coordination; release schedules; or interagency coordination for permitting are made by the CNFH Project Leader, in consultation with the California-Nevada Fish Health Center (CA-NV FHC), the Hatchery Evaluation Program at the Red Bluff Fish and Wildlife Office (RBFWO), and the Northern California Area Office (NCAO) of the USBR, collectively referred to the CNFH Technical Team. When agreement cannot be reached by the CNFH Technical Team, decisions are elevated to the CNFH Policy Team, consisting of Project Leaders of the CNFH, RBFWO, and CA-NV FHC, with representation of Reclamation's NCAO, as appropriate. When agreements cannot be reached at the field level, decisions are elevated to the Service Regional Office for resolution. Impacts that the CNFH has on listed species are considered by NMFS and CDFW through the issuance of a biological opinion, which includes detailed operational plans for the CNFH.

IV. BCRP AMP

This MOU does not change any aspect of the April 2004 BCRP AMP and the BCRP 1999 MOU. Per Section 9.1.A.2 of the BCRP 1999 MOU, the goal of the BCRP AMP is to implement specific actions to protect, restore, enhance, and monitor salmonid habitat associated with Federal Energy Regulatory Commission (FERC) Project No. 1121 within the Restoration Project Area[1], to guard against false attraction of adult migrants, and to ensure Chinook Salmon and Steelhead are able to fully access and utilize available habitat in a manner that benefits all life stages, thereby maximizing natural production and full utilization of the Battle Creek ecosystem.

[1] MOU 2.19 - "Restoration Project Area" means the areas in and around the following PG&E facilities: Coleman Diversion Dam, Inskip Diversion Dam, South Diversion Dam, Wildcat Diversion Dam, Eagle Canyon Diversion Dam, North Battle Creek Feeder Diversion Dam, and Asbury Pump Diversion Dam; Battle Creek, North Fork Battle Creek and South Fork Battle Creek, up to the natural barriers at 14 miles and 19 miles above the confluence, respectively; and Eagle Canyon Springs, Soap Creek (and Bluff Springs), Baldwin Creek, and Lower Ripley Creek and each of their adjacent water bodies.

The BCRP AMP describes coordination and governance processes specific to implementation of the BCRP AMP based on details provided in the BCRP 1999 MOU. The basic organizational structure of the BCRP AMP consists of the Adaptive Management Technical Team and Adaptive Management Policy Team.

A. BCRP Adaptive Management Technical Team (BCRP AMTT)

<u>Role:</u>
The BCRP AMTT was created by the 2004 BCRP AMP and will continue to operate as provided in that document. The BCRP AMTT is a technical group with appropriate training and experience to effectively address the technical aspects of implementing the BCRP AMP. The BCRP AMTT is responsible for the reporting component of the BCRP AMP and provides a forum for presenting and discussing technical information, facilitating administrative and implementation recommendations and that are technical and science-driven.

The BCRP AMP describes coordination and governance processes specific to implementation of the BCRP AMP based on details provided in the BCRP 1999 MOU. This MOU does not change any aspect of the April 2004 BCRP AMP and the BCRP 1999 MOU.

<u>Membership:</u>
The BCRP AMTT consists of one voting member from CDFW, NMFS, the Service, and PG&E.

B. BCRP Adaptive Management Policy Team (BCRP AMPT)

<u>Role:</u>
The BCRP AMPT was created by the 2004 BCRP AMP and will continue to operate as provided in that document. The BCRP AMPT is a management-level cooperative group that makes all final decisions regarding the implementation of the BRCP AMP and provides policy direction and resolves any disputes forwarded by the BCRP AMTT

<u>Membership:</u>
The BCRP AMPT consists of one voting member from CDFW, NMFS, the Service, and PG&E.

C. BCRP AMP Decision Making Process

Per the 2004 BCRP AMP, all decisions made by the BCRP AMTT are made by consensus or are referred to the BCRP AMPT.

In the event the BCRP AMPT is unable to reach Consensus on a decision within 30-days, dispute resolution procedures are enacted. The first step of dispute resolution is a structured process of non-binding mediation. If mediation does not resolve the dispute, for those actions the Parties agree are within FERCs jurisdiction, the Resource Agencies (Service, CDFW, and NMFS), and PG&E may petition FERC to resolve the dispute.

FERC is the ultimate arbiter for disputed issues that fall within FERC jurisdiction. For issues outside the jurisdictional authorities of FERC, any one of the parties to the BCRP AMPT may seek resolution.

D. BCRP AMP Funding

Pursuant to the 1999 MOU, funding has been secured for implementation of certain elements of the BCRP AMP. Sources of funding for the implementation of the BCRP AMP identified to date are the CALFED Monitoring Fund, the Water Acquisition Fund (WAF), the Adaptive Management Fund (AMF), and the Licensee (PG&E).

- The CALFED Monitoring Fund of $1,000,000 is intended for monitoring costs associated with the Restoration Project.

- The WAF is a Federal fund of $3,000,000 administered by the Resource Agencies per BCRP AMP protocols and intended for the sole purpose of acquiring additional instream flow releases in Battle Creek recommended under the BCRP AMP for a ten-year period following the initial prescribed instream flow releases.

- The AMF of $3,000,000 is for the purpose of funding possible future changes to the Restoration Project developed under the BCRP AMP. The AMF is to be limited to actions under the Restoration Project directly associated with FERC Project No. 1121, and is expressly not available for funding of monitoring or construction cost overruns. In the event of the exhaustion or termination of the WAF, the AMF may be used to secure additional instream flow releases developed under the BCRP AMP.

- In the event of exhaustion of the WAF and AMF, the Licensee (PG&E) has committed up to a total of $6,000,000 for all Adaptive Management actions for Authorized Modifications to project facilities or flow operations which are determined to be necessary under Adaptive Management.

- In cooperation, CDFW, NMFS, and the Service shall conduct or fund or seek funding from sources other than the Licensee (PG&E) for any necessary unfunded element of the BCRP AMP (i.e. monitoring and data assessments including those associated with all fish population objectives; data collection and report preparation,…as described in Section III.D.3 of the BCRP AMP).

V. Integrated BCRP and CNFH Adaptive Management

Integrated adaptive management of the BCRP and CNFH will help ensure the BCRP and CNFH are coordinated and operated, based on the best available information, to achieve the objectives of both projects. The basic organizational structure of the Integrated AMP brings together the existing management process at the CNFH with the governance process described in the BCRP AMP. The combined governance structure mirrors that of the

BCRP AMP, consisting of the Integrated Adaptive Management Technical Team (Integrated AMTT), an Integrated Adaptive Management Policy Team (Integrated AMPT) - see figure**,** entitled, *"Integrated Adaptive Management of the Battle Creek Restoration Project and Coleman National Fish Hatchery"*.

A. Integrated Adaptive Management Technical Team (Integrated AMTT)

Role:
The role of the Integrated AMTT, similar to that of the BCRP AMTT, is to provide a forum for reporting and discussing the monitoring and data analysis of the BCRP and CNFH AMPs, presentations of and discussions on technical information, and making recommendations that are technical and science-driven.

Membership:
The Integrated AMTT consists of members of the BCRP AMTT and the CNFH Technical Team. The BCRP AMTT (described earlier) consists of NMFS, CDFW, PG&E, and the Service's Battle Creek Salmonid Monitoring Team. The CNFH Technical Team consists of representatives from the Service's CNFH, Hatchery Evaluation Program, and CA-NV FHC, and Reclamation's NCAO. The Integrated AMTT members should have appropriate training and technical experience to effectively address the technical aspects of the Integrated AMP.

B. Integrated Adaptive Management Policy Team (Integrated AMPT)

Role:
The Integrated AMPT is a local management-level group that provides policy direction to the science-based recommendations coming from the Integrated AMTT. Additionally, the Integrated AMPT may resolve disagreements and disputes of the Integrated AMTT. Members of the Integrated AMPT will jointly work together to seek funding and develop funding recommendations to assist the Service in implementation of the CNFH AMP.

Membership:
The Integrated AMPT consists of management-level members of the BCRP AMPT and CNFH Policy Team, including NMFS, CDFW, PG&E, the Service (Red Bluff Office, Regional Office, and CNFH Project Leader), Reclamation NCAO, and Reclamation Mid-Pacific Regional Office.

Meetings:
- The Integrated AMTT will meet at least annually with the Integrated AMPT and on an as needed basis if the Integrated AMTT needs to seek resolutions on issues of mutual concern to the BCRP and CNFH AMPs.
- The Integrated AMPT will hold at least one regularly-scheduled annual meeting.
- All Integrated AMTT and Integrated AMPT meetings are open to the public.
- When appropriate, the Integrated AMTT and Integrated AMPT meetings will be held in conjunction with the BCRP AMTT and BCRP AMPT meetings.

The intent of holding Integrated AMTT and Integrated AMPT meetings is to provide a forum that will maximize the sharing of data and information and to encourage discussions regarding interpretations of data and potential future adaptive management actions.

C. Integrated AMP Decision Making Process

The existing decision making processes of the CNFH and BCRP AMP will be used to seek resolution on issues of mutual concern to the two AMPs, in an effort to form a single framework of adaptive management leading to the accomplishment of goals and objectives of both the BCRP and CNFH. This MOU does not change the Service's authority and responsibility to make decisions regarding the operation of the CNFH. The Service, working with the fishery agencies, has primary responsibility to make decisions that have implications to the achievement of CNFH production and contribution goals. The Service's decision making authority includes management strategies that are associated with recognized best hatchery management practices (e.g., collection of broodstock across the range of spawn timing), such as described within the ESA section 7 consultation between the Service and NMFS (biological assessment and biological opinion). Decision-making authorities for the BCRP are unchanged from those described in the BCRP AMP.

Issues that meet one or more of the following criteria will be forwarded to a Multi-Agency Management Team (MMT):

- Involve management actions that are inconsistent with the goals of either the BCRP and CNFH AMPs;
- Involve management actions that are in dispute and cannot be resolved at the level of the Integrated AMPT; or
- Involve issues that are expected to be highly controversial or risky.

Membership:

The MMT is an upper-level management team, consisting of regional leadership (Regional Managers and Directors) of the Service, Reclamation, NMFS, CDFW, and PG&E.

Decision-making Authorities:

Decision making authorities within the MMT are unchanged from existing management authorities, which are mandated by agency missions, policies, jurisdictional responsibilities, laws, etc. For example, decision making authorities associated with mitigation responsibilities of the CNFH reside with Reclamation and the Service.

Meetings:

Meetings of the MMT are intended to provide a forum that will facilitate information sharing and discussion amongst agency leadership when considering issues associated with implementation of integrated adaptive management that meet one or more of the identified criteria (above). Meetings of the MMT will be held at the discretion of MMT members on an "as needed" basis. Meetings of this body are not expected to be open to public.

D. Existing Authority Not Affected by the Adaptive Management Decision Making Process

The Parties signing onto this charter recognize that the decision making authorities of each agency cannot be altered or abrogated through the integrated BCRP and CNFH adaptive management decision-making process. Further, the Parties recognize that the decisions may be guided partly by scientific information resulting from the AMP process and policy, public, and stakeholder input, legal constraints, and fiscal resources.

E. Public Involvement

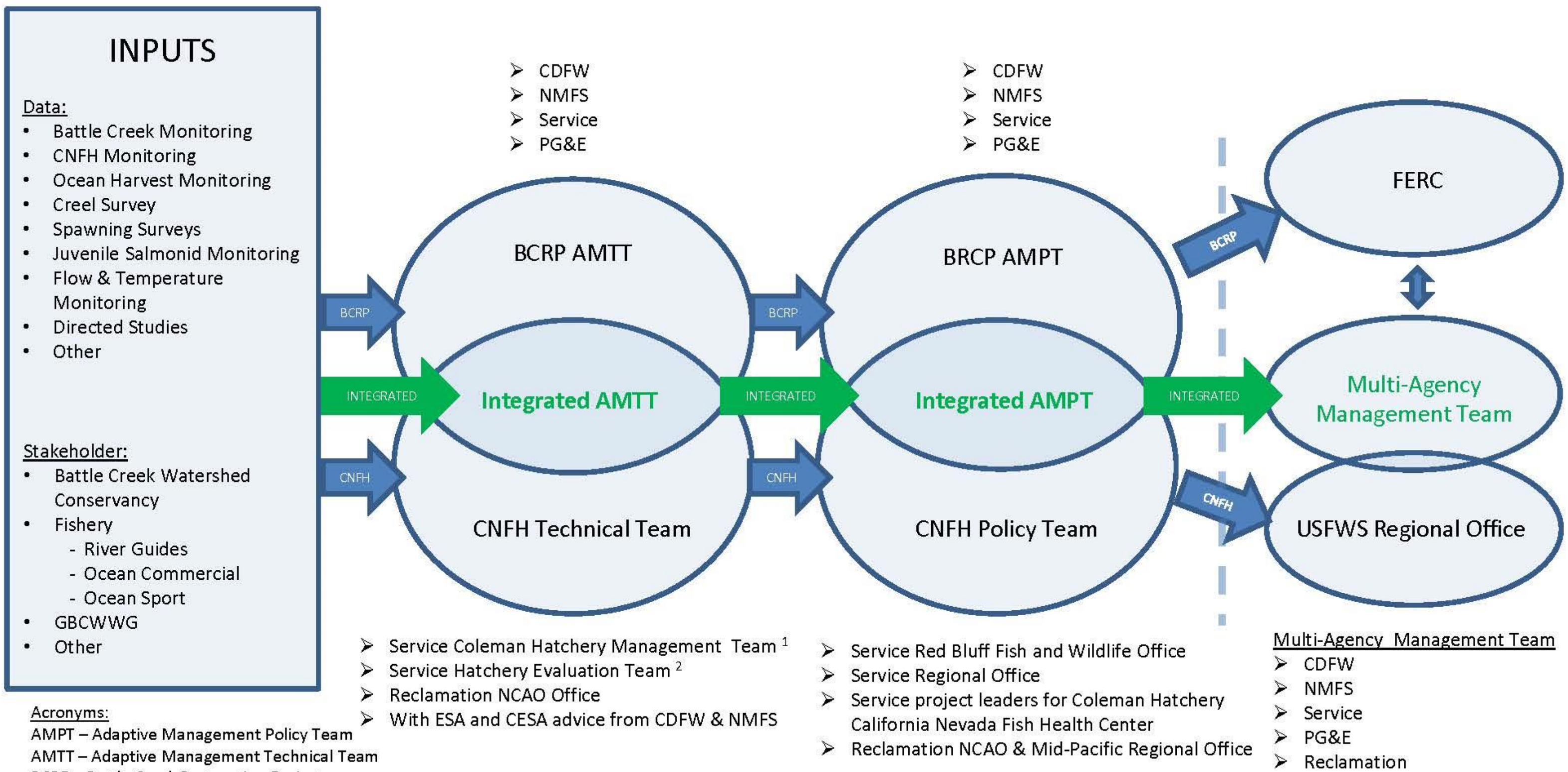
All regularly scheduled and ad hoc Integrated AMTT and Integrated AMPT meetings will be open to the public. Notice of any such meetings will be formally announced to any person or group requesting such notification. Interested persons may attend any Integrated AMTT and Integrated AMPT meetings, contribute to discussions, and provide suggestions regarding the implementation and of the CNFH AMP and the integration framework with BCRP AMP. Public comments can be conveyed verbally during the meetings or in writing to Integrated AMTT and Integrated AMPT contacts that are identified on the meeting notice. When adaptive management issues are elevated to the MMT, the public can convey their written comments in a letter to the MMT.

F. Funding

Reclamation received funding from the State of California to prepare a CNFH AMP and to perform diagnostic studies identified in the CNFH AMP. Additional funding will be needed to perform all necessary diagnostic studies, and to implement CNFH AMP and integrated BCRP and CNFH adaptive management actions, including monitoring and reporting requirements.

For integrated CNFH and BCRP activities and findings, the Integrated AMTT and Integrated AMPT will work together to identify funding needs and to secure available funding to support these needs. While this is a commitment to work together to identify available sources of funding, this is not a commitment by any party to provide that funding.

Integrated Adaptive Management of the Battle Creek Restoration Project and Coleman National Fish Hatchery



Acronyms:
AMPT – Adaptive Management Policy Team
AMTT – Adaptive Management Technical Team
BCRP – Battle Creek Restoration Project
CDFW – California Department of Fish and Wildlife
CNFH – Coleman National Fish Hatchery
FERC – Federal Energy Regulatory Commission
GBCWWG – Greater Battle Creek Watershed Working Group
NMFS – National Marine Fisheries Services
PG&E – Pacific Gas and Electric Company
Reclamation – U.S. Bureau of Reclamation
Service – U.S. Fish and Wildlife Service
NCAO – Northern California Area Office

Footnotes:
1 Hatchery Management Team consists of CNFH fish production supervisor, maintenance supervisor, project leader, and deputy project leader and may includes the Hatchery Coordination Team.
2 Hatchery Evaluation Team consists of personnel from CNFH, the Service Red Bluff Fish and Wildlife Office, and the California Nevada Fish Health Center.

Memorandum of Understanding
Regarding Integrated Adaptive Management of the Battle Creek Salmon and Steelhead Restoration Project and Coleman National Fish Hatchery

SIGNATURES

Signatory	Date
______________________________	______________
David Murillo, Regional Director Mid-Pacific Region, Bureau of Reclamation	Date
______________________________	______________
Ren Lohoefener, Regional Director Pacific Southwest Region, U.S. Fish and Wildlife Service	Date
______________________________	______________
Maria Rea, Assistant Regional Administrator National Marine Fisheries Service	Date
______________________________	______________
Charlton H. Bonham, Director California Department of Fish and Wildlife	Date
______________________________	______________
Randal Livingston, Vice President of Power Generation Pacific Gas and Electric Company	Date

Appendix C: Conceptual Models and Issue Analysis

Prepared for:

Bureau of Reclamation and the Battle Creek Technical Advisory Committee

Prepared by:

Bradly J. Cavallo, Dennis P. Lee, and Zachary P. Hymanson

March 1, 2016

Table of Contents

1. Introduction

Four conceptual models were developed to structure the evaluation of ten CNFH and four BCRP issues that may affect the timely and successful restoration of target anadromous salmonid populations in upper Battle Creek. The issues were developed in consultation with the CNFH-AMP Technical Advisory Committee (TAC) with the aim of describing all potential problems as specifically as possible. The issues were then evaluated in the context of the relevant conceptual model. Evaluation of each issue involved a detailed analysis of existing data and information, and where appropriate, examination of quantitative Chinook and steelhead life cycle model (LCM) results (presented in Appendixes D and E respectively). The results of these analyses were used to determine issue importance and understanding.

2. Issue Statements

The adaptive management cycle used in this plan generally follows the adaptive management cycle used in the Battle Creek Restoration Project Adaptive Management Plan (BCRP-AMP) (see Chapter 2 for more details about this adaptive management cycle). Describing the issues (i.e., problem statements) as specifically as possible is a critical step in this adaptive management cycle, and this section fulfills that step.

2.1 CNFH Issues Statements

Unlike most other anadromous fish hatcheries in California, the CNFH is not situated immediately downstream of an existing dam and reservoir. Instead, the CNFH was established in the lower reach of a unique watershed that is undergoing restoration to support self-sustaining populations of anadromous salmonids (Jones and Stokes 2005a). Thus, the overarching CNFH issue is the existence of the hatchery and the effects its ongoing operations may have on the restoration of anadromous salmonid populations in upper Battle Creek. This overarching issue can be parsed into ten specific issues, which are described in the statements below.

1. CNFH Issue Statement 1 (IS-1) – An unscreened water diversion used at times to deliver water to the CNFH may result in the entrainment of Battle Creek juvenile salmonids.
2. CNFH Issue Statement 2 (IS-2) – The current CNFH steelhead program excludes naturally produced (unmarked) fish from the broodstock. This practice leads to continued domestication and potential for reduced fitness when hatchery fish spawn in the restoration area.
3. CNFH Issue Statement 3 (IS-3) – Current operations at CNFH and at the fish barrier weir cannot always identify and prevent passage of (1) hatchery origin salmonids, and (2) non-target runs of Chinook salmon.
4. CNFH Issue Statement 4 (IS-4) – Fall Chinook (hatchery or wild), hatchery late-fall Chinook, and hatchery-origin steelhead may reach the restoration area during high flow events where they may have adverse effects on Battle Creek steelhead, late-fall, spring, and winter Chinook salmon.

5. CNFH Issue Statement 5 (IS-5) – Trapping, handling, and sorting, of salmonids within CNFH and at the CNFH fish ladder results in migratory delay and may result in direct mortality or sub-lethal effects to natural-origin winter Chinook, late-fall Chinook, spring Chinook, and steelhead trying to access the restoration area.
6. CNFH Issue Statement 6 (IS-6) – Pathogens resulting from CNFH operations may be transmitted to and expressed among wild fish in the restoration area.
7. CNFH Issue Statement 7 (IS-7) – In-stream flows in upper Battle Creek are reduced by CNFH water diversion(s) between the diversion site(s) downstream to the return effluent site (distance of 1.2 to 1.6 miles depending on location of the water intake). These diversions may result in inadequate in-stream flows or increased water temperatures in this segment of the river during drought conditions and in association with operations at upstream hydropower facilities.
8. CNFH Issue Statement 8 (IS-8) – High abundance of hatchery-origin adult salmon in lower Battle Creek may create adverse effects including (1) reduction of in-stream spawning success due to the physical destruction of redds; (2) interbreeding between natural and hatchery origin Chinook salmon; and (3) increased mortality of juvenile salmonids emigrating from upper Battle Creek.
9. CNFH Issue Statement 9 (IS-9) – Releases of hatchery-produced juvenile Chinook salmon and steelhead from CNFH may result in predation on and behavior modifications to natural-origin fish produced in the restoration area.
10. CNFH Issue Statement 10 (IS-10) – Current production releases of CNFH juvenile fall Chinook salmon may contribute to exceeding the carrying capacity for Chinook salmon in the Sacramento River, San Francisco Estuary, or the Pacific Ocean leading to reduced success of Battle Creek origin salmonids.

2.2 BCRP Issues Statements

The BCRP-AMP (Terraqua 2004) identified eleven objectives related to population, habitat and passage within the Battle Creek. Terraqua (2004) generated hypotheses, suggested monitoring, and identified triggers associated with each of the eleven objectives. These eleven objectives are simplified into four issues in order to facilitate linkage and comparison with CNFH issues. The four BCRP issues are:

1. BCRP Issue Statement A (IS-A) – Habitat quality and quantity may be insufficient to support BCRP population objectives.
2. BCRP Issue Statement B (IS-B) – Battle Creek water temperatures may not be suitable to support salmonid populations consistent with BCRP population objectives.
3. BCRP Issue Statement C (IS-C) – Natural and man-made barriers may not be sufficiently passable to support BCRP salmonid population objectives.
4. BCRP Issue Statement D (IS-D) – Redd scouring and related egg mortality may limit BCRP salmonid populations.

3. Conceptual Models

Conceptual models were prepared for four life history events identified in the BCRP-AMP (Terraqua 2004): (1) adult immigration (i.e., upstream migration); (2) adult spawning and egg incubation; (3) juvenile rearing and emigration (i.e., outmigration); and (4) river, estuary, and ocean rearing (Figure 1). Each conceptual model identifies the relationships among drivers (D), linkages (L), and outcomes (O), generally following the approach described by DiGennaro et al. (2012). Drivers are physical, chemical, or biological forces (natural or human created) having a large influence on the system or species of interest. Drivers may be uncontrolled (i.e., not under management control or influence) or managed (i.e., under direct management control or influence). Linkages are cause and effect relationships between drivers and outcomes depicted by one-way arrows. Outcomes are the intermediate or terminal response variables predicted to emerge from the influence of drivers and associated linkages. Outcomes are the elements the conceptual model attempts to predict and explain; they may be physical, chemical, or biological.

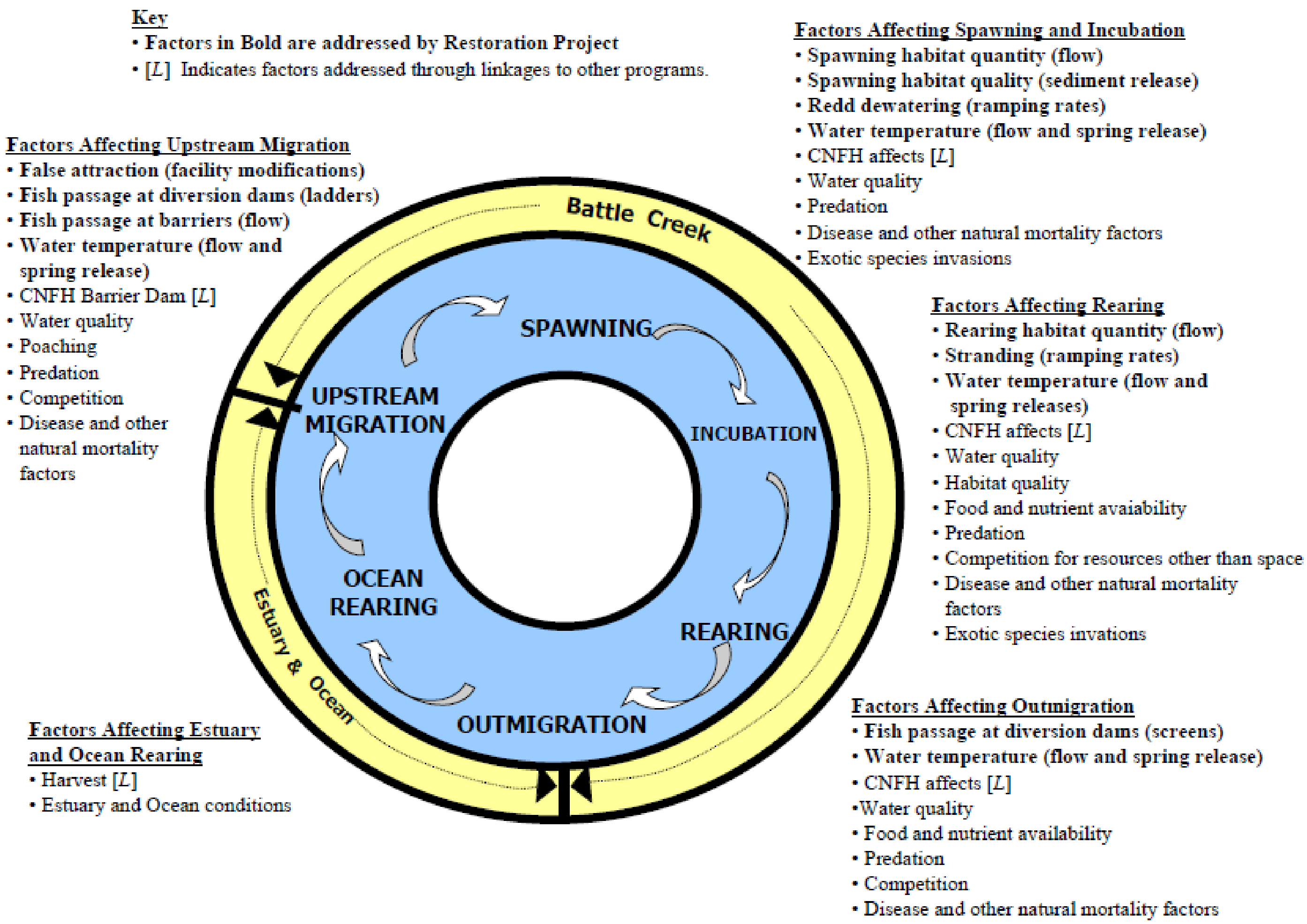


Figure 1. Battle Creek Restoration Project conceptual model identifying limiting factors and key uncertainties (from Terraqua 2004). Note that CNFH affects are listed as a limiting factor for most life-stage events.

Drivers in each conceptual model only include: 1) the relevant restoration actions identified in the BCRP-AMP; 2) the issue statements arising from one or more CNFH propagation program that may influence the life history event; and 3) the intermediate outcomes that directly influence the life history event. This approach was taken to focus the conceptual models on the interactions between the CNFH and the BCRP and their compatibility, or lack thereof. However, the detailed analyses associated with each conceptual model focuses on examination of the relevant issue statements. Detailed analyses of the BCRP restoration actions were completed by Terraqua (2004). This chapter provides further analyses in the context of linkages between CNFH effects and BCRP issues.

Ecosystem responses and primary biological responses identified in the conceptual models are considered intermediate outcomes expected to occur in response to restoration actions (Terraqua 2004). Terminal outcomes focus on increasing the life stage considered in the model (e.g., increasing juvenile emigrant survival in Battle Creek), or improving conditions for that life stage (e.g., improving flow and habitat conditions required for adult spawning).

The specific attributes of each linkage are described by incorporating three key features:

- Type of effect the driver has on the outcome, either positive (+) or negative (-). A positive effect indicates a driver that helps to obtain the desired outcome. A negative effect indicates a driver that has a detrimental effect on the desired outcome.
- Importance of the linkage in influencing the outcome: Importance reflects the degree to which a driver influences or controls the intermediate or terminal outcome in the model and is identified as low, medium or high using the criteria in Table 1. Importance also is indicted by arrow line-thickness in the revised conceptual models.
- Understanding of the linkage: Understanding describes the known, established, and/or generally agreed upon scientific understanding of the cause-effect relationship between a driver and outcome. Understanding may be limited due to (1) lack of knowledge and information, (2) disagreements in the interpretation of existing data and information, or (3) because the basis for assessing the understanding of a linkage relies on studies done elsewhere and/or on different organisms. Understanding was rated as either low, medium, or high based on the criteria in Table 1. Understanding also is indicated by arrow line-type (solid, dashed, or dotted) in the revised conceptual models.

Table 1. Criteria for assessing and rating importance and understanding of the linkage between a driver and outcome. LCM: quantitative life-cycle model.

High	Medium	Low
Importance		
LCM indicates 15% or greater change in equilibrium abundance, and/or qualitative assessment of existing data and information suggests the driver has a large impact on the outcome. Large impact drivers will affect the species or ecosystem attribute over a relatively large spatial or temporal scale, or a substantial proportion of the population will be influenced by the driver (e.g., most adult salmon immigrate through one route which contains multiple barriers). Spatial or temporal variability in the driver's influence also is considered in estimating importance. Note that the temporal scale considers both duration and frequency of influence.	LCM indicates a 5% to 15% change in equilibrium abundance, and/or qualitative assessment of existing data and information suggests the driver has a moderate impact on the outcome. Medium impact drivers will have a more limited spatial or temporal effect on the species or ecosystem attribute, or only a portion of the population will be influenced by the driver (e.g., adult salmon immigration can occur through multiple routes, some of which have a barrier). Spatial or temporal variability in the driver's influence also is considered in estimating importance. Note that the temporal scale considers both duration and frequency of influence.	LCM indicates a less than 5% change in equilibrium abundance, and/or qualitative assessment of existing data and information suggests the driver has a low impact on the outcome. Low impact drivers will have a limited spatial or temporal effect on the species or ecosystem attribute, or only a small fraction of the population will be influenced by the driver (e.g., adult salmon immigration can occur through multiple routes, only one route has a barrier). Spatial or temporal variability in the driver's influence also is considered in estimating importance. Note that the temporal scale considers both duration and frequency of influence.
Understanding		
Understanding about how a driver influences an outcome and the associated variability are based on local studies with data reported or peer reviewed publications. Scientific reasoning is supported by most experts within the system and a commonly accepted understanding exists. The need for additional applied research is low.	Understanding about how a driver influences an outcome and the associated variability are based on peer-reviewed studies from outside the system or from incomplete local studies Scientific reasoning may vary somewhat among experts, but a commonly accepted understanding exists among several experts. Some additional applied research may be beneficial.	Understanding about how a driver influences an outcome and the associated variability are not based on peer-reviewed research nor from studies within the system or elsewhere. Scientific reasoning varies among experts and a commonly accepted understanding is lacking. The need for additional applied research is high.

4. Adult Salmonid Immigration Conceptual Model and Issue Analysis

This conceptual model focuses on the issues that may affect the immigration of adult salmonids through Battle Creek (Figure 2). The conceptual model diagram includes restoration actions relevant to this life-stage event, which aim to improve adult fish passage and in-stream flows in upper Battle Creek.

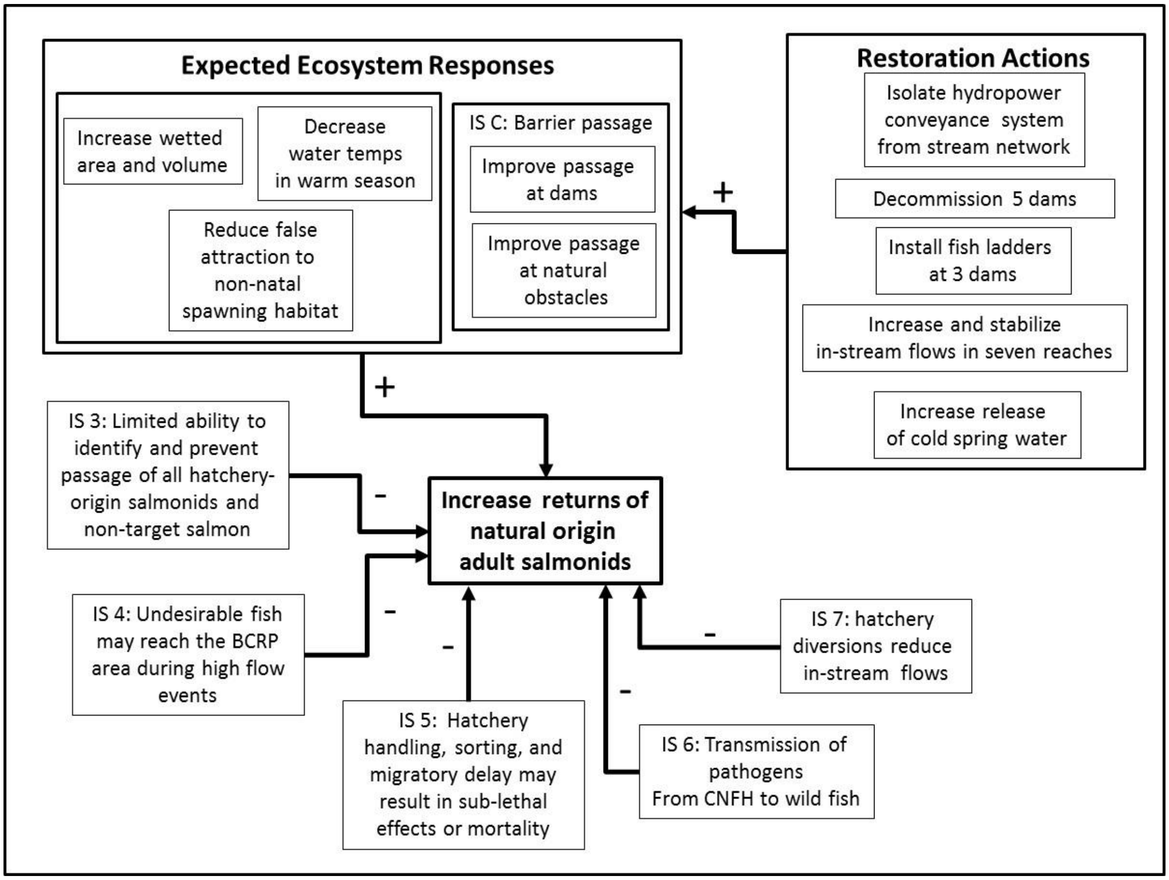


Figure 2. Conceptual model diagram of factors affecting the immigration of adult salmonids through Battle Creek. Levels of understanding and importance are not shown in this diagram.

Terraqua (2004) identified five hypotheses to describe the cause and effect relationships between the restoration actions (drivers), and the expected ecosystem responses (intermediate outcomes). Specifically, the hypotheses state that implementation of in-stream flow levels and facilities modifications specified in the BCRP description, implementation of PG&E's facilities monitoring plan, and implementation of any adaptive responses affecting in-stream flows or hydroelectric project facilities will:

1. Provide at least 95% of the maximum usable habitat quantity for critical life stages among priority species.
2. Provide in-stream water temperatures that are suitable for critical life stages among species at appropriate stream reaches.
3. Ensure water discharges from the powerhouse tailrace connectors or water conveyance system are confined to times and amounts that avoid false attraction.

4. Ensure natural in-stream barriers do not impede upstream migration of adult salmon and steelhead at prescribed flows and normal wet season flow regimes.
5. Ensure unimpeded passage of adult salmon and steelhead at fish ladders relative to contemporary standards/guidelines.

Sustained improvements in these habitat conditions and ecosystem responses are expected to positively affect the terminal outcome: increased returns of natural-origin adult salmonids.

Five issues related to CNFH programs and one issue related to the BCRP may have the potential to adversely affect adult salmonid immigration through Battle Creek (Figure 2). Each issue is analyzed to estimate the importance and understanding of the issue's influence on the terminal outcome. Collective ratings of importance and understanding are presented at the end of this section (Table 13). A revised conceptual model diagram incorporating results from the issue analyses also is presented at the end of this section (Figure 12).

4.1 Analysis of CNFH Issue Statement 3: Current operations at CNFH and at the fish barrier weir cannot always identify and prevent passage of: (1) hatchery origin salmonids and (2) non-target runs of Chinook salmon

During normal flow conditions, hatchery origin or non-target adult salmonids may reach the BCRP area in two ways: (1) during periods when all upstream migrants are not processed through CNFH or through fish barrier weir trapping, or (2) when hatchery origin fish cannot be reliably distinguished from salmonid stocks targeted for restoration (hereafter referred to as 'target species'). The presence of an adipose fin clip (mark) identifies many, but not all hatchery-produced Chinook salmon in the Central Valley. Since 1998, all *O. mykiss* produced at CNFH have received an adipose fin clip; thus, essentially all hatchery-origin *O. mykiss* returning to Battle Creek after 2002 would be marked. All late-fall Chinook salmon produced at CNFH have been marked and coded wire tagged since 1992. In contrast, at least 25% of the fall Chinook salmon produced at CNFH (and all other Central Valley hatcheries) have been marked and coded wire tagged as part of a Constant Fractional Marking (CFM) program only since 2006 (USFWS 2011).

During the period of broodstock collection at CNFH (October 1 – March 15) all fish brought into the hatchery are examined for marks and tags, and only unmarked fish (presumed natural-origin) representing restoration area target species are passed upstream. Fish passed upstream are intended to include natural-origin *O. mykiss*, late-fall Chinook, spring Chinook, and winter Chinook salmon. No fall Chinook salmon (marked or unmarked) are passed upstream of the barrier weir and hatchery during the months of October and November. Thus, during broodstock collection, hatchery or non-target salmonids may reach the restoration area only due to mark failure (e.g., a partial adipose fin clip, which allows the fin to grow back), or by failure to accurately identify race or origin of passed fish. Unmarked fall Chinook (either hatchery or natural-origin) exhibiting a late-fall phenotype might be mistakenly passed into the restoration area during broodstock collection. However, available evidence indicates that fall, late fall and winter Chinook can be reliably distinguished by date and external condition (USFWS 2011).

After broodstock collection ends (after March 15th) the fish ladder leading to CNFH is closed, and upstream migrating fish are instead allowed to proceed through the ladder leading to upper Battle Creek. Fish passage through the upstream fish ladder continues through July 31st, and is monitored in two ways during this period:

1. From March 1st into April or May, all adult fish are trapped and examined for marks and tags. All marked Chinook salmon trapped during this period are euthanized, and CWTs removed and analyzed to determine fish origin and brood year. All unmarked fish are measured, tissues samples collected for genetic identification, and then passed into upper Battle Creek.

2. The second monitoring approach begins when water temperatures become too high (i.e., ≥ 60ºF, see Appendix A for more details) typically beginning in May or June, and continuing through the end of July. During this period fish are allowed free access to the BCRP area, and passage through the upstream fish ladder is monitored through the use of an underwater video surveillance system. Between 2001 and 2011, fish video monitoring has occurred annually for an average of 10.3 weeks (out of 22 available weeks between March 1st and July 31st). Video monitoring has occurred for as few as seven and for as many as twelve weeks (Figure 3). Years with a greater number of video monitoring weeks (and therefore fewer trapping weeks) would potentially allow a larger number of hatchery or non-target anadromous salmonids to reach the restoration area.

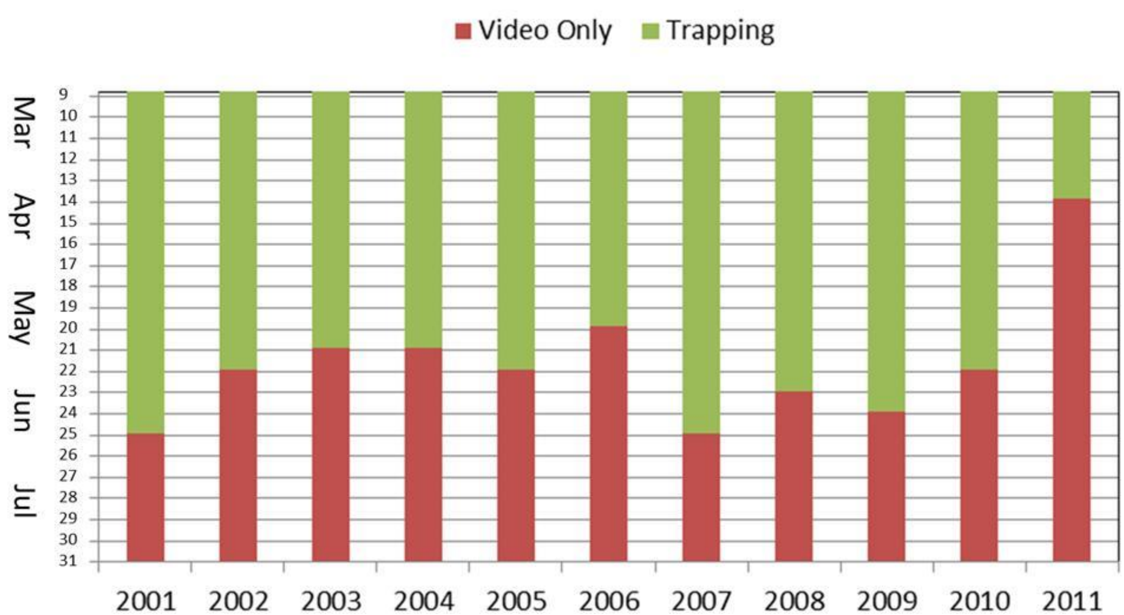


Figure 3. Weeks beginning with March 1st (y-axis) of video only monitoring (red bars) or trapping (green bars) in the upstream fish ladder at the fish barrier Weir on Battle Creek. During the video monitoring period migrating fish have free access to the restoration area in upper Battle Creek.

The USFWS (2011) provided information on handling and sorting of salmon and *O. mykiss* at CNFH, and Appendix A provided a more complete description of these operations. Brown and Alston (2007), Alston et al. (2007), Newton et al. (2007a), Newton et al. (2007b), Newton et al. (2008), Newton and Stafford (2011), and Stafford and Newton (2010), Bottero and Brown (2012) provide information on handling and sorting of fish during adult monitoring activities at the CNFH fish barrier weir. A review of those reports indicates:

O. mykiss

- Size and arrival timing of observed fish suggest *O. mykiss* (both anadromous steelhead and resident rainbow trout) occur in Battle Creek.
- Since the 2008 -2009 season and as part of current operations, the CNFH steelhead program is operated as a segregated program; only marked (hatchery origin) *O. mykiss* entering CNFH are included in the broodstock. All unmarked *O. mykiss* (presumed natural-origin) entering CNFH during broodstock collection are released upstream of the fish barrier weir into the restoration area. (Table 2).

Table 2. Estimated number of marked and unmarked *O. mykiss* entering CNFH during broodstock collection (October through February) and the number of those fish passed upstream into the restoration area.

	Entering CNFH[1/]			Passed upstream into the restoration area[2/]		
Year	Marked	Unmarked	**Total[3/]**	Marked	Unmarked	**Total**
2002-2003	2,261	427	**2,688**	769	416	**1,185**
2003-2004	1,378	225	**1,603**	314	179	**493**
2004-2005	1,343	312	**1,655**	0	270	**270**
2005-2006	994	282	**1,276**	0	249	**249**
2006-2007	1,380	164	**1,544**	0	132	**132**
2007-2008	2,968	184	**3,152**	0	159	**159**
2008-2009	1,987	196	**2,183**	0	196	**196**
2009-2010	624	266	**890**	0	265	**265**
2010-2011	1,108	200	**1,308**	0	198	**198**
2011-2012	1,512	206	**1,718**	0	198	**198**
Total	**15,555**	**2,462**	**18,017**	**1,083**	**2,262**	**3,345**
Mean	**1,556**	**246**	**1,802**	**181**	**226**	**335**

1/ Source USFWS (2011) and R. Null, pers. comm.

2/ Since 1998 progeny of all hatchery-origin *O. mykiss* spawned at CNFH have been marked with an adipose-fin clip prior to release.

3/ Prior to return year 2003 differentiating hatchery- and natural-origin *O. mykiss* was not possible.

- Since 2002, 166 marked and 1,451 unmarked *O. mykiss* have been reported to have passed through the upstream fish ladder during adult fish monitoring activities (trapping and video monitoring periods combined) (Table 3). During trapping, 85% of *O. mykiss* observed were greater than 40cm (>14.7 in) suggesting a relatively large component of fish sufficiently large enough to represent the anadromous life history type. Comparable length-frequency data is not currently available for the video monitoring period.
- Since the 2004 – 2005 season, no marked *O. mykiss* have been deliberately passed upstream into the restoration area either during CNFH broodstock collection or during trapping in the upstream fish ladder.

- Trapping in the upstream fish ladder effectively prevents passage of hatchery origin *O. mykiss* into the BCRP area, except during high flow events. However, the period of video monitoring (when no trapping occurs) represents a relatively long period (Figure 3) during which marked *O. mykiss* may freely access the restoration area. Available data indicates that in three of nine years, marked *O. mykiss* comprised more than 10% of the *O. mykiss* entering the restoration area during video monitoring (Figure 4). The fraction of marked *O. mykiss* entering the restoration during video monitoring area was highest in 2011, in excess of 50%.

Table 3. Estimated number of marked and unmarked *O. mykiss* passing into the restoration area during trapping in the upstream fish ladder and during video monitoring in the fish ladder system and trapping + video. Data from Brown and Alston 2007, Alston et al 2007, Newton et al 2007a, Newton et al 2007b, Newton et al 2008, Stafford and Newton 2010, and Newton and Stafford 2011, Bottaro and Brown 2012, L. Earley pers. comm., and M. Brown pers. comm.).

	Trapping			**Video monitoring**			**All periods**		
Year [1/]	Marked [2/]	Unmarked	**Total**	Marked [2/]	Unmarked	**Total**	Marked	Unmarked	**Total all fish** [3/]
2002	13 (11.2)	103 (88.8)	**116**	1 (1.6)	60 (98.4)	**61**	14 (7.1)	183 (92.9)	**197**
2003	1 (1.6)	62 (98.4)	**63**	2 (3.4)	56 (96.6)	**58**	3 (2.5)	118 (97.5)	**121**
2004	7 10.1)	62 (89.9)	**69**	8 (11.3)	63 (88.7)	**71**	15 (10.7)	125 (89.3)	**140**
2005	0	44 (100)	**44**	0	30 (100)	**30**	0	74 (100)	**74**
2006	0	126 (100)	**126**	1 (1.6)	63 (98.4)	**64**	1 (0.5)	189 (99.5)	**190**
2007	0	75 (100)	**75**	3 (3.1)	141 (97.9)	**144**	3 (1.4)	216 (98.6)	**219**
2008	0	101 (100)	**101**	1 (5.0)	19 (95.0)	**20**	1 (0.8)	120 (99.2)	**121**
2009 [4/]	0	76 (100)	**76**	20 (25.3)	59 (74.7)	**79**	20 (12.9)	135 (87.1)	**155**
2010	0	69 (100)	**69**	18 (23.7)	58 (76.3)	**76**	18 (12.4)	127 (87.6)	**145**
2011 [5/]	0	42 (100)	**42**	91 (100)	-3	**88**	91 (70.0)	39 (30.0)	**130**
2012 [5/]	0	0	**0**	-11	125 (100)	**114**	0	125 (100)	**125**
Total	**21 (2.7)**	**760 (97.3)**	**781**	**134 (16.6)**	**671 (83.4)**	**805**	**166 (10.3)**	**1,451**	**1,617**

1/ Prior to 2002 - 2003 season differentiating hatchery-origin *O. mykiss* was not possible.
2/ Number in parenthesis is percentage of total
3/ 'Total all fish' includes all *O. mykiss* counted during trapping and video monitoring
4/ In 2009, the fish barrier weir was modified to reduce unintentional fish passage.
5/ Negative numbers of fish passing the barrier were reported in 2011 and 2012 and reflect a greater number of fish observed passing downstream during video monitoring.

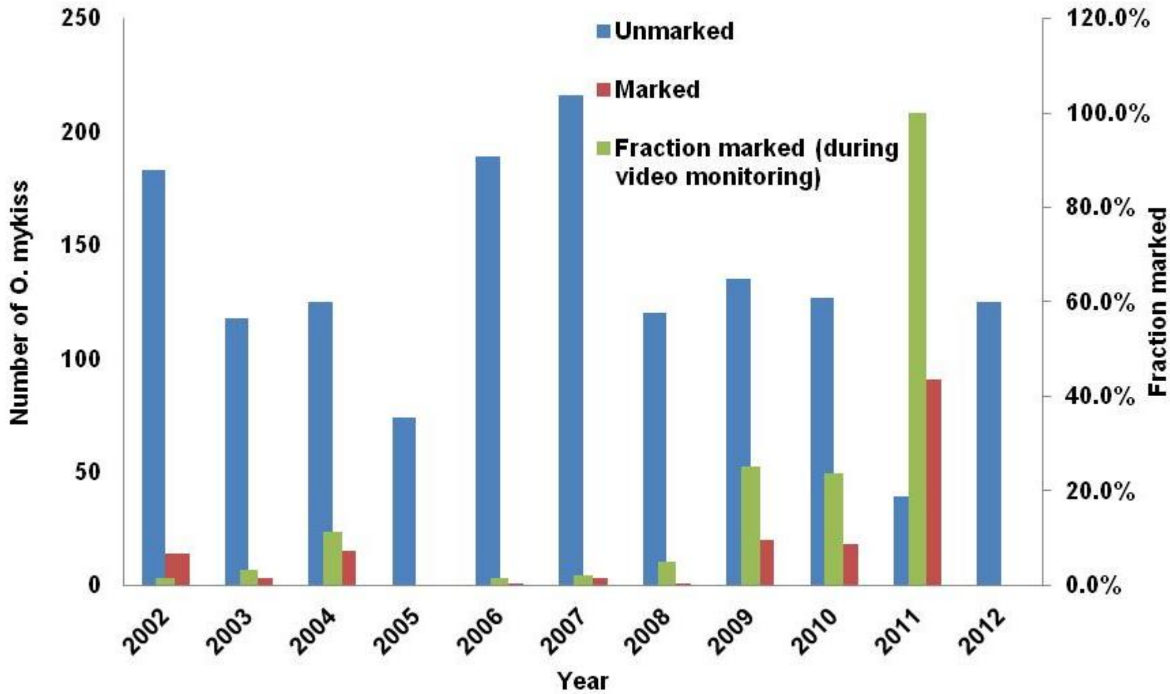


Figure 4. Number of marked and unmarked *O. mykiss* estimated trapped and detected during video monitoring in the upstream fish ladder, and fraction of marked *O. mykiss* entering the restoration area during video monitoring (green bar).

- During spring weir operations, *O. mykiss* have generally demonstrated two peaks in movement past the fish barrier weir, the first in March (which is thought to represent the tail end of the winter immigration period), and a second, smaller peak during the mid-May through mid-June period (Figure 5).

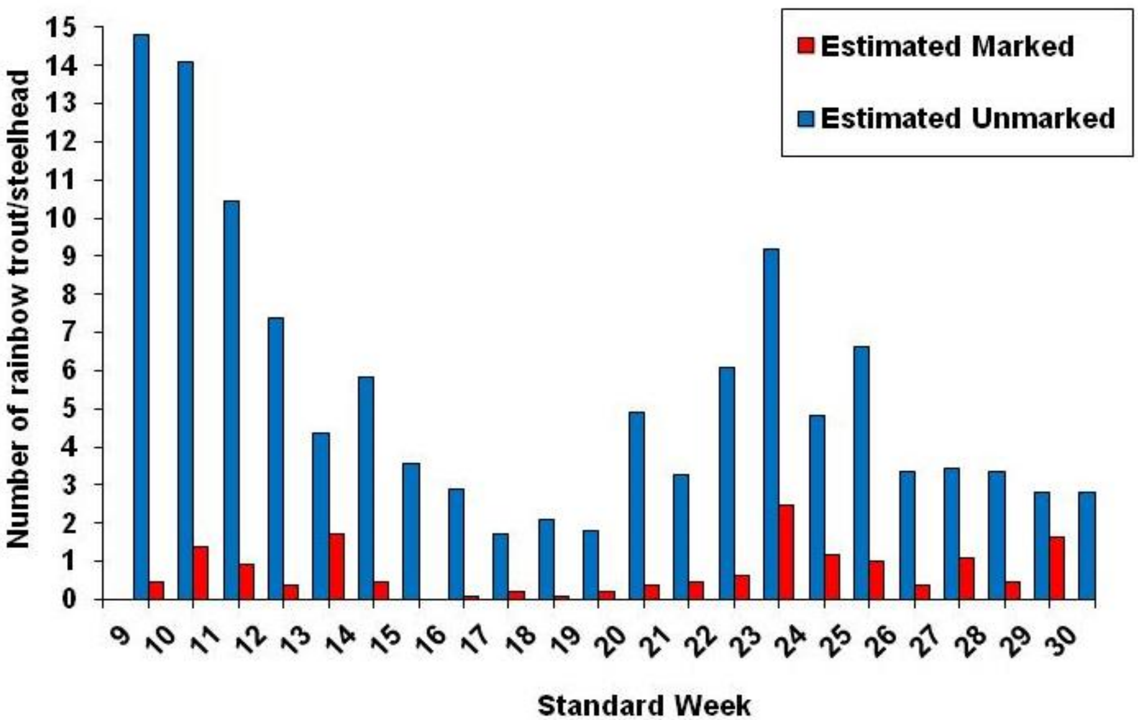


Figure 5. Mean number of marked and unmarked *O. mykiss* estimated to have reached upper Battle Creek through the CNFH barrier weir fish ladder during adult monitoring 2002 through 2012 by standard week. Fish trapping usually begins March 1 (standard week 9) and video surveillance monitoring (no trapping) usually began in May (between standard weeks 19 through 24). All monitoring in the upstream fish ladder is typically terminated at the end of July (standard week 30). Prior to 2002 - 2003 season differentiating hatchery-origin *O. mykiss* was not possible.

- Summing *O. mykiss* passage observations across both CNFH and barrier weir operations, it is evident that since 2005 the majority of *O. mykiss* entering the BCRP area of natural origin (Figure 6).

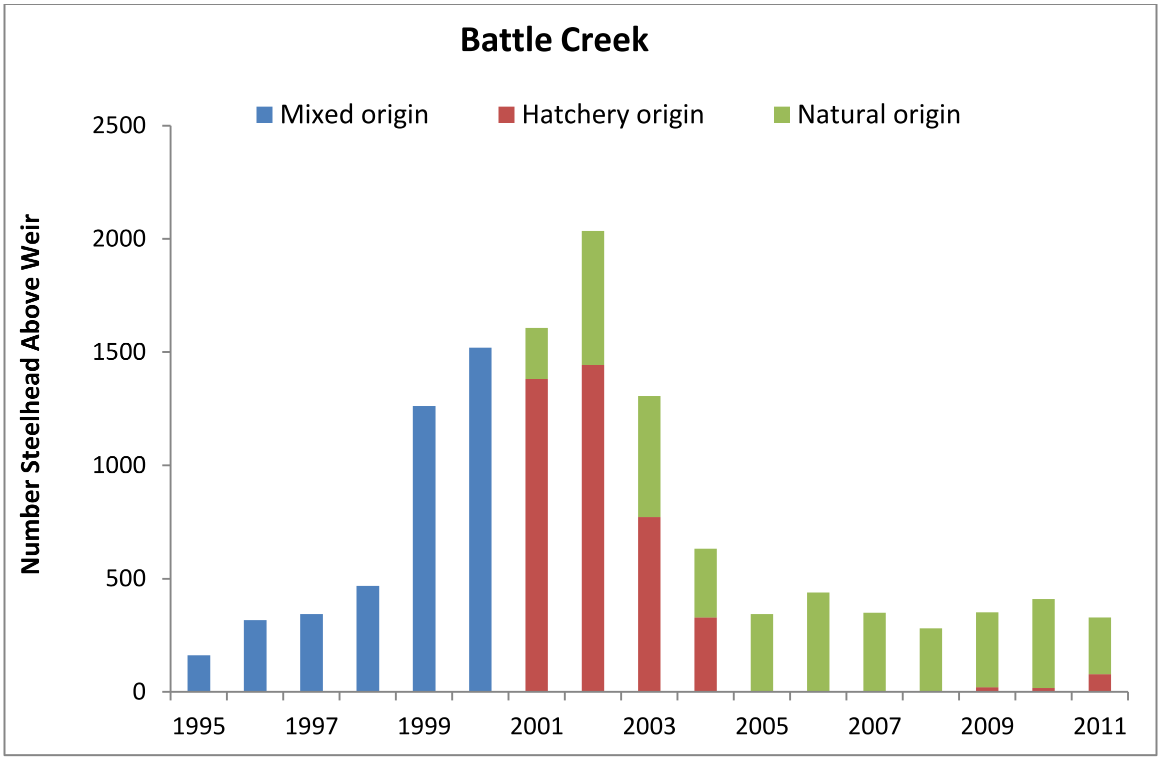


Figure 6. Number of *O. mykiss* returning to Battle Creek from 1995-2011. Starting in 2001, fish were classified as either wild (unclipped) or hatchery produced (clipped). Includes fish passed above the weir during broodstock collection and fish passing through the fish ladder March 1 to August 31. Data are from USFWS.

<u>Chinook salmon</u>

- No fall Chinook salmon are intentionally passed upstream of the fish barrier weir during CNFH fall Chinook salmon broodstock collection.

- During broodstock collection all unmarked, phenotypic late-fall Chinook salmon are passed upstream into the BCRP area. Hatchery personnel report a high level of phenotypic differentiation among adult fall, late-fall, and winter Chinook. Unmarked fall Chinook salmon (possibly hatchery-origin fish) are reportedly not mistaken for unmarked late-fall or winter Chinook salmon during CNFH late-fall Chinook salmon broodstock collection, since the timing of migration and maturity are markedly different between the three runs. USFWS (2011) provides genetic analysis, which supports the reliability of this phenotypic run classification method. Spring and winter Chinook could be difficult to visually distinguish under some circumstances, but both would be passed into the BCRP area; therefore this difficulty does not present a management challenge.

- Since the 2000 – 2001 season, 662 unmarked late-fall Chinook salmon collected at CNFH have been passed upstream of the barrier weir (Table 4).

Table 4. Total number of late fall Chinook salmon collected at CNFH, and number of unmarked (presumed natural-origin) late fall Chinook salmon passed into the restoration area during broodstock collection.

Season	Number collected at CNFH[1/]	Number passed above barrier weir	Percent passed above the barrier weir[2/]	Total
2000 -2001	2,439	98	3.9%	**2,537**
2001 - 2002	4,186	216	4.9%	**4,402**
2002 - 2003	3,183	57	1.8%	**3,240**
2003 - 2004	5,166	40	0.8%	**5,206**
2004 - 2005	5,562	23	0.4%	**5,585**
2005 - 2006	4,822	50	1.0%	**4,872**
2006 - 2007	3,360	72	2.1%	**3,432**
2007 - 2008	6,334	19	0.3%	**6,353**
2008 - 2009	6,429	32	0.5%	**6,461**
2009 - 2010	5,505	27	0.5%	**5,532**
2010 - 2011	4,374	14	0.3%	**4,388**
2011 - 2012	3,001	14	0.5%	**3,015**
Total	**54,361**	**662**	--	**55,023**
Mean	**4,530**	**55**	1.2%	**4,585**

1/ USFWS (2011) and R. Null pers. comm.

2/ Percentage of total number collected at CNFH

- During the 2001 – 2011 seasons, USFWS personnel reported trapping 1,331 marked Chinook salmon, and 690 unmarked Chinook salmon in the upstream fish ladder (Table 5).
- During the 2001 – 2011 seasons, about 68% of the Chinook salmon trapped in the upstream fish ladder were marked (Table 5).
- During the 2001 – 2011 seasons, about 12% of the Chinook salmon identified during video surveillance monitoring were marked (Table 5).

Table 5. Estimated number of marked and unmarked Chinook salmon trapped and estimated number passing during video monitoring at the CNFH barrier weir upstream fish ladder 2001 – 2012 (data from Brown and Alston 2007, Alston et al 2007, Newton et al 2007a, Newton et al 2007b, Newton et al 2008, Stafford and Newton 2010, and Newton and Stafford 2011, Bottaro and Brown 2012, and Matt Brown, USFWS, pers. comm.).

	Trapping period					Video monitoring			
Year	Marked 1/ 2/	Marked/ Total	Unmarked	Unk	Total	Marked	Marked/ Total	Unmarked	Total
2001	14	31.1%	30	1	**45**	5	5.1%	93	**98**
2002	166	56.8%	126	0	**292**	0	0.0%	67	**67**
2003	13	7.8%	154	0	**167**	10	6.1%	154	**164**
2004	61	49.2%	63	0	**124**	2	6.7%	28	**30**
2005	69	72.6%	26	0	**95**	0	0.0%	47	**47**
2006	163	54.0%	139	0	**302**	0	0.0%	81	**81**
2007	229	69.0%	103	0	**332**	5	1.4%	354	**359**
2008	175	86.2%	28	0	**203**	5	6.1%	77	**82**
2009	214	94.7%	12	0	**226**	9	4.7%	182	**191**
2010	93	91.2%	9	0	**102**	50	30.3%	115	**165**
2011	105	100.0%	0	0	**105**	41	22.7%	140	**181**
2012	29	100.0%	0	0	**29**	152	18.9%	652	**804**
Totals	**1,331**	**--**	**690**	**1**	**2,022**	**279**	**--**	**1,990**	**2,269**
Mean	**111**	**67.7%**	**58**	**--**	**169**	**23**	**8.5%**	**166**	**189**

1/ All hatchery–origin winter, spring, and late-fall Chinook salmon are marked, 25% of fall Chinook salmon are marked.
2/ Marked fish were euthanized and CWT's removed.

- During the 2001 – 2011 seasons, USFWS personnel estimated 279 marked Chinook salmon and 1,990 unmarked Chinook salmon passed through the upstream fish ladder during video surveillance monitoring (Table 5). The occurrence of marked Chinook salmon immigrating into the restoration area is higher in March during trapping activities than during the video surveillance monitoring period (Figure 7).

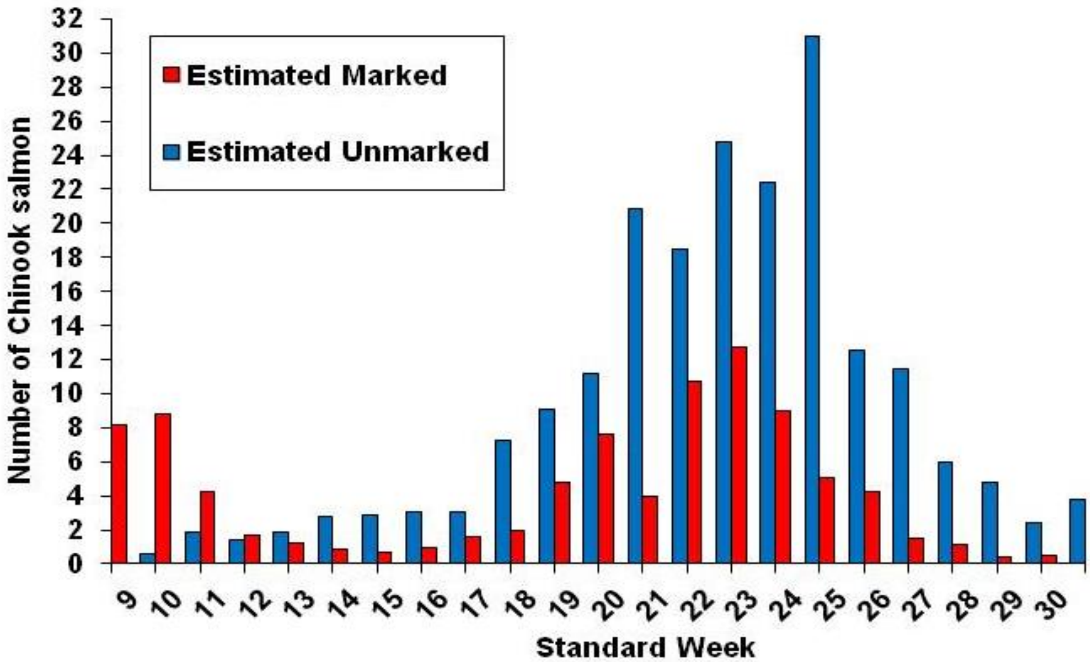


Figure 7. Mean number of marked and unmarked Chinook salmon estimated to have reached Battle Creek above the CNFH fish barrier weir during adult monitoring 2001 through 2012 by standard week. Trapping usually begins March 15 (standard week 11) and video surveillance monitoring usually begins in May (between standard weeks 19 through 24). All monitoring in the upstream fish ladder is typically terminated at the end of July (standard week 30) when the upstream ladder is closed.

- Of the 1,346 marked Chinook salmon trapped in the upstream fish ladder and CWT's retrieved, 1,338 fish were CNFH late fall Chinook salmon, while eight fish were identified as non-CNFH origin (Table 6).

Table 6. Number and origin of coded wire tags recovered during trapping in the upstream fish ladder (Data from L. Earley, USFWS). LSNFH: Livingston Stone National Fish Hatchery. FRH: Feather River Fish Hatchery.

	LSNFH	CNFH		FRH		Butte Creek (wild)			
Year	Winter	Late-fall	Fall	Spring	Fall	Spring	Total	Unk 1/	Total all fish
2001	0	14	0	0	0	0	**14**	0	**14**
2002	0	143	0	0	0	0	**143**	25	**168**
2003	0	130	0	0	0	0	**130**	3	**133**
2004	0	58	0	0	0	1	**59**	2	**61**
2005	0	65	0	0	0	0	**65**	4	**69**
2006	5	148	0	1	0	0	**154**	9	**163**
2007	0	213	0	0	0	0	**213**	16	**229**
2008	0	161	0	1	0	0	**162**	13	**175**
2009	0	184	0	0	0	0	**184**	25	**209**
2010	0	99	0	0	0	0	**99**	1	**100**
2011	0	101	0	0	0	0	**101**	4	**105**
2012	0	27	0	0	0	0	**27**	2	**29**
Total	**5**	**1,343**	**0**	**2**	**0**	**1**	**1,351**	104	**1,455**

1/ Includes no tag detected, lost tags, and unreadable tags.

The race and origin of Chinook salmon reaching upper Battle Creek is of considerable interest, but cannot be fully evaluated by information currently available. The following points describe difficulties with race and origin classification.

- Marked fish encountered during trapping at the fish barrier weir have predominately been CNFH late-fall Chinook salmon (Table 6) arriving in early March. The extension of CNFH trapping until March 15th means that fewer late fall Chinook will be captured during weir trapping in the future.
- Relatively large numbers of marked fish continue to be observed during video monitoring (Table 5). However, tags have been recovered from just 23 of 279 marked fish known to have entered the restoration area (Table 7). Of these 23 recovered CWT, 17 were identified as Feather River Hatchery (FRH) spring Chinook salmon, 3 FRH fall Chinook, 1 CNFH late-fall Chinook, and 1 CNFH fall Chinook (Table 7). Although most marked fish reaching the restoration area during video monitoring are of unknown origin, none of the possibilities (i.e., CNFH fall, CNFH late-fall, FRH fall, FRH spring) are consistent with spring Chinook population objectives for Battle Creek.

Table 7. Number and origin of coded wire tagged Chinook salmon recovered during snorkel surveys in Battle Creek above the fish barrier weir, 2001 to 2012 (data from L. Earley, USFWS).

	LSNFH	**CNFH**		**FRH**		**Butte Creek (wild)**				
Year	**Winter**	**Late-fall**	**Fall**	**Spring**	**Fall**	**Spring**	**Total**	**NTD[1/]**	**Lost Tag**	**Unreadable Tag**
2001	0	0	0	1	0	0	**1**	0	0	0
2002	0	0	0	0	0	0	**0**	0	0	0
2003	0	1[2/]	0	0	0	0	**1**	0	0	0
2004	0	0	0	0	0	0	**1**	0	0	0
2005	0	0	0	0	0	0	**0**	0	0	0
2006	0	0	1[3/]	0	0	0	**1**	0	0	0
2007	0	0	0	0	0	0	**0**	0	0	0
2008	0	0	0	0	0	0	**0**	0	0	0
2009	0	0	0	0	0	0	**0**	0	0	0
2010	0	0	0	6	1	0	**7**	0	0	0
2011	0	0	0	0	2	0	**2**	0	0	0
2012	0	0	0	10	0	0	**10**	1	0	0
Totals	**0**	**1**	**1**	**17**	**3**	**0**	**23**	**1**	**0**	**0**

1/ NTD: no tag detected.
2/ 1999 brood year female CNFH late-fall Chinook salmon recovered June 26, 2003.
3/ 2003 brood year CNFH fall Chinook, collected in November following flows >350 cfs (i.e., fish defeated the old barrier weir; prior to its reconstruction).

- Genetic analysis of unmarked fish sampled during trapping at the fish barrier weir provide another means to assess race of Chinook salmon reaching the restoration area. However, Battle Creek spring Chinook salmon have no established genetic baseline (Newton and Brown 2010), so results are difficult to interpret. Complete result tables and captions from Newton and Brown (2010) are provided as tables 8 and 9. Newton and Brown (2010) summarize results from the analyses as follows:

> *GSI results for 2007-2010 samples with a >90% confidence rating assigned the majority of samples to Central Valley spring Chinook stock: 74% for the HMSC16 method, 77% for the HMSC16+Cry6 method, and 92% for the GAPS method [Table 8]. Although the GAPS method assigned the highest percentage of samples to the spring-run category, it had the fewest number of samples that achieved a >90% confidence rating. When all confidence ratings were included, the percentage assigned as spring run declined: 70% for the HMSC16 method, 74% for the HMSC16+Cry6 method, and 79% for the GAPS method [Table 8]. These results support the hypothesis that the majority of phenotypic spring Chinook in Battle Creek are genetically more similar to other Central Valley spring Chinook stock than to other run types. Still, up to 30% were assigned as fall run depending on the GSI technique used. The fish assigned to the fall-run category may have been early returning fall run, fall-spring hybrids, or a unique population of Battle Creek spring run that are genetically similar to fall run.*

Table 8. Results of Chinook salmon Genetic Stock Identification (GSI) analyses including results summarized by confidence level in the stock (i.e., run) assignment, the method of GSI used, and the number of samples categorized by run type. All samples collected from unmarked fish. Samples included in the category "no results" for the confidence level of "all" were from carcasses with highly degraded DNA. Samples were collected from Battle Creek during the spring Chinook salmon immigration and spawning period in 2007-2010. Source: Newton and Brown (2010).

Confidence Level	Method	Spring Run	Fall Run	Late-Fall Run[a]	Winter Run	Other[b]	No Results	Total
All	HMSC16	139 (70%)	60	0	0		25	224
All	HMSC16+Cry6	149 (74%)	47	5	0		23	224
All	GAPS	166 (79%)	35		0	9	14	224
>90%	HMSC16	128 (74%)	46	0	0		50	224
>90%	HMSC16+Cry6	136 (77%)	40	1	0		47	224
>90%	GAPS	129 (92%)	7		0	4	84	224

[a] The run category of late-fall is not available using the GAPS technique.

[b] The category "other" is relevant only for the GAPS technique and represents samples classified as stock originating from hatcheries and rivers in the Pacific Northwest (i.e., outside Central Valley watersheds).

Table 9. Results of Chinook salmon Genetic Stock Identification (GSI) analyses including results summarized by confidence level in the stock (i.e., run) assignment, the method of GSI used, and the number of samples categorized by run type. All samples collected from unmarked fish. Samples included in the category "no results" for the confidence level of "all" were from carcasses with highly degraded DNA. Samples were a subset of those previously analyzed from 2001-2006 using an older GSI technique. This subset consisted only of samples that were previously categorized as non-spring run yet met the phenotypic spring Chinook baseline criteria (i.e., were collected in the CNFH upstream fish ladder fish trap after April 15 and generally before June 1. Source: Newton and Brown (2010)

Confidence Level	Method	Spring Run	Fall Run	Late-Fall Run[a]	Winter Run	Other[b]	No Results	Total
All	HMSC16	39 (33%)	81	0	0		0	120
All	HMSC16+Cry6	50 (42%)	66	2	0		2	120
All	GAPS	71 (61%)	40		0	6	3	120
>90%	HMSC16	25 (25%)	74	0	0		21	120
>90%	HMSC16+Cry6	35 (40%)	53	0	0		32	120
>90%	GAPS	51 (81%)	10		0	2	57	120

[a] The run category of late-fall is not available using the GAPS technique.

[b] The category "other" is relevant only for the GAPS technique and represents samples classified as stock originating from hatcheries and rivers in the Pacific Northwest (i.e., outside Central Valley watersheds).

Although more information is needed, results available from marked fish observations, tag recoveries and genetic analyses suggest some phenotypic spring Chinook reaching the restoration area are inconsistent with spring Chinook population objectives for Battle Creek. However, many (or most) of these non-target spring run phenotypes are thought to originate from Feather River Hatchery (which propagates a spring Chinook heavily introgressed with fall Chinook). Thus, the issue does not appear to be caused by CNFH operations.

The quantitative life cycle models (Appendixes D and E) were not used to assess the consequences of stray passage on stress from competition or limited holding habitat among adults.

The importance of issue number three for all BCRP target species is rated low based on the following rationale:

1. During the period of CNFH fall Chinook salmon broodstock collection, no marked or unmarked Chinook salmon are passed above the fish barrier weir into the restoration area.
2. During the period of late fall Chinook salmon and steelhead broodstock collection, only unmarked fish (and potentially marked winter Chinook originating from LSNFH) are passed above the fish barrier weir into the restoration area. Although it is possible some unmarked hatchery fall Chinook may be passed during this period, the number is unlikely to be large enough to cause stress from competition for limited holding and spawning habitat with BCRP target species.
3. Preventing the passage of marked hatchery origin late-fall and spring Chinook appears to be very effective during the period of trapping in the upstream fish ladder.

4. Although some hatchery origin *O. mykiss* and Chinook salmon appear to reach the restoration area during the period of video monitoring, observed numbers are unlikely to be large enough to cause stress from competition for limited holding or spawning habitat.

Although hatchery and non-target species reaching the restoration area are expected to have low importance during adult immigration and holding, impacts from genetic introgression may be greater and are considered in the spawning and egg incubation conceptual model section.

The understanding of the issue is rated medium for all target species and runs based on current efforts to mark hatchery-produced fish and the effectiveness of monitoring programs as described in USFWS reports. Understanding would be high if a larger fraction of fish passed into the restoration area (particularly fish passed during video monitoring) were regularly sampled for stock identification and if better genetic baseline information for Battle Creek spring Chinook were available.

4.2 Analysis of CNFH Issue Statement 4: Hatchery or natural-origin fall and late-fall Chinook salmon and hatchery *O. mykiss* may reach the restoration area during high flow events where they may have adverse effects on Battle Creek spring and winter Chinook salmon and *O. mykiss*.

All hatchery and natural-origin adult salmon and *O. mykiss* immigrating through lower Battle Creek encounter a fish barrier weir that redirects fish into a fish ladder system. In 2008, the USFWS working cooperatively with Reclamation, modified the CNFH fish barrier weir, and constructed a new fish ladder system on Battle Creek at the hatchery. Appendix A provides details about the fish barrier weir, fish ladders, and associated operations. For the purpose of this analysis, high flow events are deemed to occur when flows in Battle Creek exceed 800 cfs.

Null et al. (2010) reported on the effectiveness of the modified barrier weir throughout two seasons. Flows ranged from 199 to 1,380 cfs during the first season, and from 199 to 1,790 cfs during the second season. However, the study approach did not allow for effective observation of fish possibly defeating the weir at flows greater than 800 cfs. Thus, results from Null et al. (2010) are considered most applicable to flows less than 800 cfs and indeterminate for flows greater than 800 cfs. During the study reported by Null et al. (2010), five fish were observed escaping past the fish barrier weir; four escaped over the overshot gate and one jumped over the main portion of the barrier weir. The main section of the barrier weir was considered successful at blocking Chinook salmon from migrating upstream of the hatchery. The single fish that escaped past the main portion of the weir was likely an *O. mykiss*. Additional modifications have subsequently been made to prevent fish passage at the overshot gate during flows below 800 cfs (S. Hamelberg pers. comm.). At flows exceeding 4,500 cfs, the barrier weir is thought to prevent fish from passing directly over the weir. However, when water levels overflow the adjacent banks, passage may be possible by circumventing the weir (TAC Input).

A review of available information suggests:

- The barrier weir is effective at preventing fish passage and redirecting fish into the fish ladder system at flows up to 800 cfs, and is expected to be effective at flows up to approximately 4,500 cfs (or until overbank flows allow fish to circumvent the weir entirely). However, effectiveness of the barrier weir has not been tested at flows between 800 cfs and 4,500 cfs. Flows greater than 800 cfs are relatively common in Battle Creek, occurring in monthly averaged from February, March and May for nearly one third of years since 1985 (Figure 8). Shorter duration flows of greater than 800 cfs occur much more frequently than shown in Figure 8.

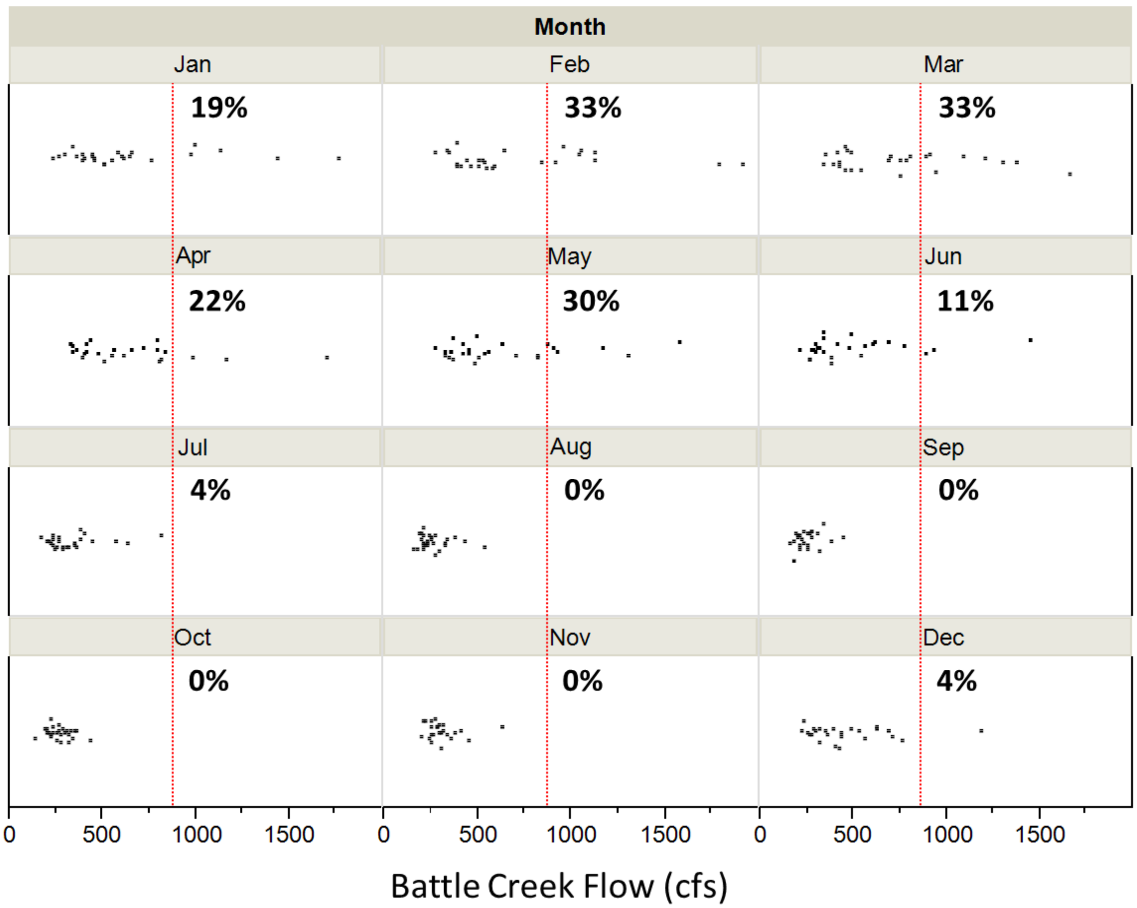


Figure 8. Monthly average flows in Battle Creek, 1985-2011. Red vertical line indicates flows of 800 cfs. Percentage values in each monthly graph indicate proportion of months in all years with average flows in excess of 800 cfs. Data from CDEC, station "BAT".

- At flows exceeding 4,500 cfs, the barrier weir is expected to create a velocity barrier that will inhibit but not necessarily prevent all fish passage. The effectiveness of the velocity barrier or of the fish ladder in attracting fish at flows greater than 4,500 cfs has not been tested. However, flows greater than 4,500 cfs are uncommon and have occurred on less than 2% of days between October 1961 through February 2013 (Figure 9), mostly between December and March. Late-fall Chinook, winter Chinook and *O. mykiss* would be expected to occur in Battle Creek during this period.

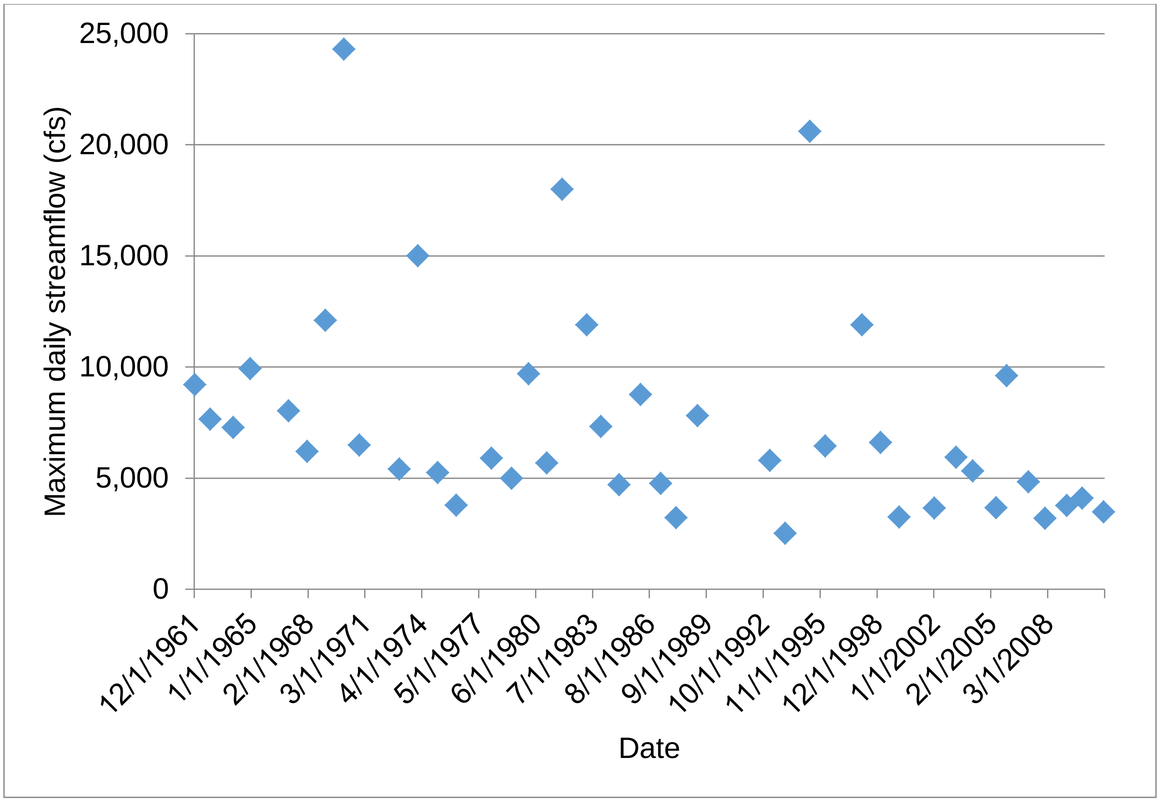


Figure 9. Dates maximum daily stream flow in Battle Creek exceeded 3,000 cfs for the period October 1961 through February 2013.

The quantitative life cycle models (Appendixes D and E) were not used to assess the consequences of high-flow strays on stress from competition or limited holding habitat among adults.

The importance of this issue is ranked low for all BCRP target species because under typical operating conditions no hatchery fish are expected to be able to defeat the weir. Higher flows may allow some passage of hatchery fish, but the numbers are likely to be relatively low, and thus unlikely to cause stress from competition for limited holding or spawning habitat.

Fish defeating the barrier weir and reaching the restoration area may cause adverse impacts from interspecific interactions during spawning and from genetic introgression, but these impacts are considered in the conceptual model for adult spawning and egg incubation.

The understanding of the issue is ranked low, due to the lack of data during flows >800 cfs.

4.3 Analysis of CNFH Issue Statement 5: Handling, sorting, and migratory delay due to operations within CNFH and the CNFH fish ladder may result in direct mortality or sub-lethal effects, which reduce reproductive success of natural-origin winter and spring Chinook salmon and *O. mykiss* trying to access the restoration area.

All anadromous salmonids immigrating into Battle Creek encounter the fish barrier weir. This weir provides important management functions, although it also has the potential to adversely affect fishes targeted for restoration. From October through mid-March, the hatchery fish ladder is operational and directs immigrating adults into CNFH for broodstock collection. The ladder into CNFH is open regularly (with intermittent closure to minimize crowding in hatchery) between October 1st and mid-November. Entrance to CNFH is continuous beginning in mid-December following a 10-day closure interval between fall and late-fall Chinook broodstock collection. Typically this temporary closure occurs in early to mid-December. During normal CNFH fish ladder operations, fish are provided continuous access to the hatchery ladder and the lower part of pond two. Access to pond three is controlled, and collected fish are routed into the spawning building using mechanical fish crowders. The spawning building includes a spawning and sorting facility, where fish are periodically handled, sorted, and identified as to origin. Natural-origin *O. mykiss*, late-fall Chinook, and winter Chinook salmon are passed upstream into the restoration area.

The USFWS (2011) reported that late fall and winter Chinook salmon (if and when present) collected from Battle Creek may reside in the hatchery holding ponds from one to seven days before initial sorting.

During the initial sorting process, natural-origin fish are measured, a tissue sample is collected, and then individuals are placed into a sorting tube that returns them directly to Battle Creek above the fish barrier weir. However, mortality may occur prior to any handling or sorting event. From 2002 through 2008, pre-sorting mortality of unmarked Chinook during late-fall Chinook broodstock collection has ranged from zero to 66 fish per year (0 to 54%) (USFWS 2011). Mortality also may occur after release. Total post-sorting mortality of marked late-fall Chinook salmon (including fish sorted and held for later spawning) ranged between 13.2% and 42.3% (mean 29.5%) for return years 2001 through 2008 (USFWS 2011). There is no equivalent data currently available for post-sorting mortality rates of unmarked late-fall or winter Chinook salmon, which may occur after sorting and release but before spawning, since these fish are not tracked after release into Battle Creek upstream of the weir.

O. mykiss also enter CNFH between October and February, and thus *O. mykiss* also reside in the hatchery holding ponds for one to seven days before initial sorting. *O. mykiss* generally arrive at the hatchery prior to being ready to spawn, and are in good physical condition. Pre-sorting mortality of *O. mykiss* averaged 1.2% from 2001 through 2012 (Table 10). Methods of sorting *O. mykiss* are similar to those used for late-fall and winter Chinook salmon and after the initial sorting, all unmarked *O. mykiss* are released upstream of the fish barrier weir.

After the broodstock collection period, the hatchery fish ladder is closed and immigrating adult fish are instead allowed to pass into upper Battle Creek through the upstream fish ladder at the fish barrier weir. Passage through the upstream fish ladder begins on March 15th and continues through July. Null et al. (2010) deployed radio tagged fish to examine fish behavior and potential migratory delays at the fish barrier weir. They reported the median time required for radio tagged fish to move upstream 0.5 miles to the barrier weir tailrace was 55.7 hr (hours). Once at the tailrace, the median and mean time required for fish to enter the fish ladder was 1.7 hr and 11.4 hr, respectively. The maximum amount of time to move from the tailrace into the fish ladder was 116.8 hr. The mean time was highly influenced by outliers and the authors indicated the median was a more robust and accurate measure of central tendency. Once inside the fish ladder, the median time required for salmon to ascend the "entrance ladder" (three baffles) was 0.1 hr. Null et al. (2010) found no evidence to suggest the barrier weir or fish ladders were causing injury to fish entering the restoration area. The rate of injury incurred near the barrier weir and fish ladder was low, observed injuries were minor, and could not be directly attributed to the barrier weir or fish ladders.

After fish have successfully ascended the entrance ladder, passage through the upstream fish ladder occurs in two ways. During the first period (beginning in March) all adult fish are trapped and examined for marks and tags. Newton and Stafford (2011) reported that during a contiguous eight-hour interval, the trap is checked every 30 minutes. This eight-hour interval is selected based upon the peak of diel immigration observed in previous studies (see Appendix A for more details). The trap is closed for the remaining 16 hours of the day, preventing upstream passage. During trap checks, fish are netted by hand for processing and data collection. Unmarked salmon and *O. mykiss* are passed upstream of the fish barrier weir. All marked Chinook salmon trapped during this period (other than LSFNH origin winter Chinook) are euthanized and CWT's removed and analyzed to determine fish origin and brood year.

Table 10. Observed injuries and mortalities of *O. mykiss* and Chinook salmon resulting from *in situ* fish trapping in the upstream fish ladder. (Data from M. Brown, USFWS, unpub. data.)

Year	Species	Injury	Mortality	Total Unclip	Comments	Percent Mort/Unclip
2001	RBT/STT	3	0	61	Observed injuries but may not be directly caused by trapping	0%
	CHN	1	2	31	Sampling caused mortality	6.0%
2002	RBT/STT	0	0	103		0%
	CHN	0	0	129		0%
2003	RBT/STT	0	1	63	Trap mortality	2.0%
	CHN	0	0	67		0%
2004	RBT/STT	0	0	62		0%
	CHN	1	0	63	Banged up	0%
2005	RBT/STT	0	0	44		0%
	CHN	0	0	26		0%
2006	RBT/STT	0	0	126		0%
	CHN	0	0	139		0%
2007	RBT/STT	0	2	76	Trap mortality	3.0%
	CHN	1	0	103	Banged up	0%
2008	RBT/STT	1	6	107	Trap/Sample mortality [a]	6.0%
	CHN	1	0	28	Wound observed on fish	0%
2009	RBT/STT	1	0	76		0%
	CHN	0	1	13	Trap mortality [b]	8.0%
2010	RBT/STT	1	0	78		0%
	CHN	1	0	8	Lesion observed on fish	0%
2011[c]	RBT/STT	N/A	N/A	N/A		N/A
	CHN	N/A	N/A	N/A		N/A
2012[d]	RBT/STT	0	0	25		0%
	CHN	0	0	0		0%
Total	RBT/STT	6	9	731		1.2%
	CHN	5	3	607		0.5%

[a] Occurred during the first sample of the season due to the high number of fish captured and a new procedure to accommodate construction of the new barrier weir fish ladder. Operational changes were made to avoid future mortalities.
[b] A Chinook jumped out of the trap and was found the next day. Modifications were made to prevent further incidents.
[c] All fish were processed in the spawning building, trap was not used.
[d] Fish were processed using both the spawning building and trap during the trapping period. Only fish passed at the trap are included.

The USFWS (M. Brown, USFWS, unpub. data) reported that observed direct mortality of unmarked salmonids due to handling and trap operations at the barrier weir has averaged 1.2% for *O. mykiss* and 0.5% for Chinook salmon (Table 10). Mortality or sub-lethal effects (e.g., reduced reproductive success associated with migratory delay, fall-back, stress and injury) may occur even after adult immigrants have successfully passed through the upstream fish ladder. Although no site-specific data are currently available to quantify those effects, studies do suggest trapping can induce a significant stress response in salmonids (Clements, et al. 2002). Spring Chinook, winter Chinook and *O. mykiss* are the species potentially impacted, given the timing of fish trapping operations.

To avoid thermal stress, trapping at the fish barrier ladder is discontinued when water temperatures exceed 60°F and the barrier weir is closed to fish passage for the day. Trapping is discontinued for the season when water temperatures exceed 60°F for a majority of the daily trapping operation. Thereafter fish are allowed free passage and video monitoring is implemented. Between 2001 and 2011, video monitoring in the upstream fish ladder has occurred for an average of 9.3 weeks (out of 22 available weeks between March 1st and the end of July). Video monitoring has occurred for as few as seven and for as many twelve weeks (Figure 3). Years with a greater number of video monitoring weeks (and therefore fewer trapping weeks) would potentially have reduced impacts from stress associated with trapping, but also would potentially allow a larger number of hatchery or non-target anadromous salmonids to reach the restoration area.

Direct mortality during the period of video monitoring at the fish barrier weir has not been observed and is thought to be very low (M. Brown pers. comm.). However, mortality or sub-lethal effects (e.g., reduced reproductive success associated with migratory delay, fall-back, stress and injury) may still occur as a result of the fish barrier weir during video monitoring. Data are not currently available to quantify these effects, but given the timing of video monitoring, spring Chinook salmon, and *O. mykiss* are the species that would potentially be affected.

The fish ladder system is closed during the months of August and September, and thus no access to the restoration area is available at this time. This closure of access to upper Battle Creek might be expected to contribute to direct mortality or sub-lethal effects. However, no BCRP target species are expected to immigrate into Battle Creek during August and September, and thus adverse effects should not occur.

Analysis of available information and likely impacts suggests:

- BCRP target species of natural-origin late-fall Chinook, winter Chinook salmon, and *O. mykiss* passing through either the CNFH collection facilities or the *in situ* fish trap used in the upstream fish ladder are exposed to some risk of mortality, migratory delay, stress or other sub-lethal effects. Available data show direct mortality does occurs.
- For natural-origin late fall Chinook, pre-sorting mortality in CNFH has reportedly been as high as 54%.
- Data on direct mortality rates of winter Chinook in CNFH are unavailable, due to the current absence of winter Chinook in Battle Creek. Trapping of winter Chinook adults at the Keswick Dam fish trap provides one example, and resulted in an average of 8% direct mortality between 2000 and 2008 (USFWS 2011). Based on historical fish passage counts at the Red Bluff Diversion Dam, 17% of the annual winter Chinook run might be expected to reach the fish barrier weir before March 1st (during the earlier period of CNFH broodstock collection). Thus, there is some potential for CNFH broodstock collection to adversely affect the Battle Creek winter Chinook population.
- For natural-origin *O. mykiss* pre-sorting mortality has averaged 2.9%.
- No data are currently available for any BCRP target species on post-release mortality or reduced reproductive success, which may result from handling and processing during broodstock collection at CNFH.

- Direct mortality associated with trapping in the upstream fish ladder has averaged between 0.5 and 1.2% for Chinook salmon and *O. mykiss* respectively. However, there are no data on delayed mortality or reduced reproductive success, which may result from trapping activities in the upstream fish ladder.
- Adverse impacts due to video monitoring and due to upstream passage closure (August-September) are likely to be very low for BCRP target species.

Quantitative Chinook life cycle model analysis (Appendix D) for issue five estimated low (<5%) population effects, except for the effect of CNFH handling on late fall Chinook which was high (20.9%). However, the modeling results are substantially limited by inadequate information regarding indirect mortality and sub-lethal effects.

Overall, the importance of issue five for late-fall Chinook is rated high, and medium for *O. mykiss* and winter Chinook. Qualitative factors supporting these rankings for *O. mykiss,* winter Chinook and late-fall Chinook include the following: (1) the holding period at CNFH may result in up to a seven day delay from initial sorting to release, (2) mortality within CNFH during broodstock sorting collection can be high, and (3) delayed mortality and impacts to reproductive success after release are unknown, but potentially substantial given the small size of the natural populations. The importance of this issue for spring Chinook salmon is rated low because: (1) spring Chinook salmon are not brought into CNFH, and (2) the run either passes during fish ladder trapping or during video monitoring both expected to cause minimal stress or mortality relative to CNFH effects.

Understanding is low for all BCRP target species and runs because insufficient data are available to quantitatively assess post-release mortality rates (particularly the effects from CNFH broodstock collection), and sub-lethal effects resulting from CNFH operations and trapping in the fish ladder system.

4.4 Analysis of CNFH Issue Statement 6: Pathogens resulting from CNFH operations may be transmitted to wild fish in the restoration area.

The Technical Review Panel (2004) evaluating the compatibility of CNFH with the BCRP stated,

> *Crowding and stress associated with large numbers of returning hatchery adults results in optimal conditions for transmission of infectious hematopoietic necrosis virus (IHNV), and may also increase the presence of other primary or secondary pathogens. Wild adult salmon, including spring and winter Chinook, may thus encounter pathogens at doses and durations of exposure above those anticipated in a system without artificial impoundment of adult salmon. Transmission of IHNV from late-fall Chinook adults to sac fry and fry (the most susceptible life stages) of natural-origin steelhead and spring Chinook salmon may represent a potential negative impact to the survival of juveniles emigrating from the Battle Creek watershed. Another potential source of pathogen amplification that could affect restoration efforts is hatchery effluent water from production lots of salmon and steelhead.*

The health of fish reared at CNFH is routinely monitored by CNFH personnel and fish pathologist from the California/Nevada Fish Health Center located at CNFH. Monitoring protocols follow the USFWS Aquatic Animal Health Policy (USFWS 2004). This policy includes a chapter from the American Fisheries Society's "Fish Health Blue Book" (Thoesen 1994), entitled *Standard Procedures for Aquatic Animal Health Hatchery Inspections*, which describes procedures and protocols for conducting fish health inspections at anadromous fish hatcheries.

Spawning of BCRP target species and egg incubation occurs in Battle Creek upstream from CNFH. As such, transmission of any diseases from hatchery-origin salmonids during spawning could possibly occur if: (1) infected hatchery-origin salmonids reached the restoration area; or (2) natural-origin salmonids become infected as they are processed through the hatchery during broodstock collection, and are subsequently released upstream (or downstream for fall Chinook).

Current efforts to prevent fall Chinook salmon from entering upper Battle Creek and the low numbers of other species in the restoration area suggests factors contributing to disease outbreak (i.e., crowding and stress) are not problems in upper Battle Creek. However, large numbers of adult fall Chinook salmon are often present in lower Battle Creek downstream of the fish barrier weir, creating conditions that might amplify transmission of diseases and pathogens to late-fall Chinook salmon and *O. mykiss* passing through lower Battler Creek.

Both natural and hatchery origin salmonids are subjected to similar pathogen transmission opportunities during upstream migration and during broodstock holding and sorting. Water used in the CNFH adult holding facilities comes from Battle Creek and is not passed through the hatchery filtering or ozone treatment facilities. Use of treated water would not reduce or eliminate opportunities for pathogen transmission between hatchery and natural-origin salmonids during the holding and sorting process.

A number of diseases (bacterial, viral, and parasitic pathogens) are present among Central Valley salmonid populations. The characteristics of these diseases and an assessment of how they may transmit from hatchery to natural-origin salmonids are briefly discussed below:

- <u>Infectious Hematopoietic Necrosis Virus (IHNV)</u>

Wolf (1988) reported that IHNV is virtually endemic to all watersheds in North America that support salmonid populations, and is endemic to Chinook salmon populations in several major rivers in Northern California including the Sacramento, San Joaquin, and Feather rivers. Foott et al. (2000) reported that transmission of IHNV to wild or natural Chinook salmon populations in the Sacramento River system from infected hatchery fish is a concern for resource managers. Both hatchery- and natural-origin adult Chinook salmon and steelhead carry IHNV. The pathogen is routinely isolated from adult stocks returning to state and federal hatcheries in the Sacramento basin and routinely recovered from wild spawning salmonids with no clinical signs of IHNV (Mulcahy et al 1983, 1987, LaPatra et al. 1991a; and Meyers1998 as cited in True 2004).

IHNV was a significant Chinook salmon disease problem at CNFH since the hatchery began operations in the 1940's (Ross et al. 1960). Prior to 2000, IHNV epizootics were common in the fall Chinook salmon production at CNFH, with high mortality and subsequent release of large numbers of IHNV exposed juveniles (True 2004).

Foott et al. (2000) exposed natural-origin Chinook salmon to IHNV to simulate brief and "worst case" natural fish contacts with a massive hatchery release of infected fish. He reported that the inability to detect the virus in exposed natural fish, regardless of their duration of exposure, or post-exposure stress indicated a low ecological risk to natural populations if infected hatchery fish are released into the Sacramento River. Foott et al. (2006) also indicated that since operation of the CNFH ozone water treatment plant (circa 2000) the virus has not been detected in any production fish at the hatchery. (Appendix A provides more details on the CNFH ozone water treatment plant.) Given this information, IHNV seems to present little risk of problematic disease transfer between hatchery and wild origin salmonids during spawning in the restoration area.

- <u>Infectious Pancreatic Necrosis Virus (IPNV)</u>

IPNV is a severe viral disease of salmonid fish that affects young salmonids, although adult fish may carry the virus without showing symptoms. It is highly contagious and found worldwide; however it has been eradicated or greatly reduced in some areas. IPNV has not been isolated in California for over three decades and has never been detected at CNFH (S. Foott, pers. comm.). As such, IPNV is not considered a risk for problematic disease transfer between hatchery and wild origin salmonids during spawning in upper Battle Creek.

- <u>Furunculosis</u>

This disease has been identified in salmonids since 1894 and is caused by the bacteria *Aeromonas salmonicida.* It may cause severe mortality in hatchery fish, but is not an invasive pathogen. Infections only occur when the pathogen is ingested or has ready access to fish through external injuries (Warren 1991). Furunculosis appears to present little risk of problematic disease transfer between hatchery and wild origin salmonids during spawning in upper Battle Creek.

- <u>Enteric Redmouth Mouth (ERM)</u>

This disease is caused by the enteric bacteria *Yersinia ruckeri* and restricted to *O. mykiss*. ERM is particularly associated with intensive fish culture and poor water quality. Fish appear able to withstand exposure to large numbers of bacteria without developing disease in the absence of stress. Warren (1983) reported that there were no known outbreaks of ERM in wild fish. ERM appears to present little risk of problematic disease transfer between hatchery and wild origin salmonids during spawning in upper Battle Creek.

- <u>Bacterial Kidney Disease (BKD)</u>

BKD is caused by the bacteria *Renibacterium salmoninarum* and may cause severe losses in juvenile trout and salmon reared in Pacific Northwest fish hatcheries. It has not been reported to be a major problem in California hatcheries (Leitritz and Lewis 1976). BKD can be transmitted from fish to fish (horizontal transmission) and with the sexual products among parents and to their progeny (vertical transmission). *O. mykiss* are more resistant to BKD than other salmon species, although Foott (1992) did find high incidence of BKD in wild steelhead populations in the Trinity River. Among CNFH stocks, adult late fall Chinook tend to have the highest prevalence of BKD infection, but no CNFH juveniles with BKD since 1990 (S. Foott, pers. comm). This disease is subtle, because juvenile salmon or steelhead may survive well into their journey downstream, but are unable to make appropriate changes in kidney function for a successful transition to seawater (Foott, 1992). Stress during migration also may cause this disease to flare up (Schreck, 1987). BKD could present a risk of problematic disease transfer between hatchery and wild origin salmonids during spawning in upper Battle Creek, although the severity is unknown.

- Whirling Disease (WD)

Myxobolus cerebralis is the causative agent of whirling disease (Modin 1998). It has become widely established in wild California salmonid populations since its initial discovery in Monterey County in 1965 (Bartholomew and Reno 2002). *O. mykiss* from the South Fork of Battle Creek have been found to be infected with *M. cerebralis* (Horsch 1987), and the disease may be transmitted to both *O. mykiss* and steelhead (Densmore et al 2001). Past infrastructure investments and internal processes to address fish health issues and hatchery water quality suggest the issue of WD pathogen transmission from CNFH produced salmonids to natural-origin spawning salmonids and egg incubating in Battle Creek is low.

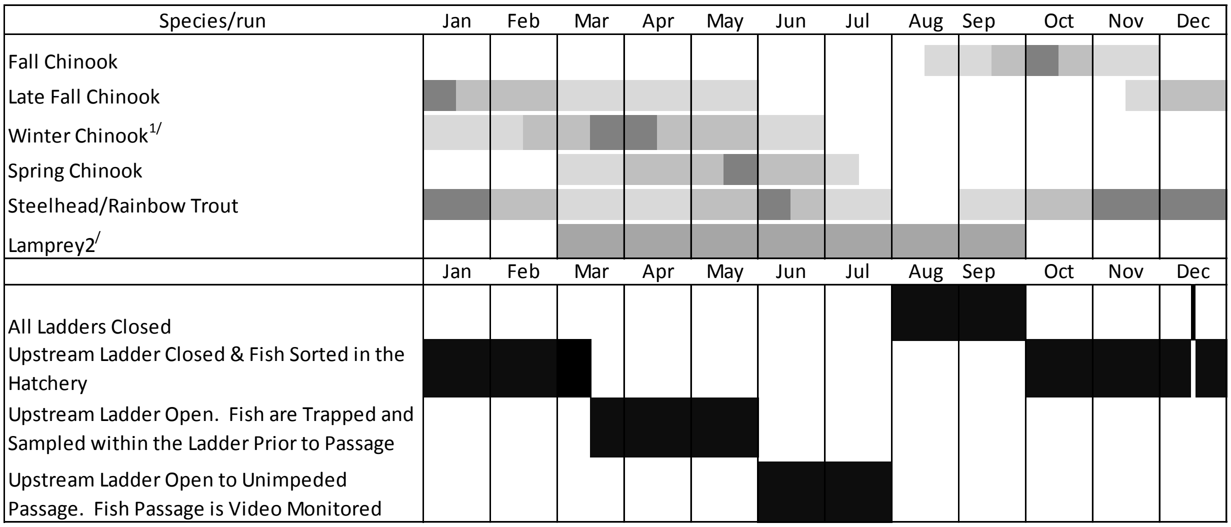
Overall, there are reduced opportunities for disease outbreak and transfer from CNFH and its production due to infrastructure and operational improvements, particularly the treatment of all water used for egg incubation and juvenile rearing. The importance of this issue is rated low due to the very low incidence of CNFH-mediated diseases in the system. Understanding is rated high based on historical information and studies of diseases and pathogens associated with CNFH fish production, and studies from other similar Central Valley rivers.

Importance for fall Chinook is NA (not applicable) because fall Chinook are not currently targeted for recovery in the restoration area and therefore cannot be adversely affected by disease transfer into the BCRP area.

4.5 Analysis of CNFH Issue Statement 7: In-stream flows in Battle Creek are reduced by CNFH water diversion(s) between the diversion site(s) downstream to the site of discharge from the hatchery (distance of 1.2 to 1.6 miles depending on location of the water intake). These diversions may result in inadequate in-stream flows or increased water temperatures in this segment of Battle Creek during drought conditions and in association with operations at upstream hydropower facilities.

Adult anadromous fish immigrate into Battle Creek during most months of the year and time of entry varies by species and run (Table 11). Adult salmonids have free passage (via fish ladders) past the fish barrier weir after the termination of *in situ* trapping (April to May) through the end of July.

Table 11. Probable adult migration period of anadromous salmonids stocks in Battle Creek, and CNFH barrier weir fish ladder operational status. Density of shading indicates intensity of run timing at the barrier weir. Darker shading indicates higher intensity. (Table provided by K. Niemela, USFWS).



1/ Winter Chinook migration timing is speculative in Battle Creek. Information presented is based on historic run timing in the Sacramento River past Red Bluff Diversion Dam.

2/ Bar racks in place to preclude salmonid movement during August and September do not impede lamprey movement through the ladder.

Minimum flows are required to provide for the immigration of adult anadromous salmonids in Battle Creek. Minimum releases from Eagle Canyon and Inskip dams will be 35 cfs and 40 cfs, respectively, from May through November, and 46 and 86 cfs the remainder of the year, except 61 cfs in the South Fork in April (Jones and Stokes 2005c, USFWS 2011). These minimum releases, combined with additional accretion flows (approximately 5 to 10 cfs) from small feeder streams (Payne and Associates 1998), are estimated to yield a minimum monthly flow in Battle Creek upstream of the Coleman Powerhouse tailrace of approximately 80 cfs. Battle Creek flows upstream from the Coleman Power House coupled with releases from Coleman Power House (including the CNFH diversion range) result in monthly average flows ranging from a low of 260 cfs during September to a high of 742 cfs during January (Figure 10).

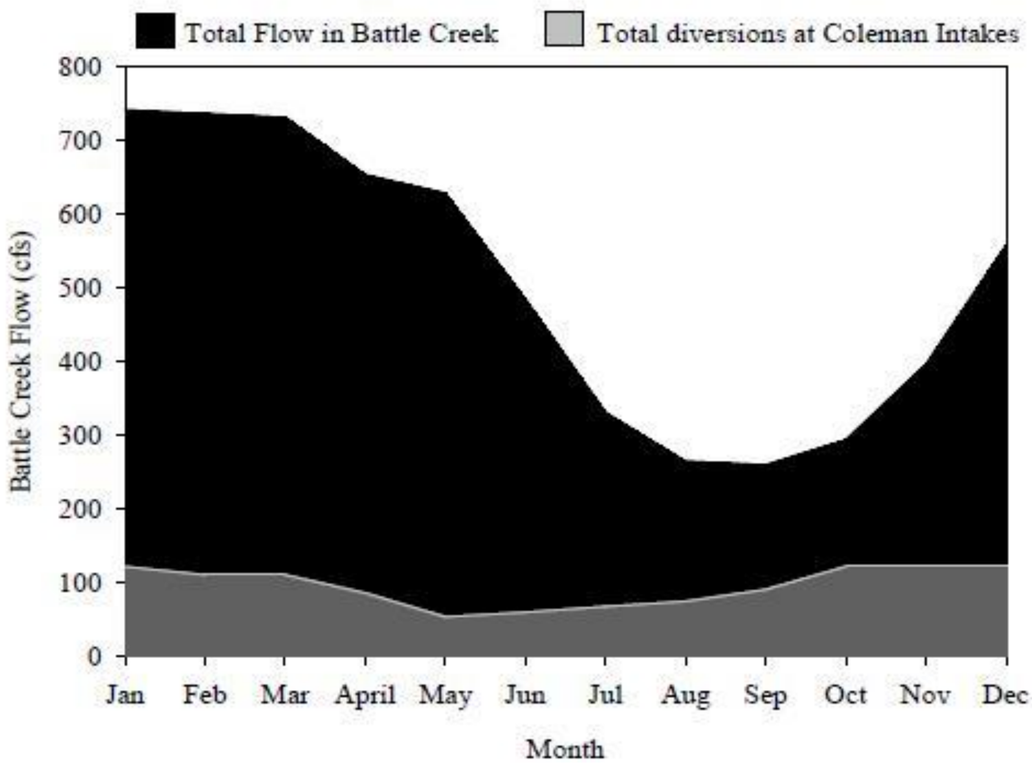


Figure 10. Annual average hydrograph for Battle Creek and expected diversions at CNFH. Total diversion for the hatchery includes approximately 13 cfs delivered to downstream water users. Monthly flow averages are based on data for Battle Creek from 1961 through 2008 (Figure from USFWS 2011).

Changes in operation of upstream power facilities and CNFH diversions affect the amount of water in Battle Creek. Stream flows also determine water depths and a minimum water depth of 9.5 and 7.0 inches is recommended to provide adequate transportation depths for immigrating adult Chinook salmon and *O. mykiss* respectively (Thompson 1972 as cited in Bjornn and Reiser 1991). A minimum depth related to stream flow was not addressed using quantitative in-stream flow studies in either planning documents for the BCRP (Payne and Associates1998) or the biological assessment of the CNFH (USFWS 2011). As such, it is unclear what minimum flow releases are necessary to provide for adult fish transportation depths during low flow periods.

The USFWS (2011) indicated that emergency low flow situations due to PG&E operations would not result in complete dewatering of the channel and a corridor would remain open for immigration of adult salmonids in the hatchery-affected section of Battle Creek.

Emergency outages because of PG&E operations have been reported from Battle Creek hydropower facilities causing unplanned interruptions in water flow from the Coleman tailrace. Under these circumstances, the Coleman tailrace empties, and no water is available for Intake One, or for return to Battle Creek downstream of Coleman Powerhouse. When Intake One is not available Intake Two automatically opens (Intake Three may also be used), supplying CNFH with water for hatchery operations. When this happens, water from the Coleman Canal overfills the Coleman Forebay (this takes approximately 45 minutes to 1 hour), eventually spills over the side of the canal, and cascades down the hillside into Battle Creek. Depending on the time of year, CNFH water requirements, and PG&E hydropower diversions, interruptions of flow through the Coleman tailrace could reduce flows in the 1.6-mile hatchery affected section of Battle Creek.

USFWS (2011) suggested several factors would ameliorate this issue:

- Water within the penstocks and Coleman Powerhouse would continue to drain through the tailrace, so the Coleman tailrace would not drain immediately.
- Coleman Forebay fills and overflows relatively quickly (usually less than 1 hour), the location of the Forebay ensures that overflow water returns to Battle Creek above the hatchery intakes, and water withdrawals from hatchery diversions should not decrease Battle Creek flows below the recommended levels for very long (probably less than an hour).
- Hatchery intakes cannot divert all of the water in Battle Creek, even at low flows, because of design constraints.

Payne and Associates (1998) and Ward and Kier (1999a) provided specific information about generating estimated minimum flows for Battle Creek. Habitat index (expressed in terms of weighted usable area, or WUA) were related to discharge throughout the Battle Creek system. Weighted usable area is defined as the wetted area of a stream weighted by its suitability for use by species and life stage (Stalnaker et al. 1995). The USFWS (2011) reported that drought conditions might result in flows below recommended minimum levels in the hatchery-affected section of Battle Creek. They reported that between October 1961 and March 2011, average daily flows in Battle Creek (minimum recommended stream flows and CNFH water requirements) were <100% of the weighted usable area (WUA) 3.05% of the time, and <95% of the WUA 0.93% of the time (Table 12). Months when flows were <95% of the WUA were largely consistent with periods of drought (late-1970s, late-1980s, and early-1990s).

Table 12. Number of days and percentage of time minimum stream flows would not be met in the 1.6-mile hatchery-affected section of Battle Creek (Data based on 17,943 days of USGS records from October 1961 to March 2011 (from USFWS 2011).

	Days and percentage of time minimum stream flows would not meet weighted useable area criteria for the period October 1961 to March 2011.			
Month	**Days <100% WUA 1/**		**Days <95% WUA**	
January	114	(0.60%)	33	(0.18%)
February	0	--	12	(0.07%)
September	50	(0.28%)	0	(0.00%)
October	102	(0.57%)	28	(0.16%)
December	216	(1.20%)	94	(0.52%)
All other months	65	(0.36%)	0	(0.00%)
Total	**547**	**(3.05%)**	**167**	**(0.93%)**

1/ Number in parenthesis is percentage of total days.

Multi-species reviews indicate that river flow, water temperature, photoperiod, and turbidity can all affect the timing and speed of upstream fish movements (Banks 1969, and Jonsson 1991 as cited in Keefer et al. 2004). Water temperatures during the months of July and August exceed 70ºF in most years in lower Battle Creek (Figure 11). However, it is unclear how temperatures are affected by the upstream CNFH diversion. Water temperatures in Battle Creek near and above the Coleman Powerhouse tailrace appear to be marginal for salmonids during the summer months. Limited data (one year and not the same year as for other data sites) suggest water temperatures in the Coleman Powerhouse tailrace exceed 70° F during the summer. The CNFH primary water diversion is from the tailrace, and summer water temperatures at CNFH are not detrimental for juvenile fish rearing (USFWS 2011).

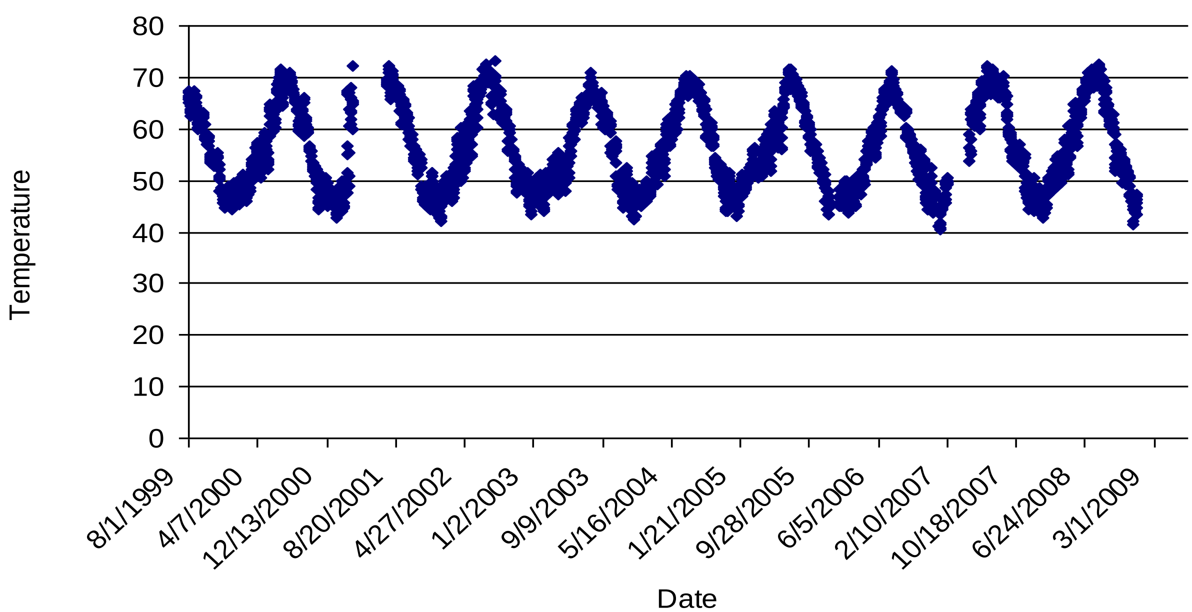


Figure 11. Daily water temperatures in lower Battle Creek, 1998 through 2008.

CNFH diversions reduce the volume of water in Battle Creek between the point of diversion and the hatchery outfall. However, a comparison of in-stream water temperatures above and below the hatchery does not indicate an appreciable increase in water temperatures. Based on the available data, it does not appear that reducing CNFH water diversions during the summer would provide a major reduction in Battle Creek water temperatures in the 1.6 mile hatchery affected section or further downstream.

A more complete water temperature monitoring network could address this issue. The impacts of high water temperatures on adult salmonid immigration in Battle Creek is unknown, although adult Chinook salmon have been identified passing the fish barrier weir during the summer months (Brown and Alston 2007, Alston et al 2007, Newton et al 2007a, Newton et al 2007b, Newton et al 2008, Stafford and Newton 2010, and Newton and Stafford 2011, Bottaro and Brown 2012) (Figure 7).

Results of these analyses suggest:

- During extreme drought conditions, water withdrawals from hatchery diversions could decrease stream flows below the diversions (a 1.6-mile segment of Battle Creek). At these times, flows would be below the 95% weighted usable area.
- It is uncertain if flows in the 1.6-mile hatchery affected reach of Battle Creek are sufficient for fish migration during drought periods. The greatest potential effect would be on spring Chinook migrating in early summer (Figure 7).
- CNFH has the ability to make operational changes during drought periods to maximize compatibility between in-stream flows that encourage and facilitate fish passage, but still allow hatchery operations. For example, USFWS (2011) suggested water from the hatchery raceways could be reused in the adult holding ponds from October through February. This operational change would reduce CNFH water requirements by approximately 22 cfs with minimal risks to the propagation programs. Based on the flow data from 1961 through 2011, this change would reduce the failure to meet the 95% weighted usable from 0.9% to 0.3%. However, in-stream flow diagnostic studies may produce alternative minimum flow recommendations, which could change the influence of the hatchery raceway re-operations.
- High water temperatures in lower Battle Creek have the potential to affect adult spring Chinook salmon entering in June or July. However, it is unclear if current late summer water temperatures are influenced by CNFH operations, or if changes in operations could influence fish immigration into Battle Creek.

The importance of this issue for all BCRP target species is rated low because:

1. Late-fall and winter Chinook salmon, and *O. mykiss* immigrate into Battle Creek during periods in which the amount and quality of stream flows are not adverse factors.
2. Spring Chinook salmon can immigrate during early summer when they might be affected; however, recorded water temperatures have not been found to be harmful, and increases in water temperature may not be related to CNFH operations. Battle Creek discharge necessary for successful immigration of adult spring Chinook is not well understood, but does not appear problematic (R. Null, pers. comm.). There is no

information available to suggest reduced flows are an impediment to successful immigration of spring Chinook salmon.

Understanding is rated high for all BCRP target species except spring Chinook salmon, based on known immigration timing. Understanding for spring Chinook salmon is rated medium based on remaining uncertainties regarding what constitutes minimum stream flows during dry years necessary to support immigration of adult salmonids.

4.6 Analysis of BCRP Issue Statement C: Natural and man-made barriers may not be sufficiently passable to support BCRP salmonid population objectives

Removing barriers and providing fish passage at hydroelectric facilities was a central element of the Battle Creek Restoration Project. Consultation with the TAC indicated uncertainty regarding the ability of adult fish to pass above many natural barriers within the BCRP area. We incorporated this natural barrier information into the quantitative life cycle model to assess effects on anadromous fish populations. Results showed that natural barrier passage in South and North Battle Creek had the largest observed influence of any issue on the equilibrium abundance of spring and winter Chinook (Appendix D) and steelhead (Appendix E).

BCRP Issue Statement C was determined to have high importance and medium understanding for spring Chinook, winter Chinook and steelhead. Importance to late fall Chinook was determined to be low because late fall are expected to occur primarily in portions of Battle Creek unaffected by natural barriers. BCRP IS-C is not applicable to fall Chinook which only occur in lower Battle Creek. While there is little uncertainty regarding the importance of habitat accessibility within Battle Creek, the medium understanding is appropriate because insufficient data is currently available to assess actual fish passage at these natural barriers. Furthermore, LCM outcomes are based upon expected fish distributions, water temperatures, flows and fish capacities. These inputs and model results have not in most cases been verified by empirical observations. In many cases, empirical observations will not be possible until BCRP implementation is complete.

Table 13. Collective ratings of importance and understanding of issue affecting adult immigration of BCRP target stocks (L = low, M = medium, H = high).

		Battle Creek restoration area anadromous salmonid stocks 1/				
Issue Statement		**SH**	**SC**	**FC**	**LFC**	**WC**
CNFH IS-3 – Current operations at CNFH and at the fish barrier weir cannot always identify and prevent passage of: (1) hatchery origin salmonids, and (2) non-target runs of Chinook salmon.	Importance	L	L	NA	L	L
	Understanding	M	M	NA	M	M
CNFH IS-4 – Fall Chinook (hatchery or wild), late fall Chinook (hatchery or wild) and hatchery *O. mykiss* may reach the restoration area during high flow events where they may have adverse effects on Battle Creek *O. mykiss*, spring run and winter Chinook.	Importance	L	L	NA	L	L
	Understanding	L	L	NA	L	L
CNFH IS-5 – Handling, sorting, and migratory delay due to operations within CNFH and the CNFH fish ladder may result in direct mortality or sub-lethal effects to natural-origin winter Chinook, late fall Chinook, spring Chinook and *O. mykiss* trying to access the restoration area.	Importance	M	L	NA	H	M
	Understanding	L	L	NA	L	L
CNFH IS-6 - Pathogens resulting from CNFH operations may be transmitted to wild fish in the restoration area.	Importance	L	L	NA	L	L
	Understanding	H	H	NA	H	H
CNFH IS-7 – Instream flows in upper Battle Creek are reduced by CNFH water diversion(s) between the diversion site(s) downstream to the return effluent site (distance of 1.2 to 1.6 miles depending on location of the water intake). These diversions may result in inadequate in-stream flows or increased water temperatures in this segment of the river during drought conditions and in association with operations at upstream hydropower facilities.	Importance	L	L	L	L	L
	Understanding	H	M	H	H	H
BCRP IS-C – Natural and man-made barriers may not be sufficiently passable to support BCRP salmonid population objectives.	Importance	H	H	NA	L	H
	Understanding	M	M	NA	M	M
1/ SH = *O. mykiss*, SC = spring Chinook salmon, FC = fall Chinook salmon, LFC = late fall Chinook salmon, WC = winter Chinook salmon						

The issue analyses presented above and the associated assessments of importance and understanding support a revised conceptual model of the factors affecting adult salmonid immigration through Battle Creek (Figure 12). BCRP issue C is estimated to be of high importance. CNFH issue five and six are estimated to be of medium importance. All other issues are estimated to be of low importance.

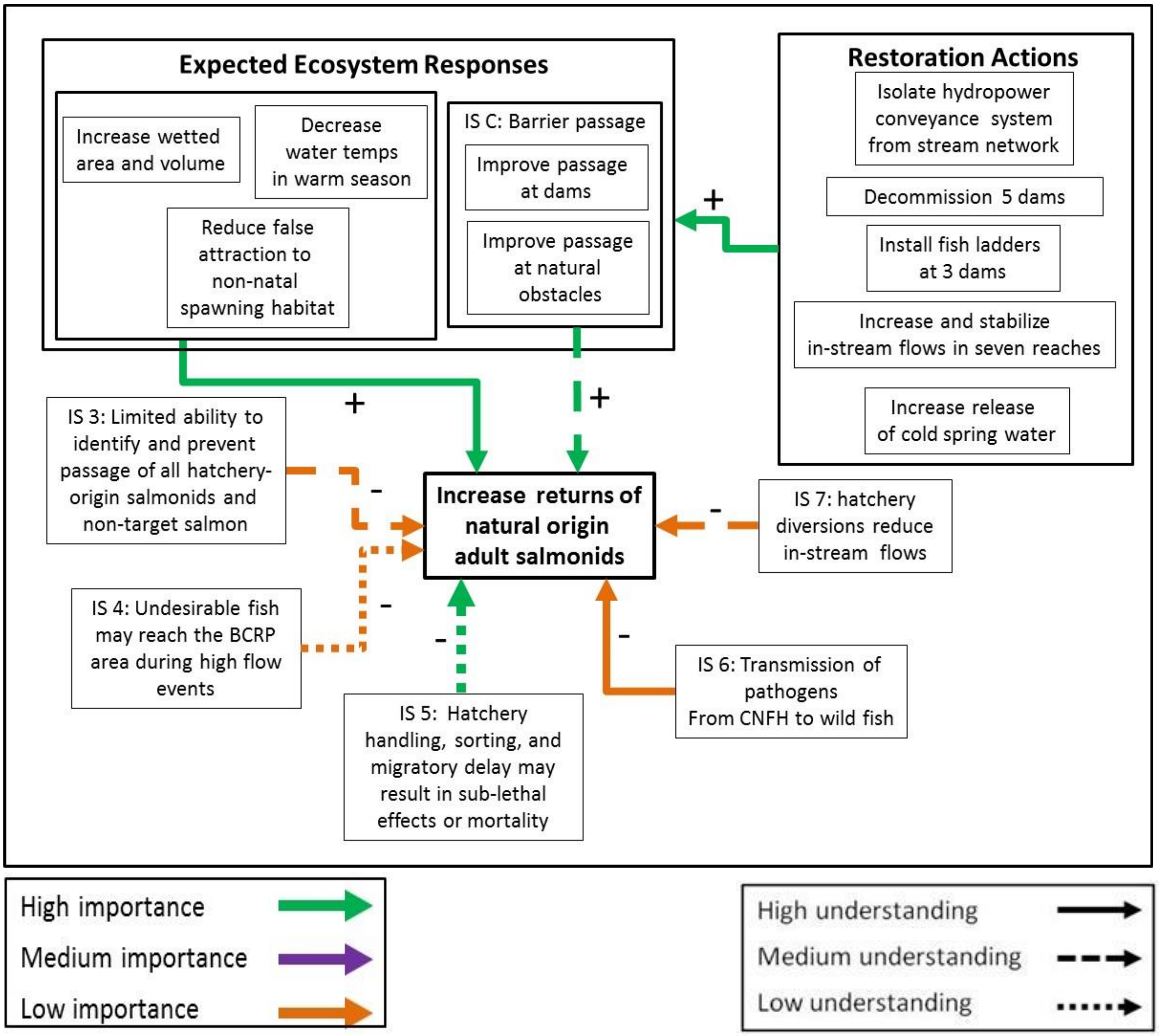


Figure 12. Revised conceptual model diagram of factors affecting the immigration of adult salmonids through Battle Creek. This diagram includes the six issues analyzed under this life-stage event. Variations in arrow color and line-type are used to indicate importance and understanding based on the issue analyses. Definitions for the different arrows are provided in the legends below the diagram. The highest level of importance and lowest level of understanding are indicated for an issue in cases where these factors vary among the fish stocks (see Table 13 for details).

5. Spawning and Egg Incubation of Natural-origin Salmonids in Battle Creek

Conceptual Model and Issue Analysis

This conceptual model focuses on factors that affect natural-origin salmonid spawning and egg incubation in Battle Creek (Figure 13). Battle Creek restoration actions relevant to this life-stage event aim to positively affect the ability of adult salmonids to reach suitable spawning habitat, increase the quantity and quality of spawning habitat, and improve conditions for egg incubation. Terraqua (2004) identified six hypotheses to describe the cause and effect relationships between the restoration actions (drivers), and the expected ecosystem responses (intermediate outcomes). Specifically, the hypotheses state that implementation of in-stream flow levels and facilities modifications specified in the BCRP description, implementation of the BCRP facilities monitoring plan, and implementation of any adaptive responses affecting in-stream flows or hydroelectric project facilities will:

1. Ensure that juvenile salmon and steelhead production is within the expected level given the number of spawning adults and relevant ecological factors.
2. Provide at least 95% of maximum usable habitat quantity for critical life stages among priority species.
3. Provide in-stream water temperatures that are suitable for critical life stages among species at appropriate stream reaches.
4. Ensure water discharges from the powerhouse tailrace connectors or water conveyance system are confined to times and amounts that avoid false attraction.
5. Ensure that variations in flow regimes, following forced or scheduled outages where the available diversion flow has been released to the natural stream channel, do not strand salmon and steelhead or isolate them from their habitat when diversions are resumed.
6. Ensure natural in-stream barriers do not impede upstream migration of adult salmon and steelhead at prescribed flows and normal wet season flow regimes.
7. Ensure unimpeded passage of adult salmon and steelhead at fish ladders relative to contemporary standards/guidelines.

Sustained improvements in the habitat conditions and ecosystem responses are expected to positively affect the terminal outcome: increased spawning success and egg survival.

Four issues directly related to CNFH programs and three BCRP issues may have the potential to affect adult spawning and egg incubation in Battle Creek (Figure 13). Information related to each issue is analyzed to estimate the importance and understanding of the issue's influence on the terminal outcome. Collective ratings of importance and understanding are presented at the end of this section (Table 15). A revised conceptual model diagram incorporating results from the issue analyses also is presented at the end of this section (Figure 14).

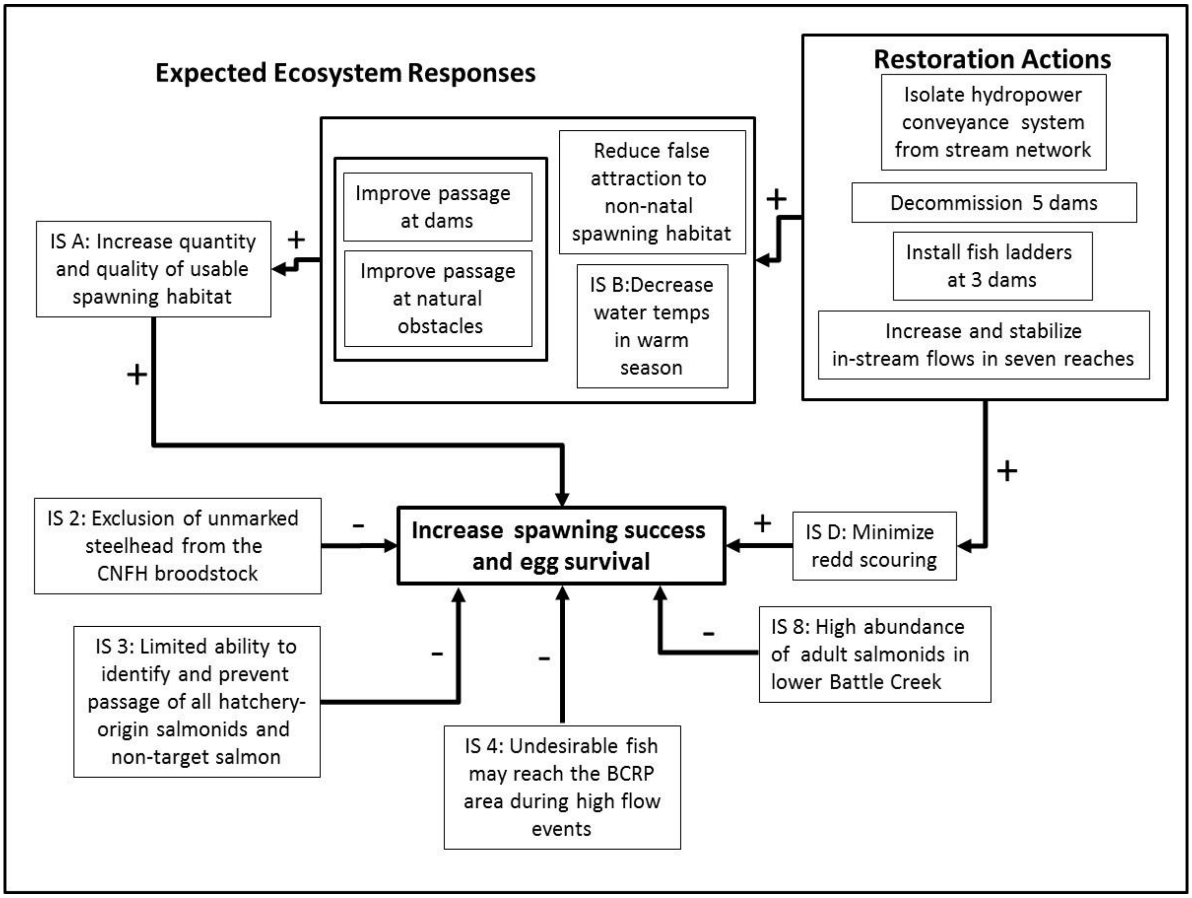


Figure 13. Conceptual model diagram of factors affecting natural-origin salmonid spawning and egg incubation in Battle Creek. Levels of importance and understanding are not shown in this diagram.

5.1 Analysis of CNFH Issue Statement 2: The current CNFH steelhead program excludes naturally produced (unmarked) fish from the broodstock. This practice leads to continued domestication and potential for reduced fitness when hatchery fish spawn in the restoration area.

Fish propagation can lead to domestication (e.g. Reisenbichler et al 2004) whereby characteristics advantageous to a hatchery environment are selected over characteristics advantageous in a natural environment (Harada et al 1998). The California Hatchery Scientific Review Group (HSRG 2012) recognized that the negative consequences of hatchery fish interbreeding with natural-origin fish are exacerbated when hatchery fish are more genetically divergent. Incorporating natural-origin fish into the hatchery broodstock decreases genetic divergence between hatchery and natural populations (Reisenbichler and McIntyre 1986, Lichatowich and McIntyre 1987, Cuenco et al. 1993 as cited in HSRG 2012), and thereby reduces adverse impacts when interbreeding occurs in the natural environment. (The effects of hatchery introgression are evaluated in the analysis of issue statements 3 and 4.)

Steelhead broodstock for CNFH are collected concurrently with fall and late-fall Chinook salmon from October through February. Since 2009, all natural-origin steelhead (or *O. mykiss*) encountered during broodstock collection are released upstream of the fish barrier weir and are not used for CNFH broodstock. (Appendix A provides more details about the CNFH steelhead propagation program.) Under present operations, hatchery-origin steelhead have been able to pass above the fish barrier weir into upper Battle Creek during the period of video monitoring (~May through July; Table 3). This situation is likely to continue if present operations continue unchanged.

The HSRG (2012) recommended the incorporation of natural-origin fish into hatchery broodstock in the highest proportion possible based on work by Harada et al. (1998). Incorporating at least 10% natural-origin fish into the broodstock (pNOB) is considered a minimum guideline to reduce the divergence of hatchery and natural-origin components of integrated populations. However, this recommendation assumes the hatchery program is already properly integrated and that the natural component of the stock consists of less than 30% hatchery origin fish. The proportion of natural-origin fish among in-river spawning Battle Creek/Sacramento River steelhead is unknown, but given that CNFH currently includes zero natural-origin fish, a proportion much greater than 10% might initially be necessary. However, HSRG (2012) also recognized that use of natural-origin fish as broodstock must be achieved without decreasing the viability of the natural population due to the demographic effects of removing mature fish from the in-river population.

Minimum spawning targets necessary to meet production goals at CNFH require approximately 400 adult steelhead, with a male to female ratio of 1:1 (USFWS 2011). Thus, approximately 40 adult natural-origin steelhead would be required to meet the minimum HSRG (2012) recommendation for maintaining program integration. Taking 40 adult natural-origin steelhead for hatchery propagation would represent about 16% (40/246) of the average number of unmarked *O. mykiss* passed through CNFH during steelhead broodstock collection annually (Table 14). However, a properly integrated CNFH steelhead program will require either a larger fraction of natural-origin *O. mykiss* to be included in the hatchery broodstock, or a larger natural-origin in-river spawning steelhead population.

Table 14. Number of marked and unmarked steelhead (*O. mykiss*) handled at Coleman National Fish Hatchery 2002-2003 through 2011-2012 seasons.

	Handled at CNFH[1/]		
Season	**Marked**	**Unmarked**	**Total fish[2/]**
2002-2003	2,261	427	**2,688**
2003-2004	1,378	225	**1,603**
2004-2005	1,343	312	**1,655**
2005-2006	994	282	**1,276**
2006-2007	1,380	164	**1,544**
2007-2008	2,968	184	**3,152**
2008-2009	1,987	196	**2,183**
2009-2010	624	266	**890**
2010-2011	1,108	200	**1,308**
2011-2012	1,512	206	**1,718**
Mean	**1,556**	**246**	**1,802**

1/ Sources USFWS (2011), R. Null pers. comm.

2/ Differentiating all hatchery- and natural-origin steelhead was not possible prior to the 2002-2003 season.

The quantitative life cycle model was used to examine this issue in two ways: 1) by assuming that introgression between natural and hatchery origin steelhead would not occur; and 2) by assuming that the CNFH steelhead program was perfectly integrated such that domestication selection would not occur (Appendix E). Both approaches indicate the influence of issue five on steelhead population abundance is medium (a 9 to 11% change). Thus, the importance of this issue is rated medium based upon adverse effects likely to result from interbreeding between a segregated hatchery steelhead population and a restoration area steelhead population.

Understanding is rated high based on: (1) the information available on the number of marked and unmarked steelhead handled in CNFH during broodstock collection; (2) estimates of fish passed upstream of the fish barrier weir during trapping and video surveillance monitoring; and (3) information provided by HSRG (2012) and other sources on the effects of hatchery- and natural-origin steelhead interbreeding. Importance and understanding are not rated for any of the salmon stocks, since the issue is specific to steelhead.

5.2 Analysis of CNFH Issue Statement 3: Current operations at CNFH and at the fish barrier weir cannot always identify and prevent passage of: (1) hatchery origin salmonids, and (2) non-target runs of Chinook salmon.

Hatchery origin or non-target adult salmonids may reach the restoration area in two ways: (1) during periods when all upstream migrants are not processed through CNFH or through trapping in the upstream fish ladder, or (2) when hatchery origin fish cannot be reliably distinguished from target species. The absence of an adipose fin clip identifies hatchery origin winter, spring, late-fall Chinook and steelhead but is not an indicator of origin for fall Chinook. Since 2006, just 25% of fall Chinook salmon produced at CNFH (and most other Central

Valley hatcheries) are marked and coded wire tagged as part of a CFM program (USFWS 2011).

During the period of broodstock collection at CNFH (October 1 – March 15) all fish brought into the hatchery are examined for marks and tags, and only unmarked fish (presumed natural-origin) representing restoration area target species are passed upstream. Fish passed upstream are intended to include natural-origin *O. mykiss*, late-fall Chinook, and winter Chinook salmon. No fall Chinook salmon (marked or unmarked) are knowingly released above the fish barrier weir. In order to minimize fall Chinook reaching the restoration area, no Chinook salmon (marked or unmarked) are passed upstream during the months of October and November. Thus, during broodstock collection, hatchery or non-target salmonids may reach the restoration area only due to mark failure (e.g., a partial adipose fin clip, which allows the fin to grow back), or by failure to accurately identify race or origin of passed fish. Unmarked fall Chinook (either hatchery or natural-origin) exhibiting a late-fall phenotype might be mistakenly passed into the restoration area during broodstock collection. How often such misidentification might occur is unknown, but previous difficulties with phenotype-based race identification indicate such misidentifications can easily occur (Williams 2006; DWR 2004).

After broodstock collection ends (after March 15th) the hatchery fish ladder is closed and immigrating fish are instead allowed to proceed through the upstream fish ladder into upper Battle Creek. Upstream passage through the fish barrier weir continues through July 31st. Fish passage through the upstream fish ladder is monitored in two ways during this period:

1. From March into May, all adult fish are trapped while passing through the upstream fish ladder and examined for marks and tags. All marked Chinook salmon trapped during this period are euthanized, and CWT's removed and analyzed to determine fish origin and brood year. Marked steelhead are reconditioned and released downstream.

2. The second monitoring approach begins when water temperatures exceed 60^{o}F (see Appendix A for more details) typically beginning between April and May, and continuing through the end of July. During this period fish are allowed free access to the restoration area, and passage is monitored through the use of an underwater video surveillance system. Between 2001 and 2011, video monitoring has occurred for an average of 10.3 weeks (out of 22 available weeks between March 1st and July 31st). Video monitoring has occurred for as few as seven weeks and for as many as twelve weeks (Figure 3). Years with a greater number of video monitoring weeks (and therefore fewer trapping weeks) would potentially allow a larger number of hatchery or non-target anadromous salmonids to reach the restoration area.

The USFWS (2011) provided information on handling and sorting of salmon and *O. mykiss* at CNFH, and Appendix A provided a more complete description of these operations. Brown and Alston (2007), Alston et al. (2007), Newton et al. (2007a), Newton et al. (2007b), Newton et al. (2008), Stafford and Newton (2010), and Newton and Stafford (2011), Bottaro and Brown (2012) provide information on handling and sorting of fish during adult monitoring activities at the fish barrier weir. A review of those reports indicates:

O. mykiss

- Size and arrival timing of observed fish suggest both anadromous (steelhead) and resident (rainbow trout) *O. mykiss* occur in Battle Creek. Available data indicates considerable interchange between anadromous and resident life history forms in Battle Creek (Null et al. 2012).
- Since the 2008 -2009 season and as part of current operations, the CNFH steelhead program is operated as a segregated program; only marked (hatchery origin) *O. mykiss* entering CNFH are included in the broodstock. All unmarked *O. mykiss* (presumed natural-origin) entering CNFH during broodstock collection are released upstream of the fish barrier weir into the restoration area. (Table 2).
- Since 2002, 155 marked and 1,451 unmarked *O. mykiss* have been reported to have passed through the upstream fish ladder during adult fish monitoring activities (trapping and video monitoring periods combined) (Table 3). During trapping, 85% of *O. mykiss* observed were greater than 40cm (>14.7 in) suggesting a relatively large component of fish sufficiently large to be representative of the anadromous life history type (Donahoe and Null 2013). Comparable length-frequency data are not currently available for the video monitoring period.
- Since the 2004 – 2005 season, no marked *O. mykiss* have been deliberately passed upstream into the restoration area either during CNFH broodstock collection or during trapping at the fish barrier weir.
- Trapping in the upstream fish ladder effectively prevents passage of hatchery origin *O. mykiss*. However, the period of video monitoring represents a relatively long period (Figure 3) during which marked *O. mykiss* may freely access the restoration area. Available data indicates that in three of nine years, marked *O. mykiss* composed more than 10% of the *O. mykiss* entering the restoration area during video monitoring (Figure 4). The fraction of marked *O. mykiss* was highest in 2011, in excess of 50%.
- During weir operations, immigrating *O. mykiss* have generally demonstrated two peaks in movement past the barrier weir, the first in March (which is thought to represent the tail end of the winter immigration period), and a second, smaller peak during the mid-May to mid-June period (Figure 5).
- Across both CNFH and weir passage of *O. mykiss*, it is evident that most (>90%) *O. mykiss* enter Battle Creek during the period of CNFH broodstock collection (October through March 15) when marked (hatchery origin) fish are effectively excluded. Though marked *O. mykiss* do pass into the BCRP during weir video monitoring, the number of fish is small (<10%) relative to the number of natural origin fish entering during the earlier period.

Chinook salmon

- No fall Chinook salmon are intentionally passed upstream of the fish barrier weir during CNFH fall Chinook salmon broodstock collection.

- During broodstock collection all unmarked, phenotypic late-fall Chinook salmon are passed upstream into the restoration area. Hatchery personnel report a high level of phenotypic differentiation among adult fall, late-fall, and winter Chinook. Unmarked fall Chinook salmon (possibly hatchery origin fish) are reportedly not mistaken for unmarked late-fall or winter Chinook salmon during CNFH late-fall Chinook salmon broodstock collection, since the timing of migration and maturity are markedly different between the three runs.
- Since the 2000 – 2001 season, 662 unmarked late fall Chinook salmon collected at CNFH have been passed upstream of the barrier weir (Table 4).
- During the 2001 – 2011 seasons, USFWS personnel have reported trapping 1,331 marked Chinook salmon and 690 unmarked Chinook salmon in the upstream fish ladder (Table 5).
- During the 2001 – 2011 seasons, USFWS personnel estimated 279 marked Chinook salmon and 1,990 unmarked Chinook salmon passed through the upstream fish ladder during video surveillance monitoring (Table 5).
- The occurrence of marked Chinook salmon attempting to immigrate into the restoration area appears to be higher in March during trapping activities than later during the video surveillance monitoring period (Figure 7).
- During the 2001 – 2011 seasons, about 68% of the Chinook salmon trapped in the upstream fish ladder had been adipose fin marked (Table 5).
- During the 2001 – 2011 seasons, about 12% of the Chinook salmon identified during video surveillance monitoring were marked (Table 5).
- Of the 1,346 marked Chinook salmon trapped at the fish barrier weir and CWT's retrieved, 1,338 fish were CNFH late fall Chinook salmon, while eight fish were identified as non-CNFH origin (Table 6)

The race and origin of Chinook salmon reaching upper Battle Creek is of considerable interest but cannot be fully evaluated with information currently available. The following points describe difficulties with race and origin classification.

- Marked fish encountered during trapping in the upstream fish ladder in March through May are predominately CNFH late-fall Chinook salmon (Table 6) and marked fish continue to be observed during video monitoring (Table 5). However, between 2001 and 2012 tags have been recovered from just 23 of 279 marked fish known to have entered the restoration area (Table 7). Of these 23 recovered CWT, 17 were identified as Feather River Hatchery (FRH) spring Chinook salmon, 3 FRH fall Chinook, 1 CNFH late-fall Chinook, and 1 CNFH fall Chinook (Table 7). Although most marked fish reaching the restoration area during video monitoring are of unknown origin, none of the possibilities (i.e. CNFH fall, CNFH late-fall, FRH fall, FRH spring) are consistent with spring Chinook population objectives for Battle Creek.

- Genetic analysis of unmarked fish sampled during trapping at the fish barrier weir provides another means to assess race of Chinook salmon reaching the restoration area. However, Battle Creek spring Chinook salmon have no established genetic baseline (Newton and Brown 2010), so results are difficult to interpret. Complete result tables and captions from Newton and Brown (2010) are provided as Tables 8 and 9. Newton and Brown (2010) summarize results from the analyses as follows:

  > *GSI results for 2007-2010 samples with a >90% confidence rating assigned the majority of samples to Central Valley spring Chinook stock: 74% for the HMSC16 method, 77% for the HMSC16+Cry6 method, and 92% for the GAPS method (Table 8). Although the GAPS method assigned the highest percentage of samples to the spring-run category, it had the fewest number of samples that achieved a >90% confidence rating. When all confidence ratings were included, the percentage assigned as spring run declined: 70% for the HMSC16 method, 74% for the HMSC16+Cry6 method, and 79% for the GAPS method (Table 8). These results support the hypothesis that the majority of phenotypic spring Chinook in Battle Creek are genetically more similar to other Central Valley spring Chinook stock than to other run types. Still, up to 30% were assigned as fall run depending on the GSI technique used. The fish assigned to the fall-run category may have been early returning fall run, fall-spring hybrids, or a unique population of Battle Creek spring run that are genetically similar to fall run.*

Although more information is needed, results available from marked fish observations, tag recoveries and genetic analyses suggest many phenotypic spring Chinook reaching the restoration area are not consistent with spring Chinook population objectives for Battle Creek. However, many (or most) of these non-target spring run phenotypes are thought to originate from Feather River Hatchery (which propagates a spring Chinook heavily introgressed with fall Chinook). Thus, it does not appear that CNFH is contributing substantially to this problem.

Hatchery-origin or other non-target Chinook salmon and steelhead reaching the restoration area may interact and spawn with BCRP target species potentially reducing reproductive success and fitness (Reisenbichler et al. 2003; Araki et al. 2006, 2007, 2008, 2009). The HSRG (2012) also indicated that straying of hatchery-origin fish with consequent interbreeding with natural-origin fish might impair fitness and local adaptation. In addition, when abundance is high, hatchery or non-target adult salmonids may compete for limited spawning habitat and disturb BCRP target species via redd superimposition.

Access to the restoration area for hatchery origin steelhead, hatchery origin late-fall Chinook, and for fall Chinook (both hatchery and natural-origin) may be relatively well controlled for much of the immigration season. However, there are times and circumstances which appear to allow hatchery origin *O. mykiss* and non-target phenotypic spring Chinook to reach the restoration area.

The importance of this issue is rated low for winter Chinook because hatchery origin winter Chinook, originating from the conservation program at Livingston Stone National Fish Hatchery, would not be considered a risk to restoration area stocks. The importance of this issue also is rated low for late-fall Chinook because hatchery late-fall Chinook are 100%

marked and most of the run tends to arrive either during CNFH broodstock collection or during trapping in the upstream fish ladder. Thus, the risk of hatchery late-fall Chinook reaching the restoration area appears to be very low.

In contrast, the importance of this issue is rated medium for spring Chinook and *O. mykiss* because:

1. Quantitative life cycle model analysis for spring Chinook and *O. mykiss* indicate a medium effect of hatchery genetic introgression on equilibrium abundance (Appendixes D and E).

2. The occurrence and impact of hatchery introgression may be under-represented in the model. Current marking programs do not allow for the identification of all hatchery-origin fall Chinook salmon, thus hatchery fall Chinook with atypical migration timing might reach upper Battle Creek through unintentional passage during fish trapping in the upstream fish ladder, or through volitional passage during video monitoring. Once in the restoration area, hatchery fall Chinook might interbreed with or superimpose upon redds of spring Chinook salmon. The number of fall Chinook reaching upper Battle Creek is thought to be low because of phenotypic- and mark-selective passage at CNFH during broodstock collection and in the upstream fish ladder during trapping. However, Chinook salmon that have successfully reached upper Battle Creek (whether via CNFH or the upstream fish ladder) have not been subjected to extensive genetic analysis or to CWT recovery to identify race and stock of origin. Studies indicate that relatively low numbers of strays (straying rates that result in interbreeding rates between 5 and 15%) are sufficient to depress fitness in an established natural-origin salmonid population (Mobrand et al. 2005, Ford 2002, Lindley et al. 2007). However, Chinook salmon and steelhead populations in upper Battle Creek are small, and not yet well established. Thus, it is likely that low numbers of fall Chinook salmon or other non-target strays reaching upper Battle Creek may be sufficient to slow or suppress recovery of BCRP target Chinook stocks. This possibility was not fully addressed within the life cycle model where large spring Chinook populations at habitat carrying capacity were established relatively quickly.

3. Hatchery steelhead are 100% marked, but are known to reach the restoration area during video surveillance monitoring in the upstream fish ladder. Once in the restoration area, hatchery steelhead may spawn with natural-origin steelhead and studies suggest introgression rates between 5 and 15% are sufficient to depress fitness of natural-origin stocks (Mobrand et al. 2005, Ford 2002, Lindley et al. 2007).

Understanding of this issue is rated high for winter Chinook for reasons explained previously. Understanding for late fall Chinook and *O. mykiss* is rated medium due to 100% marking, but not high because passage during video monitoring is poorly understood. Understanding for spring Chinook is low given the fall Chinook are not 100% marked and because a large fraction of phenotypic spring Chinook arrive during video monitoring when selective passage is lacking.

Fall Chinook are identified as NA (not applicable) because fall Chinook are not influenced by this issue.

5.3 Analysis of CNFH Issue Statement 4: Hatchery or natural-origin fall and late-fall Chinook salmon, and hatchery steelhead may reach the restoration area during high flow events where they may have adverse effects on Battle Creek steelhead, spring and winter Chinook salmon.

All hatchery and natural-origin adult salmon and *O. mykiss* immigrating through lower Battle Creek encounter a fish barrier weir that redirects fish into a fish ladder system. In 2008, the USFWS working cooperatively with Reclamation, modified the CNFH fish barrier weir, and constructed a new fish ladder system on Battle Creek at the hatchery. Appendix A provides details about the fish barrier weir, fish ladders, and associated operations. For the purpose of this analysis, high flow events are deemed to occur when flows in Battle Creek exceed 800cfs, which is the maximum flows for which the barrier weir was designed to be completely effective at blocking passage.

Null et al. (2010) reported on the effectiveness of the modified barrier weir throughout two seasons. Flows ranged from 199 to 1,380 cfs during the first season, and from 199 to 1,790 cfs during the second season. However, the study approach intended only to address barrier effectiveness at 800 cfs or less, and did not allow for effective observation of fish possibly defeating the weir at greater flows. Thus, results from Null et al. (2010) are considered most applicable to flows less than 800 cfs and indeterminate for flows greater than 800 cfs. During the study reported by Null et al. (2010), five fish were observed escaping past the fish barrier weir; four escaped over the overshot gate and one jumped over the main portion of the barrier weir. The main section of the barrier weir was considered successful at blocking Chinook salmon from migrating upstream of the hatchery. The single fish that escaped past the main portion of the weir was likely an *O. mykiss*. Additional modifications have subsequently been made to prevent fish passage at the overshot gate during flows below 800 cfs (S. Hamelberg pers. comm.). At flows exceeding 4,200 cfs, flows overtop the river bank allowing fish to laterally circumvent the weir (M. Brown pers. comm.).

A review of available information suggests

- The barrier weir is effective at preventing fish passage and redirecting fish into the fish ladder system at flows up to 800 cfs, and has a flow capacity of approximately 3,000 cfs. However, effectiveness of the barrier weir has not been tested at flows between 800 cfs and 3,000 cfs. Flows greater than 800 cfs are relatively common in Battle Creek, for example occurring in February, March and May for nearly one third of years since 1985 (Figure 8). Shorter duration flows of greater than 800 cfs occur much more frequently than shown in Figure 8.

- At flows exceeding 4,200, overbank flows may allow fish to pass around the barrier weir. At flows greater than 800 cfs the effectiveness of the fish ladder in attracting fish away from the barrier is unknown. However, flows greater than 4,200 cfs are uncommon and,have most often between December and February. Late-fall Chinook, winter Chinook and *O. mykiss* would be expected to occur in Battle Creek during this period.

Access to the restoration area for hatchery origin steelhead, hatchery origin late-fall Chinook, and fall Chinook (both hatchery and natural-origin) appears to be relatively well controlled by the fish barrier weir (not including passage associated with CNFH broodstock collection or ladder operations). However, there are circumstances under which Battle Creek flows may allow at least some hatchery origin Chinook and steelhead to reach the restoration area. Hatchery-origin or other non-target Chinook salmon and steelhead reaching the restoration area are a concern because these fish may interact and spawn with BCRP target species potentially reducing reproductive success and fitness (Reisenbichler et al. 2003; Araki et al. 2006, 2007, 2008, 2009, HSRG 2012). In addition, hatchery or non-target adult salmonids may compete for limited spawning habitat and disturb BCRP target species via redd superimposition. Although the number of non-target anadromous salmonids defeating the fish barrier weir and reaching the restoration area may be small, studies indicate that relatively low numbers of strays can be sufficient to depress fitness in an established natural-origin salmonid population (Mobrand et al. 2005, Ford 2002, Lindley et al. 2007). However, quantitative life cycle model analyses evaluating the consequences of high-flow strays, indicate low population impact for all target anadromous salmonids (Appendixes D and E).

Based on the information presented above, the importance of this issue is rated low for *O. mykiss*, spring Chinook, and late-fall Chinook. Reliable information is not available for flows above 800 cfs, and expectations for weir performance at greater flows is unknown. Thus, the understanding of the issue is rated low for *O. mykiss*, spring Chinook and late-fall Chinook. A high level of understanding would be achieved if diagnostic studies or monitoring were completed to quantify fish passing the weir at flows greater than 800 cfs. The level of importance could be considered low if studies confirmed that very little interbreeding occurred as a result of fish defeating the fish barrier weir.

The importance of this issue is rated low, and understanding is rated high for winter Chinook because, as indicated previously, hatchery winter Chinook reaching the restoration area would be considered a contribution rather than a threat to BCRP goals.

Importance and understanding for this issue is rated NA (not applicable) for fall Chinook because fall Chinook are not currently targeted for passage into the restoration area (fall Chinook reaching the BCRP may be problematic for spring Chinook, but is irrelevant to the fall Chinook population)

5.4 Analysis of CNFH Issue Statement 8: High abundance of hatchery-origin adult salmon in lower Battle Creek may create adverse effects including (1) reduction of in-stream spawning success due to the physical destruction of redds; and (2) undesirable interbreeding between natural and hatchery origin steelhead and fall and late-fall Chinook salmon.

Lower Battle Creek (the stream segment from the CNFH fish barrier weir downstream to the confluence with the Sacramento River) is currently managed primarily as fall Chinook salmon spawning and rearing habitat. Although *O. mykiss*, late-fall Chinook, winter Chinook, and spring Chinook are expected to use lower Battle Creek as a migration corridor, it is not expected that spawning or rearing in this segment would contribute directly to restoration objectives for the BCRP.

The impacts of CNFH fall Chinook salmon spawning on emigration and rearing of juvenile salmonids from upper Battle Creek is considered in Section 6.4. Here we consider the potential impacts of hatchery origin fall Chinook on the reproductive success and fitness of natural-origin anadromous salmonids in lower Battle Creek.

Returning fall Chinook salmon in Battle Creek are a mixture of hatchery fish from the CNFH, naturally produced fish from Battle Creek, and fish that strayed from their natal stream or hatchery. The USFWS (2011) reported that expansion of mark rate data suggests the majority of fall Chinook salmon in Battle Creek are of CNFH-origin, and Kormos et al. (2012) confirmed that in 2010 and 2011 about 90% of the adult fall Chinook salmon in lower Battle Creek were of hatchery origin. The CNFH fall Chinook program is considered to be integrated with the natural-origin fall Chinook. However, the natural component of that integrated stock is currently expected to complete its life cycle without access to upper Battle Creek. Thus, interbreeding between hatchery and natural-origin fall Chinook in lower Battle Creek could adversely affect reproductive performance and fitness of this stock. Furthermore, HSRG standards for an integrated program require that pHOS on the spawning grounds be below 50% (HSRG 2012). Overall, the proportion of natural influence for the Battle Creek/CNFH fall Chinook program is well below recommended levels (HSRG 2012).

The CDFW and USFWS cooperatively operate a fish-counting weir near the mouth of Battle Creek during the immigration of adult fall Chinook. Counts of fishes passing this counting weir are used to make estimates of the fall Chinook run-size in Battle Creek and to provide "real-time" data that are used to inform operational decisions related to opening and closing of the hatchery fish ladder. For example, when fish counts at the weir are substantially higher than the hatchery's broodstock collection targets, the hatchery ladder may be opened longer to collect fall Chinook salmon in excess of the number needed to meet the hatchery-spawning target. This is done to help reduce the abundance of fall Chinook salmon in lower Battle Creek and improve natural reproduction. In the absence of this action, fall Chinook salmon may become overcrowded in the creek, and suffer decreased spawning success due to pre-spawn mortality and physical destruction of redds (D. Killam CDFW pers. comm.).

The USFWS and CDFW have informally established a spawning escapement maximum of 20,000 fall Chinook salmon for lower Battle Creek; however, no specific research has been conducted to determine if this is an appropriate maximum number of spawners for lower Battle Creek, given the amount and condition of available habitat.

Limited information is available on the effects of physical destruction of salmon redds in lower Battle Creek due to redd superimposition, although the BCWC (2001) suggested hatchery returnees disrupt natural spawning below the hatchery. While disruption of successful spawning and egg incubation may occur downstream of the fish barrier weir, this would only affect natural-origin fall Chinook. *O. mykiss*, late-fall Chinook, winter Chinook and spring Chinook that contribute to the BCRP goal and objectives are assumed to spawn exclusively upstream of the fish barrier weir.

Quantitative life cycle model analysis indicates a high effect on fall Chinook population abundance associated with this issue. When CNFH origin fall Chinook were assumed to be excluded from lower Battle Creek, the equilibrium abundance of natural-origin fall Chinook increased by approximately a factor of ten (Appendix D). However, managing lower Battle Creek exclusively for natural origin fall Chinook (excluding hatchery origin fish) would not necessarily increase overall production (hatchery + natural). Production by CNFH would continue to be largest component of Battle Creek fall Chinook. If excluding hatchery origin fall Chinook from lower Battle Creek inhibited CNFH operations, then total production could actually decrease.

The importance of this issue for winter, late-fall, spring Chinook and *O. mykiss* is rated NA (not applicable) because these stocks are not expected to spawn in appreciable numbers in lower Battle Creek. Understanding for these stocks is also rated not applicable. In contrast, the high abundance of hatchery origin fall Chinook in lower Battle Creek and the lack of access to an isolated spawning area support a ranking of high importance and high understanding for natural-origin fall Chinook.

5.5 Analysis of BCRP Issue Statement A: Habitat quality and quantity may be insufficient to support BCRP population objectives.

Enhanced availability and improved productivity of spawning and egg incubation habitat was an implicit expectation for the BCRP (Terraqua 2004). The quantitative life cycle models represented this expectation by applying reach-specific spawning and rearing capacities and productivity per habitat area expressed in BCRP documents (see Appendixes D and E). Model results indicate there is considerable capacity for supporting Battle Creek population objectives. However, model results also demonstrate the sensitivity of population performance to habitat quantity and quality. For example, changes in habitat accessibility associated with natural barriers or changes in survival associated with water temperatures, had considerable influence on equilibrium population abundances.

BCRP Issue Statement A was determined to have high importance and medium understanding for spring Chinook, winter Chinook, late fall Chinook and steelhead. BCRP IS-A is not applicable to fall Chinook because they are not currently a BCRP target species. While there is little uncertainty regarding the importance of habitat quality and quantity within Battle Creek, the medium understanding is appropriate because insufficient data is currently available to assess areas suitable for spawning and egg incubation. LCM outcomes are based upon an expectation for high quality and highly productive habitats, but these inputs and model assumptions which not been verified by field studies or empirical observations.

5.6 Analysis of BCRP Issue Statement B: Battle Creek water temperatures may not be suitable to support salmonid populations consistent with BCRP population objectives.

Water temperatures suitable to support spawning and egg incubation was an implicit expectation for the BCRP (Terraqua 2004). The quantitative life cycle models represented this expectation by applying reach-specific water temperature data (model-based) to assess spawning and egg incubation success (see Appendixes D and E). Model results indicate modeled water temperatures can support Battle Creek population objectives, but also demonstrate sensitivity of population performance to water temperatures. For example, the spatial distribution of successful spring Chinook, winter Chinook and steelhead in the BCRP area appeared to be strongly influenced by suitable water temperatures. The effect was not quantified, but patterns suggest water temperatures will be a critical factor for determining realized spatial distribution for spawning and rearing success; especially if water temperatures are warmer than earlier projections.

BCRP Issue Statement B was determined to have high importance and medium understanding for spring Chinook, winter Chinook, and steelhead. BCRP IS-B is of low importance to late fall Chinook and not applicable to fall Chinook because they are not currently a BCRP target species. While there is little uncertainty regarding the importance of water temperatures within Battle Creek, the medium understanding is appropriate because insufficient data is currently available to assess actual water temperatures in Battle Creek. LCM outcomes are based upon modeled daily average water temperatures, but these inputs and model assumptions which not been verified by field observations.

5.7 Analysis of BCRP Issue Statement D: Redd scouring and related egg mortality may limit BCRP salmonid populations.

The BCRP adaptive management plan (Terraqua 2004) identified that egg mortality resulting from high-flow streambed mobilization could limit success of Battle Creek salmonid populations. Redd scour effects were incorporated into the life cycle models for both Chinook salmon and steelhead (see Figure 11, Appendixes D and E). However, the effect of scour events on populations was not explicitly assessed with the model. Flow events of sufficient magnitude due to induce redd scour (>3,000 cfs according to TAC input) occur primarily between January and May (Figure 9). Late fall Chinook and steelhead are the only BCRP target species spawning or with egg incubating eggs during this time period. Pending further investigation with the LCM, for late fall Chinook and steelhead the importance of this issue is ranked medium. The issue is of low importance to spring Chinook, winter Chinook because spawning and egg incubation does not correspond to months when redd scouring flows are likely to occur.

BCRP Issue Statement D was determined to have medium understanding for late fall Chinook and steelhead because no empirical information regarding the incidence, distribution or biological consequences of redd scour are available from Battle Creek. Understanding is considered high for spring Chinook and winter Chinook because these species do not spawn or incubate eggs during months likely to experience redd scouring flow events.

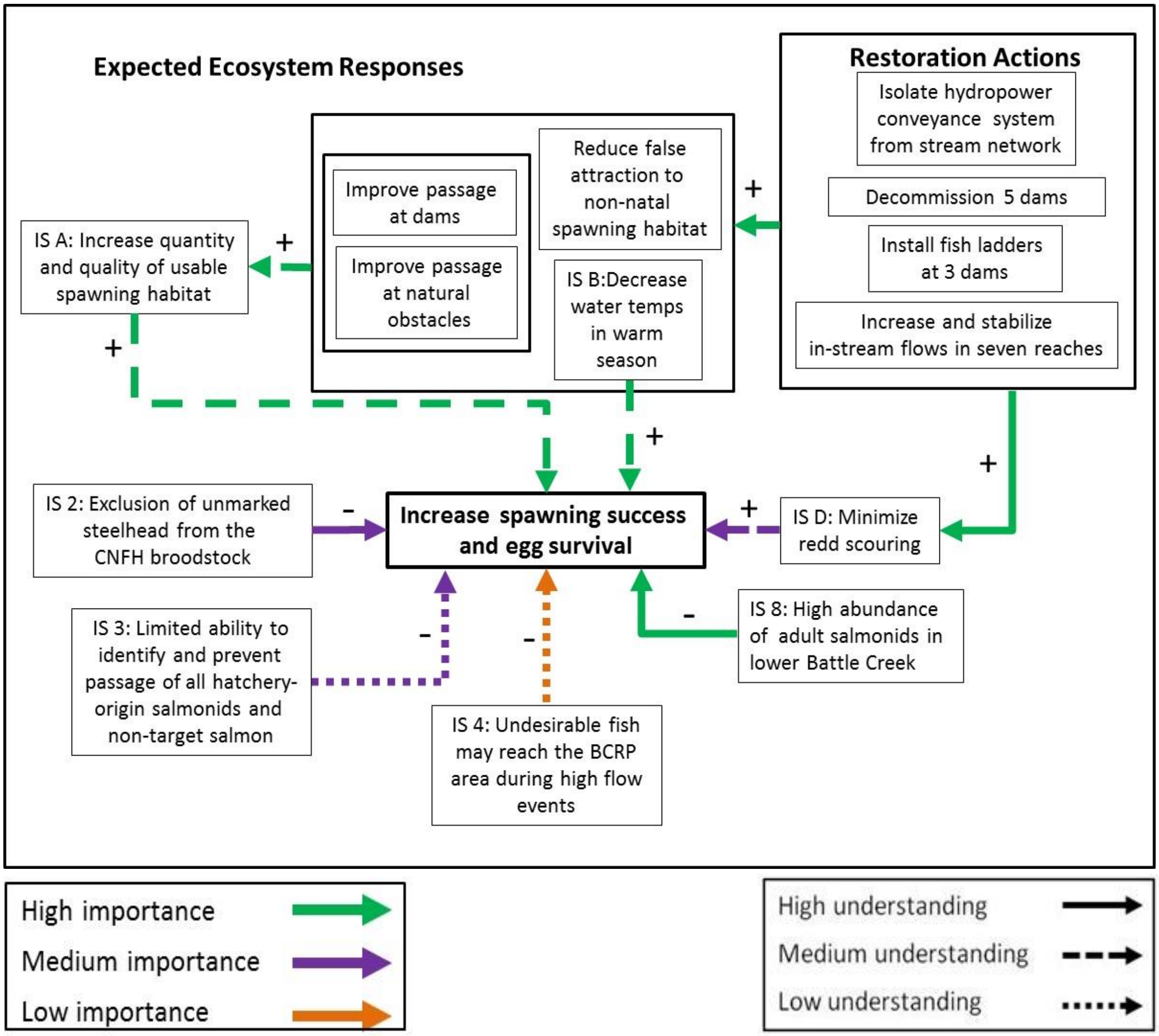


Figure 14. Revised conceptual model diagram of factors affecting natural-origin salmonids spawning and egg incubation in Battle Creek. This diagram includes the seven issues analyzed under this life-stage event. Variations in arrow color and line-type are used to indicate importance and understanding based on the issue analyses. Definitions for the different arrows are provided in the legends below the diagram. The highest level of importance and lowest level of understanding are indicated for an issue in cases where these factors vary among the fish stocks (see Table 15 for details).

The issue analyses presented above and the associated assessments of importance and understanding support a somewhat revised conceptual model of the factors affecting natural-origin salmonid spawning and egg incubation in Battle Creek (Figure 14). CNFH issue eight and BCRP issues A and B were all found to be of high importance to one or more BCRP target stocks (Table 15). Understanding of CNFH issues two, four, and eight was found to be high where applicable. Understanding of CNFH issues three and 4, and BCRP issues A, B, and D was found to be medium or low for most target species.

Table 15. Collective ratings of importance and understanding of issues affecting spawning and egg incubation of natural-origin salmonids in Battle Creek.

		Battle Creek restoration area anadromous salmonid stocks 1/				
Issue Statement		SH	SC	FC	LFC	WC
CNFH IS-2 – The current CNFH steelhead program excludes naturally produced (unmarked) fish from the broodstock. This practice leads to continued domestication and potential for reduced fitness when hatchery fish spawn in the restoration area.	Importance	M	NA	NA	NA	NA
	Understanding	H	NA	NA	NA	NA
CNFH IS-3 – Current operations at CNFH and at the fish barrier weir cannot always identify and prevent passage of 1) hatchery origin salmonids, and 2) non-target runs of Chinook salmon.	Importance	M	M	NA	L	L
	Understanding	M	L	NA	M	H
CNFH IS-4 – Fall run Chinook (hatchery or wild), hatchery late fall run Chinook and hatchery-origin steelhead may reach the restoration area during high flow events where they may have adverse effects on Battle Creek steelhead, late fall, spring run and winter run Chinook.	Importance	L	L	NA	L	L
	Understanding	L	L	NA	L	H
CNFH IS-8 – High abundance of hatchery-origin adult salmon in lower Battle Creek may create adverse effects including (1) reduction of in-stream spawning success due to the physical destruction of redds; (2) undesirable interbreeding between natural and hatchery origin steelhead and fall and late-fall Chinook salmon	Importance	NA	NA	H	NA	NA
	Understanding	NA	NA	H	NA	NA
BCRP IS-A – Habitat quality and quantity may be insufficient to support BCRP population objectives	Importance	H	H	NA	H	H
	Understanding	M	M	NA	M	M
BCRP IS-B – Battle Creek water temperatures may not be suitable to support salmonid populations consistent with BCRP population objectives	Importance	H	H	NA	L	H
	Understanding	M	M	NA	M	M
BCRP IS-D – Redd scouring and related egg mortality may limit BCRP salmonid populations.	Importance	M	L	NA	M	L
	Understanding	M	H	NA	M	H
1/ SH = steelhead, SC = spring Chinook salmon, FC = fall Chinook salmon, LFC = late fall Chinook salmon, WC = winter Chinook salmon						

6. Rearing and Emigration of Natural-origin Juvenile Salmonids in Battle Creek Conceptual Model and Issue Analysis

This conceptual model focuses on factors affecting the rearing and emigration of juvenile salmonids in Battle Creek. BCRP restoration actions relevant to this life-stage event aim to reduce juvenile fish entrainment at hydropower diversions and improve the quantity and quality of in-stream flows (Figure 15). These restoration actions are expected to positively affect the growth and survival of juvenile salmonids, while rearing in Battle Creek, and during emigration. Terraqua (2004) identified five hypotheses to describe the cause and effect relationship between the restoration actions (drivers), and the expected improvements in habitat conditions and ecosystem responses (intermediate outcomes). Specifically, the hypotheses state that implementation of in-stream flow levels and facilities modifications specified in the BCRP description, implementation of the BCRP facilities monitoring plan, and implementation of any adaptive responses affecting in-stream flows or hydroelectric project facilities will:

1. Ensure that juvenile salmon and steelhead production is within the expected level given the number of spawning adults and relevant ecological factors.
2. Provide at least 95% of maximum usable habitat quantity for critical life stages among priority species.
3. Provide in-stream water temperatures that are suitable for critical life stages among species at appropriate stream reaches.
4. Ensure that variations in flow regimes, following forced or scheduled outages where the available diversion flow has been released to the natural stream channel, do not strand salmon and steelhead or isolate them from their habitat when diversions are resumed.
5. Ensure that hydraulic parameters at fish screens meet contemporary criteria at all times.

Sustained improvements in the ecosystem responses are expected to positively affect the primary biological responses, and ultimately, the terminal outcome: improve juvenile salmonid rearing and emigrant survival.

Three issues related to CNFH programs may directly affect juvenile salmonid rearing and emigration in Battle Creek, and two issues may have indirect affects through their impacts on expected ecosystem responses (Figure 15). Two BCRP issues may also have indirect effects on expected ecosystem responses. Information related to each issue is analyzed to estimate the importance, understanding, and predictability of the issue’s influence on the relevant intermediate outcome (ecosystem responses) or the terminal outcome (improved salmonid rearing and emigrant survival). Collective ratings of importance and understanding are provided at the end of this section (Table 16). A revised conceptual model diagram incorporating results from the issue analyses also is presented at the end of this section (Figure 16).

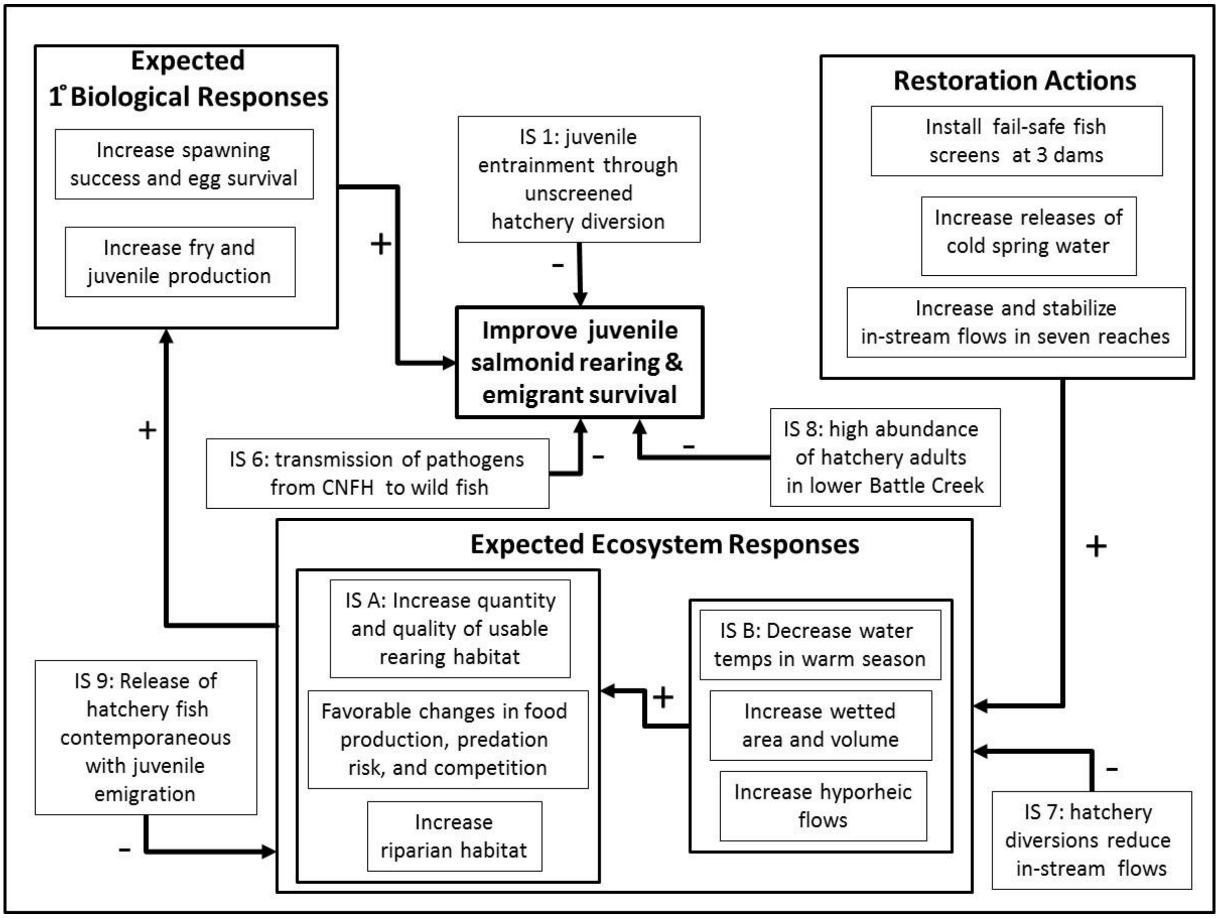


Figure 15. Conceptual model diagram of factors affecting the rearing and emigration of natural-origin juvenile salmonids in Battle Creek. Levels of importance and understanding are not shown in this diagram.

6.1 Analysis of CNFH Issue Statement 1: An unscreened water diversion used at times to deliver water to the CNFH may result in the entrainment of Battle Creek juvenile salmonids.

The CNFH has three water intakes located upstream of the hatchery to support its operations. Substantial improvements to the intakes and associated infrastructure were completed in 2009, in anticipation of the BCRP; however, the potential for juvenile fish entrainment still exists. Appendix A provides more details about the intakes and these modifications.

USFWS (2011) provided a review of (1) the proportion of Battle Creek flow diverted to CNFH; (2) the magnitude and timing of planned diversions at Intake 2; and (3) the magnitude and timing of juvenile salmonid emigrations past the CNFH intake structures. They concluded there would be no listed fish take at Intake One (anadromous fish do not occur at that location) or Intake Three (this intake is screened). However, Intake Two may entrain juvenile ESA-listed and unlisted salmonids from Battle Creek because this intake is unscreened.

Intakes One and Three are the primary intakes for CNFH and the CNFH full water right is for 122 cfs at Intake One. The normal operating condition of the Coleman powerhouse involves discharge of flow from the Coleman Powerhouse Forebay, through the penstocks and turbine, and into the tailrace where hatchery Intake One is located. Occasionally, water is blocked from entering the Coleman powerhouse to perform maintenance or repairs of the PG&E canals and turbine. Planned maintenance activities are typically scheduled during August to avoid impacts to fish.

Intake Two can only divert water when Intake One is inoperable, which occurs when discharge from the Coleman Powerhouse ceases due to a planned or unplanned facility outage. Use of Intake Two varies among years, and some extreme events requiring sustained use of Intake Two have occurred. For example, between late 2005 and mid-2006, intakes Two and Three (both unscreened at the time) were used to supply water to the hatchery facility for approximately 270 days (December 2, 2005 to mid-April 2006; S. Hamelberg pers. comm.). As a result of extended outages in 2006 and 2010, the long term average operation of Intake Two has increased from 17.2 days per year to approximately 40 days per year (considering the recent 20 year record), or approximately 57 days per year (considering the recent 10 year record) (USFWS 2011). Extended outages of PG&E infrastructure of the magnitude witnessed in 2006 and 2010 are unusual, and although they are not expected to reflect future conditions, emergency outages can occur at any time. The reliability of water to serve Intake One is anticipated to improve relative to historical levels.

To estimate future entrainment of juvenile salmonids, USFWS (2011) assumed the unscreened Intake Two would be used an average of 412 hours (~17.2 days) annually. USFWS (2011) further assumed that half of the hours of operation for Intake Two (206 hours) will occur during May and June (as part of scheduled PG&E maintenance) and the remaining 206 hours will occur at randomly timed emergency, unplanned events. To estimate potential take of juvenile salmonids at Intake Two during emergency events, USFWS (2011) apportioned the hours equally from July through April.

USFWS (2011) estimated the magnitude and timing of juvenile salmonid emigrations from Battle Creek using juvenile fish monitoring data (Colby et al 2012, Whitten et al 2006, 2007a, 2007b, 2007c, 2010, 2011). Data from December 2009 through July 2010 were used to derive a take estimate for spring Chinook salmon, as the greatest numbers of juveniles were estimated at that time. During that time, 96,533 juvenile spring Chinook were estimated to have emigrated from Battle Creek, with the greatest number emigrating in December and January. Likewise, during that same period, 5,112 juvenile *O. mykiss* were estimated to have emigrated from Battle Creek. USFWS assumed that emigrations of ESA-listed spring Chinook salmon and *O. mykiss* would follow similar seasonal patterns (i.e., similar monthly percentages) as observed during the December 2009 – July 2010 period.

Based on the analyses and assumptions described above, the USFWS (2011) estimated total annual take of ESA-listed juvenile salmonids at the CNFH Intake Two to be 243 spring Chinook and six *O. mykiss*. During the period 1995 through 2009, less than five adult winter Chinook salmon have been reported in Battle Creek above the fish barrier weir (Bottaro and Brown 2012) and no take of juvenile winter Chinook at CNFH Intake Two was estimated or reported; however this will change when winter Chinook salmon are reintroduced into Battle Creek. USFWS (2011) noted these numbers have been considered lethal take resulting from water diversions at Intake Two, and do not account for salvage of entrained fishes from the hatchery water supply system. Salvaged fish could potentially be relocated and “taken” only at the level of harassment rather than lethal take: however the usage and success of salvage efforts is based on limited, but focused ongoing investigations.

Prior to the recent modifications of intakes One and Three, the USFWS conducted periodic salvage to capture and relocate fishes entrained in the hatchery's water delivery system. Fish salvage was conducted by a variety of methods including seining, dip nets, cast nets, and electrofishing (USFWS 2011). Salvage efforts were developed in consultation with NMFS and were conducted in both the CNFH water delivery canal (to capture and relocate fishes diverted through unscreened Intake Two) and the settling basins (to capture and relocate fishes diverted through Intake Three). The new fish screen at Intake Three was installed in late 2009. No salmonids were observed during salvage of the settling basins in 2010, indicating that the new screen structure was preventing the entrainment of emigrating juvenile salmonids (USFWS 2011). With the functioning fish screen now in place at Intake Three, annual fish salvage efforts in the settling basins are no longer considered necessary.

Salvage efforts continue to be necessary to capture and relocate fishes entrained during the operation of Intake Two into the hatchery's water supply canal. Recent efforts demonstrated that a fyke net salvage operation conducted in the CNFH canal could be used to execute real-time salvage of entrained fishes (Whitton et al. 2007a). USFWS (2011) reported an extended outage at PG&E's Coleman Powerhouse from February through March 2010 resulted in the need to operate Intake Two for an extended period. A fyke weir was installed and real time fish salvage was successfully accomplished (USFWS 2010). CNFH personnel retain all components of a complete fyke weir including pontoons, live box, nets, and fyke panels. The equipment is maintained and readily accessible for rapid deployment into the Coleman Canal during (1) extended periods of Intake Two operation; and (2) a period when Intake Two operation coincides with expected substantial juvenile salmonid emigration. USFWS will consult with NMFS to determine need for salvage operations during usage of Intake Two.

Operation of Intake Two may not warrant real-time salvage efforts at times when emigration of juvenile salmonids is either not expected, or is anticipated to be minimal. For example, the primary water intake for the CNFH was disabled from July 22 to Sept 22, 2010 due to a failure at the PG&E Coleman Powerhouse, necessitating use of Intake Two (USFWS 2011). During this period, salvage efforts were not implemented in the hatchery canal. Through consultation with NMFS and using data from the USFWS's juvenile salmonid monitoring program in Battle Creek, the USFWS demonstrated that the timing of the outage coincided with the summer period when few salmonids were expected to emigrate from Battle Creek (USFWS 2011).

Determining the overall importance of issue one is challenging, since usage of Intake Two could occur at any time and duration due to an unplanned outage. Although the entrainment of juvenile salmonids into Intake Two may be infrequent in most years, it could result in direct take of emigrating juvenile salmonids (rearing fish would not be moving and therefore not exposed to entrainment). In addition, Battle Creek is undergoing major restoration, including reintroduction of winter Chinook salmon. Salmonid population numbers are expected to increase; thus, numbers of juvenile fish entrained could potentially increase considerably. The quantitative life cycle models (LCM) for Chinook and steelhead were able to incorporate and consider complex factors such as probability of outages co-occurring with target species outmigration, the duration of the outage, and the likely entrainment rate during outages. As explained further in Appendix D, probabilities for outage frequency, outage duration, and entrainment rate were based upon historical data. The LCM analysis indicated issue one had a low effect on equilibrium abundance for all target species. These model results are consistent with the results of USFWS investigations (USFWS 2011); thus, the importance of issue one is rated low for all target species.

It is important to note that while population-level impacts from the probabilistic analysis of this issue are low, there is potential for substantial impacts within a single year or a series of years if an outage of long-duration occurs during peak juvenile salmonid emigration. To evaluate consequences from such an outage, we used the LCM to run twelve, 25-year long simulations assuming a month-long outage for each of the twelve months in a year. Other than outage duration and frequency, all other settings were as described in Appendix D. From the results of these simulations, we calculated the percentage difference from the baseline scenario (no outages) for each month for each Chinook salmon run and tested for statistical significance (alpha = 0.05). We found the month-long outages in April had a significant negative impact on late-fall Chinook equilibrium abundance (-4.2%). Month-long outages in December, January and March had a significant negative impact on spring Chinook equilibrium abundance (-13.5%, -8.6%, and -5.2% respectively). Winter Chinook equilibrium abundance declined significantly with month-long outages occurring in September through January. The largest decline in equilibrium abundance was observed for winter Chinook in September (-9.0%), October (-10.6%), and November (-11.8%). These results are relevant in representing a worst-case scenario, but do not change the original LCM-based importance rating, which were based on the full range of likely outage events.

Overall, the understanding of this issue is rated medium given data on the historical use of Intake Two, past efforts to quantify the potential magnitude of juvenile entrainment, and past efforts to monitor the timing of juvenile emigration from upper Battle Creek. The continued possibility of unplanned (i.e., emergency) outages of the Coleman Powerhouse precludes a rating of high understanding.

Importance and understanding for this issue is rated NA (not applicable) for fall Chinook because fall Chinook are not currently targeted for passage into the restoration area.

6.2 Analysis of CNFH Issue Statement 6: Pathogens resulting from CNFH operations may be transmitted and expressed among wild fish in the restoration area.

Diseases affecting salmonids and their transmission from hatchery-origin to natural-origin salmonids were analyzed in Section 4.4, above. Diseases or pathogens transmitted by adults during spawning may be retained by juveniles during rearing and emigration (i.e., vertical transmission). Hedrick (1998) reported that although human activities have directly altered the health of fish populations by direct perturbation of habitats and ecosystems, diseases are natural phenomena in wild fish populations (Sindermann 1990; Whittington et al. 1997 as cited in Hedrick 1998).

Before 1999, water supply disease and sediment problems confounded fish culture at CNFH (USFWS 2011). High sediment loads, generally associated with high flow events in Battle Creek, have caused mortality of juvenile and adult salmonids at the hatchery. Likewise, recurrent disease outbreaks possibly associated with the hatchery water supply resulted in increased mortality of juveniles (Foott et al. 1997). More than ten significant pathogens have been detected in salmonids at CNFH (Foott 1996)

Fish health is routinely monitored by CNFH personnel and a fish pathologist from the California/Nevada Fish Health Center located at CNFH. Monitoring protocols follow the USFWS Aquatic Animal Health Policy (USFWS 2004). This policy includes a chapter from the American Fisheries Society's "Fish Health Blue Book" (Thoesen 1994), entitled *Standard Procedures for Aquatic Animal Health Hatchery Inspections*, which describes procedures and protocols for conducting fish health inspections at anadromous fish hatcheries.

To reduce sediment in the hatchery water supply and to alleviate recurrent disease problems, a water treatment facility capable of filtering 45,000 gallons per minute (gpm) and ozonating 30,000 gpm was constructed at CNFH. (Appendix A provides more details on this water treatment facility.) Operation of the ozone water treatment facility has substantially reduced the occurrence of disease in hatchery production and the potential for disease transmission to naturally produced stocks (USFWS 2011). Since brood year 1999, juvenile salmonids propagated at the Coleman NFH have been reared and released with no incidence of IHNV (USFWS 2011).

Issues associated with introduction and amplification of pathogens has been largely eliminated with the installation and operation of the ozone water treatment facility at CNFH. This subsequently reduces the potential for development and amplification of pathogens at CNFH but does not eliminate the possibility of pathogens developing in CNFH produced fish, or the possible transmission of pathogens in the effluent water from entering Battle Creek.

Water use at the CNFH is non-consumptive. All water diverted from Battle Creek (except that lost to evaporation) is returned to the creek through an overflow channel, the fish ladder, a wastewater ditch, or the pollution abatement pond outfall. The facility discharges an average of 40.8 million gallons/day. Approximately 3.3 million gallons/day of hatchery wastewater is diverted through the pollution abatement pond prior to discharge into Battle Creek. The pollution abatement pond is used primarily to reduce the discharge of solids (i.e., fish fecal matter, unconsumed food, algae, and silt) associated with cleaning the raceways and filtering the incoming water prior to passage through the ozone water treatment plant.

Water discharged from the CNFH is regulated by a National Pollution Discharge Elimination System (NPDES) permit issued by the California Regional Water Quality Control Board, although pathogens are not included in the standards. As a provision of this permit, the USFWS conducts monthly sampling of total suspended solids, pH, dissolved oxygen, turbidity, and temperature in both supply- and receiving-waters in Battle Creek. The permit also covers chemicals used for fish health maintenance and treatment at the hatchery (e.g., formalin, and antibiotics).

The importance of this issue for all BCRP target stocks is rated low because of past infrastructure investments and internal processes to address fish health issues and hatchery water quality at CNFH. The understanding of the issue is rated high given the priority placed by the USFWS on fish health issues, past and current fish health studies and reporting processes, full-scale implementation of the ozone treatment plant, and issuance of an NPDES permit.

6.3 Analysis of CNFH Issue Statement 7: In-stream flows in upper Battle Creek are reduced by CNFH water diversion(s) between the diversion site(s) downstream to the location where hatchery water is returned to Battle Creek (a distance of 1.2 to 1.6 miles depending on location of the water intake). These diversions may result in inadequate in-stream flows or increased water temperatures in this segment of the river during drought conditions.

Terraqua (2004) identified two issues related to the CNFH water diversions and in-stream flows in Battle Creek:

1. The quantity of fish habitat as affected by in-stream flow levels may be a limiting factor to all life stages of all anadromous salmonids in Battle Creek. Warm water temperatures may be a limiting factor during June through September and may affect upstream migration of adult spring and fall Chinook salmon and possibly late-arriving winter Chinook or early arriving steelhead; spawning of winter Chinook and spring Chinook; fry/juvenile production of winter- and late-fall Chinook and steelhead; and migrating juvenile fall- and late-fall Chinook and steelhead.
2. Water use at CNFH is non-consumptive and all water diverted from Battle Creek for the hatchery is returned to the creek through an overflow channel, the fish ladder, a wastewater ditch, or the pollution abatement pond outfall. However, water quantity and temperatures may be adversely affected in the reach between CNFH water diversions and the effluent return site, particularly during drought conditions.

The impacts of CNFH on Battle Creek water temperature and Battle Creek flow are considered separately in this analysis.

6.3.1 Battle Creek Water Temperature

Ward and Kier (1999b) reported that several factors cause warming in Battle Creek during the summer months of June through September. Dry and warm meteorological conditions tend to increase water temperature, whereas wet and cold conditions lead to lower water temperatures. Water diversions from North Fork to South Fork Battle Creek tend to warm the North Fork Battle Creek by removing its cool water, and to cool the South Fork Battle Creek by introducing relatively cold water at South and Inskip Powerhouses. The flow released below diversion dams also affects in-stream water temperature. In general, larger stream flows warm more slowly than smaller stream flows. Finally, diversions of relatively cold spring water out of the stream channel increase in-stream water temperatures.

Juvenile salmonid habitat quality is related to suitable conditions including water temperatures. Based on available summer water temperature data for lower Battle Creek, juvenile Chinook salmon and *O. mykiss* would not exhibit prolonged rearing or residence in the 1.6-mile hatchery-affected reach during the summer months. Emigrating juvenile salmon and *O. mykiss* must traverse the hatchery-affected reach to exit Battle Creek and enter the

Sacramento River. Juvenile spring Chinook emigrate primarily during the months of November through May, juvenile winter Chinook salmon would emigrate from April through June, late-fall Chinook salmon from April through December, and juvenile *O. mykiss* during all months (Jones and Stokes 2005a).

Myrick and Cech (2001) reported:

> *Juvenile Chinook salmon and steelhead thermal tolerances are a function of acclimation temperature and exposure time. Fish acclimated to high temperatures tend to show greater heat tolerance than those acclimated to cooler temperatures. Once temperatures reach a chronically lethal level (approximately 25°C, [77°F]), the time to death decreases with increasing temperature. The chronic upper lethal limit for Central Valley Chinook salmon is approximately 25°C (77°F), with higher temperatures (up to 29°C [84°F]) tolerated for short periods.*

Nielsen et al (1994) suggested 24°C (75°F) was the upper lethal temperature for juvenile steelhead in northern California. Myrick and Cech (2001) indicated that Central Valley steelhead can be expected to show significant mortality at chronic temperatures exceeding 25°C (77°F), although they can tolerate temperatures as high as 29.6°C [85°F] for short periods.

Myrick and Cech (2001) also reported that juvenile salmonids:

> *Are more stenothermal, requiring temperatures between 15 and 19°C (59°F and 66°F) for maximum growth under optimal conditions. In order to complete the parr-to-smolt transformation, however, cooler temperatures (10 - 17°C [50°F – 62.5°F] for Chinook salmon; 6 - 10°C [43°F – 50°F] for steelhead) are needed to maximize saltwater survival. Cooler temperatures also reduce the risk of predation and disease, both of which are enhanced at higher temperatures.*

The planned temperature regime for the BCRP was developed using the SNTEMP model (TRPA 1998a and TRPA 1998b). Information was presented in the EIS/EIR (Jones & Stokes 2005a), the action specific implementation plan (Jones & Stokes 2005a), and summarized in Appendix K of the EIS/EIR (Jones and Stokes 2005b). The temperature analysis was presented for Battle Creek under a Proposed Action (removal of five dams) and No Action alternatives, and assessed in relation to temperature tolerances of anadromous salmonids. For most of the year, water temperatures are sufficiently cool to provide high-quality habitat for *O. mykiss* and Chinook salmon in the restoration project area (Jones & Stokes 2005a). However, water temperatures predicted for main-stem Battle Creek at the Coleman Powerhouse exceeded 65°F and were often much higher for both the Proposed Action and No Action alternatives during the period June through September.

The primary water supply for the CNFH is via Intake One located in the tailrace of the PG&E Coleman Powerhouse, which originates in upper Battle Creek. Water temperatures in the CNFH raceways have been reported as high as 69°F during the months of July and August in previous years (S. Hamelberg, Pers. Comm.), and reached 76°F in the summer of 2015 (K. Neimela, Pers. Comm.). During a portion of the summer months, the USFWS (2011) reported that elevated water temperatures preclude juvenile salmonid movement into lower Battle Creek.

Analysis of water temperatures immediately upstream from the Coleman Powerhouse during summer indicates water temperatures may exceed 70^o F. As such, the initial conditions are undesirable, but data are not available nor have studies been conducted to determine what affect the CNFH diversions, if any, have on water temperatures in the 1.6-mile hatchery affected section of Battle Creek or further downstream.

6.3.2 Battle Creek Flow

Kier and Associates (1999) recommended minimum in-stream flows that provided the maximum weighted usable area (WUA) for limiting life stages and biologically-optimum ecosystem restoration in the main-stem Battle Creek of 72 cfs during June, 59 cfs during July and August, and 69 cfs during the period September through November. The USFWS (2004) reported that the amount of water diverted into CNFH varies throughout the year, depending on the water demands for fish culture activities associated with various cycles of collecting, spawning, and rearing three stocks of anadromous salmonids (Figure 10). Total water use at the hatchery is highest from October through early-March (generally >100 cfs) when broodstock collection, spawning, egg incubation, and rearing all occur simultaneously. Lowest water use at CNFH occurs in May (54 cfs) following the release of juvenile fall Chinook salmon. Total diversion through the CNFH intakes also includes 13 cfs that is delivered to downstream water users without being used at the hatchery (USFWS 1986).

Lowest stream flows in Battle Creek occur during the late summer months (Figure 10). Average monthly flow in Battle Creek during September is 260 cfs, although the minimum daily stream flow for the period of record is 102 cfs and was recorded on October 27, 1992 (USGS 2012).

USFWS (2011) reported that drought conditions could cause hatchery water withdrawals to lower Battle Creek flows in the hatchery-affected section of Battle Creek below recommended minimum flows. For example, between October 1961 and March 2011, average daily flows in Battle Creek were less than total water requirements (CNFH water requirements plus minimum recommended flows by month) 3.0% of the time (547 days out of 17,943 days on record, based on USGS historic flow records) (USFWS 2011).

The USFWS (2011) also examined the flow data for number of days and distribution of days where: (1) recommended minimum flow values would not be met in the 1.6-mile reach affected by the hatchery diversion, and (2) periods when the weighted usable area (WUA) was less than 95%. From October 1961 through March 2011, flows in the hatchery-affected reach failed to meet the flow necessary for the 95% WUA approximately 0.9% of the time; 167 out of 17,943 days on record. Days with mean flows that were less than that necessary to maintain 95% WUA were limited to December (94 days), October (28 days), January (33 days) and February (12 days). Times when flows were less than 95% WUA were largely consistent with known drought years (late-1970s, late-1980s, and early-1990s).

The results of the USFWS (2011) analyses indicate that during extreme drought conditions, water withdrawals for hatchery diversions could decrease flow in the 1.6-mile hatchery-affected reach of Battle Creek below the recommended minimum levels and, at times, below the 95% weighted usable area level. In these situations, modifications to CNFH operations could be implemented. For example, USFWS (2011) suggested water from hatchery raceways could be reused in the adult holding ponds from October through February. This operational change would reduce CNFH water requirements by approximately 22 cfs. Based on the flow data from 1961 through 2011, this change would result in a failure to meet the 95% weighted usable area only 0.3% of the time, equating to a 67% reduction of impact (i.e., 0.9% reduced to 0.3%).

Overall, the importance of this issue (i.e., the effect of hatchery diversions on in-stream water temperature and flows) is considered low. Understanding for both flow and temperature effects is considered high based on temperature modeling work and the use of those modeling results in subsequent analyses to develop the BCRP alternatives, and to select the proposed action. In addition, water temperature monitoring has occurred immediately upstream of the fish barrier weir as part of juvenile fish monitoring. CNFH diversions affected suitable flows in the 1.6 mile segment of Battle Creek less than 1% of the available days over a 50-year period (USFWS 2011). Furthermore, in circumstances where CNFH diversion could reduce flows below suitable levels, hatchery personnel can alter hatchery operations to minimize diversions.

6.4 Analysis of CNFH Issue Statement 8: High abundance of hatchery-origin adult salmon in lower Battle Creek may create adverse effects including (1) reduction of in-stream spawning success due to the physical destruction of redds; (2) undesirable interbreeding between natural and hatchery origin steelhead and fall and late-fall Chinook salmon; and (3) increased mortality of juvenile salmonids migrating from upper Battle Creek.

Lower Battle Creek (the stream segment from the CNFH fish barrier weir downstream to the confluence with the Sacramento River) is currently managed primarily as fall Chinook salmon spawning and rearing habitat. Although *O. mykiss*, late fall Chinook, winter Chinook, and spring Chinook are expected to use lower Battle Creek as a migration corridor, it is not expected that spawning or rearing by *O. mykiss*, late fall Chinook, winter Chinook or spring Chinook in this segment would contribute to (or appreciably harm) restoration objectives for the BCRP.

Impacts of CNFH fall Chinook salmon spawning on reproductive success and fitness of natural-origin anadromous salmonids were considered previously. Here we consider the potential impacts of hatchery origin fall Chinook and hatchery origin *O. mykiss* on the emigration and rearing of juvenile salmonids in Battle Creek.

The CDFW and USFWS cooperatively operate a fish-counting weir near the mouth of Battle Creek during the immigration of adult fall Chinook. Counts of fishes passing this counting weir are used to make estimates of the fall Chinook run-size in Battle Creek and to provide "real-time" data that are used to inform operational decisions related to opening and closing of the hatchery fish ladder. For example, when fish counts at the weir are substantially higher than the hatchery's broodstock collection targets, the hatchery ladder may be opened longer to collect fall Chinook salmon in excess of the number needed to meet the hatchery-spawning target. This is done to help reduce the abundance of fall Chinook salmon in lower Battle Creek and improve conditions for natural reproduction. In the absence of this action, fall Chinook salmon may become overcrowded in the creek, and suffer decreased spawning success due to pre-spawn mortality and physical destruction of redds.

The USFWS and CDFW have informally established a spawning escapement maximum of 20,000 fall Chinook salmon for lower Battle Creek (D. Killam pers. comm.), and UFWS has removed excess fish via collections at CNFH. However, no specific research has been conducted to determine if this is an appropriate maximum number of spawners for lower Battle Creek, given the amount and condition of available habitat.

The USFWS (2011) reported that natural-origin juvenile salmonids emigrating from the restoration area during the months of October through November could be negatively affected as they emigrate through large congregations of hatchery-origin fall Chinook salmon in lower Battle Creek. Negative effects could occur as stress, alteration of migratory patterns, or predation.

Although limited information is available on the effects of this issue for the juvenile rearing and emigration life stage, the importance of this issue is rated low all BCRP target stocks. For *O. mykiss* and spring Chinook, peak juvenile emigration does not occur when adult fall Chinook are present (between October and November). Late-fall and winter juveniles do emigrate during this period, but the scientific literature and hypothesized mechanism of spawning adults adversely impacting emigrating juveniles do not appear to support an importance ranking greater than low.

Understanding for all stocks is rated medium due to the lack of scientific information on the direct adverse effects of large numbers of adult salmon in lower Battle Creek on juvenile emigration.

6.5 Analysis of CNFH Issue Statement 9: Releases of hatchery-produced juvenile Chinook salmon and steelhead from CNFH may result in predation on and behavior modifications to natural-origin fish produced in the restoration area.

Interactions between hatchery- and natural-origin salmonids in streams may have important negative ecological consequences (Weber and Faush 2003). Negative effects of these interactions on natural-origin juvenile fish may include:

1. Hatchery fish predation on natural-origin juvenile salmonids that may be influenced by management decisions such as location and timing of fish release, or number or size of fish released.

2. Altered migration patterns due to the presence of large numbers of hatchery-origin juveniles.

3. Competition for limited resources (e.g., food and space) and habitat displacement.

Predation by CNFH steelhead is thought to have the largest potential adverse effect, and is the focus of analysis.

Hatchery releases can have substantial indirect effects (negative or positive) on natural-origin fish, either by attracting predators and aggravating predation (Brown and Mate 1983; Collis et al. 2001), or by swamping natural prey thereby reducing predation on natural-origin salmon (Marnell 1986; White et al 1995). Predation is part of salmonid natural ecology, and the significance is inversely related to population size. Predation by hatchery-produced juvenile salmonids on natural-origin salmonids would reduce the number of natural-origin fish, but the population-level effects are harder to elucidate. In freshwater, juvenile steelhead have been reported to feed on a variety of food items of which aquatic insects and other invertebrates make up the greatest proportion (Shapavolov and Taft 1954, Johnson and Johnson 1981, Angradi and Griffith 1990, Pert 1993, Merz and Vanicek 1996, Merz 2002, Unger 2004, Rundia and Lindely 2007). However, some juvenile steelhead have also been reported to feed on small fish (Busby et al 1996, Merz 2002). Hallock (1989) reported that the stomach contents of steelhead yearlings released into Battle Creek in February and March 1975 contained an average of 1.4 fall Chinook salmon per steelhead.

Based on juvenile fish trapping in lower Battle Creek, juvenile spring Chinook salmon are present in lower Battle Creek from early November through early February, with a peak in early January (Whitton et al 2006, 2007a, 2007b, 2007c, 2007d, 2007e, Whitton et al 2008, Whitton et al 2010, and Whitton et al 2011). Juvenile *O. mykiss* have been detected in lower Battle Creek from December through June with the majority of fish occurring during the April through early June period (Whitton et al 2006, 2007a, 2007b, 2007c, 2007d, 2007e, Whitton et al 2008, Whitton et al 2010, and Whitton et al 2011).

The USFWS (2011) evaluated impacts of juvenile releases from CNFH and LSNFH based on a qualitative assessment of risks. The authors concluded,

> *While substantial information exists to quantitatively determine levels of negative impacts resulting from various hatchery activities (e.g., broodstock collection, hatchery water supply, and facility operations), we cannot explicitly quantify with a reasonable level of certainty the effects of juvenile [hatchery] releases. The difficulty in quantifying impacts is complicated by the complex biology of salmon and steelhead and the multitude of factors that can simultaneously affect both hatchery and natural salmonids.*

Approximately 12 million fall Chinook salmon smolts (75 mm fork length, 90 fish/lb) are released into Battle Creek downstream of the barrier weir during April. Juvenile late-fall Chinook salmon are reared at CNFH for approximately one year and released into Battle Creek from December through early-January at approximately 135 mm fork length (13 fish/lb) with a release target of one million juvenile fish. Ecological interactions between the larger juvenile hatchery-produced late-fall Chinook salmon and naturally produced juvenile salmonids are poorly understood.

Releases of juvenile late-fall Chinook salmon do not exceed program production targets by more than 15% (i.e. ±150,000). Releases are conducted over the course of one or two days and are timed to coincide with high flow and turbidity events, which promote rapid emigration and afford protection to emigrating natural-origin juveniles by discouraging predation.

All CNFH produced juvenile steelhead are released as yearlings at a size of approximately 200 mm (4 fish/lb) in the Sacramento River 13 miles downstream from the confluence of Battle Creek near Bend Bridge (see Figure 2 in Appendix A) during late January. Hatchery-origin steelhead remaining in the release area (i.e., residualizing in the Sacramento River) could potentially consume spring and winter Chinook salmon juveniles as they emigrate from the restoration area down through the Sacramento River. However, steelhead are opportunistic feeders and more likely to prey on the abundant and less-agile newly-emerged fall Chinook fry rather than winter and spring Chinook salmon, which are larger and less abundant. In addition, naturally produced resident *O. mykiss* are known to occur in the Sacramento River in the release area and downstream, and may have a larger effect on juvenile salmonids produced in the restoration area.

The best available information to characterize possible predation losses associated with this issue were incorporated in the Chinook life cycle model. Results indicate low population effects for fall Chinook, and medium population effects for late-fall, spring and winter Chinook.

Based upon the collective information, this issue is considered to have low importance for fall Chinook, but of medium importance for late-fall, spring and winter Chinook. The importance on steelhead smolts emigrating from the BCRP area is considered low because steelhead emigrants will be of sufficient size to avoid predation by hatchery juveniles.

The understanding of this issue is estimated as medium for all Chinook salmon stocks, based upon information on timing and size of migrant fish and prior behavioral interaction investigations. The understanding of this issue for BCRP-origin steelhead is considered high based upon expected size and swimming performance of emigrating steelhead smolts.

6.6 Analysis of BCRP Issue Statement A: Habitat quality and quantity may be insufficient to support BCRP population objectives.

Enhanced availability and improved productivity of juvenile salmonid rearing habitat was an implicit expectation for the BCRP (Terraqua 2004). The quantitative life cycle models represented this expectation by applying reach-specific rearing capacities as expressed in BCRP documents (see Appendixes D and E). Model results indicate there is considerable capacity for supporting Battle Creek population objectives. However, model results also demonstrate the sensitivity of population performance to rearing habitat quantity and quality. For example, changes in habitat accessibility associated with natural barriers or changes in survival associated with water temperatures, had considerable influence on equilibrium population abundances

BCRP Issue Statement A was determined to have high importance and medium understanding for spring Chinook, winter Chinook, late fall Chinook and steelhead. BCRP IS-A is not applicable to fall Chinook because they are not currently a BCRP target species. While there is little uncertainty regarding the importance of rearing habitat quality and quantity within Battle Creek, the medium understanding is appropriate because insufficient data is currently available to assess realized juvenile salmonid rearing capacity. LCM outcomes are based upon an expectation for high quality and highly productive habitats, but these inputs and model assumptions have not yet been verified by field studies or empirical observations.

6.7 Analysis of BCRP Issue Statement B: Battle Creek water temperatures may not be suitable to support salmonid populations consistent with BCRP population objectives.

Water temperatures suitable to support rearing juvenile salmonids were an implicit expectation for success of the BCRP (Terraqua 2004). The quantitative life cycle models represented this expectation by applying reach-specific water temperature data (model-based) to assess capacity to support rearing juvenile salmonids (see Appendixes D and E). Model results indicate expected water temperatures can support Battle Creek population objectives, but also demonstrate sensitivity of population performance to water temperatures. For example, the spatial distribution of target species in BCRP area appeared to be strongly constrained by suitable water temperatures. The effect was not quantified, but patterns suggest water temperatures will be a critical factor for determining realized spatial distribution and productivity for rearing juveniles.

BCRP Issue Statement B was determined to have high importance and medium understanding for all BCRP target species. This issue is not applicable to fall Chinook because they do not occur in the BCRP area. While there is little uncertainty regarding the importance of water temperatures within Battle Creek, the medium understanding is appropriate because insufficient data is currently available to assess actual water temperatures in Battle Creek. LCM outcomes are based upon modeled daily average water temperatures, but these inputs and model assumptions which not been verified by field observations.

The assessments of importance and understanding from the issue analyses presented above are summarized in Table 16. These assessments support a revised conceptual model of the factors affecting natural-origin juvenile salmonid rearing and immigration in Battle Creek (Figure 16). None of the CNFH issues considered were found to be of high importance, although both of the BCRP issues considered were found to be of high importance to one or more BCRP target stocks (Table 16). One of the CNFH issues considered was found to be of medium importance to one or more BCRP target stocks. Understanding was found to be medium for CNFH issues one, eight and nine, and BCRP issues A and B. Understanding was found to be high for CNFH issues six and seven.

1 **Table 16. Collective ratings of importance and understanding of issue affecting natural-origin**
2 **juvenile fish rearing and emigration from the Battle Creek Restoration Project area.**

Issue Statement	Factors Evaluated	Battle Creek restoration area anadromous salmonid stocks				
		SH	**SC**	**FC**	**LFC**	**WC**
CNFH IS-1 – An unscreened water diversion used at times to deliver water to the CNFH may result in the entrainment of Battle Creek juvenile salmonids.	Importance	L	L	NA	L	L
	Understanding	M	M	NA	M	M
CNFH IS-6 – Pathogens resulting from CNFH operations may be transmitted to wild fish in the restoration area.	Importance	L	L	L	L	L
	Understanding	H	H	H	H	H
CNFH IS-7 – In-stream flows in upper Battle Creek are reduced by CNFH water diversion(s) between the diversion site(s) downstream to the return effluent site (distance of 1.2 to 1.6 miles depending on location of the water intake). These diversions may result in inadequate in-stream flows or increased water temperatures in this segment of the river during drought conditions.	Importance	L	L	L	L	L
	Understanding	H	H	H	H	H
CNFH IS-8 – High abundance of hatchery-origin adult salmon in lower Battle Creek may create adverse effects including (3) increased mortality of juvenile salmonids emigrating from upper Battle Creek.	Importance	L	L	NA	L	L
	Understanding	M	M	NA	M	M
CNFH IS-9 – Releases of hatchery-produced juvenile Chinook salmon and steelhead from CNFH may result in predation of and behavior modifications to natural-origin fish produced in the restoration area.	Importance	L	M	L	M	M
	Understanding	H	M	M	M	M
BCRP IS-A – Habitat quality and quantity may be insufficient to support BCRP population objectives	Importance	H	H	NA	H	H
	Understanding	M	M	NA	M	M
BCRP IS-B – Battle Creek water temperatures may not be suitable to support salmonid populations consistent with BCRP population objectives	Importance	H	H	NA	H	H
	Understanding	M	M	NA	M	M

1/ SH = steelhead, SC = spring Chinook salmon, FC = fall Chinook salmon, LFC = late fall Chinook salmon, WC = winter Chinook salmon

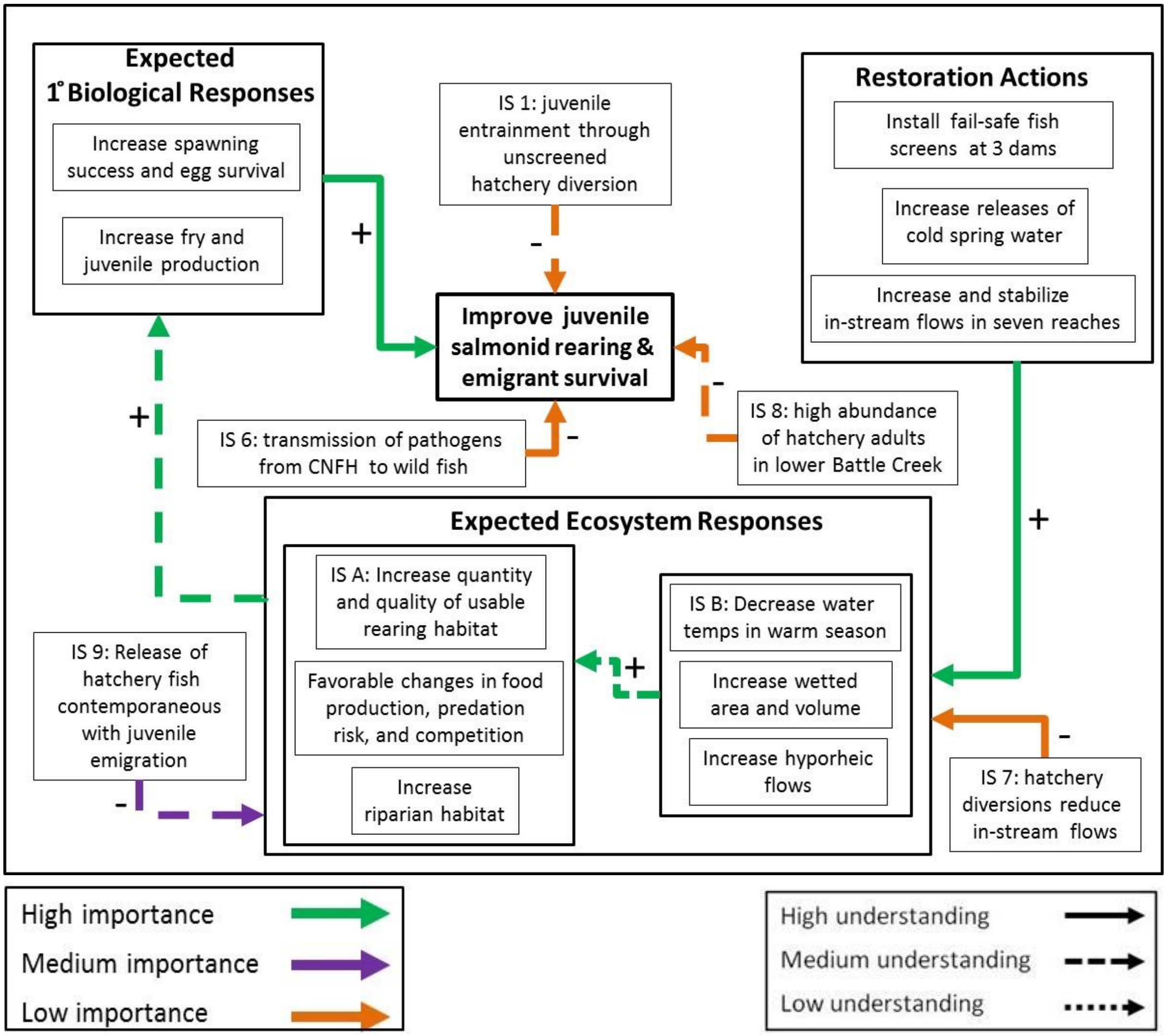


Figure 16. Revised conceptual model diagram of factors affecting natural-origin juvenile salmonid rearing and emigration in Battle Creek. This diagram includes the seven issues analyzed under this life-stage event. Variations in arrow color and line-type are used to indicate importance and understanding based on the issue analyses. Definitions for the different arrows are provided in the legends below the diagram. The highest level of importance and lowest level of understanding are indicated for an issue in cases where these factors vary among the fish stocks (see Table 16 for details).

7. River Estuary and Ocean Rearing and Survival of Salmonids Conceptual Model and Issue Analysis

This conceptual model focuses on the CNFH issues and life history factors related to river, estuary and ocean rearing of juvenile salmonids produced in upper Battle Creek (Figure 17). The model identifies restoration actions that aim to increase the survival of natural-origin salmonids produced in upper Battle Creek. Restoration actions are expected to positively affect adult salmonid immigration, spawning and egg incubation, and juvenile rearing and emigration from Battle Creek primarily through improvements in habitat conditions and ecosystem responses (Terraqua 2004). The model also identifies the major stressors in the

Sacramento River, San Francisco Estuary, and Pacific Ocean that impact salmonid rearing and survival; however, the importance and understanding of these stressors are not analyzed here (see Williams 2012 for a recent thoughtful review). One issue related to CNFH programs has the potential to affect the rearing and survival of target salmonids outside the Battle Creek watershed. Information related to this issue is analyzed to estimate the importance and understanding of the issue's influence on the terminal outcome (increased survival of natural-origin salmonids). Ratings of importance and understanding are provided at the end of this section (Table 17). A revised conceptual model diagram incorporating results from the issue analyses also is presented at the end of this section (Figure 18).

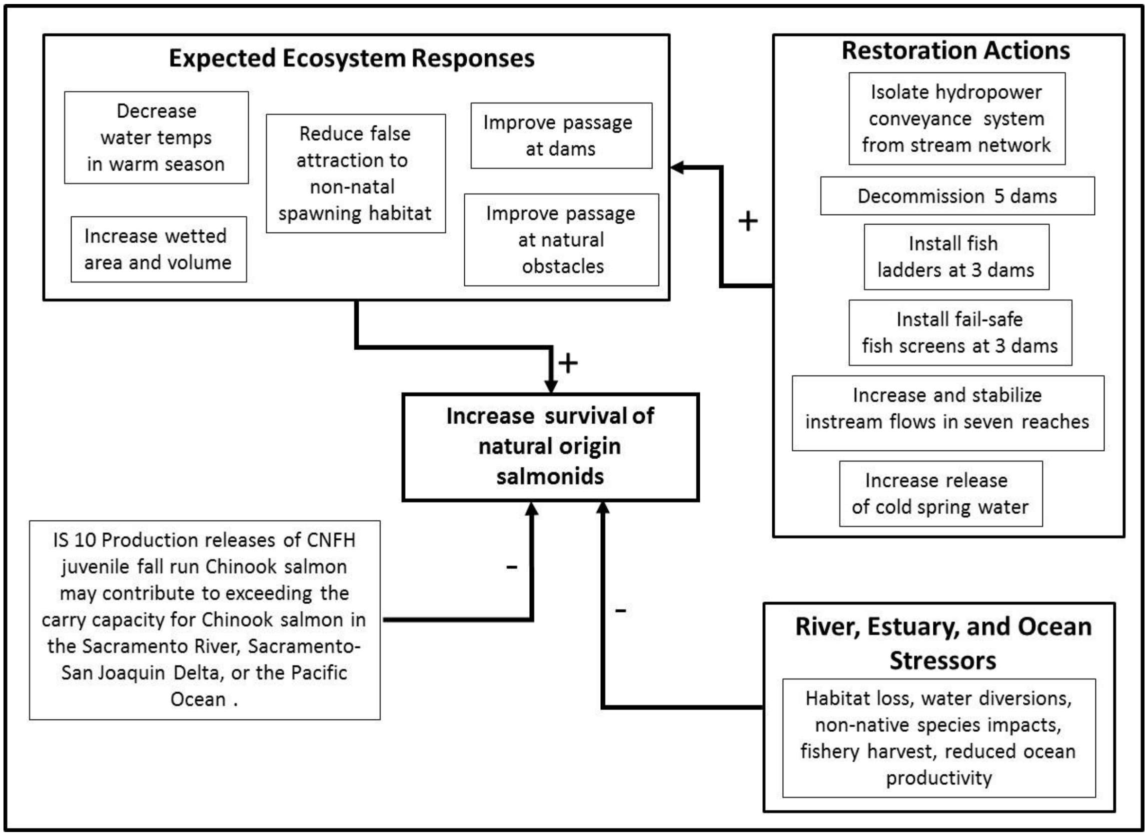


Figure 17. Conceptual model of CNFH issues, Battle Creek Restoration actions, Expected Ecosystem Responses, and River, Estuary, and Ocean stressors affecting the survival of natural-origin Battle Creek salmonids. Levels of importance and understanding are not shown in this diagram.

7.1 Analysis of CNFH Issue Statement 10: Current production releases of CNFH juvenile fall run Chinook salmon may contribute to exceeding the carrying carry capacity for Chinook salmon in the Sacramento River, Sacramento-San Francisco Estuary, or the Pacific Ocean leading to reduced success of Battle Creek origin salmonids.

The CNFH annually releases approximately 12 million fall Chinook, 1 million late-fall Chinook and 600,000 steelhead. With the exception of steelhead, fish are released primarily to lower

Battle Creek in April and December/January. Fall Chinook are released at 90 fish/lb, late-fall Chinook salmon released at 13 fish/lb, and steelhead released at 4 fish/lb. The impacts of CNFH produced steelhead and Chinook salmon due to predation on emigrating of naturally produced juvenile salmonids are considered in Section 6.5.

The release of large numbers of hatchery fish in the Central Valley may result in conditions where the carrying capacity of the aquatic environment is exceeded. This may lead to reduced survival of both hatchery and naturally produced salmon that rely on this environment for rearing and migration purposes. Unfortunately, biologists' ability to quantify possible effects to carrying capacity from hatchery releases is quite poor. This is due to the fact that system carrying capacity for salmonids is influenced by a myriad of factors that vary in both time and space, and therefore affect the quality and quantity of available habitat which determines carrying capacity. These factors include, but are not limited to:

1. Flow timing, duration, amount, magnitude and variation.
2. Water temperature, timing and variation.
3. Water quality (pollutants present, pH, oxygen and nutrient levels).
4. Stream structure (habitat types and diversity, amounts and location).
5. Food type, production and availability to salmon.
6. Predator abundance, size, distribution and type (birds, fishes, and mammals).
7. Competition with other species whose abundance also varies over time.
8. Climatic variation (e.g., changing ocean conditions).

In addition, human manipulation of all the above factors on an annual or decadal basis further complicates biologists' ability to conduct evaluations to measure system carrying capacity for salmonids. The size of the system being measured also is problematic from both a research and cost perspective.

An exception comes from a study of interactions of hatchery and natural-origin Chinook at the Sacramento River near the mouth of Battle Creek. In this study, Weber and Fausch (as cited in USFWS 2011) concluded that hatchery-origin fish were not likely to utilize the stream margins as much as the naturally produced fish due to their advanced state of smoltification. However, when hatchery- and natural-origin fish did co-occur, natural-origin fish experienced a negative growth effect due to the presence of or competition with hatchery-origin fish. The authors also examined duration of concurrent residence between hatchery and natural fall Chinook in the upper Sacramento River and concluded that mid-April was a relatively effective time to release hatchery fall Chinook to reduce potential interactions with natural-origin Chinook in stream margin rearing areas. Although this study assessed the potential for interactions within the upper Sacramento River, it did not investigate interactions within the lower river, estuary, or ocean environments.

Studies of salmon and steelhead carrying capacity in the Estuary or off the coast of California are not currently available. However, Levin et al. (2001) evaluated and observed a strong, negative relationship between the number of hatchery fish released and the survival of natural-origin Chinook salmon from the Colombia River basin. The authors found this effect was particularly strong in years of poor ocean conditions.

Even with the studies described above, it is currently not possible to quantify the effect CNFH releases have on the carrying capacity of the Sacramento River, the San Francisco Estuary (particularly the Sacramento-San Joaquin Delta), or the marine environment; nor is it possible to determine if current hatchery release numbers, or size at release, are leading to the reduced survival of Battle Creek natural-origin juveniles.

What is known, however, is that while natural juvenile fish abundance varies as the environment changes, hatchery production is fairly constant. The CNFH is able to release the same number of juveniles regardless of environmental conditions present in Battle Creek, the Sacramento River, Estuary, or Pacific Ocean. Although speculative, when survival conditions are poor for naturally produced juveniles, the release of large numbers of hatchery fish likely results in increased competition for food, which in turn reduces natural-origin fish survival even further. As survival conditions improve, hatchery releases may have less effect on natural-origin juvenile survival, but again this is speculation.

For Battle Creek, CNFH fall Chinook are released at a size and time similar to those of naturally produced smolt-sized spring Chinook (Whitton et. al 2008 and 2011). It is important to note however, many spring Chinook emigrate in January as fry and this life history strategy would be less likely to compete with CNFH fall Chinook releases (M. Brown, pers. comm.). Nevertheless, hatchery impacts to these fish may be quite high as they may have similar habitat and food source requirements. Impacts are potentially greater in the Sacramento River as both groups of fish are migrating rapidly from Battle Creek at this time of year.

In contrast, CNFH late-fall Chinook are released at a size substantially larger than naturally produced juveniles in Battle Creek. Therefore, competition between the two components (hatchery and natural) of the population should be quite low within the basin.

Winter Chinook juveniles are expected to emigrate from Battle Creek from September through November, when reestablished. Since hatchery fish are not released during this period, there should be no hatchery impacts to winter Chinook in Battle Creek. Competition between CNFH fall Chinook and winter Chinook could occur in the Sacramento River and Estuary if winter Chinook are present in these areas after April, given the release of CNFH fall Chinook in April. NMFS (2009) has reported that the peak emigration of winter Chinook salmon through the Sacramento-San Joaquin Delta occurs from January through April, but may extend from September through June. They also noted that winter Chinook were about 30 mm larger than fall Chinook. This size differential likely reduces the amount of competition between winter Chinook and CNFH fall Chinook and late-fall Chinook (NMFS 2009).

Based upon the analysis provided above, both importance and understanding of this issue are rated low. Much rearing of BCRP target stocks is expected to occur within Battle Creek, and CNFH produced fall Chinook have been observed to migrate quickly through the system (M. Brown, pers. comm.).

As recommended by a technical review of the draft CNFH AMP (TRP 2013), "a coordinated series of ecological studies are needed to assess carrying capacity, density dependent effects, predation, and other ecological effects of large-scale hatchery releases and ecological interactions of hatchery salmonids within the Battle Creek Watershed, as well as within the Sacramento River, and the San Francisco estuary and bay." Such studies will be needed to improve understanding of this issue, but involve many elements outside CNFH and the Battle Creek watershed and therefore are beyond the scope of diagnostic study recommendations for this AMP.

Table 17. Collective ratings of importance and understanding of issues affecting river, estuary, and ocean rearing and survival of anadromous salmonids.

		Battle Creek restoration area anadromous salmonid stocks 1/				
Issue Statement		**SH**	**SC**	**FC**	**LFC**	**WC**
CNFH IS-10 – Current production releases of CNFH juvenile fall run Chinook salmon may contribute to exceeding the carry capacity for Chinook salmon in the Sacramento River, Sacramento-San Joaquin Delta, or the Pacific Ocean leading to reduced success of Battle Creek origin salmonids.	Importance	L	L	L	L	L
	Understanding	L	L	L	L	L

1/ SH = steelhead, SC = spring run Chinook salmon, FC = fall run Chinook salmon, LFC = late fall run Chinook salmon, WC = winter run Chinook salmon

The issue analyses presented above and the associated assessments of importance and understanding support a revised conceptual model of the factors affecting the survival of natural-origin salmonids in the Sacramento River, San Francisco Estuary, and Pacific Ocean (Figure 18).

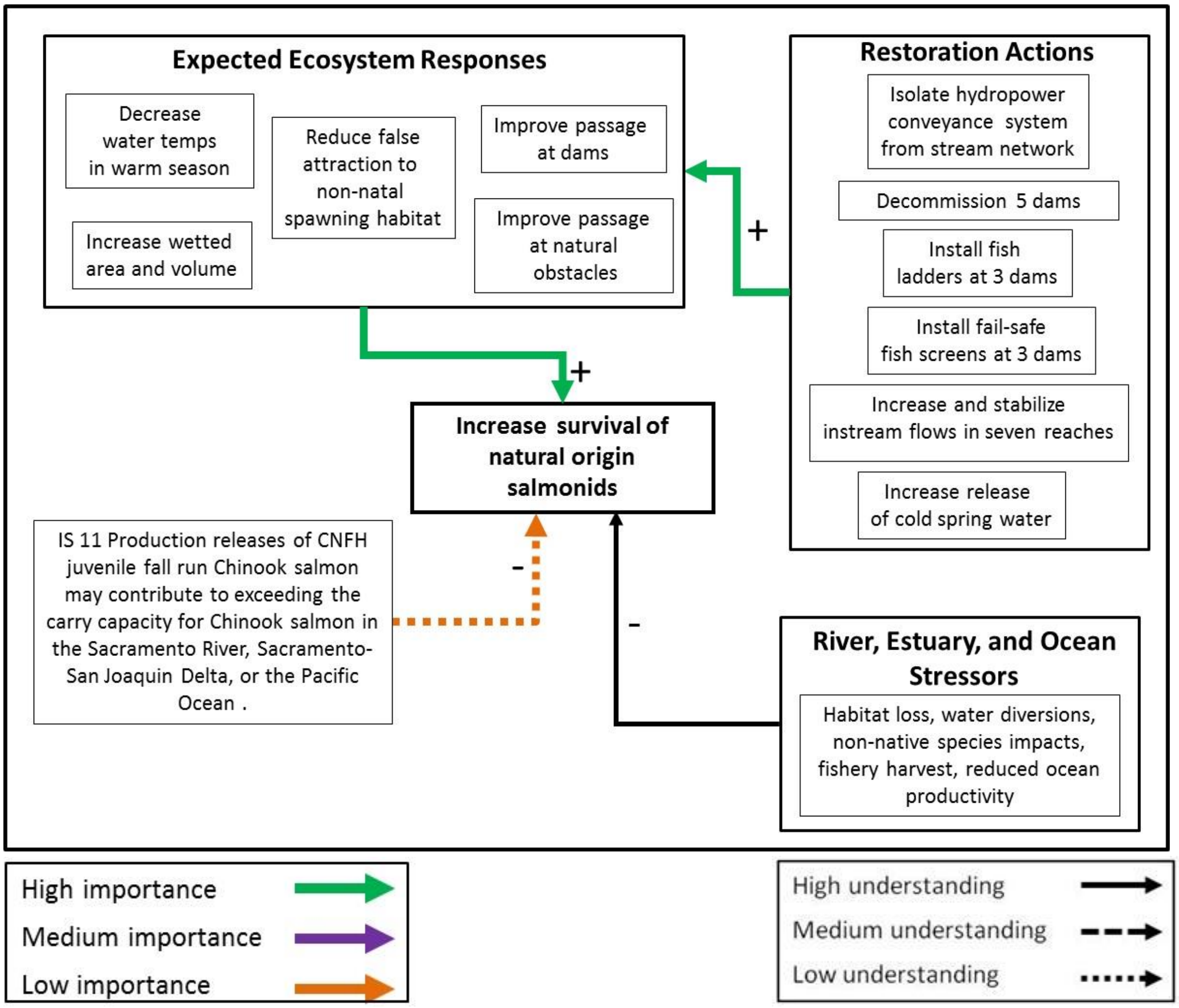


Figure 18. Revised conceptual model of CNFH issues, Battle Creek Restoration actions, and River, Estuary, and Ocean stressors affecting the survival of natural-origin Battle Creek salmonids. This diagram includes the one issue analyzed under this life-stage event. Variations in arrow color and line-type are used to indicate importance and understanding based on the issue analysis. However, no level of importance or understanding is provided for River, Estuary, and Ocean stressors, because these stressors were not examined in this analysis. Definitions for the different arrows are provided in the legends below the diagram. The highest level of importance and lowest level of understanding are indicated for an issue in cases where these factors vary among the fish stocks (see Table 17 for details).

8. Cumulative Analysis of Issues Affecting Salmonid Stocks Targeted for Restoration

This section attempts to summarize the issue ratings of importance and understanding for each of the stocks targeted for restoration in upper Battle Creek. The ratings are examined in an overall sense to help elucidate priorities for pursing one or more potential actions. While life-stage specific effects were analyzed earlier in this appendix, the cumulative analysis presented here focuses on species-life stages where issues appear to cause the most substantial effects. For CNFH issues, the analysis also identifies the hatchery program most closely linked with the issue. An overall summary of key results summarized in Tables 18 – 22 is presented below.

- CNFH Issue 1 (unscreened diversion) could result in substantial losses if long outages occur during peak juvenile emigration. However, the quantitative modeling approach indicates such events are rare and therefore of low importance for overall population performance of BCRP target stocks.
- CNFH Issue 3 (non-target passage) would most influence spawning and egg incubation (via introgression that might occur at this life stage) and was determined to have medium importance for BCRP steelhead and spring Chinook, but low importance for all other stocks.
- CNFH Issue 4 (high flow passage) would most influence spawning and egg incubation (via introgression that might occur at this life stage) and was determined to have low importance for all BCRP stocks.
- CNFH Issue 5 (handling effects) would most influence adult immigrants and was determined to have high importance for late fall Chinook, and medium importance for winter Chinook and steelhead.
- CNFH Issue 8 (abundant hatchery Chinook) would most influence spawning and egg incubation, but was of high importance only for fall Chinook in lower Battle Creek.
- CNFH Issue 9 would most influence juvenile emigrants and was determined to have medium importance for spring and late fall Chinook.
- BCRP issues related to habitat suitability and productivity (issues A and B) were of high importance for all BCRP target stocks.
- Adult immigrants having access beyond natural barriers (BCRP Issue C) was of high importance to winter Chinook, spring Chinook and steelhead.
- Redd scour (BCRP Issue D) due to high flow events was of high importance to steelhead and late-fall Chinook.
- Understanding for most issues was considered low or medium, suggesting the continued need for diagnostic studies and targeted monitoring.

The quantitative life cycle models considered two hypothetical scenarios instructive for assessing cumulative effects on satisfaction of BCRP population objectives: (1) CNFH least effects, and (2) natural barriers in the BCRP. As explained in Appendices E and F, the “CNFH least effects” scenario turns off or minimizes all adverse effects associated with CNFH operations. CNFH least effects produced the largest improvement for fall Chinook salmon (>100% equilibrium abundance for natural-origin fall Chinook), 31% equilibrium abundance improvement for late fall Chinook, a 16% improvement for spring Chinook, a13% improvement for winter Chinook and a 12% improvement for steelhead. If existing natural barriers to adult immigration were assumed to remain in the BCRP, fall and late fall Chinook were not affected, but equilibrium abundance for spring Chinook, winter Chinook and steelhead were reduced by 74%, 79%, and 76%, respectively.

Although the quantitative life cycle models does not represent all possible effects. They do suggest that cumulatively, both CFNH and BCRP issues have the potential to substantially influence the population performance of BCRP target species. The evaluation of specific issues (above) provide a prioritized and structured approach for selecting and implementing management actions, which can help to address important issues, and to resolve uncertainties in the current or future performance of the CNFH and BCRP. Prioritization of related actions and diagnostic studies are provided in the main report.

Table 18. Steelhead - Overall summary for levels of importance and understanding estimated from the analysis of CNFH and BCRP issues that potentially affect natural-origin steelhead in Battle Creek. Detailed analyses and rationales for the estimates can be found in the conceptual models identified in the first column. Factor rated: I=Importance, U=Understanding. (See Section 3 above for more details about these factors and the rating criteria.) Abbreviations for hatchery propagation programs: FC: fall Chinook salmon program; LFC: late-fall Chinook salmon program; SH: Central Valley steelhead program.

				Potentially Most Affected Life Stage Event	Affecting Hatchery Program		
Issue	**Evaluation Method**[/1]	**Importance**	**Understanding**		**FC**	**LFC**	**SH**
CNFH 1. Unscreened CNFH water diversion	Model & Qualitative	L	M	Juvenile rearing and emigration	X	X	X
CNFH 2. Exclusion of unmarked steelhead from the CNFH broodstock	Model & Qualitative	M	H	Spawning and egg incubation			X
CNFH 3. Limited ability to identify and prevent passage of: (1) all hatchery-produced salmonids, and (2) non-target runs of Chinook salmon	Model & Qualitative	M	M	Spawning and egg incubation	X	X	
CNFH 4. Hatchery fish may reach the BCRP area during high flow events	Model & Qualitative	L	L	Spawning and egg incubation	X	X	X
CNFH 5. Hatchery handling, sorting, and migratory delay may result in sub-lethal effects or mortality	Model & Qualitative	M	L	Adult immigration		X	X
CNFH 6. Transmission of pathogens from CNFH production to wild fish	Qualitative	L	H	Adult immigration	X	X	X
CNFH 7. Diversions reduce flows and increase water temperatures.	Qualitative	L	H	Juvenile rearing and emigration & Adult immigration		X	X
CNFH 8. High abundance of hatchery adults in lower Battle Creek	Model & Qualitative	L	M	Juvenile rearing and emigration	X		
CNFH 9. Release of hatchery fish may result in predation and behavior modifications of natural origin fish	Model & Qualitative	L	H	Juvenile rearing and emigration			X
CNFH 10. Hatchery production may contribute to exceeding the carrying capacity in the river, delta, or ocean	Qualitative	L	L	Rearing in river, estuary, and ocean	X		
BCRP A. Availability of suitable habitat for wild-origin adult and juvenile salmonids	Model & Qualitative	H	M	Adult immigration and juvenile rearing and emigration	None		
BCRP B. Water temperature effects on salmonid mortality	Model & Qualitative	H	M	Juvenile rearing and emigration	None		
BCRP C. Natural and man-made barrier effects on adult salmonid access	Model & Qualitative	H	M	Adult immigration	None		
BCRP D. Redd scouring and egg mortality due to extreme flow events	Qualitative	H	M	Spawning and egg incubation	None		

/1 Model: Quantitative life-cycle model. Qualitative: narrative evaluation of existing data and information

Table 19. Spring Chinook - Overall summary for levels of importance and understanding estimated from the analysis of CNFH and BCRP program issues that potentially affect natural-origin spring Chinook salmon in Battle Creek. Detailed analyses and rationales for the estimates can be found in the conceptual models identified in the first column. Factor rated: I=Importance, U=Understanding. (See Section 3 above for more details about these factors and the rating criteria.) Abbreviations for hatchery propagation programs: FC: fall Chinook salmon program; LFC: late-fall Chinook salmon program; SH: Central Valley steelhead program.

				Potentially Most Affected Life Stage Event	Affecting Hatchery Program		
Issue	**Evaluation Method**	**Importance**	**Understanding**		**FC**	**LFC**	**SH**
CNFH 1. Unscreened CNFH water diversion	Model & Qualitative	L	M	Juvenile rearing and emigration	X	X	X
CNFH 2. Exclusion of unmarked steelhead from the CNFH broodstock	NA	NA	NA	NA			
CNFH 3. Limited ability to identify and prevent passage of: (1) all hatchery-produced salmonids, and (2) non-target runs of Chinook salmon	Model & Qualitative	M	L	Spawning and egg incubation	X	X	
CNFH 4. Hatchery fish may reach the BCRP area during high flow events	Model & Qualitative	L	L	Spawning and egg incubation	X	X	
CNFH 5. Hatchery handling, sorting, and migratory delay may result in sub-lethal effects or mortality	Model & Qualitative	L	L	Adult immigration		X	X
CNFH 6. Transmission of pathogens from CNFH production to wild fish	Qualitative	L	H	Adult immigration	X	X	X
CNFH 7. Diversions reduce flows and increase water temperatures.	Qualitative	L	H	Juvenile rearing and emigration & Adult immigration		X	X
CNFH 8. High abundance of hatchery adults in lower Battle Creek	Model & Qualitative	L	M	Juvenile rearing and emigration	X		
CNFH 9. Release of hatchery fish may result in predation and behavior modifications of natural origin fish	Model & Qualitative	M	M	Juvenile rearing and emigration			X
CNFH 10. Hatchery production may contribute to exceeding the carrying capacity in the river, delta, or ocean	Qualitative	L	L	Rearing in river, estuary, and ocean	X		
BCRP A. Availability of suitable habitat for wild-origin adult and juvenile salmonids	Model & Qualitative	H	M	Adult immigration and juvenile rearing and emigration	None		
BCRP B. Water temperature effects on salmonid mortality	Model & Qualitative	H	M	Spawning and egg incubation	None		
BCRP C. Natural and man-made barrier effects on adult salmonid access	Model & Qualitative	H	M	Adult immigration	None		
BCRP D. Redd scouring and egg mortality due to extreme flow events	Model & Qualitative	L	M	Spawning and egg incubation	None		

/1 Model: Quantitative life-cycle model. Qualitative: narrative evaluation of existing data and information
/2 Revised rating listed first. Previous rating listed in parentheses.

Table 20. Fall Chinook - Overall summary for levels of importance and understanding estimated from the analysis of CNFH program issues that potentially affect natural-origin fall Chinook salmon in Battle Creek. Detailed analyses and rationales for the estimates can be found in the conceptual models identified in the first column. Factor rated: I=Importance, U=Understanding. (See Section 3 above for more details about these factors and the rating criteria.) Abbreviations for hatchery propagation programs: FC: fall Chinook salmon program; LFC: late-fall Chinook salmon program; SH: Central Valley steelhead program.

				Potentially Most Affected Life Stage Event	Affecting Hatchery Program		
Issue	Evaluation Method	Importance	Understanding		FC	LFC	SH
CNFH 1. Unscreened CNFH water diversion	NA	NA	NA	NA			
CNFH 2. Exclusion of unmarked steelhead from the CNFH broodstock	NA	NA	NA	NA			
CNFH 3. Limited ability to identify and prevent passage of: (1) all hatchery-produced salmonids, and (2) non-target runs of Chinook salmon	NA	NA	NA	NA			
CNFH 4. Hatchery fish may reach the BCRP area during high flow events	NA	NA	NA	NA			
CNFH 5. Hatchery handling, sorting, and migratory delay may result in sub-lethal effects or mortality	NA	NA	NA	NA			
CNFH 6. Transmission of pathogens from CNFH production to wild fish	Qualitative	NA	NA	Adult immigration			
CNFH 7. Diversions reduce flows and increase water temperatures.	Qualitative	L	H	Juvenile rearing and emigration & Adult immigration	X	X	X
CNFH 8. High abundance of hatchery adults in lower Battle Creek	Model & Qualitative	H	H	Spawning and egg incubation	X		
CNFH 9. Release of hatchery fish may result in predation and behavior modifications of natural origin fish	Model & Qualitative	L	M	Juvenile rearing and emigration			X
CNFH 10. Hatchery production may contribute to exceeding the carrying capacity in the river, delta, or ocean	Qualitative	L	L	Rearing in river, estuary, and ocean	X		
BCRP A. Availability of suitable habitat for wild-origin adult and juvenile salmonids	NA	NA	NA	NA	None		
BCRP B. Water temperature effects on salmonid mortality	NA	NA	NA	NA	None		
BCRP C. Natural and man-made barrier effects on adult salmonid access	NA	NA	NA	NA	None		
BCRP D. Redd scouring and egg mortality due to extreme flow events	NA	NA	NA	NA	None		

Table 21. Late-fall Chinook - Overall summary for levels of importance and understanding estimated from the analysis of CNFH program issues that potentially affect natural-origin late-fall Chinook salmon in Battle Creek. Detailed analyses and rationales for the estimates can be found in the conceptual models identified in the first column. Factor rated: I=Importance, U=Understanding. (See Section 3 above for more details about these factors and the rating criteria.) Abbreviations for hatchery propagation programs: FC: fall Chinook salmon program; LFC: late-fall Chinook salmon program; SH: Central Valley steelhead program.

Issue	Evaluation Method[1]	Importance	Understanding	Potentially Most Affected Life Stage Event	Affecting Hatchery Program: FC	Affecting Hatchery Program: LFC	Affecting Hatchery Program: SH
CNFH 1. Unscreened CNFH water diversion	Model & Qualitative	L	M	Juvenile rearing and emigration	X	X	X
CNFH 2. Exclusion of unmarked steelhead from the CNFH broodstock	NA	NA	NA	NA			
CNFH 3. Limited ability to identify and prevent passage of: (1) all hatchery-produced salmonids, and (2) non-target runs of Chinook salmon	Model & Qualitative	L	M	Spawning and egg incubation	X	X	
CNFH 4. Hatchery fish may reach the BCRP area during high flow events	Model & Qualitative	L	L	Spawning and egg incubation	X	X	
CNFH 5. Hatchery handling, sorting, and migratory delay may result in sub-lethal effects or mortality	Model & Qualitative	H	L	Adult immigration		X	X
CNFH 6. Transmission of pathogens from CNFH production to wild fish	Qualitative	L	H	Adult immigration	X	X	X
CNFH 7. Diversions reduce flows and increase water temperatures.	Qualitative	L	H	Juvenile rearing and emigration & Adult immigration		X	X
CNFH 8. High abundance of hatchery adults in lower Battle Creek	Model & Qualitative	L	M	Juvenile rearing and emigration	X		
CNFH 9. Release of hatchery fish may result in predation and behavior modifications of natural origin fish	Model & Qualitative	M	M	Juvenile rearing and emigration			X
CNFH 10. Hatchery production may contribute to exceeding the carrying capacity in the river, delta, or ocean	Qualitative	L	L	Rearing in river, estuary, and ocean	X		
BCRP A. Availability of suitable habitat for wild-origin adult and juvenile salmonids	Model & Qualitative	H	M	Adult immigration and juvenile rearing and emigration	None		
BCRP B. Water temperature effects on salmonid mortality	Model & Qualitative	H	M	Juvenile rearing and emigration	None		
BCRP C. Natural and man-made barrier effects on adult salmonid access	Model & Qualitative	L	M	Adult immigration	None		
BCRP D. Redd scouring and egg mortality due to extreme flow events	Qualitative	H	M	Spawning and egg incubation	None		

/1 Model: Quantitative life-cycle model. Qualitative: narrative evaluation of existing data and information

Table 22. Winter Chinook - Overall summary for levels of importance and understanding estimated from the analysis of CNFH program issues that potentially affect natural-origin winter Chinook salmon in Battle Creek. Detailed analyses and rationales for the estimates can be found in the conceptual models identified in the first column. Factor rated: I=Importance, U=Understanding. (See Section 3 above for more details about these factors and the rating criteria.) Abbreviations for hatchery propagation programs: FC: fall Chinook salmon program; LFC: late-fall Chinook salmon program; SH: Central Valley steelhead program.

				Potentially Most Affected Life Stage Event	Affecting Hatchery Program		
Issue	Evaluation Method[/1]	Importance	Understanding		FC	LFC	SH
CNFH 1. Unscreened CNFH water diversion	Model & Qualitative	L	M	Juvenile rearing and emigration	X	X	X
CNFH 2. Exclusion of unmarked steelhead from the CNFH broodstock	NA	NA	NA	NA			
CNFH 3. Limited ability to identify and prevent passage of: (1) all hatchery-produced salmonids, and (2) non-target runs of Chinook salmon	Model & Qualitative	L	H	Spawning and egg incubation	X	X	
CNFH 4. Hatchery fish may reach the BCRP area during high flow events	Model & Qualitative	L	H	Spawning and egg incubation	X	X	
CNFH 5. Hatchery handling, sorting, and migratory delay may result in sub-lethal effects or mortality	Model & Qualitative	M	L	Adult immigration		X	X
CNFH 6. Transmission of pathogens from CNFH production to wild fish	Qualitative	L	H	Adult immigration	X	X	X
CNFH 7. Diversions reduce flows and increase water temperatures.	Qualitative	L	H	Juvenile rearing and emigration & Adult immigration	X	X	X
CNFH 8. High abundance of hatchery adults in lower Battle Creek	Model & Qualitative	L	M	Juvenile rearing and emigration	X		
CNFH 9. Release of hatchery fish may result in predation and behavior modifications of natural origin fish	Model & Qualitative	M	M	Juvenile rearing and emigration			X
CNFH 10. Hatchery production may contribute to exceeding the carrying capacity in the river, delta, or ocean	Qualitative	L	L	Rearing in river, estuary, and ocean	X		
BCRP A. Availability of suitable habitat for wild-origin adult and juvenile salmonids	Model & Qualitative	H	M	Adult immigration and juvenile rearing and emigration	None		
BCRP B. Water temperature effects on salmonid mortality	Model & Qualitative	H	M	Spawning and egg incubation	None		
BCRP C. Natural and man-made barrier effects on adult salmonid access	Model & Qualitative	H	M	Adult immigration	None		
BCRP D. Redd scouring and egg mortality due to extreme flow events	Qualitative	L	M	Spawning and egg incubation	None		

/1 Model: Quantitative life-cycle model. Qualitative: narrative evaluation of existing data and information

9. Literature Cited

Alston, N. O., J. M. Newton, and M. R. Brown. 2007. Monitoring adult Chinook salmon, rainbow trout, and steelhead in Battle Creek, California, from November 2003 through November 2004. USFWS Report. U.S. Fish and Wildlife Service, Red Bluff Fish and Wildlife Office, Red Bluff, California. 75 p.

Angradi, T.R. and J. S. Griffith. 1990. Diel Feeding Chronology and Diet Selection of Rainbow Trout (*Oncorhynchus mykiss*) in the Henry's Fork of the Snake River, Idaho, Canadian Journal of Fisheries and Aquatic Sciences, 1990, 47(1): 199-209

Araki, H., W.R. Ardren, E. Olsen, B. Cooper, and M.S. Blouin. 2006. Reproductive success of captive-bred steelhead trout in the wild: Evaluation of three hatchery programs in the Hood River. Conserv. Biol. 21(1): 181-190.

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

Araki, H. B., B. A. Berejikian, M. J. Ford, and M.S. Blouin. 2008. Fitness of hatchery-reared salmonids in the wild. Evol. Appl. 1:342-355.

Araki, H. B. Cooper, and M. S. Blouin. 2009. Carry-over effects of captive breeding reduce reproductive fitness of wild-born descendants in the wild. Biology Letters, Conservation Biology. 10 June 2009.

Banks, J. W. 1969. A review of the literature on the upstream migration of adult salmonids. Journal of Fish Biology 1:85–136.

Bartholomew, J.L. and P.W. Reno. 2002. The history and dissemination of whirling disease. American Fisheries Society Symposium 29:3-24.

BCWC (Battle Creek Watershed Conservancy). 2001. Managing Risk to Facilitate the Success of the Battle Creek Salmon and Steelhead Restoration Project. Accessed on July 23, 2012 at http://www.battle-creek.net/pos_papers.html.

Bjornn, T.C., and D.W. Reiser. 1991. Habitat requirements of salmonids in streams. Pages 83-138, W.R. Meehan editor, in Influences of Forest and Rangeland Management on Salmonid Fisheries and Their Habitats. American Fisheries Society Special Publication No. 19. Bethesda MD.

Bottaro, RJ, and M. R. Brown. 2012. Monitoring adult Chinook salmon, rainbow trout, and steelhead in Battle Creek, California, from March through November 2011. USFWS Report. U.S. Fish and Wildlife Service, Red Bluff Fish and Wildlife Office, Red Bluff, California.

Brown, M. R., and N. O. Alston. 2007. Monitoring adult Chinook salmon, rainbow trout, and steelhead in Battle Creek, California, from November 2002 through November 2003. USFWS Report. U.S. Fish and Wildlife Service, Red Bluff Fish and Wildlife Office, Red Bluff, California.

Brown, R. F, and B. R. Mate. 1983. Abundance, movements, and feeding-habits of harbor seals, *Phoca vitulina*, at Netarts and Tillamook Bays, Oregon. Fishery Bull 81:291-301.

Busby P.J., T.C. Wainwright, G.J. Bryant, L.J. Lierheimer, R.S. Waples, F.W. Waknitz, and I.V.Lagomarsino. 1996. Status review of West Coast steelhead from Washington, Idaho, Oregon, and California. National Marine Fisheries Service. NOAA Technical Memorandum NMFS-NWFSC-27.

Chilcote, M.W., K.W. Goodson, and M.R. Falcy. 2011. Reduced recruitment performance in natural populations of anadromous salmonids associated with hatchery-reared fish Can. J. Fish. Aquat. Sci. 68: 511–522.

Clements, S.P., B.J. Hicks, J.F. Carragher, and M. Dedual. 2002. The effect of a trapping procedure on the stress Response of wild rainbow trout. North American Journal of Fisheries Management. 22(3): 907-916.

Colby, D.J. and M. R. Brown. 2012. Juvenile salmonid monitoring in Battle Creek, California, November 2010 through June 2011. USFWS Data-Draft Report. U.S. Fish and Wildlife Service, Red Bluff Fish and Wildlife Office, Red Bluff, California.

Collis, K., D. D. Roby, D. P. Craig, B. A. Ryan, and R. D. Ledgerwood. 2001. Colonial waterbird predation on juvenile salmonids tagged with passive integrated transponders in the Columbia River estuary: Vulnerability of different salmonid species, stocks, and rearing types. Transactions of the American Fisheries Society 130:385-396.

Densmore, C. L., V. S. Blazer, D. D. Cartwright, W. B. Schill, J. H. Schacte, C. J. Petrie, M. V. Batur, T. B. Waldrop, A. Mack, and P. S. Pooler. 2001. A comparison of susceptibility to *Myxobolus cerebralis* among strains of rainbow trout and steelhead in field and laboratory trials. Journal of Aquatic Animal Health 13:220–227.

DiGennaro, B., D. Reed, C. Swanson, L. Hastings, Z. Hymanson, M. Healey, S. Siegel, S. Cantrell, and B. Herbold. 2012. Using Conceptual Models and Decision Support Tools to Guide Ecosystem Restoration Planning and Adaptive Management: An Example from the Sacramento-San Joaquin Delta, California. San Francisco Estuary and Watershed Science. 10(3): 1-15.

DWR (CA Department of Water Resources). 2004. Final Report: The Effects of the Feather River Hatchery on Naturally Spawning Salmonids. November 2004. Accessed on February 12, 2013 at http://www.fishsciences.net/reports/Calif_reports/Effects_Feather_R_Hatchery_natural_spawn_salmonids.pdf

Foott, J.S., D. Free, T. McDowell, K.D. Arkush, and R.P. Hedrick. 2006. Infectious Hematopoietic Necrosis Virus transmission and disease among juvenile Chinook salmon exposed in culture compared to environmentally relevant conditions. San Francisco Estuary and Watershed Science, 4(1)18 p.

Foott, J.S. 1992. Disease survey of Trinity River salmonid smolt populations. 1991 report. US Fish and Wildlife Service, California-Nevada Fish Health Center, Anderson, CA, 31 pages.

Foott, J.S. 1996. Infectious agents detected in juvenile salmonids reared on Battle Creek water at Coleman NFH: Significance to both in-hatchery and post-release health. Review report to U.S. Fish and Wildlife Service dated July 24, 1996.

Foott, J.S. and J.D. Williamson. 1997. Health and physiology monitoring of Coleman National Fish Hatchery fall-run Chinook smolts (FCS-BCW-95-COL): Component of 1996 marked out-migrant study. U.S. Fish and Wildlife Service, California-Nevada Fish Health Center, Anderson, CA.

Foott, J. K. Nichols, and R. Harmon. 2000. FY2000 Investigational Report: Lack of experimental evidence for IHN virus transmission from infected hatchery to natural Chinook salmon juveniles in the Sacramento River U.S. Fish & Wildlife Service California- Nevada Fish Health Center. Anderson, CA. 9 p.

Foott. J.S., D. Free, T. McDowell, K. Arkush, and R.P. Hedrick. 2006. Infectious hematopoietic necrosis virus transmission and disease among juvenile Chinook salmon exposed in culture compared to environmentally relevant conditions. San Francisco Estuary and Watershed Science, 4(1) 18 p.

Ford, M.J. 2002. Selection in captivity during supportive breeding may reduce fitness in the wild. Conservation Biology 16(3):815–825

Hallock, R.J. 1989. Upper Sacramento River steelhead, Oncorhynchus mykiss, 1952-1988. Report to U.S. Fish and Wildlife Service. 86 pp.

Harada, Y., M. Yokota and M. Iizuka. 1998. Genetic risk of domestication in artificial fish stocking and its possible reduction. Researches on Population Ecology Volume 40, Number 3 (1998), 311-324

Hedrick, R.P. 1998. Relationships of the Host, Pathogen, and Environment: Implications for Diseases of Cultured and Wild Fish Populations. Journal of Aquatic Animal Health 10:107–111.

Horsch, C.M. 1987. A case history of whirling disease in a drainage system: Battle Creek drainage of the upper Sacramento River basin, California, USA. Journal of Fish Diseases 10 (6), pages 453 - 460

HSRG (California Hatchery Scientific Review Group). 2012. California Hatchery Review Group report. Prepared for the US Fish and Wildlife Service, Sacramento, CA. 102 p.

Johnson, J.H. and E.Z. Johnson. 1981. Feeding periodicity and diel variation in diet composition of subyearling Coho Salmon, Oncorhychus kisutch , and Steelhead, Salmo gairdneri, in a Small Stream During Summer. Fish Bull. (Seattle). Vol. 79, no. 2, pp. 370-376. 1981.

Jones and Stokes. 2005a. Battle Creek salmon and steelhead restoration project final environmental impact statement/environmental impact report. Volume I, Report. Sacramento, CA.

Jones and Stokes. 2005c. Memorandum of understanding by an among National Marine Fisheries Service, U.S. Bureau of Reclamation, U. S. Fish and Wildlife Service, California Department of Fish and Game, and Pacific Gas and Electric Company. To memorialize the agreement regarding the proposed Battle Creek Chinook salmon and steelhead restoration project, located in the Battle Creek watershed in Tehama and Shasta Counties, California. Volume II, Appendix A. Sacramento, CA. 51p plus attachments.

Keefer, M.L., C. A. Peery, M. A. Jepson and L. C. Stuehrenberg. 2004. Upstream migration rates of radio-tagged adult Chinook salmon in riverine habitats of the Columbia River basin. Journal of Fish Biology (2004) 65, pages 1126–1141.

Kier and Associates. 1999. Battle Creek salmon and steelhead restoration plan. Prepared for the Greater Battle Creek Watershed Working Group. January. Sausalito, CA.LaPatra, S. E., K.A. Lauda, and A.W. Morton. 1991a. Antigenic and virulence comparison of eight isolates of infectious hematopoietic necrosis virus from the Hagerman Valley, Idaho, USA. In: Proceedings of the Second International Symposium on Viruses of Lower Vertebrates. Oregon State University Press, Corvallis, p. 125-129.

Leitritz, E. and E. Lewis. 1976. Trout and Salmon Culture (Hatchery Methods). California Department of Fish and Game Fish Bulleting 164. 197 p.

Levin, R.S., R.W. Zabel, and J.G. Williams. 2001. The road to extinction is paved with good Intentions: negative association of fish Hatcheries with threatened salmon. Proceedings: Biological Sciences, Vol. 268, No. 1472 (Jun. 7, 2001), pp. 1153-1158.

Lichatowich, J.A. and J.D. McIntyre. 1987. Use of hatcheries in the management of Pacific anadromous salmonids. American Fisheries Society Symposium 1:131-136.

Lindley, S.T., R.S. Schick, E. Mora, P.B. Adams, J.J. Anderson, S. Greene. 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. Accessed on December 4, 2012 at http://escholarship.org/uc/item/3653x9xc

Marnell, L. F. 1986. Impacts of hatchery stocks on wild fish populations. Pages 339-347 in R.H. Stroud, ed. Fish culture in fisheries management. American Fisheries Society, Fish Culture Section and Fisheries Management Section, Bethesda, MD.

Merz, J.E. 2002. Seasonal feeding habits, growth, and movement of steelhead trout in the lower Mokelumne River, California. California Fish and Game 88:3 95-111.

Merz, J.E., and C. D. Vanicek. 1996. Comparative feeding habits of juvenile Chinook salmon, steelhead, and Sacramento squawfish in the lower American River, California. California Fish and Game 82:4 149-159.

Mobrand, L.E., J. Barr, L. Blankenship, D.E. Campton, T.T.P. Evelyn, T.A. Flagg, C.V.W. Mahnken, L.W. Seeb, P.R. Seidel, and W.W. Smoker. 2005. Hatchery reform in Washington State: principles and emerging issues. Fisheries 30(6):11–39.

Modin, J. 1998. Whirling Disease in California: A Review of Its History, Distribution, and Impacts, 1965–1997. Pages 132-142 in Journal of Aquatic Animal Health, Volume 10, Issue 2.

Mulcahy, D., R. Pasco, and C.K. Jenes. 1983. Detection of infectious hematopoietic necrosis virus in river water and demonstration of water-born transmission. Journal of Fish Disease 6:321-330.

Myrick, C.A. and J.J. Cech, Jr. 2001. Temperature effects on Chinook salmon and steelhead: a review focusing on California's Central Valley population. Published electronically by the Bay-Delta Modeling Forum at http://www.sfei.org/modelingforum/ 51 p.

Newton, J. M., and L.A. Stafford. 2011. Monitoring adult Chinook salmon, rainbow trout, and steelhead in Battle Creek, California, from March through November 2009. USFWS Report. U.S. Fish and Wildlife Service, Red Bluff Fish and Wildlife Office, Red Bluff, California. 61 p.

Newton, J. M., and M. R. Brown. 2010. Genetic stock analysis of phenotypic spring Chinook from Battle Creek. U.S. Fish and Wildlife Service, Red Bluff Fish and Wildlife Office, Red Bluff, California. 5 p.

Newton, J. M., L. A. Stafford, and M. R. Brown. 2008. Monitoring adult Chinook salmon, rainbow trout, and steelhead in Battle Creek, California, from March through November 2007. USFWS Report. U.S. Fish and Wildlife Service, Red Bluff Fish and Wildlife Office, Red Bluff, California.

Newton, J. M., N. O. Alston, and M. R. Brown. 2007a. Monitoring adult Chinook salmon, rainbow trout, and steelhead in Battle Creek, California, from November 2004 through November 2005. USFWS Report. U.S. Fish and Wildlife Service, Red Bluff Fish and Wildlife Office, Red Bluff, California.

Newton, J. M., N. O. Alston, and M. R. Brown. 2007b. Monitoring adult Chinook salmon, rainbow trout, and steelhead in Battle Creek, California, from March through November 2006. USFWS Report. U.S. Fish and Wildlife Service, Red Bluff Fish and Wildlife Office, Red Bluff, California.

Nielsen JL, Lisle TE, Ozaki V. 1994. Thermally stratified pools and their use by steelhead in Northern California streams. Transactions of the American Fisheries Society 123:613–626.

NMFS (National Marine Fisheries Service). 2009. Public Draft Recovery Plan for the Evolutionarily Significant Units of Sacramento River Winter run Chinook Salmon and Central Valley Spring run Chinook Salmon and the Distinct Population Segment of Central Valley Steelhead. Sacramento Protected Resources Division, CA. 273p.

Null, R. E., J. Newton, C. Brownfield, S. Hamelberg, and K. Niemela. 2010. Monitoring and Evaluation of the Modified Fish Ladder and Barrier Weir at the Coleman National Fish Hatchery. U.S. Fish and Wildlife Service Report. U.S. Fish and Wildlife Service, Red Bluff Fish and Wildlife Office, Red Bluff, California.

Payne T. and Associates. 1998. Battle Creek Fisheries Studies. Task 1 Instream flow study. Prepared for the California Department of Fish and Game. 53p.

Pert, H.A. 1993. Winter food habits of coastal juvenile steelhead and Coho salmon in Pudding Creek, Northern California. Master's Thesis, University of California, Berkley. 75 p.

Reisenbichler R.R., R. Rubin, L. Wetzel, S. Phelps. 2004. Natural Selection after release from a hatchery leads to domestication in steelhead, Oncorhynchus mykiss. In: Leber KM, Kitada S, Blankenship HL, Svasand T (eds) Stock enhancement and sea ranching. Blackwell Publishing.

Reisenbichler, R. R., and McIntyre, J. D. 1986. Requirements for integrating natural and artificial production of anadromous salmonids in the Pacific Northwest. In Fish culture in fisheries management, pp. 365–374. Ed. by R. H. Stroud. American Fisheries Society, Bethesda, MD. 481 pp.

Rundia, D.E. and S.T. Lindely. 2007. Terrestrial subsidies to steelhead in Big Sur, California: Seasonal patterns and non-native prey. American Society of Limnology and Oceanography. Aquatic Sciences meeting presentation, Santa Fe, New Mexico.

Schreck, C.B. 1987. Stress measurement. In: Improving Hatchery Effectiveness as Related to Smoltification, Proceedings of Smolt Workshop, Warm Springs, OR, pages 89-96.

Shapavolov L. and A.C. Taft. 1954. The life histories of the steelhead Rainbow trout (*Salmo gairdnerii gairdnerii*) and Silver salmon (*Oncorhynchus kisutch*) with special reference to Waddell Creek, California, and recommendations regarding their management. California Department of Fish and Game Fish Bulletin No. 98. 476 p.

Stafford, L.A., and J.M. Newton. 2010. Monitoring adult Chinook salmon, rainbow trout, and steelhead in Battle Creek, California, from March through November 2008. USFWS Report. U.S. Fish and Wildlife Service, Red Bluff Fish and Wildlife Office, Red Bluff, California.

Stalnaker, C., B.L. Lamb, J. Henriksen, K. Bovee, and J. Bartholow. 1995. The instream flow incremental methodology: a primer for IFIM. National Biological Service, Fort Collins, Colorado, Midcontinent Ecological Science Center. 53 p.

Terraqua. 2004. Draft Battle Creek salmon and steelhead restoration project adaptive management plan, prepared for the U.S. Bureau of Reclamation, Pacific Gas and Electric Company, National Marine Fisheries Service, U.S. Fish and Wildlife Service, and California Department of Fish and Game. Wauconda, Washington. 238 p.

Thoesen, J. C., editor. 1994. Suggested procedures for the detection and identification of certain finfish and shellfish pathogens, 4th edition. American Fisheries Society, Bethesda, Maryland.

TRP (Technical Review Panel). 2004. Report of the Technical Review Panel: Compatibility of Coleman National Fish Hatchery Operations and Restoration of Andadromous Salmonids in Battle Creek. Prepared January 24, 2004. 66 p.

TRP (Technical Review Panel). 2013. Report of the Technical Review Panel: Review of the Coleman National Fish Hatchery Adaptive Management Plan. Submitted to the U.S. Bureau of Reclamation. May 12, 2013. 36 p.

TRPA (Thomas R. Payne and Associates). 1998a. A 1989 temperature model of lower Battle Creek, Eagle Canyon and Coleman Diversions to Coleman Powerhouse: 1 of 8 components. Prepared for California Department of Fish and Game.

TRPA (Thomas R. Payne and Associates). 1998b. A 1989 temperature model of upper Battle Creek, Al Smith Diversion to Eagle Canyon Diversion on North Fork Battle Creek and South Diversion to Inskip Powerhouse on South Fork Battle Creek: 1 of 8 components. Prepared for California Department of Fish and Game.

True, K. 2004. Fish Health Monitoring of Fall Chinook and steelhead in the Yuba and Feather Rivers (2002-2003). United States Fish and Wildlife Service, California-Nevada Fish Health Center, Oroville Facilities Relicensing Environmental Work Group, Project No. 2100, SP-F2. Evaluation of Project Effects on Fish Diseases. 54 p.

Unger, P. 2004. Release hatchery steelhead earlier or at smaller size to reduce their predation on juvenile wild salmon and steelhead. Oroville Facilities Relicensing Efforts Environmental Work Group Draft Report No. 02042004. 3 p.

USFWS (U.S. Fish and Wildlife Service). 1986. An Evaluation of Alternative Water Supply Systems for Coleman National Fish Hatchery. Prepared for U.S. Fish and Wildlife Service (Portland, Oregon) by Sverdrup & Parcel and Associates, Inc. Consulting Engineers. September 1986.

USFWS (US Fish and Wildlife Service). 2004. Aquatic Animal Health Policy, Exhibit 1, 713 FW 1 3 p. available at www.fws.gov/policy/e1713fw1.html

USFWS (U.S. Fish and Wildlife Service). 2010. Fish salvage in the Coleman National Fish Hatchery Canal concurrent with the operation of unscreened Intake 2 during March 2010. U.S. Fish and Wildlife Service, Red Bluff, California. July 2010.

USFWS (United States Fish and Wildlife Service). 2011. Biological assessment of artificial propagation at Coleman National Fish Hatchery and Livingston Stone National Fish Hatchery: program description and incidental take of Chinook salmon and steelhead. U.S. Fish and Wildlife Service, Red Bluff and Coleman National Fish Hatchery Complex, CA. 406 p.

Ward M.B. and W.M. Kier. 1999a. Battle Creek Salmon and Steelhead Restoration Plan. Prepared for the Battle Creek Working Group, Kier Associates, Sausalito, California. 157 p.

Ward, M.B. and W.M. Kier. 1999b. Maximizing compatibility between Coleman National Fish Hatchery operations, management of Lower Battle Creek, and salmon and steelhead restoration. Prepared for the Battle Creek Working Group by Kier Associates, 52 p.

Warren, J.W. 1983. Enteric Redmouth Disease. Pages 205-210 in F.P Meyer, J.W. Warren, and T.G. Carey (ed.). A guide to integrated fish health management in the Great Lakes Basin. Great Lakes Fishery Commission, Ann Arbor, Michigan, Special Publication 83-2 272 p.

Warren, J. W. 1991. Diseases of hatchery fish, 6th edition. U.S. Fish and Wildlife Service, Pacific Region, Portland, Oregon. 92 p.

Weber, E.D. and K.D. Fausch. 2003. Interactions between hatchery and wild salmonids in streams: differences in biology and evidence for competition. Canadian Journal of Fisheries and Aquatic Sciences. 60(8):1018-1036.

White, R. J., J. R. Karr, and W. Nehlsen. 1995. Better roles for fish stocking in aquatic resource management. American Fisheries Society Symposium 15:527

Whitton, K. S., D. J. Colby, J. M. Newton, and M. R. Brown. 2011. Juvenile salmonid monitoring in Battle Creek, California, November 2009 through July 2010. USFWS Report. U.S. Fish and Wildlife Service, Red Bluff Fish and Wildlife Office, Red Bluff, California. 51 p.

Whitton, K. S., D. J. Colby, J. M. Newton, and M. R. Brown. 2010. Juvenile salmonid monitoring in Battle Creek, California, November 2008 through June 2009. USFWS Report. U.S. Fish and Wildlife Service, Red Bluff Fish and Wildlife Office, Red Bluff, California.

Whitton, K. S., D. J. Colby, J. M. Newton, and M. R. Brown. 2008. Juvenile salmonid monitoring in Battle Creek, California, November 2007 through June 2008. USFWS Report. U.S. Fish and Wildlife Service, Red Bluff Fish and Wildlife Office, Red Bluff, California.

Whitton, K. S., J. M. Newton, and M. R. Brown. 2007a. Juvenile salmonid monitoring in Battle Creek, California, July 2001 through September 2002. USFWS Report. U.S. Fish and Wildlife Service, Red Bluff Fish and Wildlife Office, Red Bluff, California.

Whitton, K. S., J. M. Newton, and M. R. Brown. 2007b. Juvenile salmonid monitoring in Battle Creek, California, October 2002 through September 2003. USFWS Report. U.S. Fish and Wildlife Service, Red Bluff Fish and Wildlife Office, Red Bluff, California.

Whitton, K. S., J. M. Newton, and M. R. Brown. 2007c. Juvenile salmonid monitoring in Battle Creek, California, October 2003 through September 2004. USFWS Report. U.S. Fish and Wildlife Service, Red Bluff Fish and Wildlife Office, Red Bluff, California.

Whitton, K. S., J. M. Newton, and M. R. Brown. 2007d. Juvenile salmonid monitoring in Battle Creek, California, October 2004 through September 2005. USFWS Report. U.S. Fish and Wildlife Service, Red Bluff Fish and Wildlife Office, Red Bluff, California.

Whitton, K. S., J. M. Newton, and M. R. Brown. 2007e. Juvenile salmonid monitoring in Battle Creek, California, October 2005 through September 2006. USFWS Report. U.S. Fish and Wildlife Service, Red Bluff Fish and Wildlife Office, Red Bluff, California.

Whitton, K. S., J. M. Newton, D. J. Colby and M. R. Brown. 2006. Juvenile salmonid monitoring in Battle Creek, California, from September 1998 to February 2001. USFWS Data Summary Report. U.S. Fish and Wildlife Service, Red Bluff Fish and Wildlife Office, Red Bluff, California.

Williams, J.G. 2012. Juvenile Chinook salmon (*Oncorhynchus tshawytscha*) in and around the San Francisco Estuary. San Francisco Estuary and Watershed Science, 10(3) 24 p.

Williams, J.G. 2006. Central Valley salmon a perspective on Chinook and steelhead in the Central Valley of California. San Francisco Estuary and Watershed Science, 4(3) 416 p.

Wolf, K. 1988. Fish Viruses and Fish Viral Diseases, Cornell University Press, London.

Personal Communications

Brown, Matt. U.S. Fish and Wildlife Service, Red Bluff Field Office. Personal communications on October 24, 2012 and December 5, 2012.

Earley, Laurie. U.S. Fish and Wildlife Service, Red Bluff Field Office. Personal communications on November 12, 2012 and December 9, 2012.

Foott, Scott. U.S. Fish & Wildlife Service California- Nevada Fish Health Center. Anderson, CA. Personal communications on August 29, 2012.

Hamelberg, Scott. U.S. Fish and Wildlife Service, Coleman National Fish Hatchery. Personal communications on August 29, 2012, October 24, 2012, December 5, 2012, and March 5, 2013.

Null, Robert. U.S. Fish and Wildlife Service, Red Bluff Field Office. Personal communications on September 9, 2012 and December 12, 2012.

APPENDIX D: A LIFE CYCLE MODEL FOR CHINOOK SALMON IN BATTLE CREEK, CA

Model Documentation

Prepared for:

U.S. Department of Interior, Bureau of Reclamation

Prepared by:

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March 1, 2016

Table of Contents

1. Background

Formal protection of three salmonid stocks (i.e., winter- and spring- Chinook salmon, and Central Valley steelhead) under the California and/or Federal endangered species acts, and identification of the Battle Creek watershed as vital recovery habitat (NMFS 2014), emphasize the need to improve ecological functions in the watershed, while striving to optimize existing human services. The Coleman National Fish Hatchery (CNFH) is a dominant feature in lower Battle Creek. Minimizing or avoiding the adverse impacts its infrastructure and operations may have on the success of the Battle Creek Restoration Project (BCRP) is now a focus of resource and regulatory agencies. The BCRP focuses on restoring in-stream flows and improving fish passage through modification of existing hydropower infrastructure. The goal is to provide high quality habitat and improve fish passage, which together will support self-sustaining populations of several Chinook salmon stocks, and Central Valley steelhead throughout 48 miles of stream habitat (Terraqua 2004).

The primary goal of the CNFH fall and late-fall Chinook salmon propagation programs is to mitigate for the loss of salmonid spawning and rearing habitat above Shasta and Keswick dams, and the consequent reduction in the population size of these salmon stocks. Fall and late-fall Chinook are produced to contribute to harvest in the ocean commercial fishery, ocean sport fishery, and freshwater sport fishery. The fall Chinook propagation program annually releases approximately 12 million juvenile fish in April at a size of 90 fish/lb, which are expected to contribute a total of 120,000 fish to harvest and escapement over the life of the brood (60-75% for harvest; HSRG 2012). The late-fall Chinook propagation program annually releases approximately 1 million yearling fish in December at a size of 13 fish/lb, which are expected to contribute a total of 10,000 fish to harvest and escapement over the life of the brood (50% for harvest; HSRG 2012).

The purpose of the CNFH Adaptive Management Plan (CNFH-AMP) is to acknowledge, identify, study, and evaluate uncertainties regarding the operation of a large scale fish hatchery in a watershed being restored for natural salmonid populations. The CNFH-AMP is intended to closely coordinate with the BCRP-AMP, so that together the two adaptive management plans provide an integrated framework for adaptive management in Battle Creek (Jones and Stokes 2005).

An integrated AMP requires an analytical framework that includes and accounts for factors directly related to CNFH operations, as well as other factors that may influence success of the BCRP. Such an analytical framework has now been recommended by two science panel reviews (first for the BCRP-AMP (TRP 2004), and most recently for the CNFH-AMP (TRP 2013)). The collaborative development of an analytical framework will clarify underlying assumptions, incorporate uncertainties, and connect management options to desired outcomes. The purpose of the life-cycle model for Chinook salmon is to: (1) quantify and prioritize the likely effects of issues identified in the CNFH-AMP, and other factors that may influence the success of the BCRP, and (2) identify and understand key information gaps.

2. Life History

The Chinook salmon life cycle model simulates the life history of all four races of Chinook salmon that could occur in the Battle Creek Watershed, including both hatchery and natural-origin stocks (a separate simulation model was developed for steelhead). The Sacramento-San Joaquin River system supports four races of Chinook salmon including the fall-, late-fall-, winter-, and spring- Chinook (Moyle 2002). These races and the large runs they once supported (at least 1-2 million adults annually; Yoshiyama et al. 2001) reflect the diverse and productive habitats that historically existed within the region. Currently, winter-run Chinook salmon are not present in Battle Creek, but are expected to be reintroduced in future years. Although the timing of runs may vary from stream to stream, the four Chinook salmon races are named for the season when the majority of each spawning run enters freshwater (Moyle 2002). The majority of young salmon of these races migrate to the ocean during the first few months following emergence, although some may remain in freshwater and migrate the following year (yearlings). The BCRP ultimately intends to support natural-origin populations of all four races of Chinook salmon in Battle Creek.

3. Modeling Approach

3.1 Conceptual Model

The simulation model tracks the complete life history of all four races of Chinook salmon, beginning with spawning in the CNFH or Livingstone National Fish Hatchery (LNFH) (hatchery-origin) or Battle Creek (natural-origin). The model configuration allows for evaluation of CNFH and BCRP project effects on each individual Chinook salmon life stage, and overall cumulative impact on the population trajectories of each race. Within each Chinook salmon race, nine life history phases are modeled, including six occurring in Battle Creek (Adult Passage, Adult Holding, Spawning, Egg Incubation, Juvenile Rearing, and Battle Creek Emigration). Three of these life history phases also occur concurrently in the hatchery (Spawning, Egg Incubation, and Juvenile Rearing). Three additional phases occur outside of Battle Creek (Sacramento River Emigration, Estuary Emigration, and Ocean Residence) (Figure 1). Except for BCRP barriers where both current and future expected conditions are modeled (see Barriers section for details), model functionality and parameter values described in this documentation reflect future expected conditions in Battle Creek following restoration.

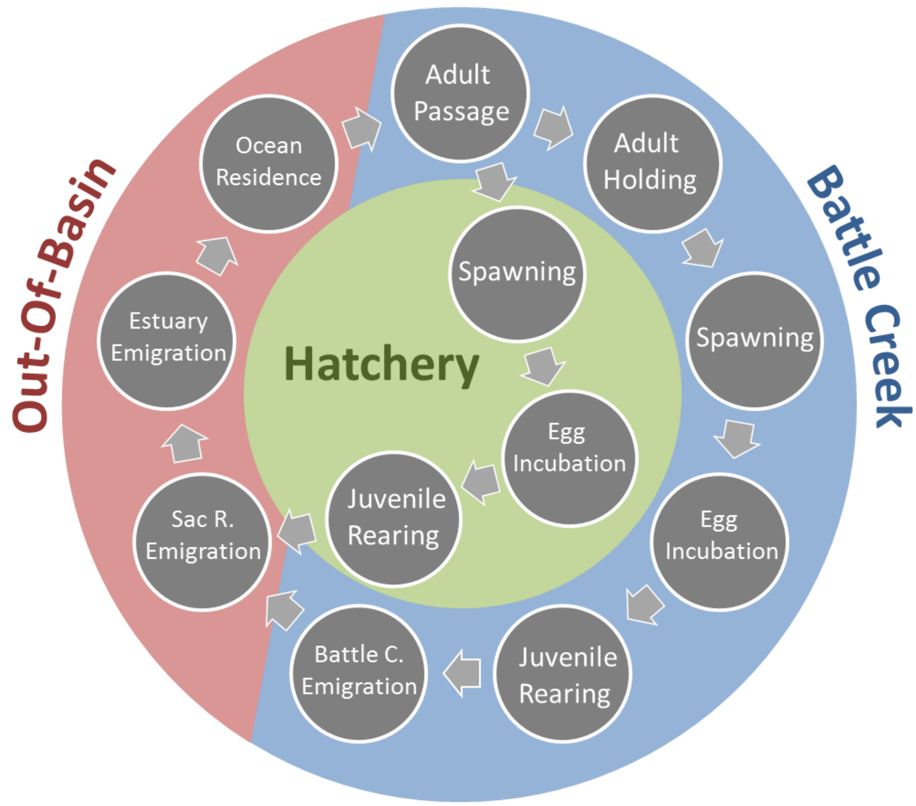


Figure 1. Life history phases modeled for four Chinook salmon races in the Chinook salmon life cycle model. The red area represents out-of-basin phases, the blue area represents phases occurring in Battle Creek, and the green area represents phases occurring within the Coleman National Fish Hatchery and Livingstone National Fish Hatchery.

3.2 Modeling Platform

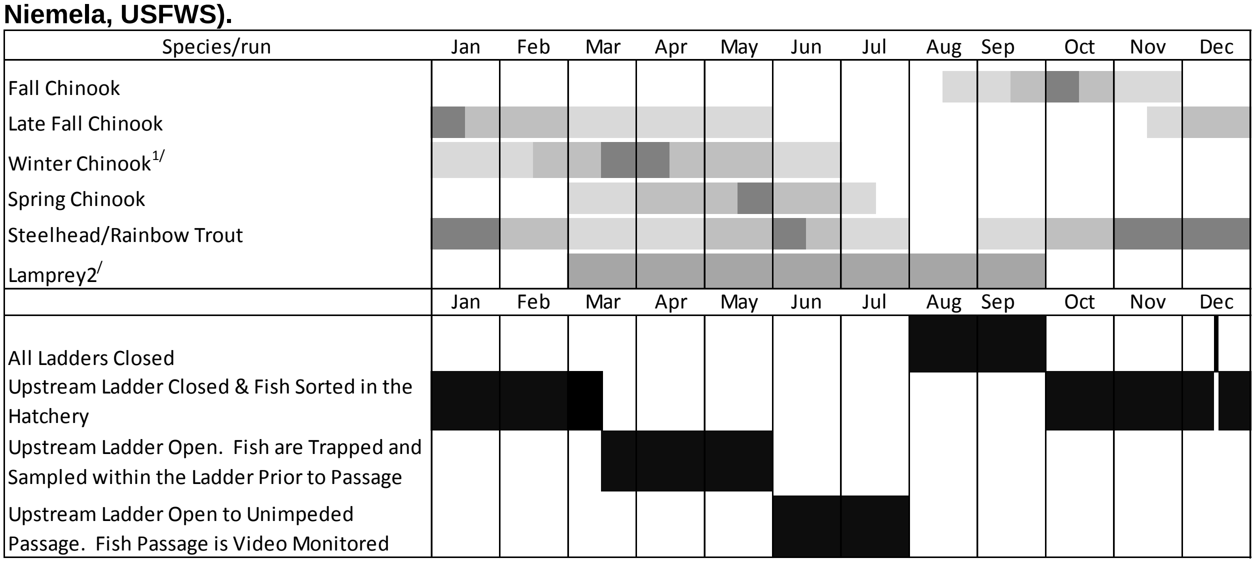
The model is built in R, a programming language and statistical computing environment. R is free, open source, and cross-platform, which facilitates code sharing and collaboration. Programming in R is interactive and efficient because high-level syntax allows writing of compact code. R contains numerous statistical functions and excellent graphical capabilities, allowing for both the execution of model runs, and the analysis and visualization of simulation results in the same computing environment. Moreover, user-created packages greatly extend the core functionality of R, including packages for the creation of web applications and improved computational performance.

3.3 Temporal Resolution and Timing of Life History Phases

The model operates on a monthly time step with monthly input data (e.g., water temperatures, flows, habitat amount, passage success) used in model calculations . This allows fish of different races, natal origins (natural or hatchery), or life history phases to interact with one another in the various spatial units in which they co-occur. The model allows for forward projections through time of population size by race, natal origin, life stage, and location. The overlap in timing among different races influences the model outcomes because the different races compete for the same resources, particularly during the spawning and juvenile rearing phases when habitat availability may be a limiting factor.

We used the average monthly observance of Chinook salmon passing through the CNFH barrier weir ladder system along with assumptions about average duration of each life history phase (for an individual cohort), to determe the timing window for each life history phase (across all cohorts) of each race. First, we determined the average peak passage of adults of each Chinook salmon race at the CNFH barrier weir by converting the qualitative monthly intensity of adult passage as defined in the CNFH-AMP (Table 1) into monthly proportional passage (Figure 2). Because we assumed a constant life history phase duration for all cohorts (see Table 2 for durations), we needed to model an abbreviated (peak) adult passage timing to ensure the period of each successive life history phase matched the expert opinion of the CNFH-AMP Technical Advisory Committee (TAC). Therefore, we removed the lower intensity passage months defined in Table 1, and only represent the peak passage timing in the model (Figure 2). Although removing lower intensity months provided less accuracy during passage, it resulted in greater accuracy in timing of occurrence of each life history phase, which we deemed more important. For each race, passage months were scored depending on the sum of shading levels occurring in that month, with dark shading given a score of 3, and intermediate shading a score of 2. Next, we divided each value by the sum of the monthly scores to determine the passage proportion occurring in each month for each race.

Table 1. Probable adult migration period of anadromous salmonids stocks in Battle Creek, and CNFH barrier weir fish ladder operational status. Density of shading indicates intensity of run timing at the barrier weir. Darker shading indicates higher intensity. (Table provided by K. Niemela, USFWS).



1/ Winter Chinook migration timing is speculative in Battle Creek. Information presented is based on historic run timing in the Sacramento River past Red Bluff Diversion Dam.

2/ Bar racks in place to preclude salmonid movement during August and September do not impede lamprey movement through the ladder.

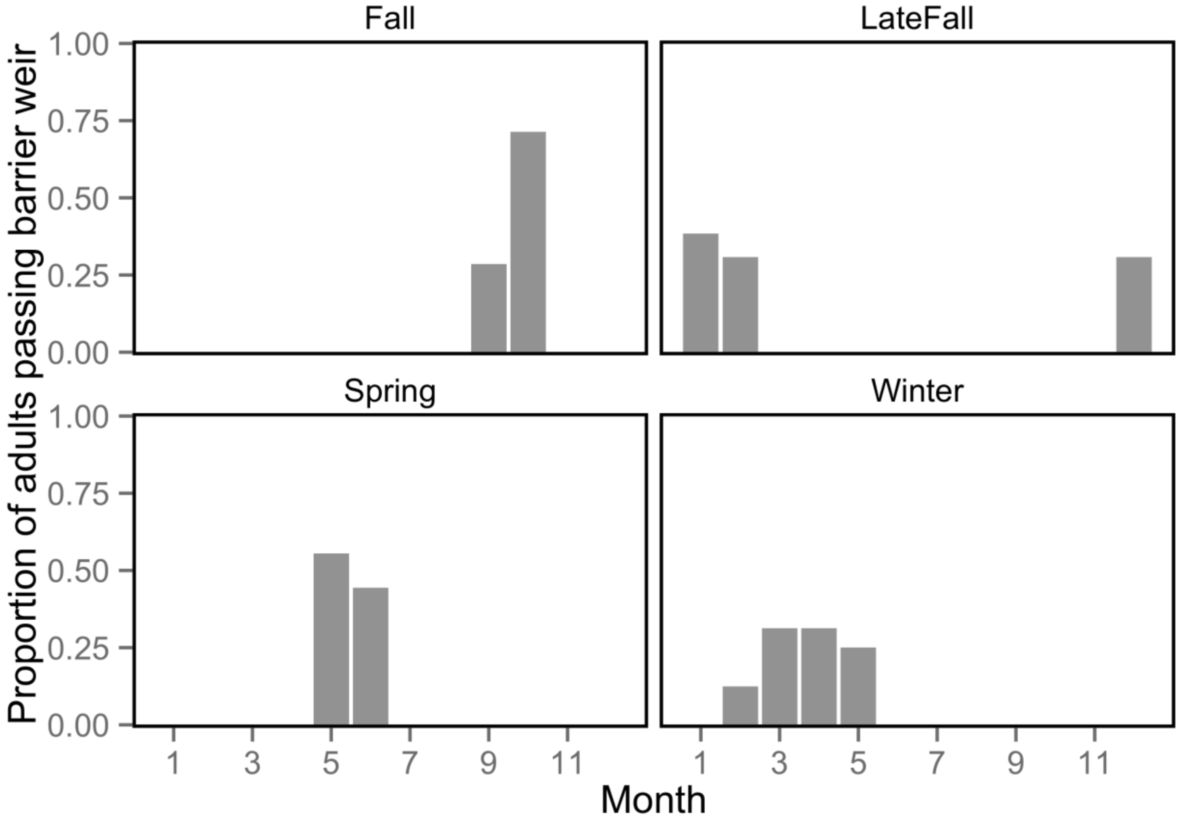


Figure 2. Average peak proportional passage of adults passing through the CNFH barrier weir ladder system applied in the Chinook salmon life cycle model. Modified from Table 1.

These passage distributions were then shifted forward by the assumed duration of each phase to determine the monthly proportional occurrence of each life history phase for each race. The timing duration of each life history phase, and the resulting timing window for each life history phase are described in Table 2.

Table 2. Duration and monthly occurence of each life history phase for each race used in the Chinook salmon life cycle model. Monthly occurrence of each life history phase for each race was determined by projecting forward the average monthly observance of Chinook salmon passing through the CNFH barrier weir ladder system by making assumptions about average duration of each life history phase.

Life History Phase	Duration (months)	Race	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Adult Passage	< 1	Winter												
		Fall												
		Late-Fall												
		Spring												
Adult Holding	3	Winter												
	N/A	Fall						N/A						
	N/A	Late-Fall						N/A						
	4	Spring												
Spawning	< 1	Winter												
		Fall												
		Late-Fall												
		Spring												
Egg Incubation	2	Winter												
		Fall												
		Late-Fall												
		Spring												
Juvenile Rearing	3	Winter												
		Fall												
		Late-Fall												
		Spring												
Battle Creek Emigration	< 1	Winter												
		Fall												
		Late-Fall												
		Spring												

4. Battle Creek Distribution

4.1 Reaches

The model includes 14 reaches within Battle Creek as identified in the BCRP (Figure 3; Table 3). The BCRP reaches of Eagle Canyon, North Battle Creek Feeder, and South Fork Battle Creek were divided into two reaches each, due to barriers occurring within each of these reaches that partially block passage (See Table 3 for details on barriers). Three additional reaches outside of Battle Creek are modeled to complete the life cycle: (1) the Sacramento River, (2) the San Francisco Estuary (Estuary), and (3) the Pacific Ocean.

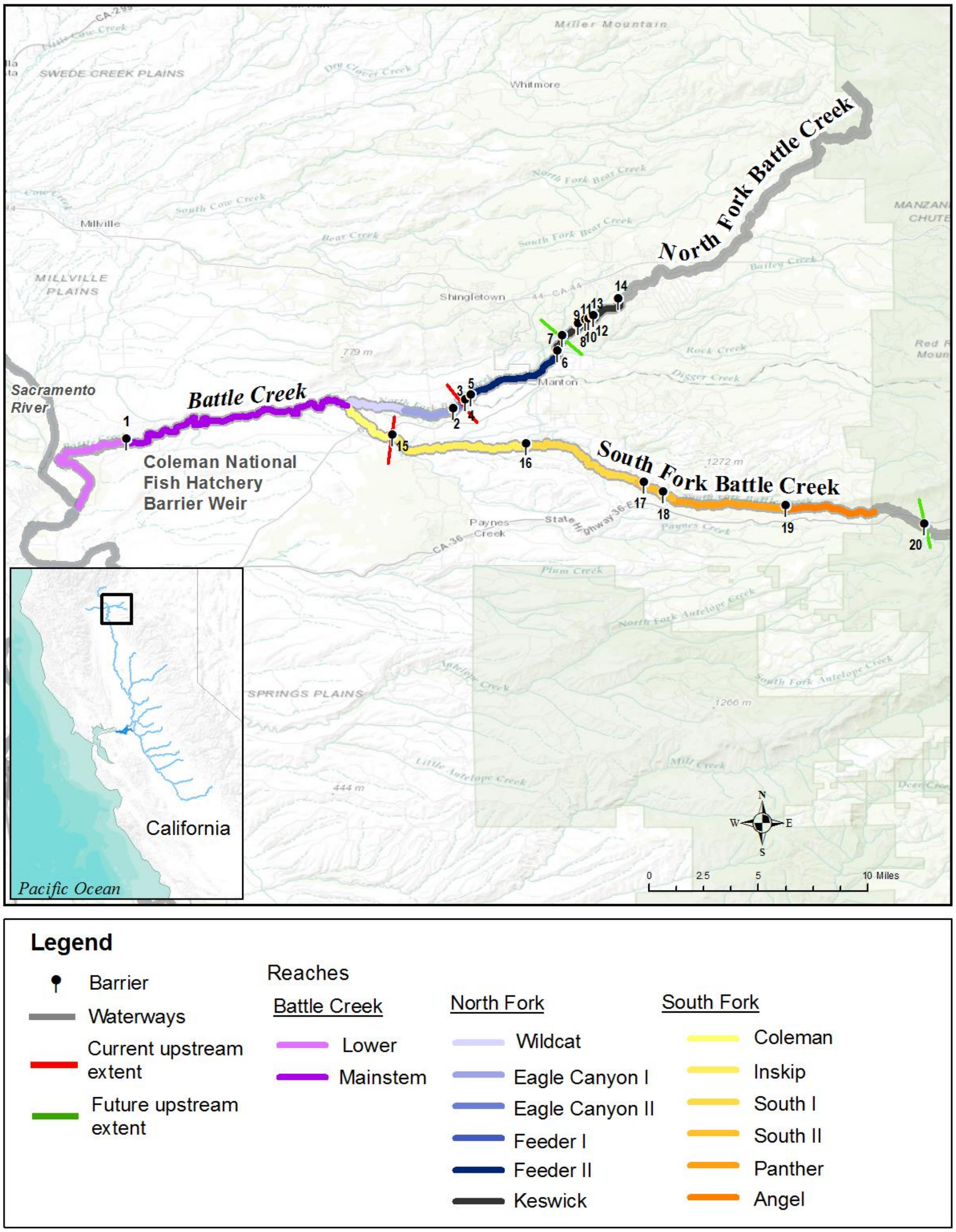


Figure 3. Relative locations of Chinook salmon habitat reaches in the Battle Creek watershed as modeled in the Chinook salmon life cycle model. The Battle Creek portion of the Life Cycle Model is composed of 14 reaches. The numbered black circles indicate locations of barriers identified by the TAC (See Table 3 for details on barriers). The red lines indicate the current upstream extent of available habitat in each Fork under current assumptions about passage. The green lines indicate the future upstream extent of available habitat under expected future conditions following restoration (See Table 3 for details on reaches).

Table 3. Reach length and downstream and upstream extents of the 14 reaches in Battle Creek BCRP as modeled in the Chinook salmon life cycle model.

Section	Reach	River Mile		Length (Miles)
		Downstream	Upstream	
Mainstem	Lower	0.00	5.97	5.97
	Mainstem	5.97	16.80	10.83
North Fork	Wildcat	0.00	2.48	2.48
	Eagle Canyon I	2.48	4.46	1.98
	Eagle Canyon II	4.46	5.23	0.77
	North Battle Creek Feeder I	5.23	5.41	0.18
	North Battle Creek Feeder II	5.41	9.42	4.01
	Keswick	9.42	13.17	3.75
South Fork	Coleman	0.00	2.54	2.54
	Inskip	2.54	8.02	5.48
	South I	8.02	13.26	5.24
	South II	13.26	14.84	1.58
	Panther	14.84	19.07	4.23
	Angel	19.07	22.47	3.40

4.2 Barriers

As spawners migrate upstream they may encounter one or more of the 20 natural or man-made fish barriers identified by the TAC (Figure 3; Table 4). Percent passage success of Chinook salmon at each barrier was defined by the TAC for current conditions and expected future conditions following restoration (Table 4). The five man-made barriers in the upper watershed are located at the upstream end of Eagle Canyon II, North Battle Creek Feeder II, Coleman, Inskip, and South II reaches (Figure 3; Table 4). Passage success at the CNFH barrier weir is described in the Adult Passage section below. Passage success at the other five man-made barriers is set at 0% under current conditions, and at 100% under future restored conditions (Table 4). The 15 natural barriers occur in multiple reaches in the North and South Forks of Battle Creek (Figure 3; Table 4). Passage success at each natural barrier varies between 0 and 50%, based on input from the TAC (Table 4). In the model, fish that fail to pass a barrier located at a reach boundary spawn in the closest downstream reach. The current upstream extent of habitat occurs at the California Department of Fish and Wildlife Blast Site (RM 5.06) on the North Fork and Inskip Dam on the South Fork (Figure 3; Table 4). The expected upstream extent under future restored conditions occurs at the unnamed natural barrier (RM 10.22) on the North Fork, and Angel Falls (RM 22.47) on the South Fork (Figure 3; Table 4).

Table 4. Natural and man-made barriers located in each section of Battle Creek (mainstem, north fork, south fork) as modeled in the Chinook salmon life cycle model. Percent passage indicates the assumed annual passage success of Chinook salmon at each barrier as defined by the TAC under current conditions, and expected future conditions following restoration. Barrier descriptions were provided by the TAC. Map numbers refer to locations in Figure 3.

		Barrier Info			Barrier Passage	
Section	Reach	Map #	Name	Location (RM)	Current	Future
Mainstem	Lower	1	Coleman Barrier	5.97	Variable	Variable
North Fork	Wildcat	N/A	N/A	N/A	N/A	N/A
	Eagle Canyon I	2	Unnamed #1	4.46	50	100
	Eagle Canyon II	3	CDFW Blast Site	5.06	0	100
		4	Eagle Canyon Dam	5.23	0	100
	North Battle Creek Feeder I	5	Unnamed #2	5.41	0	100
	North Battle Creek Feeder II	6	N. F. Feeder Dam	9.42	0	100
	Keswick	7	Unnamed #3	10.22	0	0
		8	Unnamed #4	10.97	0	0
		9	Unnamed #5	11.02	0	0
		10	Unnamed #6	11.46	0	0
		11	Unnamed #7	11.57	0	0
		12	Unnamed #8	11.76	0	0
		13	Unnamed #9	11.78	0	0
		14	Whispering Falls	13.17	0	0
South Fork	Coleman	15	Coleman Dam	2.54	0	100
	Inskip	16	Inskip Dam	8.02	0	100
	South I	17	Unnamed #10	13.26	50	50
	South II	18	South Dam	14.84	0	100
	Panther	19	Panther Falls	19.07	20	20
	Angel	20	Angel Falls	22.47	0	0

4.3 Spawner Distribution

Adult fall Chinook salmon that are not brought into the hatchery are forced to remain below the CNFH barrier weir. Further, current CNFH operations do not allow fall Chinook to proceed upstream of the fish barrier weir; thus, the model assumes that no CNFH origin fall Chinook enter the BCRP area. Any in-river spawning among these fish occurs in lower Battle Creek. During the first year of the model run, spawners from all other Chinook races are evenly distributed across all accessible reaches. For reaches that are only partially accessible due to barriers downtream, the initial allocation of spawners is reduced at the rate of passage success defined in Table 4. Each subsequent generation of spawners return to their natal reach. Differential reach-specific survival rates during egg incubation and fry rearing (due to reach-specific water temperatures, flows, and habitat amounts) affects the long-term distribution of spawners among reaches.

4.4 Fry Distribution

Although a proportion of all fry begin emigration immediately upon emergence, the remainder stay in the river and rear to smolt size (see Juvenile Rearing section). Rearing fry reside in the reach where they were spawned.

5. Quantitative Framework

The model is structured as a multistage Beverton-Holt model, similar to the SHIRAZ modeling framework (Scheurell et al. 2006) developed for Chinook salmon in the Pacific Northwest. Salmon transition between and within each life history phase in the model on a monthly basis (except for life history phases occuring out of basin) with the application of a Beverton-Holt stock-recruitment model that includes competition for habitat between each race of Chinook Salmon:

$$N_{s+1} = \frac{N_s}{\frac{1}{p_{s\rightarrow s+1}} + \frac{1}{c_{s+1}}(N_{s+}M_s)}$$

where the number of fish of a given race surviving to their next life history phase or month (N_{s+1}) is a function of the number alive of that race at the current life phase or month (N_s), the number alive of all other races at the current life phase or month (M_s), their survival to the next life phase or month ($p_{s\rightarrow s+1}$), and the capacity of the environment to support them (c_{s+1}). Life history phases occuring out of the Battle Creek Basin (Sacramento River and Estuary emigration and ocean residence) occur on an annual timestep, and therefore, only Beverton-Holt transitions among life history phases are calculated for those life phases.

The survival/productivity parameter (*p*) and capacity parameter (*c*) can assume fixed values, or they can be functions of the environment (see Functional Relationships section). Environmental factors that affect *p* alter the recruitment rate to the next life stage or month (slope), and factors that affect *c* alter the maximum number of fish that can be produced in the next life stage or month (Figure 4). Capacity is only modeled during life history phases that are believed to be limited by habitat amount (spawning and juvenile rearing). For all other life history phases, capacity is not assumed to be limited, and therefore is set at infinity, simplifying the stock-recruitment equation to the following form:

$$N_{s+1} = N_s * p_{s\rightarrow s+1}.$$

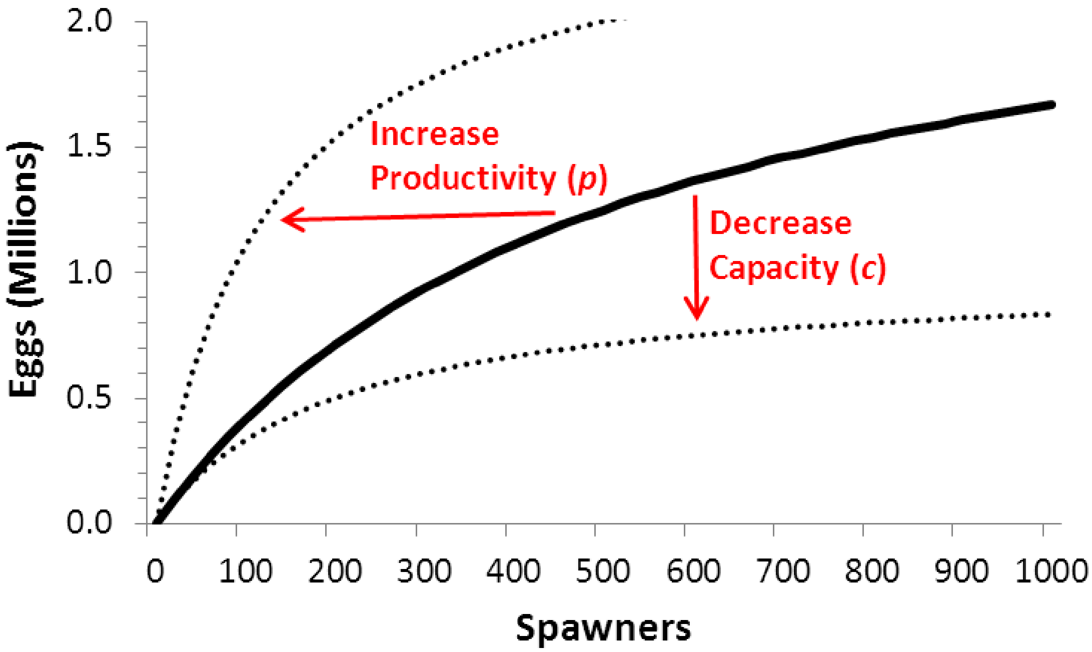


Figure 4. An Example Beverton-Holt stock-rectruitment relationship for the Spawning life history phase as modeled in the Chinook salmon life cycle model. A change in survival or productivity of spawners alters the slope of the relationship (p), while a change in habitat capacity alters the maximum number of eggs that can be supported (c).

6. Life History Phases

To evaluate CNFH and BCRP project effects, the model relates various attributes of the physical and biological environment to the survival/productivity and capacity of each life history phase (Table 5). These project or environmental drivers will alter the *p* and *c* parameters in each stock-recruitment transition. The functional form of each relationship and expected values for each driver are informed by available values from published literature, sampling data, reports, and from TAC expert opinion.

Table 5. CNFH and BCRP project effects that affect either the survival/productivity (p) or capacity (c) parameters for each life history phase in the Chinook salmon life cycle model. Flow in parentheses indicates a project driver that is influenced by monthly flow conditions.

Life History Phase	Hatchery or In-River Spawners	Project or Env. Drivers	CNFH or BCRP Effect?	Affects Productivity (*p*) or Capacity (*c*)
Adult Passage	In-River	Hatchery Passage	CNFH	*p*
		Barrier Passage (trapping)	CNFH	*p*
		Barrier Passage (w/o trapping)	CNFH	*p*
		Out-of-Basin Strays	n/a	n/a
		High Flow Passage of Hatcherys Strays (Flow)	CNFH	*p*
	Hatchery	Broodstock Requirements	CNFH	n/a
Adult Holding	In-River	Water Temperature	BCRP	*p*
Spawning	Hatchery	Broodstock Requirements	CNFH	n/a
	In-River	Water Temperature	BCRP	*p*
		Habitat Amount (Flow)	BCRP	*c*
Egg Incubation	Hatchery	None		
	In-River	Water Temperatures	BCRP	*p*
		Redd Scouring (Flow)	n/a	*p*
		Hatchery Introgression	CNFH	*p*
Juvenile Rearing	Hatchery	None		
	In-River	Water Temperatures	BCRP	*p*
		Habitat Amount (Flow)	BCRP	*c*
Battle C. Emigration	In-River	Diversion Loss	CNFH	*p*
Sac R. Residence	Both	None	n/a	n/a
Delta Residence	Both	None	n/a	n/a
Ocean Residence	Both	None	n/a	*p*

6.1 Adult Passage

The Adult Passage life history phase models adult salmon passage through the CNFH barrier weir into upstream Battle Creek reaches (in-river spawners), or into the hatchery (fall Chinook and hatchery-origin late-fall Chinook). Below, we describe adult passage relationships for natural-origin and hatchery-origin Chinook salmon, and strays that pass the CNFH barrier during high flows, or during times of no trapping. CNFH passage functionality in the model is assumed to represent future restored operations as informed by the TAC, not the current passage operations.

6.1.1 Natural-origin

The model assumes three primary routes that natural-origin adult salmon will be able take to pass through the fish barrier weir ladder system under future restored operations (Table 5):

1. Hatchery: the barrier upstream fish ladder is closed and fish enter the hatchery, are sorted, and then released upstream.
2. Barrier – trapping: Fish are trapped in the barrier fish ladder system and sampled prior to being released into the upstream fish ladder.
3. Barrier – without trapping: Fish can pass through the barrier upstream fish ladder unimpeded.

To calculate the percent of natural-origin adults of each race that experience each of the three passage routes, the relative monthly timing of peak adult passage for each race was calculated (see Temporal Resolution section for details). The timing of occurrence of each passage route through the CNFH barrier weir fish ladder system, and peak passage proportion of each race occurring in each month is described in Table 6.

Table 6. Monthly timing of occurrence of each passage route and monthly proportional passage for each Chinook salmon race as modeled in the Chinook salmon life cycle model.

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Passage Route	Hatchery	■	■								■	■	■
	Barrier - trapping			■	■	■							
	Barrier - w/o trapping						■	■					
Passage Timing	Winter		0.13	0.31	0.31	0.25							
	Late-Fall	0.38	0.31										0.31
	Spring					0.56	0.44						

Finally, we summed the monthly occurrence proportions that overlapped with the timing of each of the three passage routes, to determine the percent of natural-origin winter-, late-fall-, and spring- Chinook that experience each passage route (Table 7).

Table 7. Proportion of winter, late-fall, and spring- Chinook that experience each passage route in the Chinook salmon life cycle model.

	Passage Route		
Run	Hatchery	Barrier - trapping	Barrier - w/o trapping
Winter	0.13	0.88	0
Late-Fall	1	0	0
Spring	0	0.56	0.44

Survival (p_1) of natural-origin adults of each race past the CNFH barrier weir is a function of the proportion of each race that experiences each passage route (Table 7) and the survival experienced in each route:

$$p_1 = x_1 p_{hatchery} + x_2 p_{trapping} + x_3 p_{no\ trapping}$$

where x is the proportion of the race experiencing the respective route (Table 4) and $p_{hatchery}$, $p_{trapping}$, and $p_{no\ trapping}$ are the survival rates experienced in each route.

Survival of natural-origin adults taking the hatchery route ($p_{hatchery}$) is a function of direct mortality occurring in the Barrier weir hatchery ladder, in hatchery holding ponds, or during fish sorting ($mort_{hatchery}$) (Figure 5):

$$p_{hatchery} = 1 - mort_{hatchery}$$

where $mort_{hatchery}$ is defined as a beta-binomial distribution, which draws from estimates of pre-spawning mortality of unmarked Chinook salmon observed during collection of late-fall Chinook salmon broodstock for return years 2002 – 2014 (Data from Table 7-1 of USFWS 2011, and TAC input). The mean annual value from these data was 0.118 (dispersion = 20.65). All winter and natural-origin late-fall Chinook survivors are released upstream of the barrier weir.

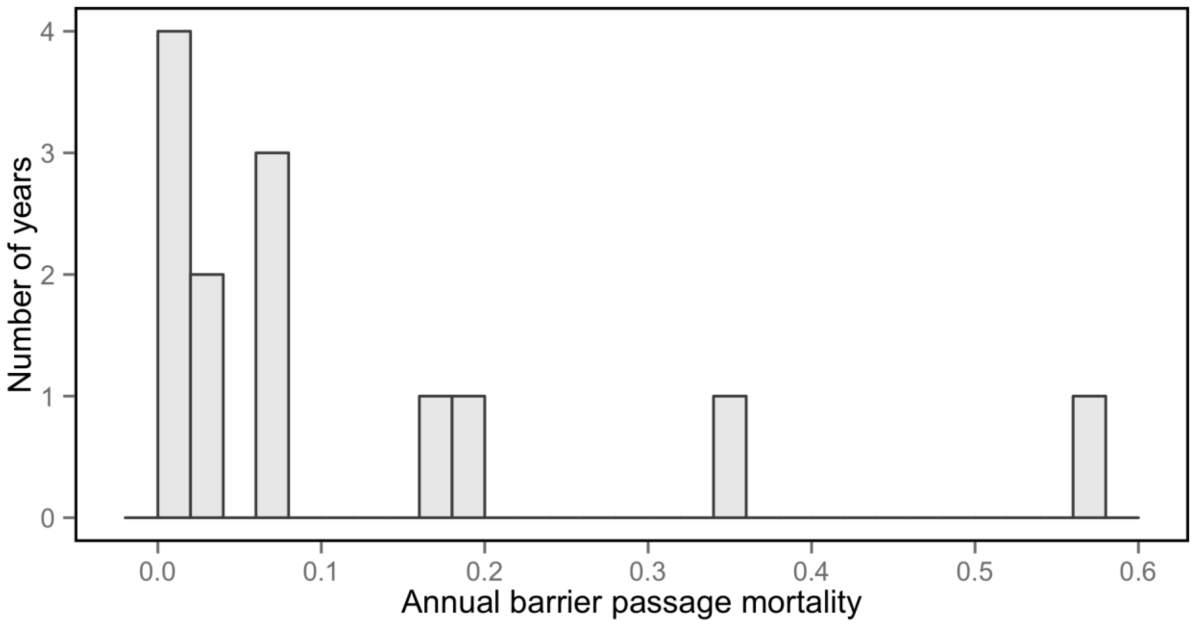


Figure 5. Observed estimates of annual pre-spawning mortality for late-fall Chinook salmon at the CNFH for years 2002 – 2014 used to inform a beta-binomial distribution of annual barrier passage mortality for natural-origin winter- and late-fall Chinook adults passing the CNFH barrier weir through the hatchery route in the Chinook salmon life cycle model.

Similar to the hatchery route, survival of natural-origin adults that are trapped in the barrier weir ladder system ($p_{trapping}$) is a function of direct trapping mortality ($mort_{trapping}$) during passage (Figure 6):

$$p_{trapping} = 1 - mort_{trapping}$$

where $mort_{trapping}$ is defined as a beta-binomial distribution, which draws from estimates of the average observed mortality rate of Chinook salmon resulting from trapping in the barrier weir ladder system for return years 2001-2012 (TAC input). The mean annual value from this data was 0.014 (dispersion = 4.32). All natural-origin winter and spring Chinook survivors are released into the upstream fish ladder.

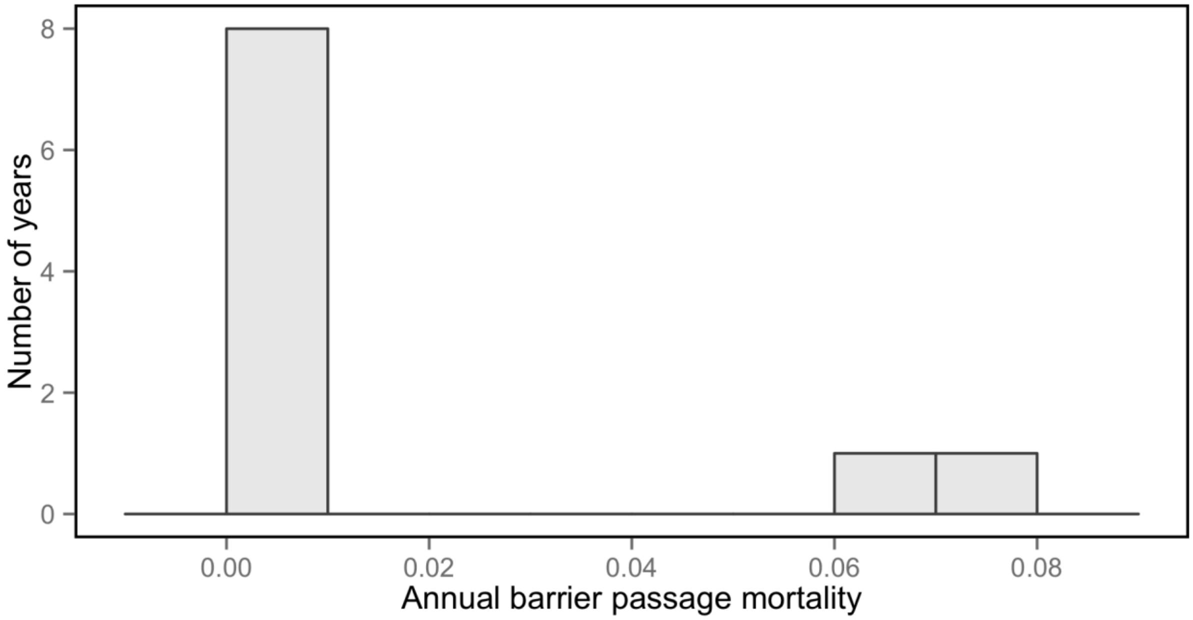


Figure 6. Observed estimates of annual mortality for late-fall Chinook salmon during trapping in the barrier weir ladder system at the CNFH for years 2001 – 2012. These estimates were used to inform a beta-binomial distribution of annual barrier passage mortality for natural-origin winter and spring Chinook adults passing the CNFH barrier weir through the ladder route in the Chinook salmon life cycle model.

Survival of natural-origin adults that pass the barrier weir through the upstream fish ladder without being trapped ($p_{no\ trapping}$) is a function of direct mortality in the fish ladder ($mort_{no\ trapping}$) during passage:

$$p_{no\ trapping} = 1 - mort_{no\ trapping}$$

where $mort_{no\ trapping}$ is currently set at 0, based on TAC input.

6.1.2 Hatchery-origin

For fall Chinook, 5,200 adults is the minimum spawning target for the CNFH annual propagation program (USFWS 2011). However, additional adults are taken into the hatchery to account for potentially high egg mortality rates (USFWS 2011), and to limit the number of fish held below the barrier weir in the Lower reach to no more than 20,000 fall Chinook spawners (informed by the TAC). Although this model functionality is a simplification of actual hatchery operations, the model assumes that the first 5,200 fall Chinook adults enter the hatchery and are spawned in October and November, while excess fish (up to 20,000) remain in the Lower reach to spawn. Any fish returning beyond the 20,000 spawner-target are assumed to be taken into the hatchery and euthanized.

For hatchery-origin late-fall Chinook, the first 540 adults enter the hatchery to meet minimum broodstock requirements. Except for fish that may pass the barrier weir under extreme high flow events (see below), hatchery-origin late-fall Chinook in excess of the 540 adults used for broodstock are assumed to be taken into the hatchery and euthanized.

6.1.3 Strays

Because late-fall Chinook adult passage occurs during the wet season (November – March), there is potential for hatchery-origin late-fall Chinook to stray above the CNFH barrier weir and spawn in Battle Creek reaches upstream during high flow events. The CNFH barrier weir is thought to become passible to returning adult salmonids at high flows ranging between 800 and 4,500 cfs (based on TAC input).

To determine when high flow passage occurs in the model, hourly flow data from water years 1995 to 2012 were used from the California Department of Water Resources (DWR) California Data Exchange Center (CDEC) gauge in the Lower Reach (BAT CDEC gauge station). This gauge station is located just below the CNFH barrier weir. For each water year type, we quantified the mean number of hours during each month that hourly flows were between 800 and 4,500 cfs at any time during each day (potential stray hours). We then divided the number of potential stray hours by the total hours in each month to calculate the proportion of time in each month that there was a potential for straying (stray potential). Monthly stray potential was then multiplied by the monthly proportional presence of spawning late-fall Chinook to calculate the monthly potential stray rate. Because the TAC estimated that the maximum annual stray rate past the CNFH barrier weir is approximately 5%, we scaled the monthly potential stray rates in order to attain an annual stray rate of 5% for late-fall Chinook in wet years. Therefore, the resulting scalar on monthly proportional passage is 0.132, implying that only 13.2% of adults eligible to stray (during flows of 800 to 4,500 cfs) successfully do so.

In addition to Battle Creek spring Chinook adults that pass through the CNFH barrier weir, Feather River Hatchery (FRH) spring Chinook adults are also known to have strayed into Battle Creek. Past estimates of successful passage of FRH strays into Battle Creek are used to inform the number of spring Chinook strays that enter the adult holding life history phase in Battle Creek. The average observed number of presumed FRH spring Chinook strays passing through the CNFH barrier weir in years 2010-2013 was 19 to 147 (L. Earley, USFWS, pers. comm.). Therefore, we modeled FRH stray rate as a uniform distribution that ranges from 0 to 150 fish and is applied annually in June, the only month during adult spring Chinook passage when fish are not being trapped in the CNFH barrier weir fish ladder system (Table 3).

6.2 Adult Holding

The adult holding life history phase models the summer holding period (Table 1) of adult spring Chinook (4 months) and winter Chinook (3 months) prior to spawning. The monthly survival (p_2) of holding Chinook salmon in each reach (*b*) is modeled as a logistic function of the reach-specific average water temperature experienced for that particular month (*T*; °C):

$$p_{2,b} = \left(-\frac{1}{1+e^{-\alpha-\beta T_b}}\right)^4$$

where α = -115.08 and β = 5.421 (Figure 7). The logistic relationship was defined by Thompson et al. (2012) by fitting eight years (2001-2008) of spring Chinook salmon pre-spawning survival data in Butte Creek, CA, to mean weekly water temperature. Although the logistic function from Thompson et al. (2012) predicts survival on a weekly basis, we applied the relationship on an average monthly basis (by raising the weekly survival calculation to the 4th power) because this is the highest resolution data available from Battle Creek water temperature modeling.

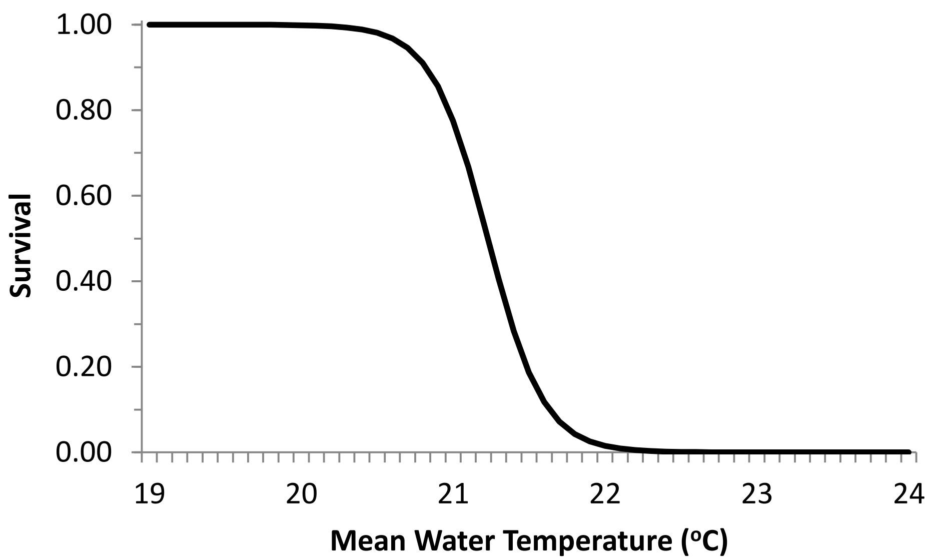


Figure 7. Monthly survival of holding adult spring and winter Chinook salmon versus mean water temperature applied in the model. The relationship was adapted from Thompson et al. (2012).

6.3 Spawning

The spawning life history phase models the transition of spawners to deposited eggs. Fall and late-fall Chinook spawners in the hatchery are transitioned to eggs as a function of race-specific fecundity, and multiple Beverton-Holt models are applied to transition natural spawners to deposited eggs in each in-river reach.

Fall and late-fall Chinook hatchery spawners are converted to eggs ($N_{hatchery}$) as a function of the proportion of female spawners (*P*, 0.5), the number of spawners that meet the broodstock requirements (*S*; late-fall ≤ 540, fall ≤ 5,200; USFWS 2011), and fecundity (5,000):

$$N_{hatchery,r} = P * S_r * F.$$

The monthly pre-spawning survival (p_3) of natural spawners in each reach (*b*) is modeled by applying the same logistic function and parameter values used for the adult holding life stage, with monthly survival modeled as a function of the average monthly water temperature experienced in each reach during spawning (*T*; °C):

$$p_{3,b} = 1 - \frac{1}{1 + e^{-\alpha-\beta T_b}}$$

The monthly capacity (c_3) of female natural spawners across all races in each reach (*b*) is modeled as a function of the reach-specific suitable habitat available for spawning (*spawning* *habitat*; ft^2), and redd area. In the model, redd area is the average size of fall and spring Chinook salmon redds observed in the Yuba River (47 ft^2; Campos and Massa 2012):

$$c_{3,b} = \frac{spawning\ habitat_b}{redd\ area};$$

where *spawning habitat* is the total amount of reach-specific suitable habitat available for spawning as a function of flow as defined by Instream Flow Incremental Methodology (IFIM) and Physical Habitat Simulation (PHABSIM) analyses detailed in Appendix H of the 2005 Battle Creek Environmental Impact Statement/Environmental Impact Report (EIS/EIR) (Jones and Stokes 2005).

Finally, natural spawners of each race (*r*) in each reach (*b*) are converted to deposited eggs ($N_{natural,r,b}$) as a function of the proportion of females (*P*, 0.5), the number of spawners of a race and reach ($S_{r,b}$), and a fecundity of 5,000 as provided by the TAC (*F*):

$$N_{wild,r,b} = P * S_{r,b} * F.$$

6.4 Egg Incubation

The egg incubation life history phase models the two-month long transition of eggs to fry. Single Beverton-Holt equations are constructed for fall and late-fall Chinook eggs in the hatchery, and multiple models are created for eggs in each in-river reach. Survival of hatchery eggs to the fry stage (p_{4a}) is defined as 0.84 for fall and 0.76 for late-fall Chinook, the average egg-to-fry survivals observed in the CNFH (USFWS 2011).

Monthly survival (p_{4b}) of eggs in each in-river reach (*b*) is modeled as a function of water temperatures, fitness loss due to introgression with hatchery spawners, and redd scouring due to high flows occurring during that particular month. First, the effect of reach-specific water temperature (*T*) on egg mortality is modeled as a series of linear relationships (Scheuerell et al. 2006; Figure 8):

$$p_{4,1,b} = \begin{cases} 0.94 & \text{if } 4.7 \le T_{inc,b,m} < 14.3 \\ -0.245T_{inc} + 4.44 & \text{if } 14.3 \le T_{inc,b,m} < 18.1 \\ 0.01 & \text{if } T_{inc,b,m} \ge 18.1 \end{cases}$$

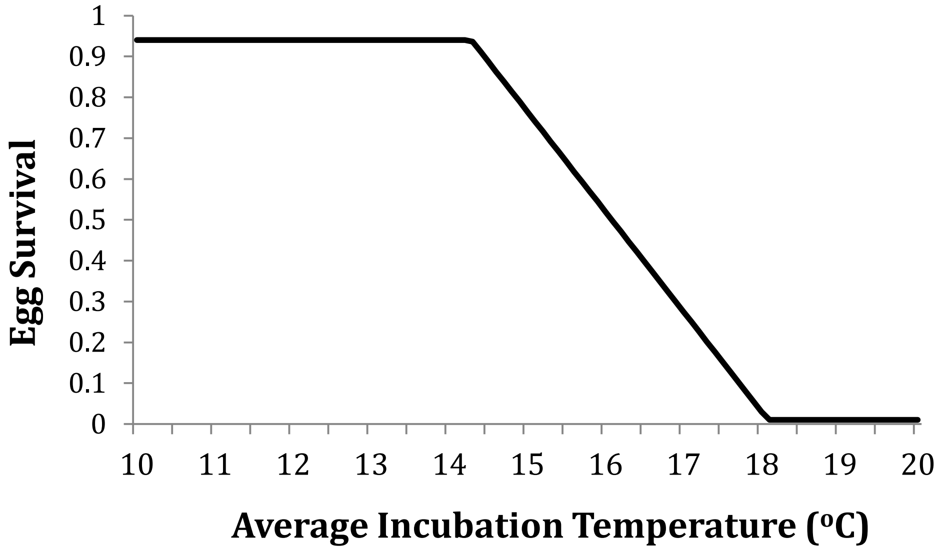


Figure 8. Monthly egg survival versus average monthly incubation temperature applied in the model. Relationship is from Scheuerell et al. (2006).

Several studies have shown lower reproductive success of hatchery salmonids compared to their natural counterparts (Chilcote et al. 1986; McLean et al. 2003; Chilcote et al. 2011), leading to the hypothesis that recruitment performance of naturally reproducing populations should vary directly with the proportion of spawners that are of hatchery-origin (Chilcote et al. 2011). Although the effect of fitness loss due to introgression with hatchery spawners on Chinook salmon productivity can occur at multiple life stages (Buhle et al. 2013), we apply this effect only in the egg incubation phase to avoid overestimating the effect on salmon productivity. Also, the effect of reduced recruitment due to introgression was not applied for winter Chinook due to the conservation focus of the Livingston Stone Fish Hatchery winter Chinook propagation program, and the perceived lack of negative introgression effects.

Chilcote et al. (2013) found a significant negative relationship between fish productivity and the proportion of spawners of hatchery-origin for 93 populations of anadromous salmonids from Oregon, Washington, and Idaho, USA. Therefore, we applied the best-fit relationship for Chinook salmon from Chilcote et al. (2013) to inform the effect of hatchery introgression on egg survival for fall, late-fall, and spring Chinook (Figure 9). Monthly egg survival ($p_{4b,2}$) is modeled as a function of the proportion of hatchery-origin spawners ($hatchery_i$) present in each reach (*b*) in that particular month:

$$p_{4,2,b} = e^{(2.20 - hatchery_i * 2.80)}/e^{2.20}$$

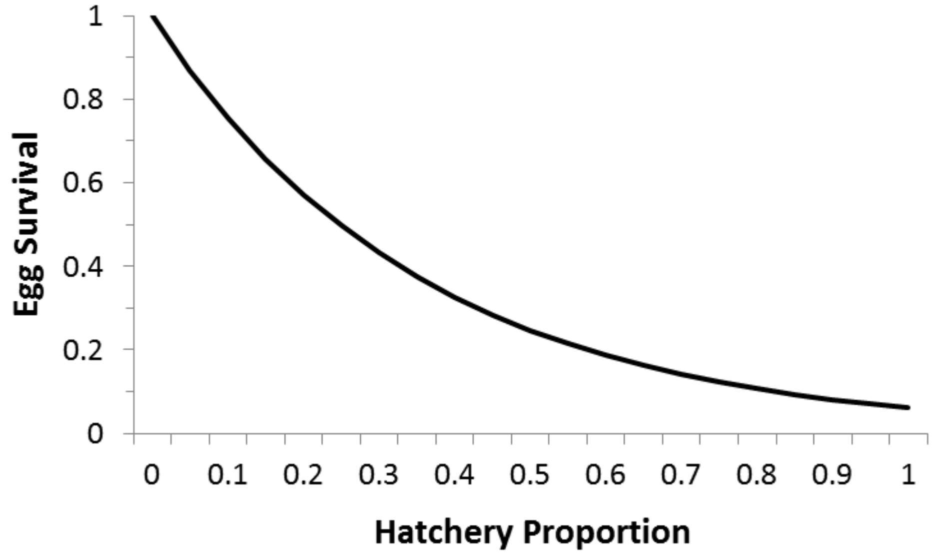


Figure 9. Relationship between Chinook salmon monthly egg survival and the proportion of spawners of hatchery-origin applied for fall, spring, and late-fall Chinook in the model. The relationship was adapted from Chilcote et al. (2013).

We applied the same relationship used by Schuerell et al. (2006) to model the effect of redd scouring on monthly egg survival ($p_{4b,3}$) in each section of Battle Creek (mainstem, North Fork, South Fork). First, normalized mean monthly flow (Q_r) during the incubation period in Battle Creek was calculated by dividing the maximum daily mean flow for each month (Q) by the maximum historical flow observed in mainstem Battle Creek ($Qmax$). Maximum historical flow (Q_{max}) was set at 20,605 cfs, the maximum mean daily flow estimated from the BAT CDEC gauge station for water years 1995 to 2012. We then fit the following relationship between monthly egg-fry survival and Q in the mainstem (Figure 10):

$$p_{4,3} = \begin{bmatrix} 0.58 - 0.844Q & if\ Q_r < 0.675 \\ 0.01 & if\ Q_r \geq 0.675 \end{bmatrix}$$

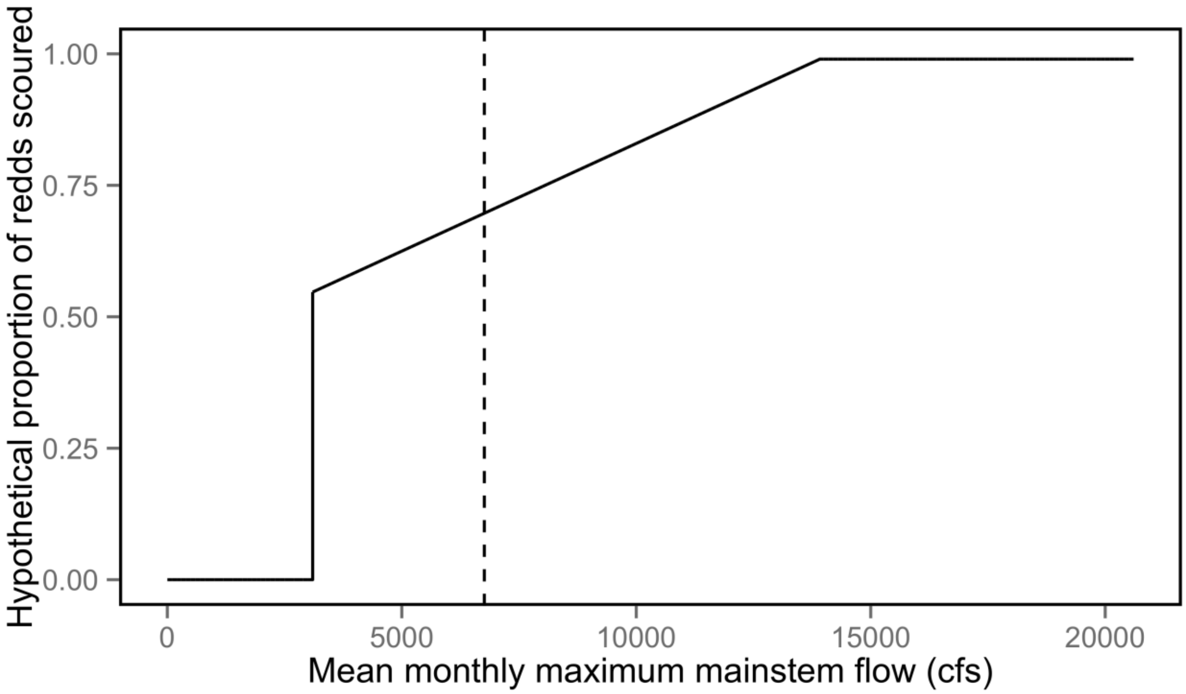


Figure 10. Relationship between redds scoured and maximum mean flow during the egg incubation period (Schuerell et al. 2006). The dashed vertical line represents the highest mean monthly maximum flow (6,759 cfs) across all years used in the model. Therefore, redd scour is never 100%.

Finally, we assume that redd scouring does not occur in Battle Creek until flows exceed 3,000 cfs (assumption based on TAC input). Therefore, if the maximum mean flow observed during the egg incubation period for each run does not exceed 3,000 cfs, the model does not incorporate mortality due to redd scour.

6.5 Juvenile Rearing

The juvenile rearing life history phase models the three-month long transition of fry-to-smolts. Single Beverton-Holt models are constructed for fall and late-fall Chinook fry in the hatchery, and multiple models are created for fry in each in-river reach. Survival of hatchery fry to the smolt stage (p_{5a}) is 0.97 for fall and 0.89 for late-fall Chinook, the average fry-to-smolt survivals observed in the CNFH (USFWS 2011).

A portion of in-river fry of each race emigrate downstream to the Sacramento River as fry and rear in the Sacramento River. Those fish immediately transition to the Battle Creek emigration stage and are not included in the Juvenile rearing calculations. We used data from the USFWS rotary screw trap (RST) located immediately above the CNFH barrier weir for years 2008-2014 to develop an estimate of the average percentage of each race that emigrate as fry for fall, late-fall, and spring Chinook.

Because larger (smolt-sized) migrants can avoid capture by swimming around the trap or back out the mouth of the trap, RST capture efficiencies can vary by fish size (Volkhardt et al. 2007). Comparison of RST catches of three different size groups of juvenile steelhead in Ten-mile

Creek, Oregon, showed an approximate two-fold decrease in capture efficiency between the smallest and largest migrants (Volkhardt et al. 2007). Therefore, when estimating the percentage of fish emigrating as fry, we doubled the catch values for smolts under the assumption that the trap was half as efficient at capturing them compared to fry and parr. This resulted in an average percentage of fry migrants of 92% for fall Chinook, 79% for late-fall Chinook, and 56% for spring Chinook. For winter Chinook, we applied the average observed annual percentage of fry passing Red Bluff Diversion Dam in the Sacramento River for brood years 2008-2010 (78%; Poytress and Carillo 2011; Poytress and Carillo 2012)

Similar to holding adults, the monthly survival of rearing juvenile Chinook salmon is modeled as a function of average monthly water temperature. We used the survival versus temperature relationship defined by Baker et al. (1995) for coded-wire tagged Sacramento River fall Chinook salmon migrating through the Sacramento-San Joaquin River Delta (Figure 11). Monthly survival (p_{5b}) in each reach (b) is modeled as a function of reach-specific average monthly water temperature (T;^{o}C), where α = -15.56 and β = 0.6765:

$$p_{5,b} = 1 - \frac{1}{1 + e^{-\alpha - \beta T_b}}$$

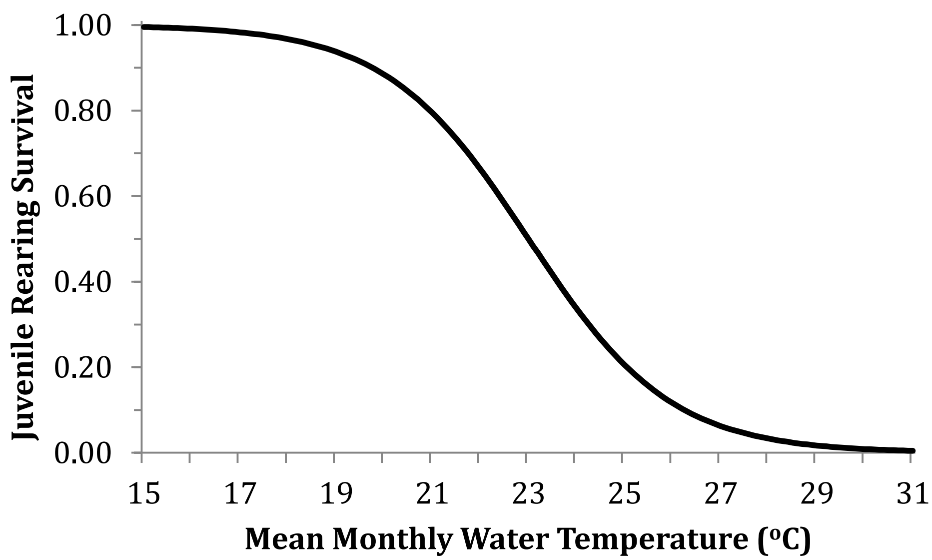


Figure 11. Monthly survival of juvenile Chinook salmon versus mean monthly water temperature applied in the model. This relationship was adapted from Baker et al. (1995).

The monthly capacity (c_{5b}) of rearing fry across all races in each reach (b) is modeled as a function of reach-specific suitable habitat available in that particular month (*rearing habitat*$_i$; ft^2), and average *territory size* of Chinook salmon fry (2.0 ft^2; Jones and Stokes 2005):

$$c_{5,b} = \left(\frac{Rearing\ Habitat_{b,r}}{Territory\ Size}\right);$$

where *rearing habitat* is the total amount of reach-specific suitable rearing habitat available for each race as a function of flow, as defined by IFIM and PHABSIM analyses detailed in Appendix H of the 2005 Battle Creek EIS/EIR (Jones and Stokes 2005).

6.6 Battle Creek Emigration

The Battle Creek emigration life history phase models the emigration of in-river juveniles from Battle Creek to the Sacramento River. Survival of juveniles emigrating out of Battle Creek (p_6) is modeled as a function of emigration mortality ($Mort_{emigration}$), which is dependent upon the distance traveled ($Distance_r$) through Battle Creek, and diversion loss associated with the CNFH unscreened water intake (i.e., Intake 2):

$$p_{6,b} = \left(1 - Mort_{emigration}\right)^{Distance_b} \left(1 - \sum Divert \times Passage_r\right)$$

Where emigration mortality is a function of the mean mortality per kilometer as observed during acoustic tagging studies of yearling late-fall Chinook salmon in the upper Sacramento River (Michel 2010), and by the reach-specific (*b*) distance traveled from the middle of a particular reach of juvenile rearing to the Sacramento River. We applied the range of per kilometer mortality rates (0.002-0.004) observed in the Sacramento River reach closest to the mouth of Battle Creek (RKM 518 to RKM 504) during the tagging study across three years of releases (2007-2009; Michel 2010). Annual downstream mortality rate in the model is determined by sampling from a uniform distribution of tagging mortality rates. Hatchery fall and late-fall Chinook smolts are planted at the upstream end of Lower Reach in the model, and therefore do not experience diversion mortality. These hatchery fish only experience the Lower Reach emigration mortality rate. Similarly, natural-origin juveniles that rear in the lower reach do not experience diversion mortality.

6.6.1 Diversion Mortality

Next, we modeled mortality associated with the unscreened CNFH water intake. Intakes 1 and 3 divert water from Battle Creek and are necessary for regular operation of CNFH (USFWS 2011). Outages at Pacific Gas and Electric Company's Coleman Powerhouse results in the temporary dewatering of the hatchery's primary water intake (Intake 1), which is located in the tailrace of the powerhouse (USFWS 2011). In these circumstances, the hatchery's water demand is supplied via the combination of hatchery Intake 3 and emergency back-up Intake 2. Intake 3 is screened to standards that meet or exceed criteria of National Marine Fisheries Service and the CA Department of Fish and Wildlife; however, the hatchery's Intake 2 is not screened, and its operation may result in entrainment of fishes from Battle Creek. Although planned outages also occur at the Powerhouse, planned outages are chosen to occur at a time when juvenile emigration is minimal, thereby limiting the impacts to fish (TAC input). Therefore, we decided not to incorporate the effect of planned outages, because the much larger effect of unplanned outages resulted in negligible effects on mean abundance (See Results section).

We used historical data associated with unplanned outages (USFWS 2011) to inform the expected frequency of these unanticipated events, and calculate the proportion of Battle Creek flow diverted into Intake 2. We extracted the event start dates and durations of all unplanned outages for years 1992-2006 from Table A-14 of Appendix 4A of the CNFH Biological

Assessment (USFWS 2011). A total of 46 unplanned outages occurred, ranging in duration from 19 minutes to 133 days (median = 4.9 hours). We used average monthly flow data at the CDEC BAT gauge in the mainstem Battle Creek to inform the average amount of flow passing the Intake 2 diversion during outage events. Our approach for calculating monthly diversion loss in the life-cycle model is to sample probabilistically from the unplanned outage data to estimate the amount of flow diverted in a month at Intake 2, and pair that data with the observed emigration timing. More specifically, the life-cycle model calculates the monthly loss by taking the following steps:

1) *Number of Events* - determine the number of outage events occurring in a month by sampling from a probability distribution of historical frequency of outage events.
2) *Event Duration* - if an event occurs in the given month, determine the duration of the outage event by sampling from a probability distribution of historical event durations.
3) *Water Volume Diverted* - calculate the monthly proportional water volume diverted by converting the event duration to water volume and dividing by the average monthly water volume passing the Intake 2 diversion.
4) *Diversion Loss* - calculate monthly loss by multiplying the proportion of water volume diverted by the modeled proportion of fish expected to be passing the diversion.

Number of Events

The number of outage events occurring during a single month in the model is determined by sampling from a negative binomial distribution of the frequency of unplanned outage events observed during years 1992-2006. The most likely number of outage events occurring in a given month is zero, with decreasing probability of occurrence as event frequency increases (Figure 12). The mean value from these data was 0.26 (dispersion = 0.42).

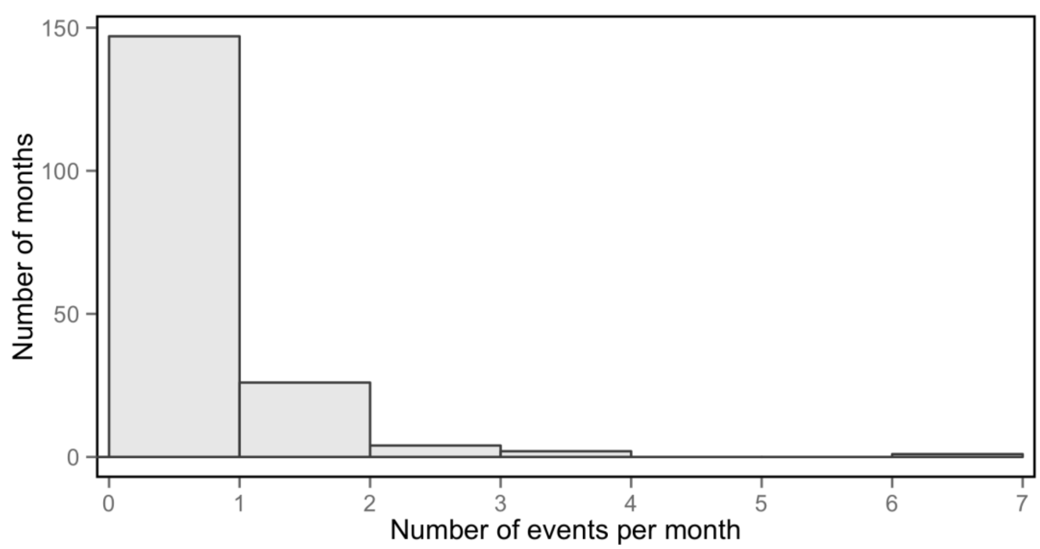


Figure 12. Observed distribution of unplanned outage events per month at Intake 2 that occurred during years 1992-2006 used to inform a beta-binomial distribution of the monthly number of unplanned outage events occurring in the Chinook salmon life cycle model.

Event Duration

The duration of each outage event occurring during a single month in the model is determined by sampling from a nonparametric probability density function of outage durations observed during years 1992-2006. Due to the random nature of the historical event duration data, we used a random variate generation algorithm (Kaczynski *et al*. 2012) to develop a nonparametric probability density function, which informs the duration of each monthly outage event. Because we are modeling on a monthly time step, sampled durations greater than one month long are truncated in the model so the longest that diversion through Intake 2 could occur was for that month (Figure 13).

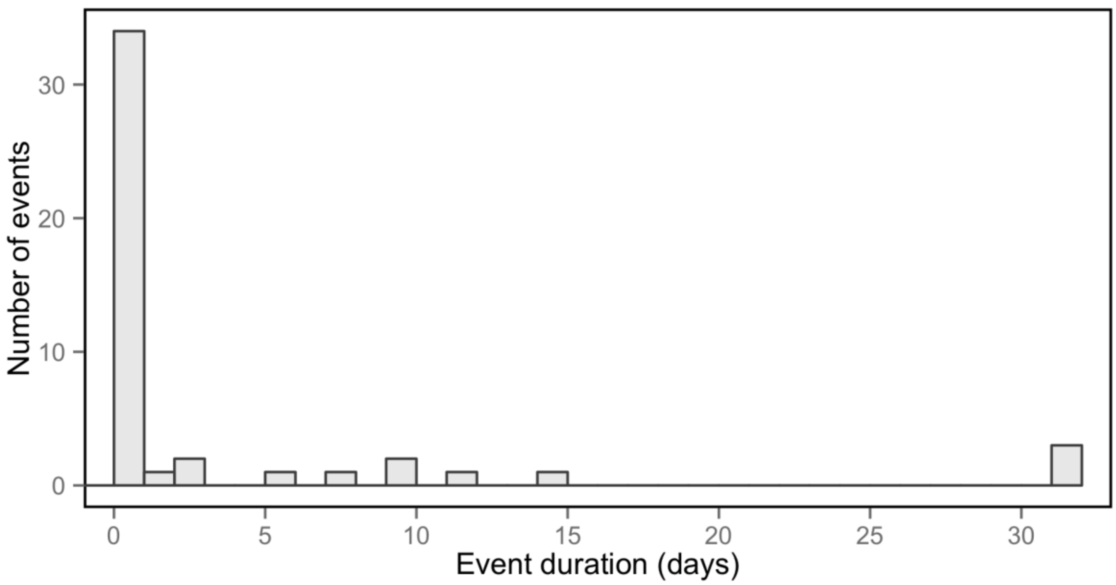


Figure 13. Observed number and duration of unplanned outage events at Intake 2 that occurred during years 1992-2006 used to inform a beta-binomial distribution of the duration of unplanned outage events occurring in the Chinook salmon life cycle model. This relationship was truncated to the total number of days in a month (31) used in the model.

Water Volume Diverted

Without information on variability of the diversion flow rate at Intake 2 between diversion events, we assumed a diversion flow rate of 64 cfs for each diversion event, which is thought to be the maximum flow rate that can be diverted through Intake 2 (based on TAC input). We multiplied each unplanned outage duration (seconds) by 64 (cfs) to obtain the total water volume diverted for each event. We then summed the diversion volumes in each month to determine the monthly water volume diverted. Next, we determined the monthly proportion of Battle Creek flow reaching Intake 2 during unplanned outages. We estimated the total volume of Battle Creek flow passing Intake 2 by multiplying the average monthly flow at the CDEC BAT gauge in the mainstem Battle Creek by the number of seconds in each month. Because the model is run under three different water year types (dry, normal, and wet), we applied the average monthly flow of the corresponding water year type scenario being modeled. We then divided the previously calculated monthly diversion volume by the volume of water passing Intake 2, to calculate the monthly proportion of flow being diverted into Intake 2 during unplanned outages.

In applying this data within the life-cycle model, in months when an outage occurs, the proportion of flow being diverted results in the proportional entrainment of juveniles present during that month.

Diversion Loss

To inform the monthly entrainment (loss) proportion of juveniles in the life-cycle model, we multiplied the monthly water volume diversion proportion due to unplanned outages by the monthly proportion of passage occurring in the model.

6.7 Sacramento River Emigration

The Sacramento River emigration life history phase models the emigration of juveniles in the Sacramento River. Hatchery-origin fall Chinook juveniles are released into Battle Creek and migrate downstream to the Sacramento River during April, while hatchery-origin late-fall Chinook are released in December (USFWS 2011). Baseline survival of juveniles emigrating in the Sacramento River (p_7) is modeled as a function of the estimated survival of Sacramento River acoustically-tagged yearling late-fall Chinook salmon from CNFH (Michel 2010). Survival was estimated from Jelly's Ferry (RKM 518) to Freeport (RKM 169), across three years of releases, 2007-2009 (Michel 2010). Annual Sacramento River survival in the model is determined by sampling from a uniform distribution of the range of overall tagging survival rates (0.178-0.304) observed across the three years of release events.

In addition to baseline mortality, we also modeled the effect of CNFH hatchery-origin steelhead predation on emigrating juveniles. All CNFH produced juvenile steelhead are released as yearlings at a size of approximately 200 mm (4 fish/lb) in the Sacramento River 13 miles downstream from the confluence of Battle Creek near Bend Bridge (RKM 415), during late January (S. Hamelberg, USFWS, pers. comm.). Steelhead production at CNFH averaged approximately 620,000 fish per year over the last 12 years (USFWS 2011). Hatchery-origin steelhead remaining in the release area (i.e., residualizing in the Sacramento River) could potentially consume Chinook salmon juveniles as they emigrate from Battle Creek down through the Sacramento River.

Without recent data informing the predation level of hatchery-origin steelhead on Chinook salmon, we set the predation rate as a range to examine the potential impact. We assume that each predator only encounters an individual prey once, defined as a gauntlet predation model, where survival is dependent on distance traveled, and independent of travel velocity (Anderson et al. 2005). We also assume that predation on smolt-sized emigrants (fish that rear in Battle Creek) does not occur because of their faster burst swimming speed (relative to fry), and because CNFH steelhead are likely gape-limited for prey as large as typical Chinook smolts.

Thus, we account for additional mortality (M) of BCRP fry emigrants that are exposed to residualized hatchery steelhead during emigration, by applying the gauntlet model of predation defined by Anderson et al. (2005):

$$M = 1 - \left(exp\left(-\frac{x}{\lambda}\right)\right);$$

where x is the assumed exposure distance (22.5 km) between the mouth of Battle Creek and the steelhead release location of Bend Bridge on the Sacramento River, and λ is the encounter length scale parameter defined as follows:

$$\lambda = \frac{1}{\pi r^2 \rho};$$

where *r* is the length that a prey can encounter a predator, and *ρ* is the predator density. We set *r* at a range of 6.6 to 10.7 cm, the estimated range in predator-prey encounter distance in the Snake River for northern pikeminnow and smallmouth bass predation on juvenile Chinook salmon (Anderson et al. 2005). We set *ρ* at 62,000 by assuming 10% of CNFH released steelhead residualize in the Sacramento River (based on TAC input). The resulting modeled range in mortality due to CNFH steelhead predation was 2 – 5%. Annually, we sample from a uniform distribution of 2 to 5% mortality, and multiply this mortality rate by the number of fry of each race entering the Sacramento River.

6.8 Estuary Emigration

The Estuary emigration life history phase models the emigration of juveniles through the San Francisco Estuary. Survival of juveniles emigrating through the Estuary (p_8) is modeled as a function of the estimated survival rates of acoustically-tagged late-fall Chinook salmon from four releases during the winters of 2009 and 2010 (Perry et al. 2012). Survival was estimated from the city of Sacramento (RKM 209) to Chipps Island (RKM 70) (Perry et al. 2012). Annual Estuary survival in the model is determined by sampling from a uniform distribution of the range of 95% confidence limits of overall tagging survival rates (0.296-0.591) observed across the four release events.

6.9 Ocean Residence

The ocean residence life history phase models the survival of Chinook salmon in the San Francisco Estuary (downstream of Chipps Island) and the ocean. Relying on ocean harvest, mortality, and returning spawner data from Grover et al. (2004), we predict ocean survival and age distribution of returning spawners for age two (8% of returning spawners), age three (88% of returning spawners), and age four (4% of returning spawners), assuming 100% of individuals that survive to age four return for spawning. Ocean survival to age two is given by:

$$A_2 = A_i(1 - M_2)(1 - M_w)(1 - H_2)(1 - S_{r2})$$

survival to age three is given by

$$A_3 = A_2(1 - M_w)(1 - H_3)(1 - S_{r3})$$

and survival to age four is given by:

$$A_4 = A_3(1 - M_w)(1 - H_4)$$

where, A_i is abundance at ocean entry (from theEstuary emigration phase), $A_{2,3,4}$ are abundances at age two - four respectively, $H_{2,3,4}$ are harvest percentages at ages two - four represented by the median historical harvest level, M_2 is average smolt-to-age two mortality,

M_w is winter mortality for ages two - four, and $S_{r2,r3}$ are returning spawner percentages for ages two and three. We used the following values from Grover et al. (2004): H_2 = 0%, H_3 = 19.5%, H_4 = 37%, M_w = 20%, S_{r2} = 8%, and S_{r3} = 96%.

Recent publications have identified the early marine residence of Chinook salmon as having significant population level consequences (Woodson et al. 2013; Satterhwaite et al. 2014). Also, survival during the first year of Chinook salmon ocean residence has been shown to vary from year to year depending on myriad factors, including size at ocean entry and ocean productivity levels (Wells et al 2007; Woodson et al. 2013; Satterhwaite et al. 2014). Therefore, we incorporated uncertainty in smolt-to-age-two mortality (M_2) by applying the range of observed early marine survival rates of hatchery-reared winter Chinook salmon smolts for brood years 1998-2007 (O'Farrell et al. 2011). Annual M_2 in the model is determined by sampling from a uniform distribution of the approximate range of early marine mortality rates (0.95-0.99) observed across all ten brood years.

7. Environmental Input Data

Best available environmental input data was selected to inform model relationships. We compiled and used modeled environmental data from draft and final versions of the BCRP EIS/EIR (Jones and Stokes 2005) and observational flow data from the CDEC BAT gauge.

In order to incorporate the effect of varying annual flow conditions on model outcomes, the model ran under three water year types: dry, normal, and wet. Each model run consisted of 50 years, with the annual occurrence of each water year type following auto-correlated occurrence probabilities observed in the Sacramento River Basin hydrologic record since 1906 (CDEC). For each of the six data input types described below, separate monthly values were used for each of the three water year types, thereby incorporating the effect of varying monthly and annual flow regimes in model results.

We applied six data input types needed to inform model functionality, including:

1. Modeled Flows – modeled reach-specific mean monthly flows
2. Modeled Spawning Habitat – modeled reach-specific spawning habitat amount as a function of flow
3. Modeled Juvenile Habitat - modeled reach-specific juvenile habitat amount as a function of flow
4. Observed Hours of High Flows – mean number of hours of high flow events by month in the mainstem section (> 800 - 4,500 cfs)
5. Observed Max. Flows – monthly maximum flows
6. Modeled Temperatures – modeled reach-specific mean monthly water temperatures

Figure 14 depicts how each of the six data input types enter the life-cycle model, including which modeled life-history phase each of the six data input types affects, and the specific effect of each data input. This section provides a description of the data sources used for each of the six data input types.

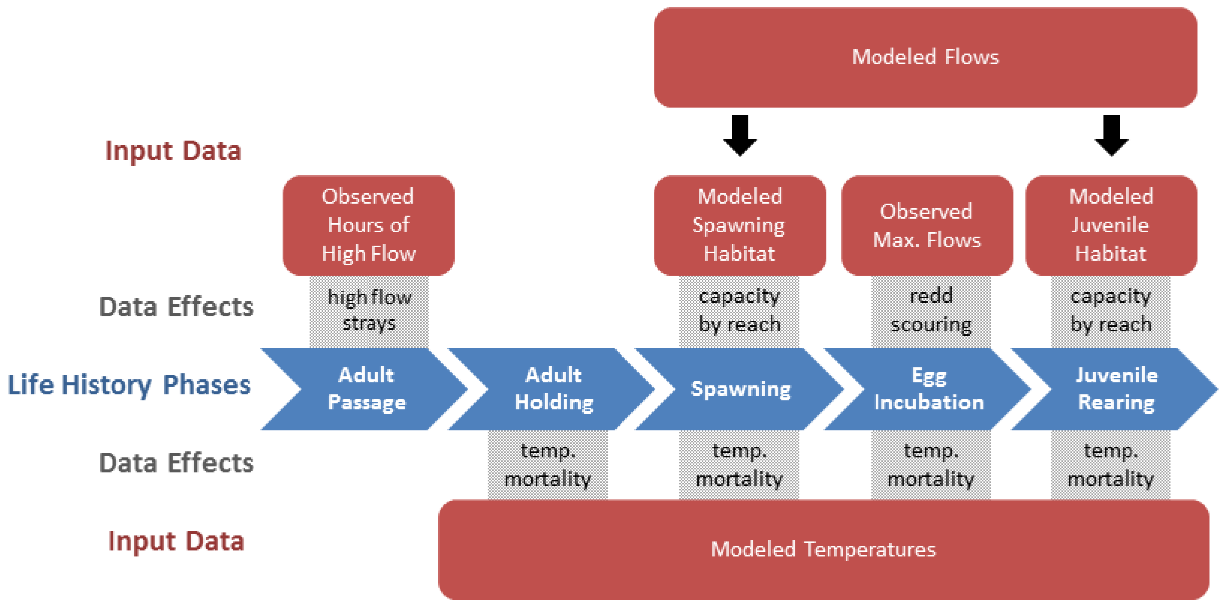


Figure 14. Six data input types used to inform the model (red boxes) and their effects (grey boxes) on each life-history phase (blue polygons).

7.1 Modeled Flows

Modeled mean monthly flow data informed the amount of suitable habitat for adult spawners and juveniles in each reach. The flow used depends on the water year type (i.e., dry, normal, and wet). The data for flow came from Appendix J of the BCRP EIS/EIR (Jones and Stokes 2005) for the "Five Dam Alternative" (Table 8). Because the data are not organized at the BCRP reach-level (except for the Mainstem Reach), we used the data from point sources within a reach to determine the flow for that reach. Where there is no data within a specific reach, we used data from the closest reach available. For a dry year, we used the 10^{th} percentile flows. For a normal year, we used the 50^{th} percentile flows. For a wet year, we used the 90^{th} percentile flows.

Table 8. Modeled flow data used in each reach of the model.

Reach	Original Caption from Appendix J of the BCRP EIS/EIR (Jones and Stokes 2005)
Lower Reach	Table J-15. Calculated Fish Habitat Flows (cfs) for All of the Alternatives at Mainstem Battle Creek
Mainstem Reach	Table J-15. Calculated Fish Habitat Flows (cfs) for All of the Alternatives at Mainstem Battle Creek
Wildcat Reach	Table J-6. Calculated Fish Habitat Flows (cfs) for All of the Alternatives below Wildcat Diversion Dam
Eagle Canyon Reach I	Table J-4. Calculated Fish Habitat Flows (cfs) for All of the Alternatives below Eagle Canyon Diversion Dam
Eagle Canyon Reach II	Table J-4. Calculated Fish Habitat Flows (cfs) for All of the Alternatives below Eagle Canyon Diversion Dam
North Battle Feeder Reach I	Table J-2. Calculated Fish Habitat Flows (cfs) for All of the Alternatives below North Fork Battle Creek Feeder Diversion Dam
North Battle Feeder Reach II	Table J-2. Calculated Fish Habitat Flows (cfs) for All of the Alternatives below North Fork Battle Creek Feeder Diversion Dam
Keswick Reach	Table J-2. Calculated Fish Habitat Flows (cfs) for All of the Alternatives below North Fork Battle Creek Feeder Diversion Dam
Coleman Reach	Table J-14. Calculated Fish Habitat Flows (cfs) for All of the Alternatives below Coleman Diversion Dam
Inskip Reach	Table J-11. Calculated Fish Habitat Flows (cfs) for All of the Alternatives below Inskip Diversion Dam
South Reach I	Table J-8. Calculated Fish Habitat Flows (cfs) for All of the Alternatives below South Diversion Dam
South Reach II	Table J-8. Calculated Fish Habitat Flows (cfs) for All of the Alternatives below South Diversion Dam
Panther Reach	Table J-8. Calculated Fish Habitat Flows (cfs) for All of the Alternatives below South Diversion Dam
Angel Reach	Table J-8. Calculated Fish Habitat Flows (cfs) for All of the Alternatives below South Diversion Dam

7.2 Modeled Spawning and Juvenile Habitat

Flow-habitat relationships from IFIM and PHABSIM analyses detailed in Appendix H of the BCRP EIS/EIR (Jones and Stokes 2005) were used to inform the amount of suitable habitat available for Chinook salmon adult spawners and juveniles under a range of flows in each reach (Table 9). Where no data was available within a specific reach, we used data from the closest reach available.

Table 9. Modeled flow-habitat relationships that are applied in each reach of the model.

Reach	Original Caption from Appendix H of the BCRP EIS/EIR (Jones and Stokes 2005)
Lower Reach	Table H-1. Flow-Habitat Relationships for the Mainstem Reach of Battle Creek
Mainstem Reach	Table H-1. Flow-Habitat Relationships for the Mainstem Reach of Battle Creek
Wildcat Reach	Table H-2. Flow-Habitat Relationships for the Wildcat Reach of Battle Creek
Eagle Canyon Reach I	Table H-3. Flow-Habitat Relationships for the Eagle Canyon Reach of Battle Creek
Eagle Canyon Reach II	Table H-3. Flow-Habitat Relationships for the Eagle Canyon Reach of Battle Creek
North Battle Feeder Reach I	Table H-4. Flow-Habitat Relationships for the North Battle Feeder Reach of Battle Creek
North Battle Feeder Reach II	Table H-4. Flow-Habitat Relationships for the North Battle Feeder Reach of Battle Creek
Keswick Reach	Table H-5. Flow-Habitat Relationships for the Keswick Reach of Battle Creek
Coleman Reach	Table H-6. Flow-Habitat Relationships for the Coleman Reach of Battle Creek
Inskip Reach	Table H-7. Flow-Habitat Relationships for the Inskip Reach of Battle Creek
South Reach I	Table H-8. Flow-Habitat Relationships for the South Reach of Battle Creek
South Reach II	Table H-8. Flow-Habitat Relationships for the South Reach of Battle Creek
Panther Reach	Table H-8. Flow-Habitat Relationships for the South Reach of Battle Creek
Angel Reach	Table H-8. Flow-Habitat Relationships for the South Reach of Battle Creek

7.3 Observed Hours of High Flows

To inform straying of Chinook salmon over the CNFH barrier during high flow events, we applied hourly flow data from the BAT CDEC gauge station from 1995 to 2012. See the Adult Passage section for details on how the flow data were applied in the model.

7.4 Maximum Flows

Redd scour can cause mortality to eggs. These events occur when high flows cause the river bed to move. Given that this activity is governed by high flow events, we use average maximum monthly flows rather than average flow data. This dataset comes from the mainstem CDEC BAT station in Battle Creek. We used water year data from 1995 to 2012. This dataset provided data on two or more years of dry, normal, and wet water year types, so this provided average monthly maximum data for the three different water type years. Because the model calculates egg survival across the entire incubation period, we calculated the mean maximum flow value across all months (Table 10) to inform redd scouring effect on egg survival in the model, which affects egg survival for each water year type. See the Egg Incubation section for details on how the flow data were applied in the model.

Table 10. For each water year type from January (1) to December (12), the mean monthly maximum value of flow was quantified from the CDEC data collected from the BAT gauge.

Water Year Type	Month	Mean Max. Flow (cfs)
Dry	1	1952.4
Dry	2	2501.6
Dry	3	1625.4
Dry	4	539.2
Dry	5	654.8
Dry	6	663.2
Dry	7	404.4
Dry	8	360
Dry	9	316
Dry	10	479
Dry	11	906
Dry	12	1235.4
Normal	1	3271.5
Normal	2	2880.8
Normal	3	2505.5
Normal	4	1340.5
Normal	5	1553
Normal	6	735
Normal	7	457.7
Normal	8	326.2
Normal	9	345.7
Normal	10	500.3
Normal	11	484.7
Normal	12	2513.8

Table 10 continued. For each water year type from January (1) to December (12), the mean monthly maximum value of flow was quantified from the CDEC data collected from the BAT gauge.

Water Year Type	Month	Mean Max. Flow (cfs)
Wet	1	6759.9
Wet	2	5793.1
Wet	3	4222
Wet	4	4992.7
Wet	5	3003
Wet	6	1824.3
Wet	7	700.7
Wet	8	497
Wet	9	428.7
Wet	10	528.4
Wet	11	1334
Wet	12	4901.9

7.5 Modeled Temperatures

Modeled mean monthly water temperature data informed the survival of multiple life-history phases (adult holding, spawning, egg incubation, and juvenile rearing) in each reach. The set of temperatures used in the model depends on the water year type (i.e., dry, normal, and wet). The temperature data for the non-critical months of October – May came from Appendix R of the final BCRP EIS/EIR for the “Five Dam Alternative” (Jones and Stokes 2005). The data for the critical months of June – September came from model output in the draft BCRP EIS/EIR for the proposed project Alternative 3 (Creek and Tu 2001).

Because the data from Appendix R (applied for months October – May) is not organized at the BCRP reach-level (except for the Mainstem Reach), we applied data from point sources within a reach (Table 11). Where there were no data within a given reach, we used data from the next closest available reach. For a dry year, we used the 10th percentile temperature values. For a normal year, we used the 50th percentile temperature values. For a wet year, we used the 90th percentile temperature values.

Modeled water temperature data for the months June - September from the draft BCRP EIS/EIR (Creek and Tu 2001) has mean monthly temperatures for seven reaches (Mainstem Reach, Wildcat Reach, Eagle Canyon Reach, North Battle Feeder Reach, Coleman Reach, Inskip Reach, and South Reach) for three different water year types (dry, normal, and wet). For the reaches with missing data we used data available from the most adjacent stream reach (Table 12).

Table 11. Modeled water temperature data used for the months October – May in each reach of the model.

Reach	Original Caption from Appendix R of the EIS/EIR (Jones and Stokes 2005)
Lower Reach	Table R-16. Calculated Battle Creek Temperatures (^{o}F) for All of the Alternatives below Confluence
Mainstem Reach	Table R-16. Calculated Battle Creek Temperatures (^{o}F) for All of the Alternatives below Confluence
Wildcat Reach	Table R-10. Calculated Battle Creek Temperatures (^{o}F) for All of the Alternatives in North Fork Battle Creek at the Confluence
Eagle Canyon Reach I	Table R-9. Calculated Battle Creek Temperatures (^{o}F) for All of the Alternatives at Wildcat Diversion Dam
Eagle Canyon Reach II	Table R-9. Calculated Battle Creek Temperatures (^{o}F) for All of the Alternatives at Wildcat Diversion Dam
North Battle Feeder Reach I	Table R-8. Calculated Battle Creek Temperatures (^{o}F) for All of the Alternatives at Eagle Canyon Diversion Dam
North Battle Feeder Reach II	Table R-8. Calculated Battle Creek Temperatures (^{o}F) for All of the Alternatives at Eagle Canyon Diversion Dam
Keswick Reach	Table R-8. Calculated Battle Creek Temperatures (^{o}F) for All of the Alternatives at Eagle Canyon Diversion Dam
Coleman Reach	Table R-15. Calculated Battle Creek Temperatures (^{o}F) for All of the Alternatives in South Fork Battle Creek at Confluence
Inskip Reach	Table R-14. Calculated Battle Creek Temperatures (^{o}F) for All of the Alternatives at Coleman Diversion Dam
South Reach I	Table R-12. Calculated Battle Creek Temperatures (^{o}F) for All of the Alternatives at Inskip Diversion Dam
South Reach II	Table R-12. Calculated Battle Creek Temperatures (^{o}F) for All of the Alternatives at Inskip Diversion Dam
Panther Reach	Table R-12. Calculated Battle Creek Temperatures (^{o}F) for All of the Alternatives at Inskip Diversion Dam
Angel Reach	Table R-12. Calculated Battle Creek Temperatures (^{o}F) for All of the Alternatives at Inskip Diversion Dam

Table 12. Modeled water temperature data used for the months June - September in each reach of the model.

Reach	Data as labeled in the draft 2001 EIS/EIR SNTEMP model (Creek and Tu 2001)
Lower Reach	Mainstem Reach
Mainstem Reach	Mainstem Reach
Wildcat Reach	Wildcat Reach
Eagle Canyon Reach I	Eagle Canyon Reach
Eagle Canyon Reach II	Eagle Canyon Reach
North Battle Feeder Reach I	North Battle Feeder Reach
North Battle Feeder Reach II	North Battle Feeder Reach
Keswick Reach	North Battle Feeder Reach
Coleman Reach	Coleman Reach
Inskip Reach	Inskip Reach
South Reach I	South Reach
South Reach II	South Reach
Panther Reach	South Reach
Angel Reach	South Reach

8. Issue/Effect Analysis

The life cycle model was used to evaluate BCRP and CNFH issues as defined in the CNFH-AMP. The model allowed quantitative assessment of six CNFH Issues and a single BCRP effect (see Issues and Effects Evaluated by Model section below for details). Issues and effects not amenable to life-cycle model analysis (described below) were evaluated by rigorous examining of existing data and information.

A sensitivity analysis provided an assessment and prioritization of individual model functions. We performed a local sensitivity analysis in which each individual CNFH Issue and individual BCRP effect (barriers) was varied, one-at-a-time, across a range of values to examine the effect on model outcomes. The proposed range in values, which in most cases will simply involve turning the effect on/off, are described below.

8.1 Methods

All issues and effects were compared to a baseline scenario of "future expected conditions." Under this scenario, model relationships were parameterized to reflect future expected conditions with a fully implemented BCRP. This scenario assumes successful removal or passage modification of natural and man-made fish barriers. For relationships not expected to change with restoration (including CNFH operations), parameter values reflect current conditions or conditions considered reasonably likely to occur in the foreseeable future. Model functionality and parameter values for this scenario are the same as those currently defined in the model documentation.

The model was run for 50 years to capture multiple generations of Chinook salmon in the model output, and to incorporate ample variation in water year type. Fifty realizations of each 50-year run were made to incorporate uncertainty in the model results and to ensure that mean differences were the result of actual model effects, and not simply model noise. Chinook salmon abundance was seeded at arbitrarily high levels in year 0 of the model run, in order to avoid early extinction events, and to support evaluation of issues and effects.

The model produces numerous potential outputs (e.g., abundance of each life stage over time) that could be used to compare the issues and effects to the baseline scenario. Because the abundances of the different life stages are highly correlated, the choice of which life stage to use in the comparison is arbitrary. We chose to compare the abundance of adult spawners, which we refer to as the pre-spawning abundance because it is a count of returning adults that potentially spawned rather than successfully spawned. Each realization of the model produces a 50-yr time series of pre-spawning abundance. We used the changepoint package in R (Killick and Eckley 2014) to identify the point in the time series when the pre-spawning abundance exhibited a significant change and calculated the mean abundance of points in the time series that occurred after the change point (Figure 15). For simplicity, we refer to the change point as the equilibrium time and mean abundance after the change point as the equilibrium abundance.

Initially, we planned to use both equilibrium abundance and equilibrium time (or time to restoration target abundance) in the issue/effect analysis under the assumption that issues and effects may influence not only the mean abundance, but the years it took for the population to reach peak or target abundance. An assessment of how each issue/effect influences the time it takes for each race to reach a restoration target abundance could provide information in addition to mean abundance to help prioritize issues/effects influencing Chinook salmon races. However, after performing initial exploratory runs of the life cycle model, we found very little variability in time to equilibrium across issues and effects. Therefore, we only used the single result metric of equilibrium abundance to perform the issue/effect analysis.

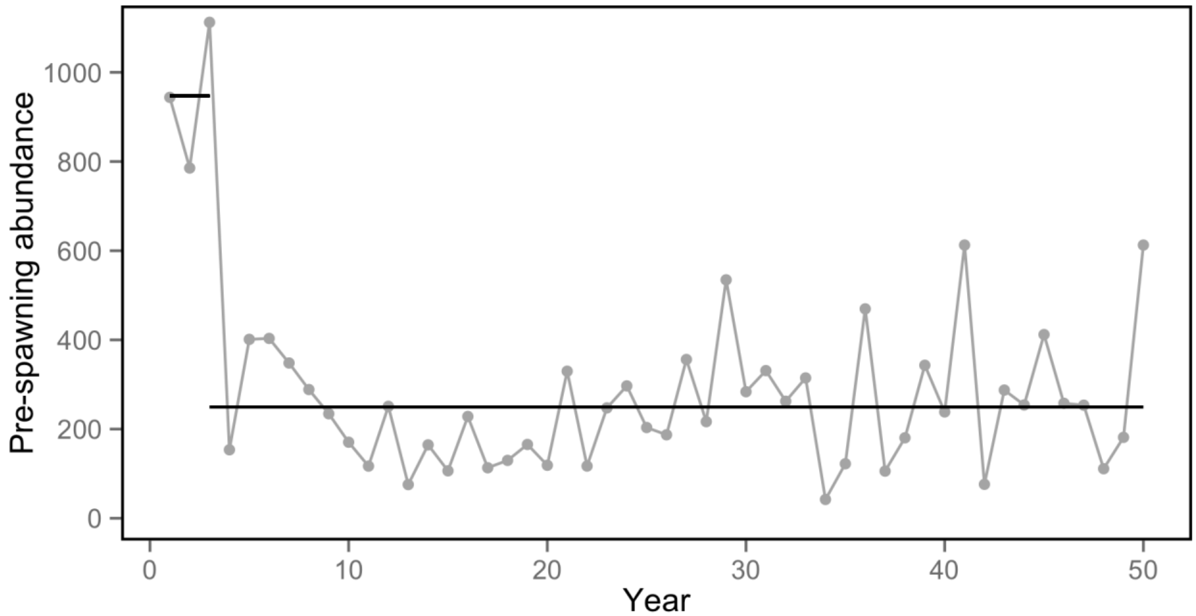


Figure 15. An example of using a changepoint analysis to find the equilibrium time and abundance in a time series of pre-spawning abundance. The horizontal black lines show the mean abundance before and after a significant change point (i.e., equilibrium time). The mean abundance after a significant change point was designated as the equilibrium abundance.

8.1.1 Issues and Effects Evaluated By Model

The following issues were evaluated by the life cycle model: 1) six CNFH issue statements developed by the TAC, 2), an additional CNFH effect of hatchery introgression 3) four key BCRP effects, and 4) a CNFH Least Effect scenario. The Least Effect scenario was an aggregate effect created by modeling multiple CNFH effects at once. Below we describe these issues in more detail, and provide information about the range in values applied for each issue/effect.

<u>CNFH Issue 1: Diversion entrainment</u> – An unscreened water diversion used at times to deliver water to the CNFH may result in the entrainment of Battle Creek juvenile salmonids. This effect was turned off to evaluate the effect on model results.

<u>CNFH Issue 3: Hatchery strays (non-flow related)</u> – Current operations at CNFH and at the fish barrier weir cannot always identify and prevent passage of (1) hatchery origin salmonids, and (2) non-target races of Chinook salmon. This effect was turned off (i.e., no strays) to evaluate the effect on model results.

<u>CNFH Issue 4: High flow hatchery strays</u> – Fall Chinook (hatchery or wild), hatchery late-fall Chinook, and hatchery-origin steelhead may reach the restoration area during high flow events where they may have adverse effects on Battle Creek steelhead, late-fall, spring, and winter Chinook salmon. This effect was turned off (i.e., no flow-related strays) to evaluate the effect on model results.

CNFH Issue 5: CNFH mortality – Trapping, handling, and sorting, of salmonids within CNFH and at the CNFH fish ladder results in migratory delay, and may result in direct mortality or sub-lethal effects to natural origin winter Chinook, late-fall Chinook, spring Chinook, and steelhead trying to access the restoration area. We only evaluated the effect of direct mortality in the model. This effect was turned off (i.e., no mortality) for fish that took the trapping route or the hatchery route, while passing through the CNFH barrier weir fish ladder system to evaluate the effect on model results

CNFH Issue 8: Hatchery fish below CNFH – High abundance of hatchery-origin adult salmon in lower Battle Creek may create adverse effects including (1) reduction of in-stream spawning success due to the physical destruction of redds; (2) interbreeding between natural and hatchery origin Chinook salmon; and (3) increased mortality of juvenile salmonids emigrating from upper Battle Creek. We only evaluated the effect of interbreeding due to high hatchery-origin salmon abundance in the model. This effect was turned off (i.e., no hatchery-origin salmon spawning below the CNFH barrier) to evaluate the effect on model results.

CNFH Issue 9: Predation by CNFH Steelhead– Releases of hatchery produced juvenile steelhead from CNFH may result in predation on and behavior modifications to natural origin fish produced in the restoration area. This effect was turned off (i.e., no predation by hatchery steelhead) to evaluate the effect on model results.

CNFH Hatchery introgression – CNFH Hatchery salmonids may have lower reproductive success compared to their natural counterparts, leading to the hypothesis that recruitment performance of naturally reproducing populations should vary directly with the proportion of adult spawners that are of CNFH hatchery-origin. The negative effect of hatchery introgression was turned off to evaluate the effect on model results.

CNFH least effect – Same as baseline (i.e., future expected condition) except the effect of all CNFH issues evaluated (above) was set to the least effect (all effects turned off). This scenario was run to help identify the upper range of possible benefits from changing CNFH operations.

Barriers (BCRP) – Same as baseline (i.e., future expected condition) except natural and man-made fish barriers were set to reflect current passability conditions (see Table 3). This allows for examination of the sensitivity of model results to removal/modification of fish barriers as defined in the baseline scenario.

8.1.2 Issues and Effects not Evaluated by the Model

The following CNFH Issue Statements defined by the TAC were either evaluated by the Steelhead life cycle model (Appendix E), or were subjected to rigorous evaluation using existing data and information (Appendix C), but they are not evaluated by the Chinook salmon life cycle model. These issues/effects were excluded either because they applied to steelhead only, or because the data were lacking to define a realistic range of effect magnitude, or to characterize circumstances or frequency of the effect occurring.

CNFH Issue 2: Steelhead integration – The current CNFH steelhead program excludes naturally produced (unmarked) fish from the broodstock. This practice leads to continued domestication and potential for reduced fitness when hatchery fish spawn in the restoration area.

RATIONALE: This effect only applies to steelhead, and therefore is not considered in the Chinook salmon life cycle model.

CNFH Issue 6: Pathogens - Pathogens resulting from CNFH operations may be transmitted to and expressed among wild fish in the restoration area.

RATIONALE: Information regarding when or how much pathogens might adversely affect Battle Creek salmonids is not currently available.

CNFH Issue 7: Reduced in-stream flows (diversion) – In-stream flows in the Mainstem reach of Battle Creek are reduced by CNFH water diversion(s) between the diversion site(s) downstream to the return effluent site (distance of 1.2 to 1.6 miles depending on the location of the water intake). These diversions may result in inadequate in-stream flows or increased water temperatures in this segment of the river during drought conditions, and in association with operations at upstream hydropower facilities.

RATIONALE: Water temperature is the more significant factor related to this issue, but modeled water temperatures with and without CNFH water diversions are not currently available.

CNFH Issue 11: Exceeding out-of-basin carrying capacity – Current production releases of CNFH juvenile fall Chinook salmon may contribute to exceeding the carrying capacity for Chinook salmon in the Sacramento River, Estuary, or the Pacific Ocean leading to reduced success of Battle Creek origin salmonids.

RATIONALE: That hatchery production may lead to density-dependent mortality is theoretically understood and accepted. However, data related to the magnitude of this effect and when/how often it is likely to occur is not currently available.

8.2 Results

Differences in mean equilibrium abundance between the baseline scenario (future expected conditions) and the implementation of each issue/effect was enumerated as percent change. Table 13 displays the percent change from baseline in equilibrium abundance as a result of each issue/effect (see “Issues and Effects evaluated by the model” section above for description of how each issue/effect was implemented). A negative value indicates a decrease in equilibrium abundance due to the issue/effect being implemented. These results are used in Appendix C to further evaluate CNFH issues and BCRP effects.

Table 13. Mean equilibrium abundance values and percent change from baseline for the Issue/Effect Analysis.

Issue/Effect	Fall		LateFall		Spring		Winter	
	Mean	% Change	Mean	% Change	Mean	% Change	Mean	% Change
Baseline	626	0.0	8659	0.0	7052	0.0	10529	0.0
CNFH 1: Diversion Entrainment	626	0.0	8601	-0.7	7115	0.9	10651	1.2
CNFH 3: Hatchery Strays (Non-Flow Related)	626	0.0	8556	-1.2	7453	5.7	10528	0.0
CNFH 4: High Flow Hatchery Strays	626	0.0	8894	2.7	7058	0.1	10528	0.0
CNFH 5: CNFH Mortality (hatchery-route)	626	0.0	10472	20.9	7051	0.0	10957	4.1
CNFH 5: CNFH Mortality (trapping-route)	626	0.0	8529	-1.5	7236	2.6	10804	2.6
CNFH 8: Hatchery Fish Below CNFH	6978	>100	8552	-1.2	7052	0.0	10529	0.0
CNFH 9: Predation by CNFH Steelhead	644	2.8	9453	9.2	7547	7.0	11235	6.7
Hatchery Introgression	9357	>100	8980	3.7	7823	10.9	10523	-0.1
CNFH least effects	7350	>100	11367	31.3	8200	16.3	12067	14.6
Barriers	626	0.0	8763	1.2	1868	-73.5	2188	-79.2

9. Discussion

Simulation models are useful for organizing existing knowledge and identifying gaps in understanding, even if model predictions are imprecise (Williams 2006). Simulation models should be thought of as experimental systems or aids that are distinct from the “real world” in which the consequences of various sets of assumptions can be examined (Peck 2004). However, model usefulness is measured by how well it captures the interactions of the most important factors and leaves out unimportant ones (Ford 1999), thereby limiting model complexity that might otherwise make interpretation of results more difficult. More complex models can be too dataset specific and have poor predictive ability mainly due to estimation error, while more simplistic models can be too general and incorporate error due to system oversimplification (Astrup *et al*. 2008). Therefore, we attempted to model the influence of CNFH and BCRP effects on Chinook salmon with adequate complexity to identify the importance of these effects, while limiting the inclusion of factors not useful for evaluating project effects or unsupported by existing scientific knowledge. In addition to the myriad modeling assumptions that we described previously in the model documentation, we discuss the major assumptions and limitations of the modeling approach below.

9.1 Major Model Assumptions and Limitations

9.1.1 Availability of Data

When local data is limited, model relationships can often be informed by field data from outside the study region, laboratory studies in controlled experimental settings, or artificially raised (hatchery) surrogates. For example, many of our model relationships rely on data from tagged hatchery surrogates, because experimental studies often rely on easily accessible hatchery-origin fish, and assume that fish responses are at least similar among individuals of different natal origins. In addition to limited data on wild fish, many of the model relationships are informed by data from a single Chinook salmon race, thereby making the assumption that all races move, grow, and survive according to the same rules. Lastly, where local data are lacking, many relationships are informed by Chinook salmon data from outside the Central Valley; thus, assuming that similar relationships exist for Chinook salmon across different geographical regions.

9.1.2 Fish Movement

Spawning migration is greatly simplified in the model due to lack of knowledge about mechanisms explaining more detailed movement behavior. In the wild, salmon may choose to spawn in reaches with better habitat quality (i.e., cooler water temperatures, more suitable substrate). However, due to lack of information to inform this behavior, we have salmon return to their natal reach for spawning, with variability in spawning distribution developing only after years of differential reach survivals affecting their reach-specific return rates. Similarly, although adult spawners in the wild may move to a different reach as spawner density increases, without data to inform a mechanism for this behavior, density of spawners only affects productivity to the egg stage.

Fry behavior is also greatly simplified in the model, with fry rearing in the same reach where they emerged from the gravel. Many fry in Battle Creek likely make migrations of varying length throughout the rearing period for various reasons, such as searching for better quality habitat, avoiding intra- or inter-specific competition, or in response to high flow events. However, because no data are available to inform the mechanisms behind this behavior, we chose to limit model complexity and not include highly uncertain movement rules.

Lastly, we assume that adult spring and winter Chinook hold in the same reaches that they spawn. Adult salmon in Battle Creek may make migrations during their holding life history phase. For example, Butte Creek Chinook salmon have been observed to move short distances prior to spawning, following the holding period (Ward et al. 2004). However, similar information (and mechanisms for this behavior) were not available for Battle Creek.

9.1.3 Redd Superimposition

Redd superimposition has been observed to occur in many Central Valley rivers, in some cases at high rates when adult spawner densities are high (Sommer et al. 2001). However, rates of superimposition in Battle Creek, and the egg mortality rate incurred by redd destruction during superimposition is unknown. Therefore, we did not model superimposition, and instead simply limited the number of successful spawners in a given reach on a monthly basis due to the amount of suitable spawning habitat available.

9.1.4 Hatchery Introgression

Hatchery-origin fish (except winter Chinook) that enter the restoration area are assumed to have a deleterious effect on natural adult spawner productivity. Although this has not been directly observed in Battle Creek, this type of interaction between hatchery and wild spawners has been documented in other watersheds. Therefore, we applied a relationship found from a meta-analysis of salmonid populations in the Pacific Northwest (Chilcote et al. 2013).

9.1.5 Environmental Input Data

We relied on simulated water temperature and fish habitat data to inform model relationships. Our ability to accurately model the trajectory of Chinook salmon in Battle Creek is closely tied to the quality of the data that informs the model. Future field validation of the simulated environmental data could help evaluate the accuracy of the data used in the model, and help calibrate future temperature and hydrologic modeling efforts.

9.2 Information Gaps

During the model-building process, we identified multiple gaps in understanding of Chinook salmon life history in Battle Creek. Below we discuss the major gaps in knowledge and reference long-term monitoring (Appendix F) or short-term diagnostic studies (Chapter 4) that could address some of these knowledge gaps.

9.2.1 Out-of-basin Data

We relied on data from limited releases of tagged hatchery Chinook salmon to inform survival of emigrating juveniles in the Sacramento River and San Francisco Estuary. Future additional data could be used to refine model relationships, and possibly model mechanisms influencing survival in these reaches. Also, no data were available to inform the CNFH hatchery steelhead predation mortality rate on Chinook salmon fry. Future investigations of predation mortality could help refine model functionality.

Studies have shown that survival of juvenile Chinook salmon in the ocean can vary due to many factors including entry timing, physical ocean conditions, trophic dynamics, and size or condition of fish upon entry (Satterwaite et al. 2014). However, because the focus of the model was to evaluate the potential effects of CNFH operations and BCRP actions, we wanted to isolate the effects occurring in Battle Creek. As with any simulation tool, model usefulness is measured by how well it captures the interactions of the most important factors, and leaving out unimportant ones to limit model complexity as much as possible (Ford 1999). Therefore, like in the Sacramento River and Estuary portions of the model, we only wanted to provide reasonable estimates of survival, not examine drivers of survival that would have only introduced greater model complexity and made result interpretation more difficult.

9.2.2 Battle Creek Mortality Data

Data were lacking to inform survival of multiple Chinook salmon life history phases in Battle Creek. No data were available to inform overall egg mortality rates in Battle Creek, or more specific information on mortality due to redd-scouring during high flow events. Instead, we relied on literature values or expert opinion to inform survival rates. Likewise, data were not available to help validate juvenile mortality rates applied in the model. Future field investigations examining egg and juvenile survival rates could help refine model relationships in the future. A plan for monitoring juvenile production using rotary screw traps in Battle Creek is described in the Integrated Monitoring Plan (Appendix F). Juvenile production estimates, along with estimates of adult spawner numbers would allow estimation of survival of salmon during early life stages (egg and fry combined) in Battle Creek.

9.2.3 Barrier Passage

Current and future passage estimates were provided by the TAC. The TAC determined what barriers impede the passage of Chinook salmon, where the barriers are, and provided estimates of current and future Chinook salmon passage. While expert opinions are important, empirical data collected from properly designed mark-recapture studies, which aim to refine passage estimates could improve the accuracy of the estimates used in the model. Barrier passage monitoring is described in the Integrated Monitoring Plan (Appendix F).

9.2.4 Stray Rates

Stray rates due to high flow events were capped at 5% and only occur between 800 – 4,500 cfs, based on TAC input and very limited data. Quantifying stray rates under high flow conditions is challenging due to Battle Creek's flashy hydrology and the increased variability occurring under high flow conditions. Further empirical studies are needed to confirm that 5% is a maximum value and that passage of strays only occurs between 800 – 4,500 cfs. A diagnostic study (DS7) evaluating high-flow passage of hatchery-origin strays above the barrier weir is described in Chapter 4.

9.2.5 Sub-lethal Project Effects

With lack of data on indirect mortality effects, we were only able to evaluate the effect of direct mortality on migrating salmon as they pass through the CNFH barrier weir. Future studies evaluating delayed impacts of stress incurred during passage through the barrier weir could support more complete evaluations of this effect in the model. A diagnostic study (DS1) evaluating the impact of stress during passage and handling at the barrier weir is described in Chapter 4.

9.2.6 Hatchery Introgression

As described above, no local data were available to inform the potential negative impact of hatchery-origin adult spawner introgression with natural-origin fish. Future studies evaluating the possible reduced fitness effect of Battle Creek Chinook salmon due to the presence of hatchery-origin spawners could be conducted to evaluate this impact.

9.2.7 Environmental Data

Gaps in environmental data are briefly presented under the Major Modeling Assumptions and Limitations Section. However, in developing this life cycle model it became clear that a detailed understanding of spatial water temperature dynamics in Battle Creek, and the influence of hatchery operations on these dynamics is lacking.

9.2.8 Model Revisions

During review of the draft AMP, multiple updates to model functionality were suggested by reviewers to best reflect the most recent life history or operational knowledge of Battle Creek. Below is a description of model updates that are expected to be made in future versions of the model.

10. Literature Cited

Anderson, J. J., E. Gurarie, and R. W. Zabel. 2005. Mean free-path theory of predator-prey interactions: application to juvenile salmon migration. Ecological Modeling 186:196-211.

Astrup, R., K. D. Coates, and E. Hall. 2008. Finding the appropriate level of complexity for a simulation model: an example with a forest growth model. Forest Ecology and Management 256:1659-1665.

Baker, P. F., T. P. Speed, and F. K. Ligon. 1995. Estimating the influence of temperature on the survival of Chinook salmon smolts (*Oncorhynchus tshawytscha*) migrating through the Sacramento-San Joaquin River Delta of California. Canadian Journal of Fisheries and Aquatic Sciences 52:855-863.

Buhle, E. 2013. Impacts of supplementation on population dynamics of Snake River spring/summer Chinook salmon. Pages 300 – 323 *in* Life Cycle models of salmonid populations in the interior Columbia River Basin. http://www.nwcouncil.org/media/6891507/ISAB2013-5.pdf

California Data Exchange Center (CDEC). http://cdec.water.ca.gov/. Accessed 15 Mar 2015.

Campos, C. and D. Massa. 2012. Lower Yuba River Accord Monitoring and Evaluation Plan. Annual Redd Survey Report. Prepared for the Lower Yuba River Accord River Planning Team. 2010-2011 Annual Report. 40p.

Chilcote, M. W., S. A. Leider, and J. J. Loch. 1986. Differential reproductive success of hatchery and wild summer-run steelhead under natural conditions. Transactions of the American Fisheries Society 115:726–735.

Chilcote, M. W., K. W. Goodson, and M. R. Falcy. 2011. Reduced recruitment performance in natural populations of anadromous salmonids associated with hatchery-reared fish. Canadian Journal of Fisheries and Aquatic Sciences 68:511–522.

Chilcote, M. W., K. W. Goodson, and M. R. Falcy. 2013. Corrigendum: reduced recruitment performance in natural populations of anadromous salmonids associated with hatchery-reared fish. Canadian Journal of Fisheries and Aquatic Sciences 70:513–515.

Creek, K. D., S. Tu. 2001. Stream temperature model for the Battle Creek Salmon and Steelhead Restoration Project. Land and Water Quality Unit, Report No.:026.11-00.256 for Technical and Ecological Services.

Ford, A. (1999). Modeling the environment: an introduction to system dynamics modeling of environmental systems. Washington:Island Press.

Grover, A., Low, A., Ward, P., Smith, J., Mohr, M., Viele, D., et al. 2004. Recommendations for developing fishery management plan conservation objectives for Sacramento River spring Chinook. SRWSC workgroup report to the Pacific Fisheries Management Council, Exhibit C.7.b. http://www.pccouncil.org/bb/2004/0304/exc7.pdf. Accessed 15 Jan 2011.

HSRG (California Hatchery Scientific Review Group). 2012. California Hatchery Review Group report. Prepared for the US Fish and Wildlife Service, Sacramento, CA 102 p.

Jones and Stokes. 2005. Battle Creek salmon and steelhead restoration project final environmental impact statement/environmental impact report. Volume I, Report. Sacramento, CA.

Kaczynski, W., L. Leemis, N. Loehr, and J. McQueston. 2012. Nonparametric random variate generation using a piecewise-linear cumulative distribution function. Communications in Statistics – Simulation and Computation 41:449-468.

Killick, R. and Eckley, I.A. 2014. An R package for changepoint analysis. Journal of Statistical Software 58: 1-19. URL http://www.jstatsoft.org/v58/i03/. Accessed 30 Mar 2015.

McLean, J.E., Bentzen, P., and Quinn, T.P. 2003. Differential reproductive success of sympatric, naturally spawning hatchery and wild steelhead trout (*Oncorhynchus mykiss*) through the adult stage. Canadian Journal of Fisheries and Aquatic Sciences 60: 433–440.

Michel, C. J. 2010. River and estuarine survival and migration of yearling Sacramento River Chinook salmon (*Onchorhynchus tshawytscha*) smolts and the influence of environment. Master's thesis. University of Santa Cruz, Santa Cruz, CA.

Moyle, P.B. 2002. Inland Fishes of California. University of California Press. Berkeley, CA.

NMFS. 2014. Recovery plan for the evolutionarily significant units of Sacramento River Winter-run Chinook salmon and Central Valley spring-run Chinook salmon and the Distinct Population Segment of California Central Valley steelhead. California Central Valley Area Office. July 2014.

O'Farrell, M. R., M. S. Mohr, A. M. Grover, and W. H. Satterthwaite. 2011. Sacramento River winter Chinook cohort reconstruction: analysis of ocean fishery impacts. National Marine Fisheries Service Report, Santa Cruz, CA.

Peck, S.L. 2004. Simulation as experiment: a philosophical reassessment for biological modeling. Trends in Ecology and Evolution 19:530-534.

Perry, R. W., J. G. Romine, and S. J. Brewer. 2012. Survival and migration route probabilities of juvenile Chinook salmon in the Sacrameno-San Joaquin Delta during the winter of 2009-10. U.S. Geological Survey Open-File Report 2012-1200.

Poytress, W. R. and F. D. Carillo. 2011. Brood-year 2008 and 2009 winter Chinook juvenile production indices with comparisons to juvenile production estimates derived from adult escapement. U.S. Fish and Wildlife Service Report. Red Bluff, CA.

Poytress, W. R. and F. D. Carillo. 2012. Brood-year 2010 winter Chinook juvenile production indices with comparisons to juvenile production estimates derived from adult escapement. U.S. Fish and Wildlife Service Report. Red Bluff, CA.

Satterthwaite, W. H., S. M. Carlson, S. D. Allen-Moran, S. Vincenzi, S. J. Bograd, and B. K. Wells. 2014. Match-mismatch dynamics and the relationship between ocean-entry timing and relative ocean recoveries of Central Valley fall run Chinook salmon. Marine Ecology Progress Series.

Scheuerell, M. D., R. Hilborn, M. H. Ruckelshaus, K. K. Bartz, K. M. Lagueux, A. D. Haas, and K. Rawson. 2006. The Shiraz model: a tool for incorporating anthropogenic effects and fish-habitat relationships in conservation planning. Canadian Journal of Fisheries and Aquatic Sciences 63:1596-1607.

Sommer, T.R., D. McEwan, & R. Brown. 2001. Factors affecting Chinook salmon spawning in the lower Feather River. In: Brown R. (Ed.), Fish Bulletin 179. Contributions to the biology of

Central Valley salmonids. Volume 1. Sacramento (CA): California Department of Fish and Game. p 269–97.

Terraqua. 2004. Draft Battle Creek salmon and steelhead restoration project adaptive management plan, prepared for the U.S. Bureau of Reclamation, Pacific Gas and Electric Company, National Marine Fisheries Service, U.S. Fish and Wildlife Service, and California Department of Fish and Game. Wauconda, Washington. 238 p.

Thompson, L. C., M. I. Escobar, C. M. Mosser, D. R. Purkey, D. Yates, and P. B. Moyle. 2012. Water management adaptations to prevent loss of spring-run Chinook salmon in California under climate change. Journal of Water Resources Planning and Management 138:465-478.

TRP (Technical Review Panel). 2004. Report of the Technical Review Panel: Compatibility of Coleman National Fish Hatchery Operations and Restoration of Anadromous Salmonids in Battle Creek. Prepared January 24, 2004. 66 p.

TRP (Technical Review Panel). 2013. Report of the Technical Review Panel: Review of the Coleman National Fish Hatchery Adaptive Management Plan. Submitted to the U.S. Bureau of Reclamation. May 12, 2013. 36 p.

USFWS. 2011. Biological assessment of artificial propagation at Coleman National Fish Hatchery and Livingston Stone National Fish Hatchery: program description and incidental take of Chinook salmon and steelhead. U.S. Fish and Wildlife Service, Red Bluff, CA.

Volkhardt, G. C., S. L. Johnson, B. A. Miller, T. E. Nickelson, and D. E. Seiler. 2007. Rotary screw traps and inclined plane screen traps *in* salmonid field protocols handbook: techniques for assessing status and trends in salmon and trout populations. American Fisheries Society, Bethesda, Maryland.

Ward, P.D., T. R. McReynolds and C. E. Garman. 2006. Butte Creek Spring-Run Chinook Salmon, *Oncorhynchus tshawytscha*, Pre-spawn Mortality Evaluation 2004. Calif. Dept. of Fish and Game, Inland Fisheries Admin. Report No.2006-1. 49 pp

Wells, B. K., Grimes, C. B., & Waldvogel, J. B. 2007. Quantifying the effects of wind, upwelling, curl, sea surface temperature and sea level height on growth and maturation of a California Chinook salmon (*Oncorhynchus tshawytscha*). Fisheries Oceanography 16:363–382.

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

Woodson, L. E., B. K. Wells, P. K. Weber, R. B. MacFarlane, G. E. Whitman, and R. C. Johnson. 2013. Size, growth, and origin-dependent mortality of juvenile Chinook salmon *Oncorhynchus tshawtscha* during early ocean residence. Marine Ecology Progress Series 487:163-175.

Yoshiyama, R.M., E.R.Gerstung, F.W. Fisher, and P.B. Moyle. 2001. Historical and present distribution of Chinook salmon in the Central Valley drainage of California. Pages 71-176 *in* R. Brown, editor, Contributions to the biology of anadromous salmonids of the Central Valley, Fish Bulletin 179, Volume 1. California Department of Fish and Game, Sacramento.

11. Personal Communications

L. Earley, Biologist, US Fish and Wildlife Service, Red Bluff, CA. Laurie_earley@fws.gov. Personal communication on July 7, 2014.

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Appendix E: A Life-Cycle Model for Partially Anadromous Rainbow Trout in Battle Creek, CA

Model Documentation

Prepared for:

U.S. Department of Interior, Bureau of Reclamation

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Table of Contents

1. Introduction

Protection of three salmonid stocks (*i.e.*, winter- and spring Chinook salmon, and Central Valley steelhead) under the California and/or Federal Endangered Species acts, and identification of the Battle Creek watershed as vital recovery habitat (NMFS 2014), emphasize the need to improve ecological functions in the watershed, while striving to optimize existing human services. To this end, the Battle Creek Restoration Project (BCRP) is focused on restoring in-stream flows and improving fish passage through modification of existing hydropower infrastructure. The goal is to provide high quality habitat and improve fish passage, which together will support self-sustaining populations of several Chinook salmon (*Oncorhynchus tshawytscha*) stocks, and Central Valley steelhead (*O. mykiss*) throughout 48 miles of stream habitat (Terraqua 2004).

The primary goal of the Coleman National Fish Hatchery (CNFH) steelhead propagation program is to mitigate for the loss of spawning and rearing habitat above Shasta and Keswick dams, and to contribute to the freshwater sport fishery. The propagation program has an annual *O. mykiss* release target of 600,000 yearling smolts in January at a size of 4 fish/lb, which is expected to contribute a total of 3,000 fish to harvest and escapement over the life of the brood (33% for harvest; HSRG 2012). For brood years 1996 to 2007, on average, 550,470 hatchery-origin *O. mykiss* were released by CNFH at the Bend Bridge (RM 258) in January of each year (USFWS 2011). The impacts of hatchery smolt releases on BCRP objectives is unknown.

The purpose of the CNFH Adaptive Management Plan (CNFH-AMP) is to acknowledge, identify, study, and evaluate uncertainties regarding the operation of a large-scale fish hatchery in a watershed being restored for natural-origin salmon and steelhead production. Implementation of the CNFH-AMP is intended to be coordinated with BCRP-AMP implementation, so that together the two plans provide an integrated framework for adaptive management in Battle Creek (Jones and Stokes 2005).

An integrated AMP requires an analytical framework that includes and accounts for factors directly related to CNFH operations, as well as other factors that may influence success of the BCRP. Such an analytical framework has now been recommended by two science panel reviews (first for the BCRP-AMP, and later for the CNFH-AMP). The development of an analytical framework, such as a quantitative life-cycle model, is useful for clarifying underlying assumptions, evaluating uncertainties, and connecting management options to desired outcomes. Both anadromous and resident *O. mykiss* occur in Battle Creek. Hence a life-cycle model developed for Battle Creek *O. mykiss* requires simulating the life-history of both resident and anadromous (steelhead) rainbow trout. This “partially anadromous” population model (representing both resident and anadromous life-histories) will better characterize fluctuations in abundance compared to a model that does not account for the resident component of the population. The life-cycle model will also represent hatchery and natural-origin components of the Battle Creek *O. mykiss* population; including interactions between the stocks.

1.1 Central Valley Steelhead Life-History and Stock Status

Rainbow trout populations with ocean access are comprised of a wide variety of life-history types including freshwater resident and anadromous types. Although phenotypically different, evidence of interdependence between resident and anadromous (steelhead) life-histories is documented, and genetic studies confirm that anadromous and resident individuals can interbreed (Pearson *et al*. 2007). Otolith microchemistry and controlled breeding experiments have found that both life-histories produce offspring of the alternate life-history type (Thrower and Joyce 2004; Courter *et al.* 2013). Expression of different life-histories is thought to reflect the trade-off between higher survival associated with non-migration, and greater reproductive output associated with growth in a marine environment (Courter *et al.* 2013).

Central Valley steelhead are federally listed as threatened, and critical habitat has been designated in Battle Creek (NMFS 1998). While it is unknown exactly how large a population Battle Creek originally supported, it is thought that Battle Creek, and nearby Mill and Deer Creeks, had some of the largest runs of steelhead in the area (Hallock 1989). By the 1950s, the Battle Creek steelhead population was extremely depressed. Anglers petitioned the hatchery to add a steelhead program. For this reason, CNFH started an integrated hatchery steelhead propagation program for Battle Creek in 1952. In more recent years, the continued low abundance of natural-origin steelhead led to exclusive use of hatchery-origin fish for broodstock (USFWS 2011). The BCRP will increase access to anadromous fish habitat in upper Battle Creek and its tributaries, with the aim of increasing the natural-origin steelhead population (Ward and Kier 1999).

1.2 Project Objectives

The project objectives of the Battle Creek *O. mykiss* life-cycle model are to: (1) quantify and prioritize the likely effects of issues identified in the CNFH-AMP (refer to Issues and Effects Evaluated by the Model section below, for the specific issues that were examined in this model), and other factors which may influence the success of the BCRP; and (2) identify and understand key information gaps.

To achieve these objectives, the model includes both resident and anadromous individuals within the population, as well as hatchery and natural-origin stocks. Inclusion of multiple life-histories is intended to improve the model's ability to represent real-world complexities, while accounting for the interaction between reproductively-mixed migratory and resident life-history types. This is particularly important when trying to quantify effects of environmental changes, such as those that occur following restoration actions.

2. Modeling Overview

Questions about the effects of restoration and hatchery management actions on anadromous and resident rainbow trout are examined with a spatially explicit quantitative life-cycle model, which tracks survival and production of specific life stages across multiple generations. To produce and appropriate but parsimonious model, we used as few relevant parameters as possible to more accurately characterize abundance fluctuations in the population. To explore potential factors influencing the distribution and abundance of resident and anadromous *O. mykiss* in Battle Creek, the Battle Creek watershed was stratified into reaches according to stream flow, temperature conditions, and migration impediments (Table 1; Figure 1) identified by the CNFH-AMP Technical Advisory Committee (TAC). The model operates on a monhtly time-step; therefore, monthly input data (water temperatures, flows, habitat amount) were used to calculate monthly survival and production rates. This allows fish of different life-history types (resident rainbow trout, or anadromous steelhead) and reproductive-origins (natural, or hatchery) to inhabit the various spatial reaches in which they co-occur (Figure 1; Figure 2). The model includes 14 reaches within Battle Creek, which were adapted from the 10 reaches identified in the BCRP plan (Ward and Kier 1999). The BCRP reaches of Eagle Canyon, North Battle Creek Feeder, and South Fork Battle Creek were each divided into two different reaches due to barriers occurring within each of these reaches that partially block passage (Table 1; Table 2).

Table 1. Reach length and downstream and upstream locations of the 14 reaches in Battle Creek.

		River Mile		
Section	Reach	Downstream	Upstream	Length (Miles)
Mainstem	Lower	0.00	5.97	5.97
	Mainstem	5.97	16.80	10.83
North Fork	Wildcat	0.00	2.48	2.48
	Eagle Canyon I	2.48	4.46	1.98
	Eagle Canyon II	4.46	5.23	0.77
	North Battle Creek Feeder I	5.23	5.41	0.18
	North Battle Creek Feeder II	5.41	9.42	4.01
	Keswick	9.42	13.17	3.75
South Fork	Coleman	0.00	2.54	2.54
	Inskip	2.54	8.02	5.48
	South I	8.02	13.26	5.24
	South II	13.26	14.84	1.58
	Panther	14.84	19.07	4.23
	Angel	19.07	22.47	3.40

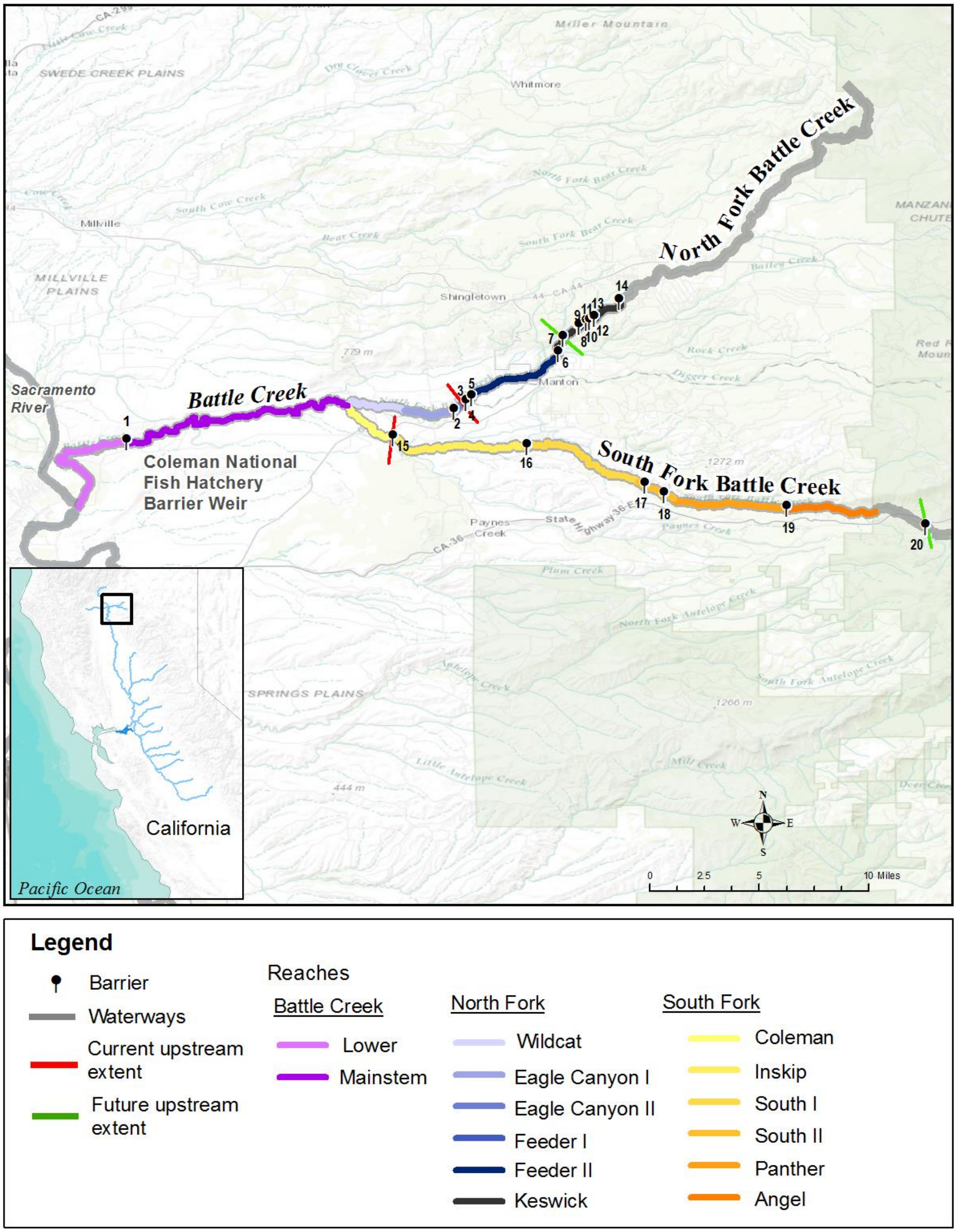

Figure 1. Relative locations of steelhead habitat reaches in the Battle Creek watershed. The Battle Creek portion of the model is composed of the 14 reaches identified in the BCRP. Black circles indicate locations of barriers identified by the TAC. The red lines indicate the current upstream extent of available habitat for steelhead in each Fork under current assumptions about passage. The green lines indicate the upstream extent of available habitat under future conditions (see Table 2 for details on barriers).

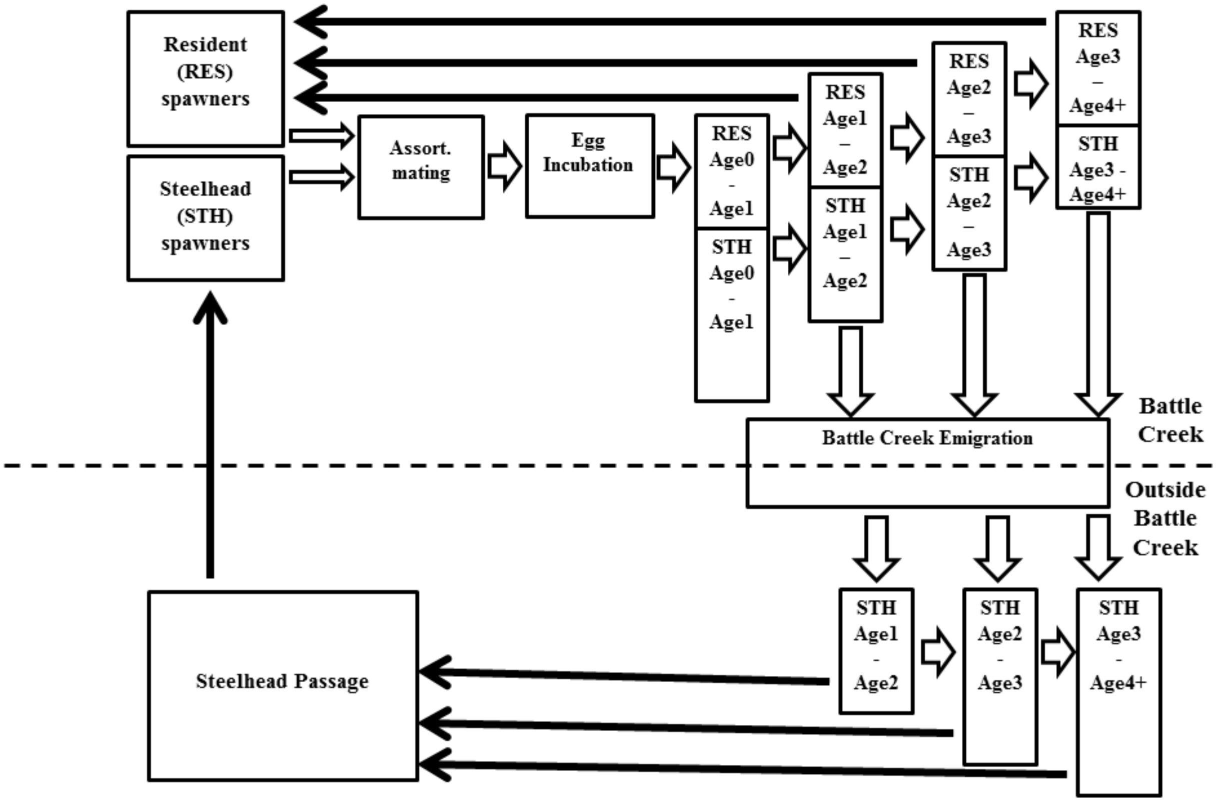

Figure 2. Life-history phases modeled for steelhead ("STH") and resident ("RES") *O. mykiss*. Below the black dashed line represents out-of-basin phases and above the line indicates life stages in Battle Creek.

Model configuration allows for evaluation of CNFH and BCRP project effects on individual *O. mykiss* life stages and overall cumulative impacts on the abundance trajectories of resident rainbow trout and steelhead. Components of the life-cycle included in the model are steelhead passage, spawning, juvenile production and freshwater rearing, adult freshwater residency, juvenile emigration, and smolt-to-adult return (SAR). Only reaches accessible to steelhead were modeled. Therefore, residents only exist in reaches accessible to anadromous fish, and upstream populations of *O. mykiss* were not modeled.

Table 2. Natural and man-made barriers located in each section of Battle Creek (Mainstem, North Fork, and South Fork). Percent passage (*i.e.*, percent of adults that can pass successfully in a year) indicates the assumed passage success of *O. mykiss* at each barrier as defined by the TAC under current conditions, and expected future conditions following restoration. Barrier descriptions were provided by the TAC. Map numbers refer to locations in Figure 1.

		Barrier Info			Barrier Passage (%)	
Section	Reach	Map #	Name	Location (RM)	Current	Future
Mainstem	Lower	1	Coleman Barrier	5.97	Variable	Variable
North Fork	Wildcat					
	Eagle Canyon I	2	Unnamed #1	4.46	50	100
	Eagle Canyon II	3	CDFW Blast Site	5.06	0	100
		4	Eagle Canyon Dam	5.23	0	100
	North Battle Creek Feeder I	5	Unnamed #2	5.41	0	100
	North Battle Creek Feeder II	6	N. F. Feeder Dam	9.42	30	100
	Keswick	7	Unnamed #3	10.22	0	0
		8	Unnamed #4	10.97	30	30
		9	Unnamed #5	11.02	30	30
		10	Unnamed #6	11.46	30	30
		11	Unnamed #7	11.57	30	30
		12	Unnamed #8	11.76	0	0
		13	Unnamed #9	11.78	0	0
		14	Whispering Falls	13.17	0	0
South Fork	Coleman	15	Coleman Dam	2.54	0	100
	Inskip	16	Inskip Dam	8.02	0	100
	South I	17	Unnamed #10	13.26	50	50
	South II	18	South Dam	14.84	0	100
	Panther	19	Panther Falls	19.07	20	20
	Angel	20	Angel Falls	22.47	0	0

2.1 Modeling Platform

The model is built in R, a programming language and statistical computing environment. R is free, open source, and cross-platform, which facilitates code sharing and collaboration. Programming in R is interactive and efficient because high-level syntax allows writing of compact code. R contains numerous statistical functions and excellent graphical capabilities allowing for both the execution of model runs and the analysis and visualization of simulation results in the same computing environment. Moreover, user-created packages greatly extend the core functionality of R, including packages for the creation of web applications and improved computational performance.

2.2 Quantitative Framework

The model is structured as a multistage Beverton-Holt model, similar to the SHIRAZ modeling framework (Scheuerell *et al*. 2006) developed for Chinook salmon in the Pacific Northwest. *Oncorhynchus mykiss* transition between, and within, each lifestage (*i.e.*, spawners, eggs, age 0-1, age 1-2, age 2-3, age 3-4+) in the model on a monthly basis (except for lifestages occuring out of basin) with the application of a Beverton-Holt stock-recruitment model that includes competition for habitat between life-history types (*i.e.*, resident and anadromous) in the same lifestage:

$$N_{s+1} = \frac{N_s}{\frac{1}{p_{s\rightarrow s+1}} + \frac{1}{c_{s+1}}(N_s + M_s)}$$

where the number of fish surviving to the next lifestage or month (N_{s+1}) is a function of the number alive of one life-history type in the current lifestage or month (N_s), the number alive of the other life-history type in the current lifestage or month (M_s), their survival to the next lifestage or month ($p_{s\rightarrow s+1}$), and the capacity of the environment to support both life-history types in the next lifestage or month (c_{s+1}). Life-history phases occuring out of the Battle Creek watershed (ocean residence and adult steelhead passage) are not modeled explicity, but rather captured in smolt-to-adult return (SAR).

The survival/productivity parameter (*p*) and capacity parameter (*c*) can assume fixed values, or can be functions of the environment. Environmental factors that affect *p* alter the recruitment rate to the next lifestage or month (slope), and factors that affect *c* alter the maximum number of fish that can be produced in the next lifestage or month (Figure 3).

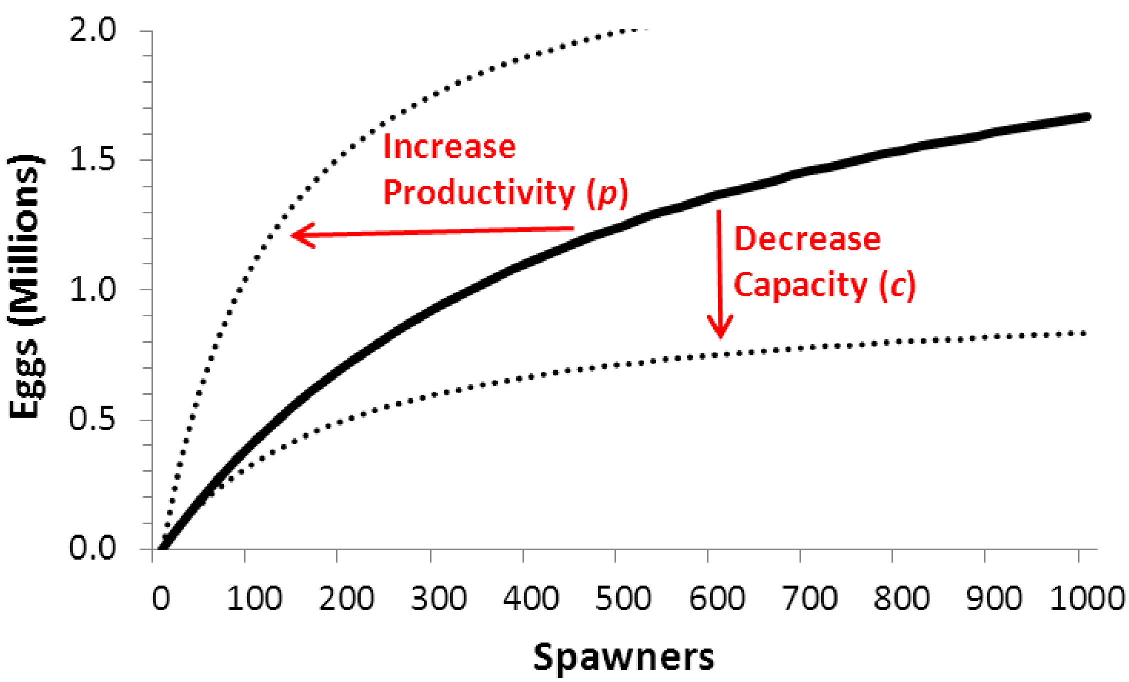

Figure 3. An example Beverton-Holt stock-recruitment relationship for the spawning life-history phase. A change in survival or productivity of spawners alters the slope of the relationship (p), while a change in habitat capacity alters the maximum number of eggs that can be supported (c).

Capacity is modeled for the following lifestage transitions: spawners to eggs, eggs to age 0-1, age 0-1 to age 1-2, age 1-2 to age 2-3, and age 2-3 to age 3-4+. For all other months during rearing or adult residency, and for all other life-history phases (steelhead passage, egg incubation, Battle Creek emigration, and ocean residence), capacity is not assumed to be limited, and therefore is set at infinity, simplifying the stock-recruitment equation to the following form:

$$N_{s+1} = N_s * p_{s \to s+1}$$

2.3 CNFH and BCRP Project Effects

To evaluate CNFH and BCRP project effects, the model relates various attributes of the physical and biological environment to the survival/productivity and capacity of each life stage (Table 3). These project or environmental drivers alter the *p* and *c* parameters in each Beverton-Holt transition occuring monthly between, and within lifestages. The functional form of each relationship and expected values for each driver are informed by available values from published literature, unpublished literature, reports, sampling data, and expert opinion from TAC feedback.

Table 3. CNFH and BCRP project effects that may affect either the survival/productivity (p) or capacity (c) parameters for each life-history phase in the model. The flow values in parentheses indicate a project driver that is influenced by monthly mean (“Average”) and monthly average maximum (“Max”) flow conditions.

Life-History Phase	Hatchery or In-River Spawners	Project or Env. Drivers	CNFH or BCRP Effect?	Affects Productivity (*p*) or Capacity (c)
Steelhead Passage	Both	1. Hatchery Passage	CNFH	*p*
		2. Barrier Passage (trapping)	CNFH	*p*
		3. Barrier Passage (without trapping)	CNFH	*p*
		4. Barrier Passage (800 - 4,500 cfs)	CNFH	*p*
		Water Temperatures	BCRP	*p*
Spawning	Hatchery	Broodstock Requirements	CNFH	*p*
	In-River	Water Temperatures	BCRP	*p*
		Habitat Amount (Average)	BCRP	*c*
Egg Incubation	Hatchery	None		
	In-River	Water Temperatures	BCRP	*p*
		Redd Scour (Max)		*p*
		Hatchery Introgression	CNFH	*p*
Juvenile Rearing (Freshwater Residency)	Hatchery	None		
	In-River	Water Temperatures	BCRP	*p*
		Habitat Amount (Average)	BCRP	*c*
Battle C. Emigration and Ocean Residence	In-River	Diversion Loss	CNFH	*p*

2.4 Timing of Life-History Phases

The timing of different life stages was estimated using Battle Creek rotary screw trap data from 2008 – 2014 (data provided by Matt Brown, USFWS), and applying assumptions about average duration of each life stage. The timing of emergence of *O. mykiss* was identified from rotary screw trap data by applying monthly catch frequency data of yolk-sac fry. The distribution in relative abundance across months was quantified by dividing the number of yolk-sac fry collected in the Battle Creek screw traps in a month by the total number of yolk-sac fry collected by these rotary screw traps (Figure 4). Next *O. mykiss* experience the juvenile rearing stage for one or more years in Battle Creek. Resident rainbow trout spend their entire lives in the study area of Battle Creek. Steelhead emigrate to the ocean one or more years after the month that their egg was incubated (January to August). We back-calculated the timing of other life-history phases (*e.g.*, egg incubation, spawning, and steelhead passage) from the rotary screw trap data. Egg incubation duration was set at one month, and occurred during the month preceding their emergence. Steelhead passage and spawning occurs the month before the resulting eggs are incubated. This produces the monthly proportional occurrence for the different *O. mykiss* monthly cohorts and the timing windows of each life stage in the model (

Table 4). Residents follow similar rules except their spawning occurs two months later (as described in the Assortative Mating section). Based on these rules, in the model, steelhead pass through Battle Creek and spawning occurs from November to April, residents spawn from January to June, eggs are incubated from December to July. Then the yolk-sac fry emerge from January to August. The timing that is generated by this approach and used in the model is within the timing of Central Valley steelhead as estimated by McEwan (2001).

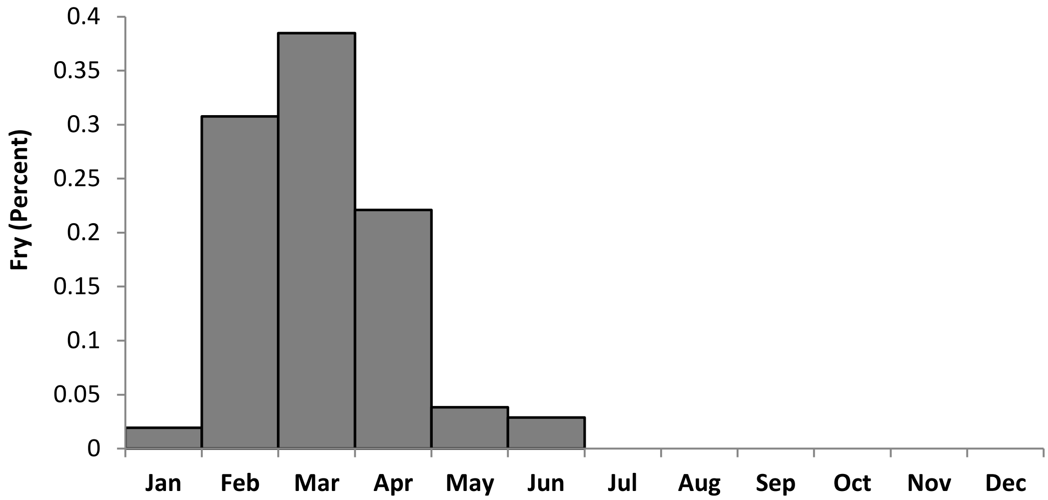

Figure 4. The proportion of yolk-sac fry caught in Battle Creek screw traps.

Table 4. Monthly timing of each life-history phase used in the model. Life-history timing and intensity of the life stage or activity is based on the monthly proportion of yolk-sac fry detected in a rotary screw trap between 2008 and 2014 (rotary screw trap data were provided by Matt Brown, USFWS).

Life History Phase	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Steelhead Passage	■	■	■	■							■	■
Steelhead Spawning	■	■	■	■							■	■
Resident Spawning	■	■	■	■	■	■						
Egg Incubation	■	■	■	■	■	■	■					■
Rearing	■	■	■	■	■	■	■	■	■	■	■	■
Emigration	■	■	■	■	■	■	■	■				

2.5 Steelhead Passage

Upstream migration survival between the ocean and the mouth of Battle Creek is accounted for within the SAR rates (see Ocean Residence section). The upstream movement of steelhead from the ocean to the CNFH barrier weir is not explicitly modeled, since no CNFH or BCRP project effects are thought to occur in this life stage and area.

2.5.1 Prespawning Survival

Spawning occurs in the hatchery as well as in-river. Survival is modeled differently for these two portions of the spawning population. Survival of natural spawners in each reach ($p_{spawning}$) is modeled as a function of water temperatures during the time of spawning. The effect of average water temperature during the residency ($T_{spawner}$; ^{o}F) period is used to estimate survival by the following relationship (Figure 5):

$$p_{spawning} = \begin{cases} 1.0 & \text{if } T_{spawner} \leq 70.0 \\ -0.0943 T_{spawner} + 7.6038 & \text{if } 70.0 < T_{spawner} \leq 80.6 \\ 0.0 & \text{if } T_{spawner} > 80.6 \end{cases}$$

The upper boundary for optimal water temperature (70 ^{o}F) was estimated by Rich (2000). Based on Moyle (2002), 100% mortality in the model occurs for spawners at water temperatures of 80.6 ^{o}F or higher.

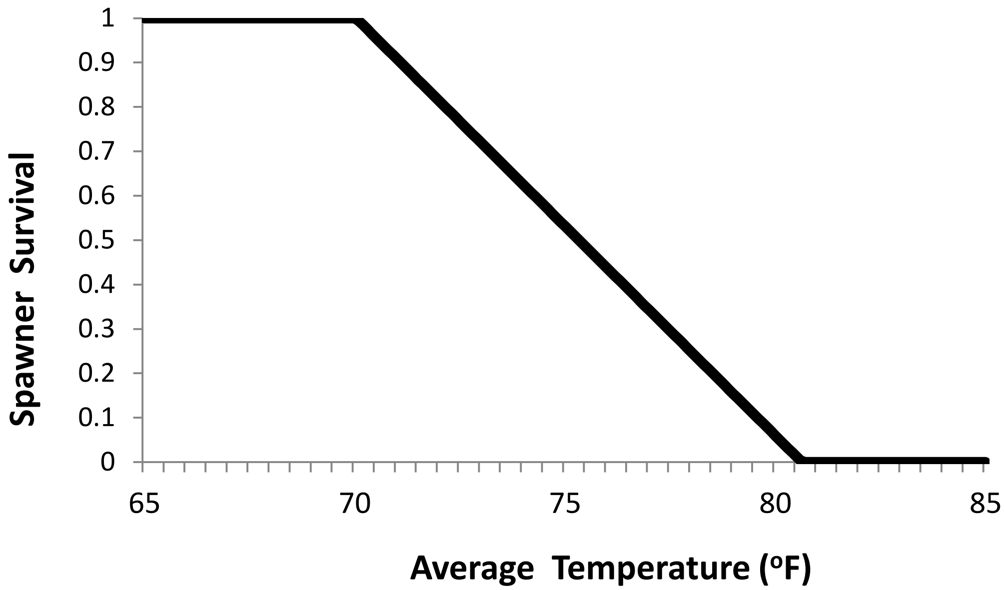

Figure 5. Monthly survival of adult *O. mykiss* versus mean monthly water temperature applied in the model.

2.5.2 Barrier Passage

As steelhead spawners return to their natal reach they may encounter one or more of the 20 fish barriers identified by the TAC (Figure 1; Table 2). Percent passage success of *O. mykiss* at each barrier was defined by the TAC for current conditions and expected future conditions following restoration. Fish that fail to pass a barrier during immigration to their natal reach attempt to spawn in the closest downstream reach. The current upstream extent of habitat occurs at CDFW blast site (barrier #3) on the North Fork, and Coleman Dam (barrier #15) on the South Fork. In the future, the upstream extent of reaches accessible to fish returning from the ocean is expected to be the natural barrier at RM 10.22 on the North Fork (barrier #7) and up to Angel Falls (barrier #20) on the South Fork.

The CNFH barrier weir can be an impediment to steelhead passage. Ideally, hatchery-origin fish enter the hatchery at this point in their migration and natural-origin fish are allowed to pass unhindered upstream. However, some mortality is expected when CNFH operations are engaged in capture and handling. Below, we describe Steelhead Passage relationships for natural-origin and hatchery-origin *O. mykiss* for the expected future operation of CNFH and its barrier weir.

There are three primary routes that natural-origin adult *O. mykiss* can take to pass the barrier weir:

1. Hatchery: the barrier upstream fish ladder is closed. Fish enter the hatchery through the hatchery fish ladder and are sorted, and released upstream. Note that fish may be held in ponds for some time before sorting and release.

2. Barrier – trapping: Fish are trapped in the barrier weir fish ladder system and sampled prior to being released into the upstream fish ladder and passing upstream.
3. Barrier – without trapping: Fish can pass through the barrier weir upstream fish ladder unimpeded.

In the model, survival of natural-origin adults that pass through the CNFH barrier weir is route-specific. The hatchery route is open from October through February. Survival of natural-origin adults taking the hatchery route ($p_{hatchery}$) is a function of direct mortality occurring in the hatchery ladder, in hatchery holding ponds, or during fish sorting ($mort_{hatchery}$):

$$p_{hatchery} = 1 - mort_{hatchery}$$

where $mort_{hatchery}$ is set by sampling a value from a distribution that is a fitted beta-binomial distribution This distribution was created from the pre-spawning barrier passage mortality data on total count and pre-spawn mortality of natural-origin steelhead collected at the CNFH, return years 2002 – 2014 (data provided by Kevin Niemela, USFWS,

Figure 6 The mean annual value from this dataset is 0.017 (dispersion = 2.92). All natural-origin *O. mykiss* survivors are released above the barrier weir. Under current hatchery practices, reconditioned (post-spawn) hatchery-origin steelhead are released below the CNFH barrier weir in March. However, we instead remove hatchery-origin steelhead from the model following spawning in CNFH.

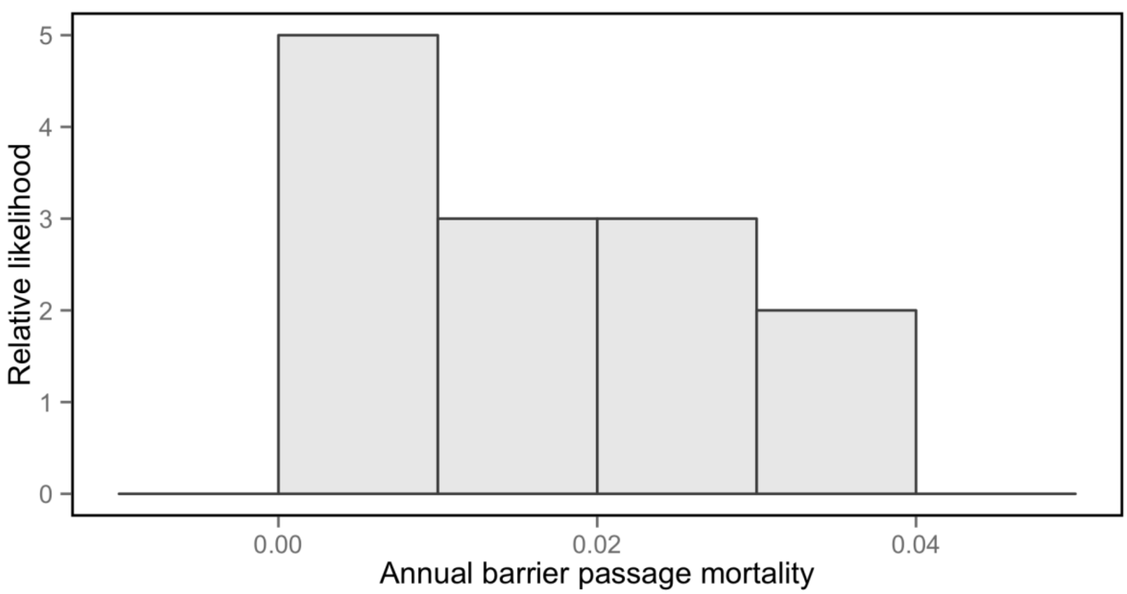

Figure 6. Distribution of hatchery route mortality of natural-origin steelhead collected at the CNFH, return years 2002-2014 (data provided by Kevin Niemela, USFWS).

In the model, the fish ladder with trapping (*i.e.*, trapping route) is available from March through May. Similar to the hatchery route, survival of natural-origin adults that are trapped at the barrier weir ($p_{trapping}$) is a function of barrier weir trapping direct mortality ($mort_{trapping}$) during passage:

$$p_{trapping} = 1 - mort_{trapping}$$

where $mort_{trapping}$ is set by sampling a value from a distribution that is a fitted beta-binomial distribution. This distribution was created from the average observed mortality rate of *O. mykiss* resulting from trapping at the barrier weir from 2001 to 2012 (CNFH-AMP Appendix C;

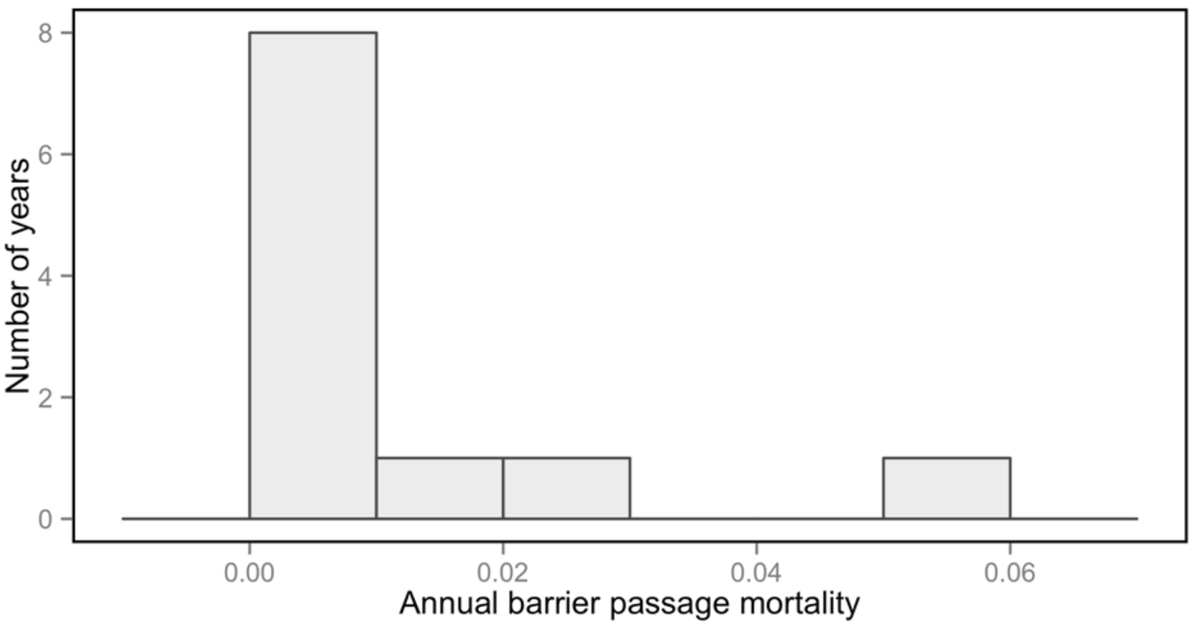

Figure **7**). Data from 2011 was not available (CNFH-AMP Appendix C). The average value was 0.009 (dispersion = 2.83). All natural-origin *O. mykiss* survivors are released above the barrier weir. Also in the model, all hatchery-origin *O. mykiss* are taken into CNFH, and are not released.

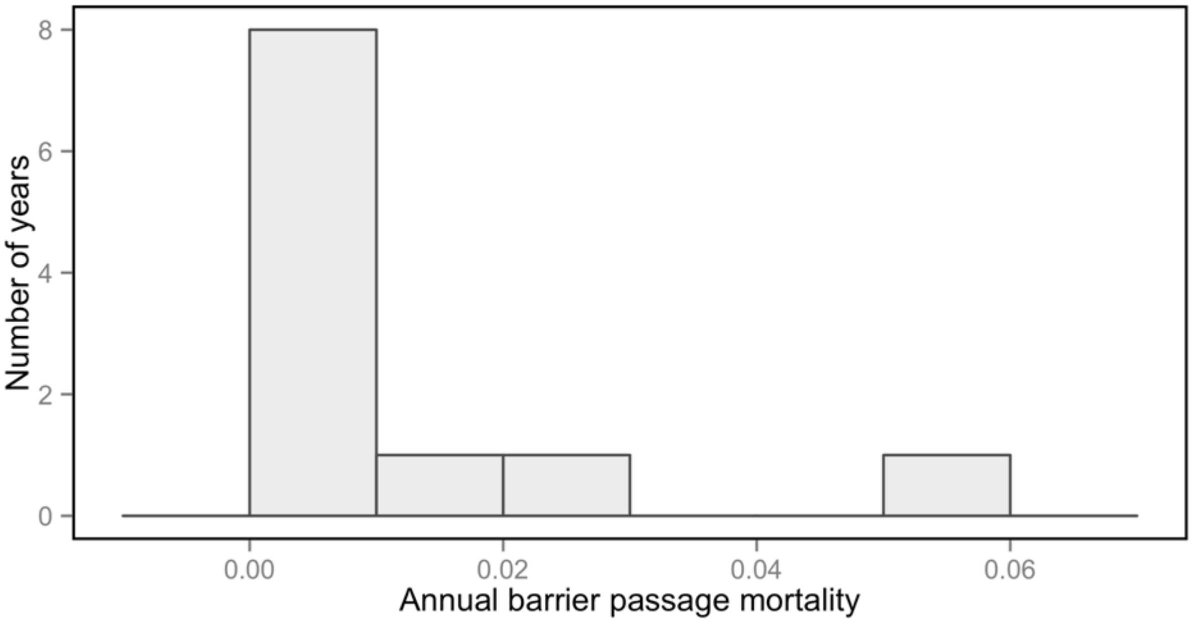

Figure 7. Distribution of trapping route mortality of *O. mykiss* from trapping at the barrier weir from 2001 to 2010 and 2012 (CNFH-AMP Appendix C).

In the model, the fish ladder is open and no trapping occurs from June through July. Survival of natural-origin adults that pass the barrier weir through the upstream fish ladder without being trapped ($p_{no\ trapping}$) is a function of direct mortality in the fish ladder system ($mort_{no\ trapping}$) during passage:

$$p_{no\ trapping} = 1 - mort_{no\ trapping}$$

where $mort_{no\ trapping}$ is set at 0, based on TAC input. The restoration area is not accessible by an open fish ladder or through the hatchery in August and September.

Hatchery-origin fish that enter the restoration area may have a deleterious effect on natural-origin spawner productivity, as shown for populations in the Pacific Northwest (Chilcote *et al*. 2011). This may impair the achievement of BCRP objectives as hatchery-origin *O. mykiss* can enter the restoration area during high flow events that may occur, especially during wet years. Therefore, there is potential for hatchery-origin *O. mykiss* to stray above the CNFH barrier weir and spawn in Battle Creek reaches upstream.

To determine the high flow passage rates, hourly flow data from years 1995 to 2012 were used from the California Department of Water Resources (DWR) California Data Exchange Center (CDEC) gauge in the Lower Reach (BAT CDEC gauge station), which is just below the CNFH barrier weir. For each water year type, we quantified the mean number of hours during each month that hourly flows were between 800 and 4,500 cfs at any time during that day (potential stray hours as defined and determined by TAC input). We then divided the number of potential stray hours by the total hours in each month to calculate the proportion of time in each month that there was a potential for straying (stray potential). Monthly stray potential was then multiplied by the monthly proportional presence of spawning steelhead to calculate the monthly potential stray rate. Because the TAC estimated that the maximum annual stray rate past the CNFH barrier weir would be approximately 5%, we scaled the monthly potential stray rates in order to attain an annual stray rate of 5% for steelhead in wet years. Therefore, our resulting scalar on monthly proportional passage is 0.141, implying that only 14.1% of adults that are eligible to stray (during flows of 800 to 4,500 cfs) are successful.

2.6 Spawning

The spawning life history phase models the transition of spawners to deposited eggs. We applied steelhead ocean return rates and rainbow trout age-at-maturity data to determine the number of steelhead and rainbow trout spawners by age class. Lastly, we applied average fecundities for steelhead and rainbow trout to transition spawners to eggs.

2.6.1 Maturity and Fecundity

In the Battle Creek life-cycle model rearing anadromous juveniles emigrate at 70%, 29%, and 1% after one, two, and three years, respectively (Hallock *et al*. 1961 modified with input from the TAC). The age distribution for returning anadromous spawners was determined from fish sampling conducted in the Yakima Basin (Conley *et al.* 2009). The majority of the Yakima steelhead run consisted of fish that emigrated to the ocean as two year old smolts, and returned to spawn after one or two years in the ocean. Adult steelhead returns are comprised of 63% and 37% of one- and two-salt fish, respectively, with a sex distribution given in Table 5.

Table 5. Spawner age and sex distribution data used in the Battle Creek *O. mykiss* population model.

Ocean Age	Female	Male
1 – Salt	52%	74%
2 – Salt	48%	26%

Rainbow trout are iteroparous, but this reproductive strategy was not incorporated into the model as it is only represented in a small proportion of the population collected at CNFH (Null *et al.* 2013). The number of resident trout spawners is a function of the number of mature male and female adults in the population. Resident females produce 1,000 eggs per female (estimated using a 14-inch rainbow trout and the relationship of fecundity and size as identified in Pearsons *et al.* 1993), and anadromous females produce 4,000 eggs per female (USFWS 2011). The difference in maturity rates between male and female rainbow trout was estimated using data from the Yakima River (Pers. Comm. G. Temple; Table 6).

Table 6. Age-at-maturity estimates for rainbow trout derived from resident fish surveys conducted in the upper Yakima River between 1990 and 1993 (Pers. Comm. G. Temple).

Sex	Age	Mature and spawning
Female	Age 1	0%
	Age 2	15%
	Age 3	40%

	Age 4	80%
Male	Age 1	10%
	Age 2	40%
	Age 3	60%
	Age 4	90%

2.7 Assortative Mating

Spawning between resident and anadromous rainbow trout is documented (McMillan *et al.* 2007; Pearsons *et al.* 2007), and the rate of interbreeding between life-histories influences the abundance of the two life-histories in subsequent generations. We incorporated assortative mating into the model through the spatial and temporal overlap between resident and anadromous rainbow trout spawning activity. This framework builds on observational evidence for rainbow trout mating systems in the Olympic Peninsula (McMillan *et al.* 2007). To incorporate the observed later spawning of residents, we shifted their spawning distribution by two months from the spawning distribution of steelhead, which is back-calculated from the observed presence of yolk-sac fry.

2.7.1 Cross-Life-History Production

There is evidence that anadromous rainbow trout produce resident offspring and vice versa (Thrower and Joyce 2004; Zimmerman *et al.* 2009). We term this “cross-life-history production” within the life-cycle model. To determine life-history and sex ratios of offspring produced in the model, we used observed values from Thrower and Joyce (2004) that were modified to better reflect Battle Creek populations (Table 7; Courter *et al.* unpublished manuscript).

The proportion of offspring that exhibited anadromy varied by parental cross-type and sex of the juveniles (Table 7). The ratio of male to female offspring produced by all parental crosses was assumed to be 1:1. Baseline smoltification rates were estimated from breeding experiments conducted near Sashin Creek, Alaska, where resident and anadromous O. mykiss were spawned in a hatchery and offspring were monitored for evidence of smoltification (Thrower and Joyce 2004). Without data available for Battle Creek populations, Sashin Creek estimates were assumed to represent plausible smolt production percentages for Battle Creek, and served as baseline values from which we constructed the hypothesis test. A simple breeding experiment carried out in the Grande Ronde Basin, Oregon (Pers. Comm. R. Carmichael) indicated potentially lower smolting rates in Rf x Rm crosses, which may be a genetic adaptation resulting from the higher cost of migration associated with interior rivers relative to coastal streams, like Sashin Creek. Whatever the causal mechanism, we deemed it appropriate to adopt the most conservative estimate of resident female contributions to anadromy for our baseline inputs.

Table 7. Proportions of female and male offspring that smolt or residualize for the different spawner cross-types. Overall sex ratio is assumed to be 50:50.

Spawner Cross-type	Female Offspring		Male Offspring	
	Smolting	Residualizing	Smolting	Residualizing
Af x Am	82%	18%	47%	53%
Af x Rm	57%	43%	21%	79%
Rf x Am	71%	29%	78%	22%
Rf x Rm	24%	76%	10%	90%

2.7.2 Hatchery Spawning

Two hundred adult steelhead is the minimum spawning target for CNFH (USFWS 2011). However, additional adults are often taken to account for potentially high egg mortality rates (USFWS 2011) and thus, the actual number spawned in the hatchery is typically over 500 adults annually.

In the model no more than 400 male and 400 female *O. mykiss* adults are taken each year for broodstock. Given the minimum length cutoff (406 mm; USFWS 2011) for the *O. mykiss* taken as broodstock, most of the broodstook are anadromous hatchery-origin fish. Yet, given that some resident fish can reach large sizes, some resident fish are used as CNFH broodstock (Donohoe and Null 2013) and this is incorporated into the model.

First, the model counts the total number of hatchery females that are detected and collected at the fish barrier weir; hatchery females detected at the weir equals total hatchery females returning minus both the hatchery females straying (≤5% of returning females) and the hatchery females remaining in the Lower Reach (1% of returning females). If the tally of females exceeds the broodstock target (400), then the model uses the broodstock target as the number of females in the hatchery program for that year. If the broodstock target is not met, the model uses the female tally as the number of females for that year. The male broodstock target is not incorporated into the model because of the assumption that a small number of males can fertilize a large number of females. In the integrated hatchery (discussed in the Issues and Effects Evaluated by the Model section), we assume that we always have 400 females as broodstock every year from another source (*i.e.*, outside the study region). For all simulations, the model calculates the number of hatchery females and males that are resident (10.2% and 3.8%, respectively) and anadromous (89.8% and 96.2%, respectively) (Donohoe and Null 2013). Then the model calculates the total eggs produced under the assumption that resident females produce 1,000 eggs per female and anadromous females produce 4,000 eggs per female. Next, the model calculates the proportion of eggs that need to be culled, and this is done equally from all crosses (resident and steelhead) to ensure production does not exceed 600,000 *O. mykiss* being raised and released each year (USFWS 2011).

2.7.3 Capacity for Redds and Egg Production

Redd capacity is specific to each reach, in each month, and in each water year type. The capacity of in-river female spawners in each reach (b) is modeled as a function of the reach-specific suitable habitat available for spawning (spawning habitat; ft^2), and redd area:

$$Female\ Spawner\ Capacity_b = \frac{Spawning\ Habitat_b}{Redd\ Area}$$

where *spawning habitat* is the total amount of reach-specific suitable habitat available for spawning as a function of flow, as defined by Instream Flow Incremental Methodology (IFIM) and Physical Habitat Simulation (PHABSIM) analyses detailed in Appendix H of Jones and Stokes (2005). The redd area is 19 and 56 ft^2 for resident and steelhead *O. mykiss* females, respectively (Gallagher and Gallagher 2005; Jones and Stokes 2005).

The number of eggs produced is a function of the number of females and eggs per female. Fecundity varies by life-history type. Hatchery egg production is the product of the number of female hatchery spawners, up to the broodstock maximum (S ≤ 400), and fecundity (F) for each life-history type (l; resident = 1,000; anadromous = 4,000):

$$N_l = \sum S_l * F_l$$

Natural-origin female spawners of each life-history type (l) in each reach (b) are converted to deposited eggs ($N_{l,b}$), as a function of the number of female spawners of each life-history type and reach ($S_{l,b}$), and fecundity ($F_{l,}$; resident = 1,000; anadromous = 4,000):

$$N_{l,b} = \sum S_{l,b} * F_l$$

2.8 Egg Incubation

The egg incubation life history phase models the one month-long transition of eggs to fry. We modeled egg incubation survival as a function of water temperature, proportion of hatchery spawners, and redd scouring due to high flow events.

2.8.1 Egg Survival

In the model, the survival of hatchery-origin eggs to the fry stage ($p_{hatchery\ eggs}$) is set at 0.82, the average egg-to-fry survival observed in the CNFH, which was quantified by multiplying the average survival of green egg to eyed egg with eyed egg to ponding (USFWS 2011).

Survival of in-river eggs in each reach ($p_{in\text{-}river\ eggs}$) is modeled as a function of water temperatures during incubation, fitness loss due to introgression with hatchery spawners, and redd scouring due to flows. First, the effect of average water temperature during the incubation (T_{inc}; °F) period is used to estimate egg survival using the following relationship (Figure 8):

$$p_{in-river\ eggs} = \begin{cases} 1.0 & \text{if } T_{inc} \le 52.0 \\ -0.091T_{inc} + 5.727 & \text{if } 52.0 < T_{inc} < 63.0 \\ 0.0 & \text{if } T_{inc} \ge 63.0 \end{cases}$$

Eggs incubate for a month and mortality is based on numbers from a literature review conducted by the IEP (1998). No egg mortality occurred at water temperature of 52 °F or colder. Total mortality of eggs in the model occurs at temperature of 63 °F or warmer (Oroville FERC relicensing 2003).

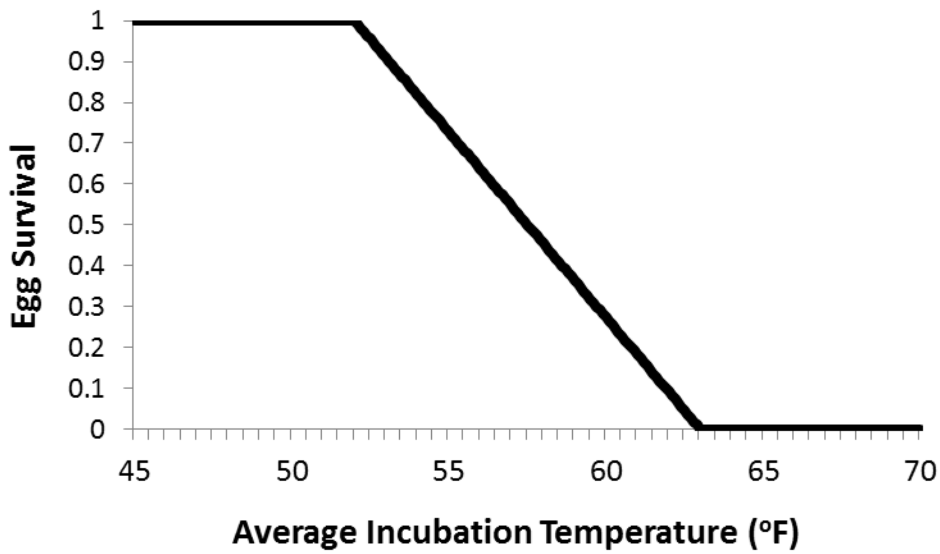

Figure 8. Egg survival versus average incubation temperature applied in the model.

Many studies have shown lower reproductive success of hatchery-origin salmonids compared to their natural-origin counterparts (Chilcote *et al.* 1986; McLean *et al.* 2003; Chilcote *et al.* 2011), leading to the hypothesis that recruitment performance of naturally reproducing populations should vary directly with the proportion of spawners that are of hatchery-origin (Chilcote *et al.* 2013). Although the effect of fitness loss due to introgression with hatchery spawners on *O. mykiss* productivity can occur at multiple lifestages, we apply this effect on a single lifestage transition (eggs to age 0-1) to avoid overestimating the effect on *O. mykiss* productivity.

Chilcote *et al*. (2013) found a significant negative relationship between fish productivity and the proportion of hatchery-origin spawners for 93 populations of anadromous salmonids from the states of Oregon, Washington, and Idaho, USA. Therefore, we applied the best-fit relationship for *O. mykiss* from Chilcote *et al*. (2013) to inform the effect of hatchery introgression on egg survival (Figure 9). The effect of introgression on monthly egg survival ($p_{introgression}$) is modeled as a function of the proportion of hatchery-origin spawners ($p_{hatchery}$) present in each reach in that particular month:

$$p_{introgression} = e^{(1.55 - p_{hatchery} * 2.80)}/e^{(1.55)}$$

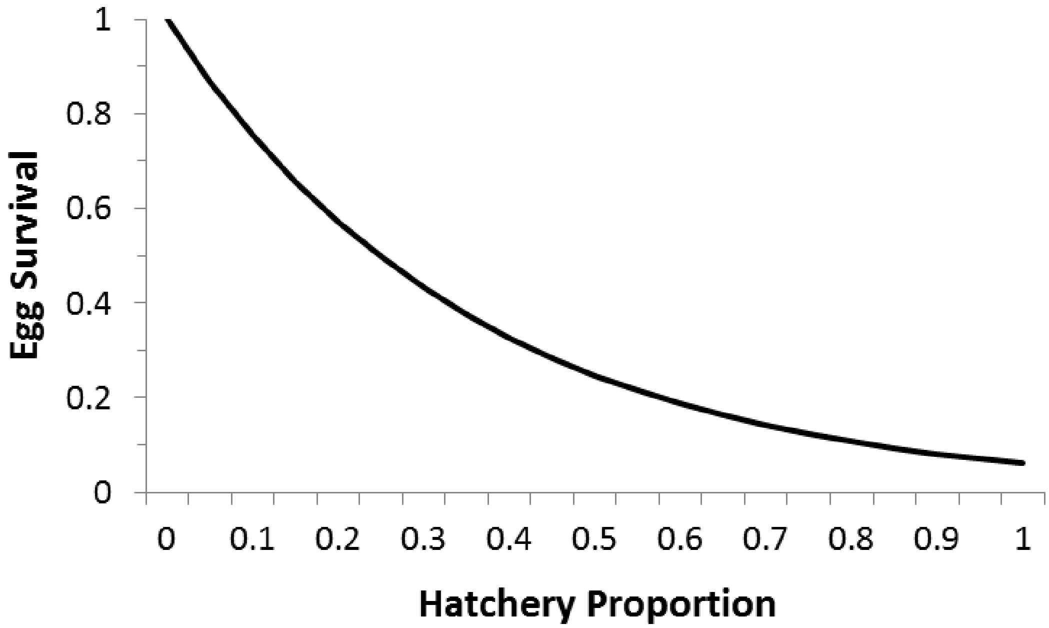

Figure 9. Relationship between monthly egg survival and the proportion of hatchery-origin spawners applied in the model. The relationship was adapted from Chilcote *et al*. (2013).

We applied the same relationship used by Scheuerell *et al.* (2006) to model the effect of redd scouring on monthly egg survival in each section of Battle Creek (mainstem, North Fork, South Fork). First, normalized mean monthly flow (Q_r) during the incubation period in Battle Creek was calculated by dividing the maximum daily mean flow for each month (Q) by the maximum historical flow observed in mainstem Battle Creek (Q_{max}). Maximum historical flow (Q_{max}) was set at 20,605 cfs, the maximum mean daily flow was estimated from the BAT CDEC gauge station for water years 1995 to 2012. We then fit the following relationship between monthly egg-fry survival and Q in the mainstem (Figure 10).

$$p_{scour} = \begin{bmatrix} 0.58 - 0.844Q & if\ Q_r < 0.675 \\ 0.01 & if\ Q_r \geq 0.675 \end{bmatrix}$$

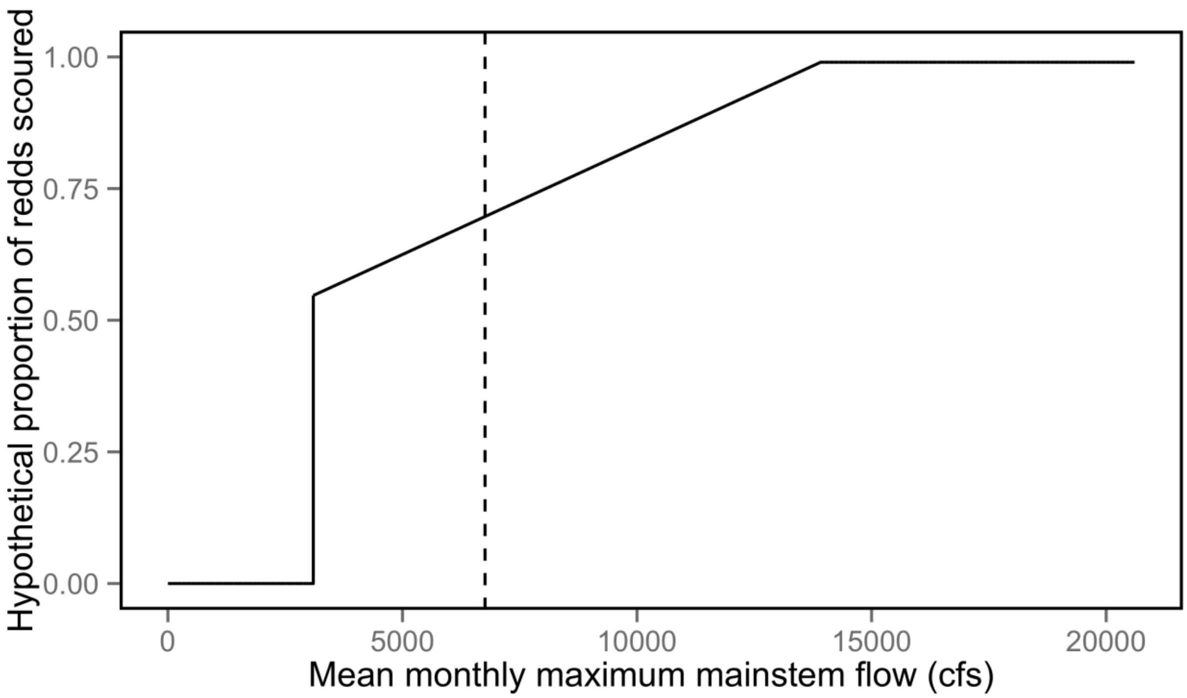

Figure 10. Relationship between redds scoured and maximum mean monthly flow during the egg incubation period (Scheuerell *et al*. 2006). The dashed vertical line is the highest mean monthly maximum flow (6,759 cfs) observed across all years used in the model. Therefore, redd scour is never 100%.

If the maximum mean monthly flow observed during the egg incubation period (December – June) does not exceed 3,100 cfs, the model does not incorporate mortality due to redd scour (assumption based on TAC input). This threshold value used in the model is the base flow for Battle Creek as quantified by the USBR (2001).

2.9 Freshwater Recruitment

We used the fork length and territory size relationship of Grant and Kramer (1990) to determine the amount of rearing habitat required for fish in each age class (*e.g.,* age 2-3):

$$TS_{m,t} = 10^{a \cdot \log_{10}(L_{m,t}/10)+b}$$

where $TS_{m,t}$ is the territory size (m²) for age class m on day t and $L_{m,t}$ is fork length (mm). a and b are constants and are 2.61 and - 2.90, respectively. Using these values provides territory sizes for all age classes in the model (Table 8).

Table 8. The estimated fork length and territory size in square meters and feet for the age classes in the model.

Age	Length (mm)	Area (sq. m.)	Area (sq. ft.)
Age 0-1	50	0.08	0.9
Age 1-2	200	3.13	33.7
Age 2-3	300	9.02	97.11
Age 3-4+	400	19.12	205.75

The territory sizes were used to calculate the carrying capacity of each reach for the four lifestages (age 0-1, 1-2, 2-3, and 3-4+) of *O. mykiss* based on available habitat area. To determine the capacity for a given lifestage (*l*) in a given reach (*b*), the amount of Weighted Usable Area (WUA) available for each lifestage (*Rearing Habitat*) is divided by its territory size requirements (*Territory Size*):

$$Capacity_{b,l} = \left(\frac{Rearing\ Habitat_b}{Territory\ Size_l}\right)$$

where rearing habitat is the total amount of reach-specific suitable habitat (ft^2) available for rearing as a function of flow, as defined by the In-stream Flow Incremental Methodology (IFIM), which provides the flow-related WUA curve (Thomas R. Payne and Associates 1998).

2.9.1 Juvenile Rearing Survival

In the hatchery, survival of hatchery fry to the juvenile stage ($p_{hat.\ juv.}$) is 0.93, the average fry-to-smolt survival observed (*i.e.*, ponding to release) in the CNFH (USFWS 2011). Survival of in-river juveniles in each reach ($p_{juvenile}$) is modeled as a function of reach-specific average monthly water temperature during their residency in freshwater. The effect of average water temperature during the residency ($T_{juvenile}$; ^oF) period is used to estimate survival using the following relationship (Figure 11):

$$p_{juvenile} = \begin{cases} 1.0 & \text{if } T_{juvenile} \le 60.0 \\ -0.0395T_{juvenile} + 3.3715 & \text{if } 60.0 < T_{juvenile} \le 85.3 \\ 0.0 & \text{if } T_{juvenile} > 85.3 \end{cases}$$

The upper boundary for optimal temperature (60 ^{o}F) was estimated by USFWS (1995). The upper boundary of juvenile survival was identified using results from Cech and Myrick (1999), as documented in Appendix A of the Oroville FERC relicensing document (2003).

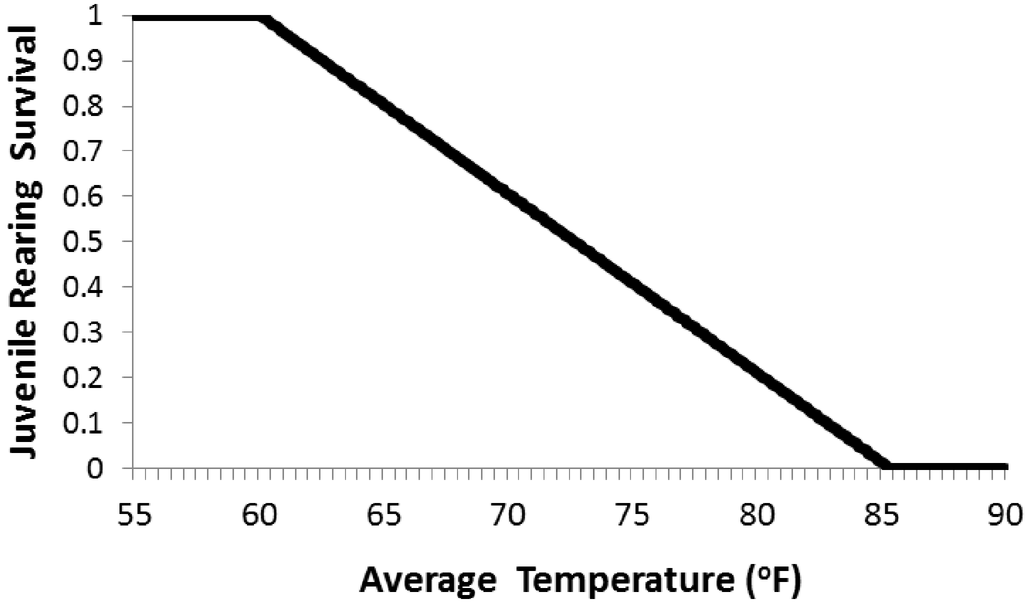

Figure 11. Monthly survival of juvenile *O. mykiss* versus mean monthly water temperature applied in the model.

In the model, for temperature-dependent survival, the juvenile survival relationship was applied to all potentially anadromous fish that have not emigrated to the ocean, and to resident fish that are less than three years old. The adult survival relationship was applied to anadromous fish after returning from the ocean, and resident fish greater than or equal to three years old.

2.10 Freshwater Residency

Survival of adults in each reach (p_{adult}) is modeled as a function of water temperatures during their residency in freshwater. The effect of average water temperature during the residency (T_{adult}; ^oF) period is used to estimate survival based on the following relationship (Figure 12):

$$p_{adult} = \begin{cases} 1.0 & \text{if } T_{adult} \leq 70.0 \\ -0.0943T_{adult} + 7.6038 & \text{if } 70.0 < T_{adult} \leq 80.6 \\ 0.0 & \text{if } T_{adult} > 80.6 \end{cases}$$

The upper boundary for optimal temperature (70 ^oF) was estimated by Rich (2000). Based on Moyle (2002), total mortality in model occurs at temperature of 80.6 ^oF or higher.

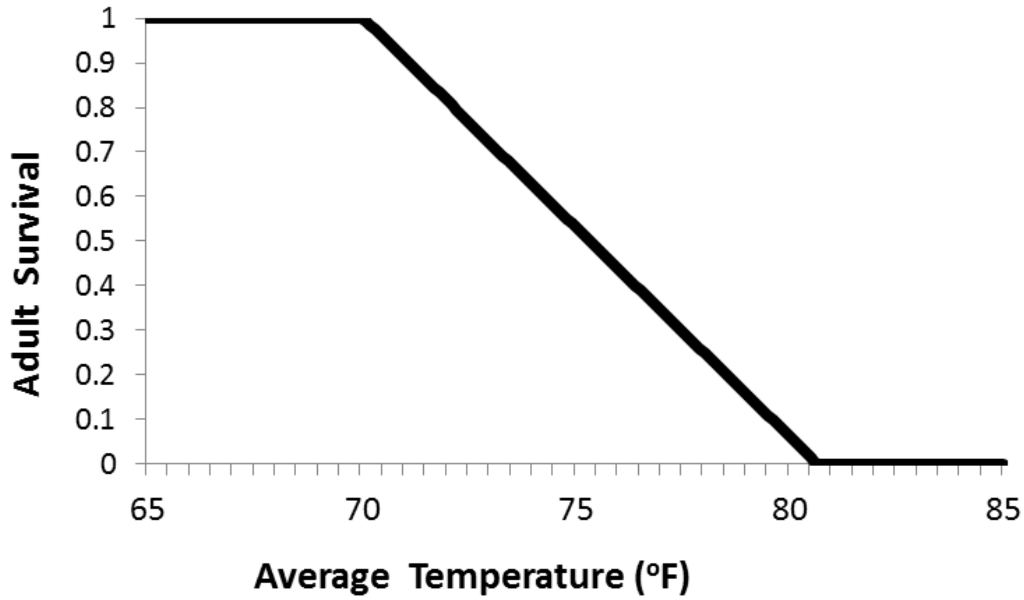

Figure 12. Monthly survival of adult *O. mykiss* versus mean monthly water temperature applied in the model.

2.11 Battle Creek Emigration

The Battle Creek emigration life-history phase models the emigration out of Battle Creek into the Sacramento River. Smolt survival depends on diversion loss and distance travelled.

2.11.1 Diversion Loss

We modeled mortality associated with the unscreened CNFH water intake. Intakes 1 and 3 divert water from Battle Creek and are necessary for regular operation of Coleman National Fish Hatchery (USFWS 2011). Unplanned outages at Pacific Gas and Electric Company's Coleman Powerhouse results in the temporary dewatering of the hatchery's primary water intake (Intake 1), which is located in the tailrace of the powerhouse (USFWS 2011). In these circumstances, the hatchery's water demand is supplied via the combination of hatchery Intake 3 and emergency back-up Intake 2. Intake 3 is screened to standards that meet or exceed National Marine Fisheries Service and CA Department of Fish and Wildlife criteria; however, the hatchery's Intake 2 is not screened and may result in entrainment of fishes from Battle Creek when in use. Although planned outages also occur at the Powerhouse, they are believed to divert much less water volume than unplanned outages (TAC input). Additionally, it should be possible to undertake planned outages at a time when juvenile emigration is minimal. Therefore, we decided not to incorporate the effect of planned outages because the much larger effect of unplanned outages resulted in negligible effects on mean abundance (See Results section).

We used historical data associated with unplanned outages provided by the CNFH Biological Assessment (BA) to inform the expected frequency of these unanticipated events, and calculate the proportion of Battle Creek flow diverted into the unscreened Intake 2. We extracted the event start dates and durations of all unplanned outages for years 1992-2006 from Table A-14 of Appendix 4A of the Biological Assessment (USFWS 2011). A total of 46 unplanned outages occurred, ranging in duration from 19 minutes to 133 days (median = 4.9 hours). We used average monthly flow data at the CDEC BAT gauge in the mainstem Battle Creek to inform the average amount of flow passing the Intake 2 diversion during outage events. Our approach for calculating monthly diversion loss in the life-cycle model is to sample probabilistically from the unplanned outage data to estimate the amount of flow diverted in a month at Intake 2, and pair that with the observed emigration timing. More specifically, the life-cycle model calculates the monthly loss by taking the following steps:

1) *Number of Events* - determine the number of outage events occurring in a month by sampling from a probability distribution of historical frequency of outage events.

2) *Event Duration* - if an event occurs in the given month, determine the duration of the outage event by sampling from a probability distribution of historical event durations.

3) *Water Volume Diverted* - calculate the monthly proportional water volume diverted by converting the event duration to water volume and dividing by the average monthly water volume passing the Intake 2 diversion.

4) *Diversion Loss* - calculate monthly loss in the model by multiplying the proportion of water volume diverted by the proportion of fish expected to be passing the diversion.

Number of Events

The number of outage events occurring during a single month in the model is determined by sampling from a negative binomial distribution of the frequency of unplanned outage events observed between 1992 and 2006. The most likely number of outage events occurring in a given month is zero, with decreasing probability of occurrence as event frequency increases (Figure 13).

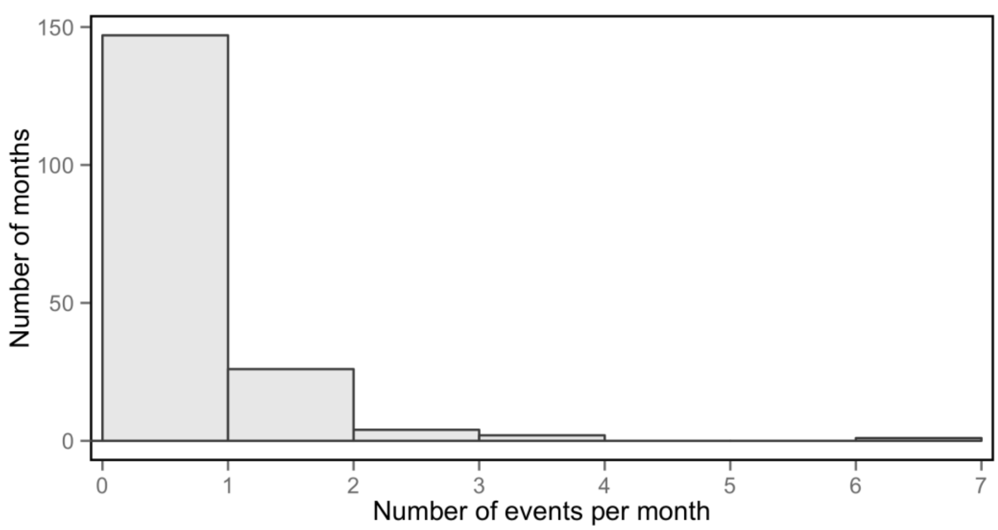

Figure 13. Observed distribution of unplanned outage events per month at Intake 2 that occurred during years 1992-2006 used to inform a beta-binomial distribution of the monthly number of unplanned outage events occurring in the Chinook salmon life cycle model.

Event Duration

The duration of each outage event occurring during a single month in the model is determined by sampling from a nonparametric probability density function of outage durations observed during years 1992-2006. Due to the random nature of the historical event duration data, we utilized a random variate generation algorithm (Kaczynski *et al*. 2012) to develop a nonparametric probability density function to inform the duration of each monthly outage event. Because we are modeling on a monthly time-step, sampled durations greater than one month long are truncated in the model so the longest that diversion through Intake 2 could occur was for that month (Figure 14).

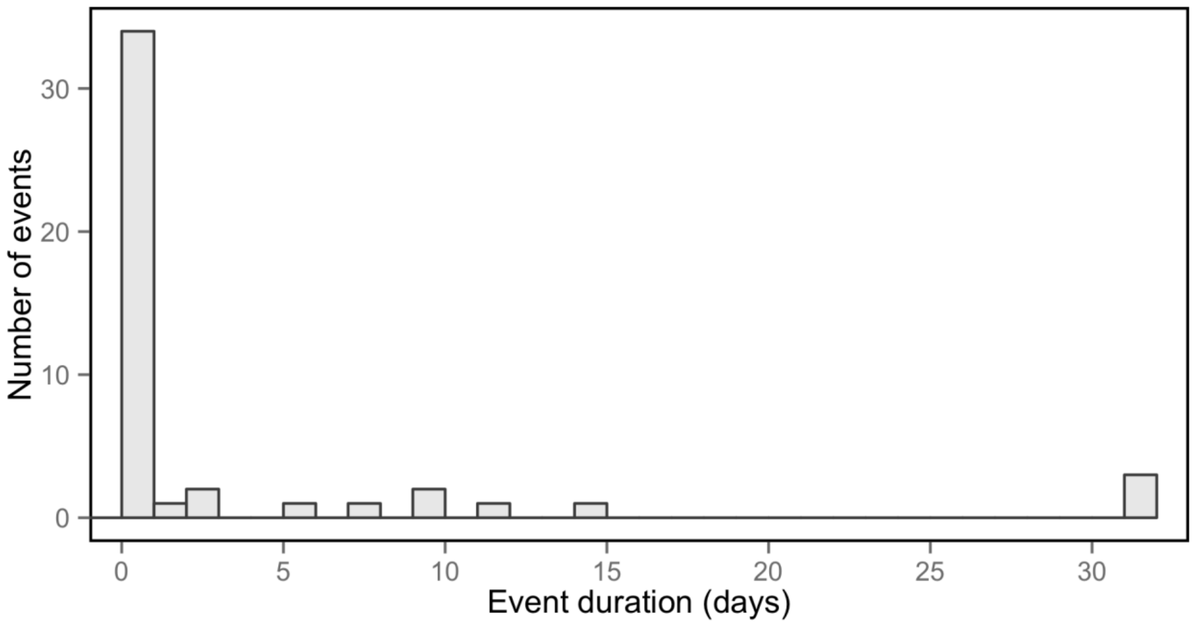

Figure 14. Observed number and duration of unplanned outage events at Intake 2 that occurred during years 1992-2006 used to inform a beta-binomial distribution of the duration of unplanned outage events occurring in the Chinook salmon life cycle model. This relationship was truncated to the total number of days in a month (31) used in the model.

Water Volume Diverted

Without information on variability of the diversion flow rate at Intake 2 between diversion events, we assumed a diversion flow rate of 64 cfs for each diversion event, which is believed to be the maximum flow rate that can be diverted through intake 2 (based on TAC input). We multiplied each unplanned outage duration (seconds) by 64 (cfs) to obtain the total volume diverted for each event. We then summed the diversion volumes in each month to determine the monthly water volume diverted. Next, we determined the monthly proportion of Battle Creek flow reaching Intake 2 during unplanned outages. We estimated the total volume of Battle Creek flow passing Intake 2 by multiplying the average monthly flow at the CDEC BAT gauge in the mainstem Battle Creek by the number of seconds in each month. Because the model is run under three different water year types (dry, normal, and wet) we applied the average monthly flow of the corresponding water year type being modeled. We then divided our previously calculated monthly diversion volume by the volume of water passing Intake 2 to calculate the monthly proportion of flow being diverted into Intake 2 during unplanned outages. In applying this data within the life-cycle model, in months when an outage occurs, the proportion of flow being diverted results in the proportional entrainment of juveniles present during that month.

Diversion Loss

To inform monthly entrainment (loss) of juveniles in the life-cycle model, we multiplied the monthly water volume diversion proportion due to unplanned outages by the monthly proportion of juvenile fish passage occurring in the model.

2.11.2 Battle Creek Smolt Survival

Survival of juveniles emigrating out of Battle Creek (S_r) is modeled as a function of emigration mortality ($Mort_{emigration} = 1.0065e^{-0.009d}$), which is dependent upon the distance traveled (*d*) from the midpoint of each reach (r) to the mouth of Battle Creek (Figure 15), and diversion loss associated with the unscreened CNFH diversion at water Intake 2:

$$S_r = (1 - Mort_{emigration})*(1 - (\sum \text{Divert} * \text{Passage})$$

where emigration survival is a function of the mean survival per kilometer as observed by telemetry studies conducted in the Alsea and Nehalem Rivers (Romer *et al*. 2013), Cowlitz River (Pers. Comm. T. Kock), and Yakima River (Conley *et al.* 2009), and mortality associated with CNFH unscreened water Intake 2. Mortality associated with the unscreened CNFH water Intake 2 is modeled as a function of the sum of the monthly products of the average water diversion proportion estimated for the unscreened Intake 2 (*Divert*) and the average proportion of passage of steelhead (*Passage*). This is the same approach as described under the Diversion Loss section above.

Hatchery-origin smolts are released outside of Battle Creek and do not experience mortality due to predation or water diversion within Battle Creek. However, we do expect these fish to incur significant mortality following release and during early migration in the Sacramento River. Mortality that occurs downstream of Battle Creek is accounted for within the modeled SAR rates.

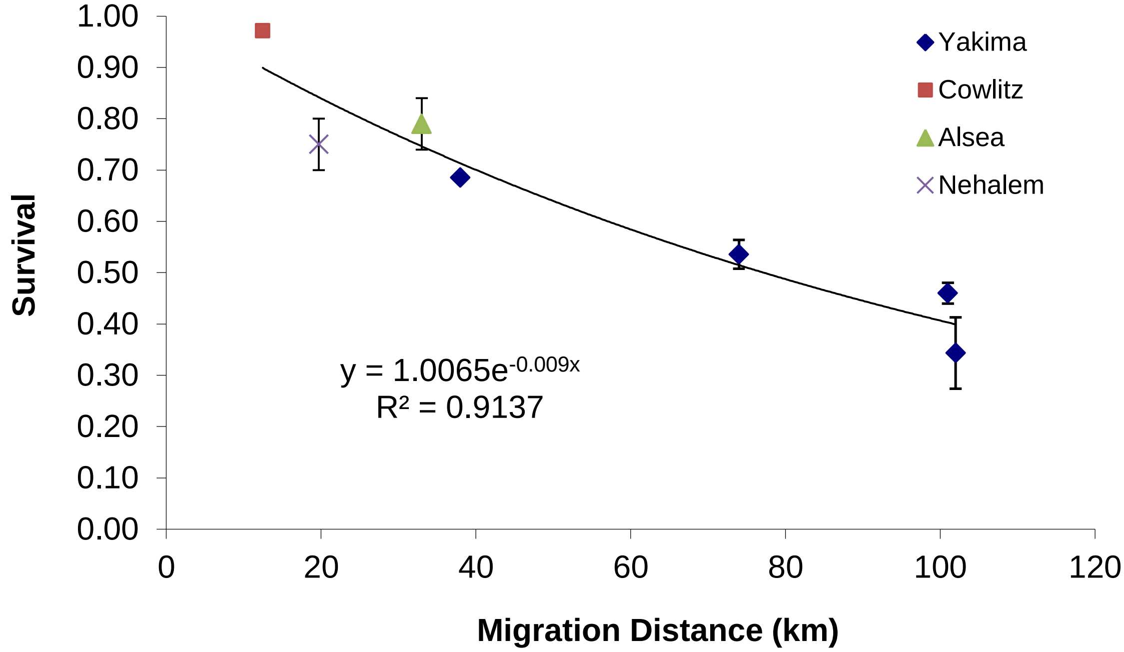

Figure 15. Relationship between migration distance and survival of emigrating smolt in Pacific Northwest rivers. Data from Conley *et al.* (2009), Romer *et al*. (2013), and Toby Kock (Pers. Comm.).

2.12 Ocean Residence

Migration from the mouth of Battle Creek to the ocean and back is accounted for by applying a SAR rate. Also, for simplification, the transition from Ocean to Spawning is instantaneously calculated by applying a SAR rate. SAR rates were estimated from smolt release and adult steelhead return data cataloged by CNFH, which is the best information available. We used data (provided by Kevin Niemela, USFWS) for the 12 brood years from 1999 – 2010 (Table 9).

Table 9. Data used to estimate SAR rates for brood years from 1999 – 2010, the year and number of release, assumed year of return, number that returned, and the number that returned per thousand smolts released.

Brood Year	Release Year	Release Number	Return Year	Return Number	Return Per Thousand Smolts Released
1999	2000	521,332	2002	3,089	5.93
2000	2001	596,343	2003	2,266	3.80
2001	2002	647,707	2004	1,393	2.15
2002	2003	529,364	2005	1,343	2.54
2003	2004	357,918	2006	995	2.78
2004	2005	689,800	2007	1,394	2.02
2005	2006	606,967	2008	2,969	4.89
2006	2007	672,125	2009	2,007	2.99
2007	2008	641,085	2010	642	1.00
2008	2009	666,725	2011	1,108	1.78
2009	2010	594,387	2012	1,798	3.02
2010	2011	715,925	2013	1,908	2.67
Average		**603,307**		**1,749**	**2.96**

SAR rates were stochastically simulated to account for observed year-to-year variability. To do this, a beta-binomial distribution was fitted to the return rate data, and we simulated annual SAR rates in the model by sampling from the distribution (Figure 16). The average SAR was 0.0029 (dispersion = 379).

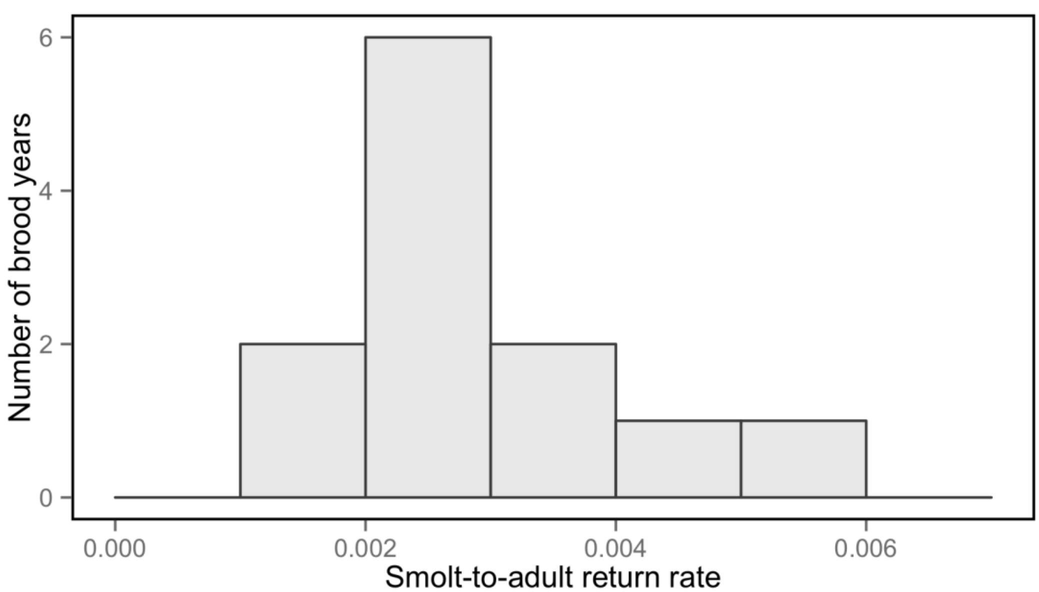

Figure 16. Distribution of the smolt-to-adult return rate data at CNFH for brood years from 1999 – 2010 and return years 2002 – 2013 (data provided by Kevin Niemela, USFWS).

3. Environmental Input Data

The best available environmental input data needs to be selected to inform model relationships. We compiled and used modeled environmental data from draft and final versions of the BCRP EIS/EIR (Jones and Stokes 2005) and observational flow data from the CDEC BAT gauge.

In order to incorporate the effect of varying annual flow conditions on model outcomes, the model ran under three water year types: dry, normal, and wet. Each model run consisted of 50 years, with the annual occurrence of each water year type following auto-correlated occurrence probabilities observed in the Sacramento River Basin hydrologic record since 1906 (CDEC). The model used separate monthly values for each of the three water year types for the following six data input types described below, thereby incorporating the effect of varying monthly and annual flow regimes in model results.

We applied six data input types needed to inform model functionality, including:

1. Modeled Flows – modeled reach-specific mean monthly flows
2. Modeled Spawning Habitat – modeled reach-specific spawning habitat amount as a function of flow
3. Modeled Juvenile Habitat - modeled reach-specific juvenile habitat amount as a function of flow
4. Observed Hours of High Flows – mean number of hours of high flow events by month in the mainstem section (> 800 - 4,500 cfs)
5. Observed Max. Flows – monthly maximum flows
6. Modeled Temperatures – modeled reach-specific mean monthly water temperatures

Figure 17 depicts how each of the six data input types enter the life-cycle model, including which modeled life-history phase each of the six data input types affects, and the specific effect of each data input. This section provides a descriptions of the data sources used for each of the six data input types.

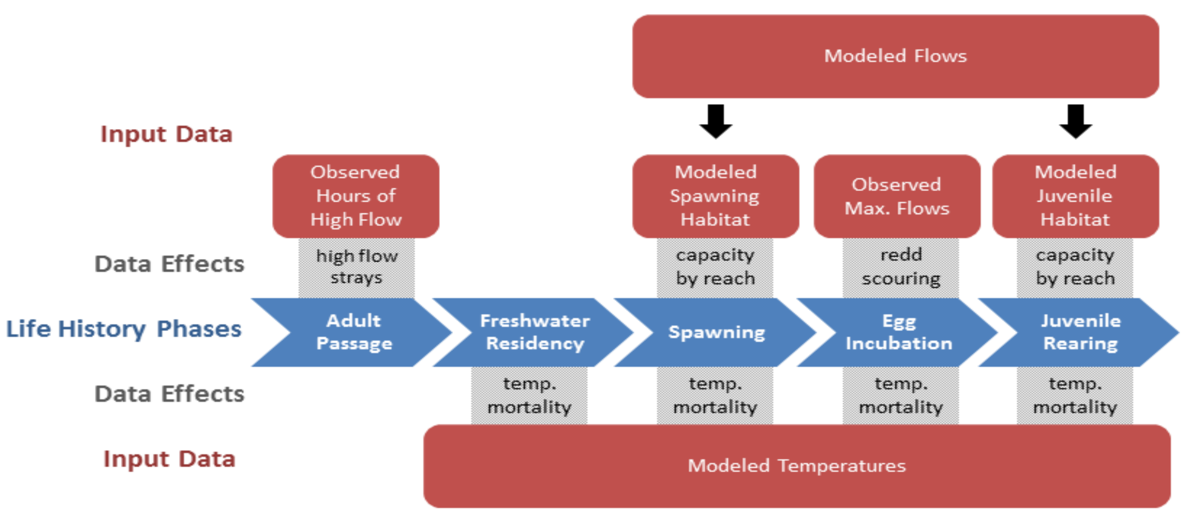

Figure 17. Six data input types used to inform the model (red boxes) and their effects (grey boxes) on each life-history phase (blue polygons).

3.1 Modeled Flows

Modeled mean monthly flow data informed the amount of suitable habitat for adult spawners and juveniles in each reach. The flow used depends on the water year type (i.e., dry, normal, and wet). The data for flow came from Appendix J of the BCRP EIS/EIR (Jones and Stokes 2005) for the “Five Dam Alternative” (Table 10). Because the data are not organized at the BCRP reach-level (except for the Mainstem Reach), we used the data from point sources within a reach to determine the flow for that reach. Where there were no data within a specific reach, we used data from the closest reach available. For a dry year, we used the 10th percentile flows. For a normal year, we used the 50th percentile flows. For a wet year, we used the 90th percentile flows.

Table 10. Modeled flow data used in each reach of the model.

Reach	Original Caption from Appendix J of BCRP EIS/EIR (Jones and Stokes 2005)
Lower Reach	Table J-15. Calculated Fish Habitat Flows (cfs) for All of the Alternatives at Mainstem Battle Creek
Mainstem Reach	Table J-15. Calculated Fish Habitat Flows (cfs) for All of the Alternatives at Mainstem Battle Creek
Wildcat Reach	Table J-6. Calculated Fish Habitat Flows (cfs) for All of the Alternatives below Wildcat Diversion Dam
Eagle Canyon Reach I	Table J-4. Calculated Fish Habitat Flows (cfs) for All of the Alternatives below Eagle Canyon Diversion Dam
Eagle Canyon Reach II	Table J-4. Calculated Fish Habitat Flows (cfs) for All of the Alternatives below Eagle Canyon Diversion Dam
North Battle Feeder Reach I	Table J-2. Calculated Fish Habitat Flows (cfs) for All of the Alternatives below North Fork Battle Creek Feeder Diversion Dam
North Battle Feeder Reach II	Table J-2. Calculated Fish Habitat Flows (cfs) for All of the Alternatives below North Fork Battle Creek Feeder Diversion Dam
Keswick Reach	Table J-2. Calculated Fish Habitat Flows (cfs) for All of the Alternatives below North Fork Battle Creek Feeder Diversion Dam
Coleman Reach	Table J-14. Calculated Fish Habitat Flows (cfs) for All of the Alternatives below Coleman Diversion Dam
Inskip Reach	Table J-11. Calculated Fish Habitat Flows (cfs) for All of the Alternatives below Inskip Diversion Dam
South Reach I	Table J-8. Calculated Fish Habitat Flows (cfs) for All of the Alternatives below South Diversion Dam
South Reach II	Table J-8. Calculated Fish Habitat Flows (cfs) for All of the Alternatives below South Diversion Dam
Panther Reach	Table J-8. Calculated Fish Habitat Flows (cfs) for All of the Alternatives below South Diversion Dam
Angel Reach	Table J-8. Calculated Fish Habitat Flows (cfs) for All of the Alternatives below South Diversion Dam

3.2 Modeled Spawning and Juvenile Habitat

Flow-habitat relationships from IFIM and PHABSIM analyses detailed in Appendix H of the BCRP EIS/EIR (Jones and Stokes 2005) were used to inform the amount of suitable habitat available for Chinook salmon and steelhead spawners and juveniles under a range of flows in each reach (Table 11). Where no data were available within a specific reach, we used data from the closest available reach.

Table 11. Modeled flow-habitat relationships that are applied in each reach of the model.

Reach	Original Caption from Appendix H of BCRP EIS/EIR (Jones and Stokes 2005)
Lower Reach	Table H-1. Flow-Habitat Relationships for the Mainstem Reach of Battle Creek
Mainstem Reach	Table H-1. Flow-Habitat Relationships for the Mainstem Reach of Battle Creek
Wildcat Reach	Table H-2. Flow-Habitat Relationships for the Wildcat Reach of Battle Creek
Eagle Canyon Reach I	Table H-3. Flow-Habitat Relationships for the Eagle Canyon Reach of Battle Creek
Eagle Canyon Reach II	Table H-3. Flow-Habitat Relationships for the Eagle Canyon Reach of Battle Creek
North Battle Feeder Reach I	Table H-4. Flow-Habitat Relationships for the North Battle Feeder Reach of Battle Creek
North Battle Feeder Reach II	Table H-4. Flow-Habitat Relationships for the North Battle Feeder Reach of Battle Creek
Keswick Reach	Table H-5. Flow-Habitat Relationships for the Keswick Reach of Battle Creek
Coleman Reach	Table H-6. Flow-Habitat Relationships for the Coleman Reach of Battle Creek
Inskip Reach	Table H-7. Flow-Habitat Relationships for the Inskip Reach of Battle Creek
South Reach I	Table H-8. Flow-Habitat Relationships for the South Reach of Battle Creek
South Reach II	Table H-8. Flow-Habitat Relationships for the South Reach of Battle Creek
Panther Reach	Table H-8. Flow-Habitat Relationships for the South Reach of Battle Creek
Angel Reach	Table H-8. Flow-Habitat Relationships for the South Reach of Battle Creek

3.3 Observed Hours of High Flows

To inform straying of hatchery-origin *O. mykiss* making it past the CNFH barrier during high flow events, we applied hourly flow data from the BAT CDEC gauge station from 1995 to 2012. See the Barrier Passage section for details on how the flow data were applied in the model. The stray rate was capped as 5% (TAC input), and different rates were applied among the three water year types (

Table 12).

Table 12. The estimated stray rate of steelhead predicted to stray above the CNFH barrier for each water year type.

Water year type	Annual stray rate
Dry	0.56%
Normal	1.49%
Wet	5.00%

3.4 Maximum Flows

Redd scour can cause mortality to eggs. These events occur when high flows cause the river bed to move. Given that this activity is governed by high flow events, we use average maximum monthly flows rather than average flow data. This dataset comes from the mainstem CDEC BAT gauge station in Battle Creek. We used water year data from 1995 to 2012. This dataset provided data on two or more years of dry, normal, and wet water year types, so this provided average monthly maximum data for the three different water type years (Table 13). Because the model calculates egg survival across the entire incubation period, we calculated the mean maximum flow value across all months (**Table 14**) to inform redd scouring effect on egg survival in the model, which affects egg survival for each water year type. The timing of egg incubation in the model is December – July for *O. mykiss*.

Table 13. Mean maximum flow value for each water year type for steelhead used to inform the redd scouring effect on egg survival in Battle Creek reaches.

Water Year Type	Flow (cfs)
Dry	2501
Normal	3272
Wet	6760

Table 14. For each water year type from January (1) to December (12), the mean monthly maximum value of flow was quantified from the CDEC data collected from the BAT gauge.

Water Year Type	Month	Mean Max. Flow (cfs)
Dry	1	1952.4
Dry	2	2501.6
Dry	3	1625.4
Dry	4	539.2
Dry	5	654.8
Dry	6	663.2
Dry	7	404.4
Dry	8	360
Dry	9	316
Dry	10	479
Dry	11	906
Dry	12	1235.4

Table 14 continued. For each water year type from January (1) to December (12), the mean monthly maximum value of flow was quantified from the CDEC data collected from the BAT gauge.

Water Year Type	Month	Mean Max. Flow (cfs)
Normal	1	3271.5
Normal	2	2880.8
Normal	3	2505.5
Normal	4	1340.5
Normal	5	1553
Normal	6	735
Normal	7	457.7
Normal	8	326.2
Normal	9	345.7
Normal	10	500.3
Normal	11	484.7
Normal	12	2513.8
Wet	1	6759.9
Wet	2	5793.1
Wet	3	4222
Wet	4	4992.7
Wet	5	3003
Wet	6	1824.3
Wet	7	700.7
Wet	8	497
Wet	9	428.7
Wet	10	528.4
Wet	11	1334
Wet	12	4901.9

3.5 Modeled Temperatures

Modeled mean monthly water temperature data informed the survival of multiple life-history phases (adult holding, spawning, egg incubation, and juvenile rearing) in each reach. The set of temperatures used in the model depends on the water year type (i.e., dry, normal, and wet). The temperature data for the non-critical months of October – May came from Appendix R of the final BCRP EIS/EIR for the "Five Dam Alternative" (Jones and Stokes 2005). Data for the critical months of June – September came from model output provided in the 2001 draft BCRP EIS/EIR for Alternative 3 (Creek and Tu 2001).

Because the data from Appendix R (applied for October – May) is not organized at the BCRP reach-level (except for the Mainstem Reach), we applied data from point sources within a reach (Table 15). Where there are no data within a given reach, we used data from the next closest available reach. For a dry year, we used the 10th percentile temperature values. For a normal year, we used the 50th percentile temperature values. For a wet year, we used the 90th percentile temperature values.

Table 15. Modeled water temperature data used for months October – May in each reach of the model.

Reach	Original Caption from Appendix R of BCRP EIS/EIR (Jones and Stokes 2005)
Lower Reach	Table R-16. Calculated Battle Creek Temperatures (°F) for All of the Alternatives below Confluence
Mainstem Reach	Table R-16. Calculated Battle Creek Temperatures (°F) for All of the Alternatives below Confluence
Wildcat Reach	Table R-10. Calculated Battle Creek Temperatures (°F) for All of the Alternatives in North Fork Battle Creek at the Confluence
Eagle Canyon Reach I	Table R-9. Calculated Battle Creek Temperatures (°F) for All of the Alternatives at Wildcat Diversion Dam
Eagle Canyon Reach II	Table R-9. Calculated Battle Creek Temperatures (°F) for All of the Alternatives at Wildcat Diversion Dam
North Battle Feeder Reach I	Table R-8. Calculated Battle Creek Temperatures (°F) for All of the Alternatives at Eagle Canyon Diversion Dam
North Battle Feeder Reach II	Table R-8. Calculated Battle Creek Temperatures (°F) for All of the Alternatives at Eagle Canyon Diversion Dam
Keswick Reach	Table R-8. Calculated Battle Creek Temperatures (°F) for All of the Alternatives at Eagle Canyon Diversion Dam
Coleman Reach	Table R-15. Calculated Battle Creek Temperatures (°F) for All of the Alternatives in South Fork Battle Creek at Confluence
Inskip Reach	Table R-14. Calculated Battle Creek Temperatures (°F) for All of the Alternatives at Coleman Diversion Dam
South Reach I	Table R-12. Calculated Battle Creek Temperatures (°F) for All of the Alternatives at Inskip Diversion Dam
South Reach II	Table R-12. Calculated Battle Creek Temperatures (°F) for All of the Alternatives at Inskip Diversion Dam
Panther Reach	Table R-12. Calculated Battle Creek Temperatures (°F) for All of the Alternatives at Inskip Diversion Dam
Angel Reach	Table R-12. Calculated Battle Creek Temperatures (°F) for All of the Alternatives at Inskip Diversion Dam

Modeled water temperature data for months June - September from the draft BCRP EIS/EIR (Creek and Tu 2001) has mean monthly temperatures for seven reaches (Mainstem Reach, Wildcat Reach, Eagle Canyon Reach, North Battle Feeder Reach, Coleman Reach, Inskip Reach, and South Reach) for three different water year types (dry, normal, and wet). For the reaches with missing data we used data available from the most adjacent stream reach (

Table 16).

Table 16. Modeled water temperature data used for months June – September in each reach of the model.

Reach	Data as labeled in the draft BCRP EIS/EIR SNTEMP model (Creek and Tu 2001)
Lower Reach	Mainstem Reach
Mainstem Reach	Mainstem Reach
Wildcat Reach	Wildcat Reach
Eagle Canyon Reach I	Eagle Canyon Reach
Eagle Canyon Reach II	Eagle Canyon Reach
North Battle Feeder Reach I	North Battle Feeder Reach
North Battle Feeder Reach II	North Battle Feeder Reach
Keswick Reach	North Battle Feeder Reach
Coleman Reach	Coleman Reach
Inskip Reach	Inskip Reach
South Reach I	South Reach
South Reach II	South Reach
Panther Reach	South Reach
Angel Reach	South Reach

4. Issue/Effect Analysis

The life-cycle model was used to evaluate BCRP and CNFH issues as defined in the CNFH-AMP (see Chapter 3). The model allowed quantitative assessment of four CNFH Issues and a single BCRP effect as discussed below. Issues and effects not amenable to life-cycle model analysis (described below) were evaluated by rigorous examination of existing data and information.

A sensitivity analysis provided an assessment and prioritization of individual model functions. We performed a local sensitivity analysis in which each individual CNFH Issue and individual BCRP effect (barriers) was varied, one at a time, across a range of values to examine the effect on model outcomes. The proposed range in values, which simply involve turning the effect on/off, are described below.

4.1 Methods

All issues and effects were compared to a baseline scenario of "future expected conditions." Under this scenario, model relationships were parameterized to reflect future expected conditions with a fully implemented BCRP. This scenario assumes successful removal or passage modification of natural and man-made fish barriers as described in Jones and Stokes (2005). For relationships not expected to change with restoration (including CNFH operations), parameter values reflect current conditions or conditions considered reasonably likely to occur in the foreseeable future. Model functionality and parameter values for this scenario are the same as those currently defined in the model documentation.

The model was run for 50 years to capture multiple generations of *O. mykiss* in the model output, and to incorporate ample variation in water year type. Fifty realizations of each 50-year run were made to incorporate uncertainty in the model results, and to ensure that mean differences were the result of actual model effects and were not simply model noise. Abundance of anadromous and resident *O. mykiss* were seeded at arbitrarily high levels in the initial model runs to allow for full evaluation of the CNFH issues and BCRP effect. Specifically, resident fish were only seeded in the first year of the model, but anadromous fish were seeded in the first three years of the model, because wild anadromous fish take a minimum of two years to spawn, and hatchery anadromous fish take three years to spawn.

The model produces numerous potential outputs (*e.g.*, abundance of each life stage over time) that could be used to compare the issues and effects to the baseline scenario (*i.e.*, Expected Future Conditions). Because the abundances of the different life stages are highly correlated, the choice of which life stage to use in the comparison is arbitrary. We chose to compare the abundance of adult spawners, which we refer to as the pre-spawning abundance because it is a count of returning adults that potentially spawned rather than successfully spawned. Each realization of the model produces a 50-year time series of pre-spawning abundance. We used the changepoint package in R (Killick and Eckley 2014) to identify the point in the time series when the pre-spawning abundance exhibited a significant change and calculated the mean abundance of points in the time series that occurred after the changepoint (Figure 18). For simplicity, we refer to the changepoint as the equilibrium time and mean abundance after the changepoint as the equilibrium abundance.

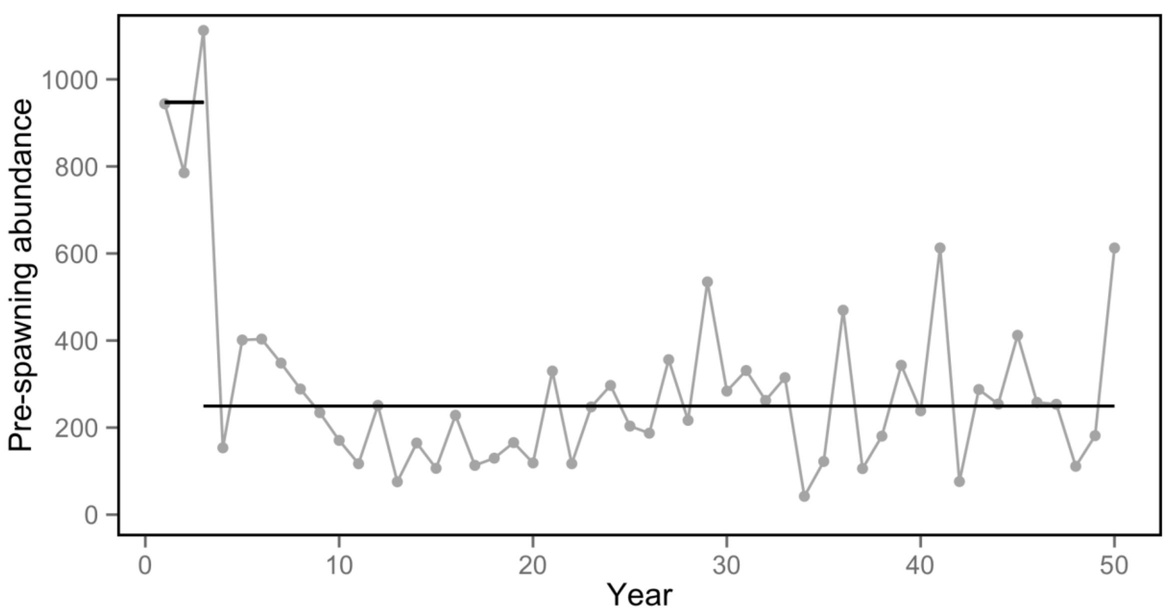

Figure 18. An example application of a changepoint analysis to find the equilibrium time and abundance in a time series of pre-spawning abundance. The horizontal black lines show the mean abundance before and after a significant changepoint (*i.e.*, equilibrium time). The mean abundance after a significant changepoint was designated as the equilibrium abundance.

Initially, we planned to use both equilibrium abundance and equilibrium time (or time to restoration target abundance) in the issue/effect analysis under the assumption that issues and effects may influence not only the mean abundance, but the years it took for the population to reach peak or target abundance. An assessment of how each issue/effect influences the time it takes for steelhead to reach a restoration target abundance could provide information in addition to mean abundance, which could help to prioritize issues/effects influencing steelhead. However, after performing initial exploratory runs of the life-cycle model, we found very little variability in time to equilibrium across issues and effects. Therefore, we only used the single result metric of equilibrium abundance to perform the issue/effect analysis.

4.1.1 Issues and Effects Evaluated by the Model

The following issues/effects were evaluated by the life-cycle model: 1) four CNFH issue statements developed by the TAC, 2) one key BCRP effect, and 3) a CNFH Least Effect scenario. The Least Effect scenario was an aggregate effect created by modeling multiple CNFH effects at once. Below we describe these issues in more detail, and provide information about the range in values applied for each issue/effect.

CNFH Issue 1: Diversion Entrainment – An unscreened water diversion used at times to deliver water to the CNFH may result in the entrainment of Battle Creek juvenile salmonids. This effect was turned off to evaluate the effect on model results.

CNFH Issue 2: Steelhead integration – The current CNFH steelhead program excludes naturally produced (unmarked) fish from the broodstock. This practice leads to continued domestication and potential for reduced fitness when hatchery fish spawn in the restoration area. To determine how big an effect this can have, we quantified the difference that occurred if all broodstock of wild steelhead came from sources outside the study area, and the introgression function was turned off.

CNFH Issue 4: High flow hatchery strays – Hatchery-origin steelhead may reach the restoration area during high flow events where they may have adverse effects on wild Battle Creek steelhead. This effect was turned off (*i.e.*, no flow-related strays) to evaluate the effect on model results on natural-origin steelhead.

CNFH Issue 5: CNFH Mortality – Trapping, handling, and sorting, of salmonids within CNFH and at the CNFH fish ladder results in migratory delay and may result in direct mortality or sub-lethal effects to natural-origin winter Chinook, late-fall Chinook, spring Chinook, and steelhead trying to access the restoration area. We only evaluated the effect of direct mortality in the model. This effect was turned off (*i.e.*, no mortality) for fish that took the trapping route or the hatchery route, while passing through the CNFH barrier weir to evaluate the effect on model results.

CNFH Least Effect – Same as baseline except the effect of all CNFH issues evaluated (above) was set to the least effect (all effects turned off). This scenario was run to help identify the upper range of possible benefits of changing CNFH operations.

BCRP Effect: Barrier Condition – Same as baseline except natural fish barriers are set to reflect current passability conditions. This allows for examination of the sensitivity of model results to removal/modification of fish barriers as defined in the baseline (future expected conditions) scenario.

4.1.2 Issues and Effects not Evaluated by the Model

The following CNFH Issue Statements defined by the TAC were either evaluated by the Chinook salmon life-cycle model (Appendix D), or were subjected to rigorous evaluation using existing data and information (Appendix C), but they were not evaluated by the steelhead life-cycle model. These issues were excluded because the effect applies to Chinook salmon only, or because the data were lacking to define a realistic range of effect magnitude, or data were lacking to characterize circumstances or frequency of the effect occurring.

CNFH Issue 3: Hatchery strays (non-flow related) – Current operations at CNFH and at the fish barrier weir cannot always identify and prevent passage of (1) hatchery-origin salmonids, and (2) non-target runs of Chinook salmon.

RATIONALE: Because of the anadromous fish passage timing used in the model, no fish pass when the fish ladder is open and, thus, no non-flow-related straying behavior is incorporated in the model.

CNFH Issue 6: Pathogens - Pathogens resulting from CNFH operations may be transmitted to and expressed among wild fish in the restoration area.

RATIONALE: Information regarding when or how much pathogens might adversely affect Battle Creek salmonids is not currently available.

CNFH Issue 7: Reduced in-stream flows (diversion) – In-stream flows in the Mainstem Reach of Battle Creek are reduced by CNFH water diversion(s) between the diversion site(s) downstream to the return effluent site (distance of 1.2 to 1.6 miles depending on location of the water intake). These diversions may result in inadequate in-stream flows, or increased water temperatures in this segment of the river during drought conditions and in association with operations at upstream hydropower facilities.

RATIONALE: Water temperature is the more significant factor related to this issue, but modeled water temperatures with and without CNFH water diversions are not currently available.

CNFH Issue 8: Hatchery fish below CNFH – High abundance of hatchery-origin adult salmon in lower Battle Creek may create adverse effects including (1) reduction of in-stream spawning success due to the physical destruction of redds; (2) interbreeding between natural- and hatchery-origin Chinook salmon; and (3) increased mortality of juvenile salmonids emigrating from upper Battle Creek.

RATIONALE: This issue was determined to only be applicable to Chinook salmon given the small number of *O. mykiss* in lower Battle Creek (HSRG 2012). Therefore, this topic was only evaluated in the Chinook salmon model.

CNFH Issue 9: Predation by CNFH Steelhead – Releases of hatchery produced juvenile Chinook salmon and steelhead from CNFH may result in predation on and behavior modifications to natural-origin fish produced in the restoration area.

RATIONALE: This issue was determined to only be applicable to Chinook salmon given that it is predation on this species. Therefore, this topic was only evaluated in the Chinook salmon model.

CNFH Issue 10: Exceeding out-of-basin carrying capacity - Current production releases of CNFH juvenile fall Chinook salmon may contribute to exceeding the carrying capacity for Chinook salmon in the Sacramento River, San Francisco Estuary, or the Pacific Ocean leading to reduced success of Battle Creek origin salmonids.

RATIONALE: This issue only relates to Chinook salmon and was not evaluated for *O. mykiss*.

4.2 Results

Differences in mean equilibrium abundance between the baseline scenario (future expected conditions) and the implementation of each issue/effect was enumerated as percent change. Table 17 displays the percent change from baseline in equilibrium abundance as a result of each issue/effect (see the Issues and Effects Evaluated by the Model section above for description of how each issue/effect was implemented). These results are used in Appendix C of the CNFH-AMP to further evaluate CNFH issues and BCRP effects.

Table 17. The mean equilibrium values of wild steelhead and percent change for the scenarios and issue statements. A positive value of percent change indicates a higher number of wild steelhead in comparison to the number in the baseline model. A negative value of percent change indicates a lower number of wild steelhead in comparison to the number in the baseline model.

Scenarios / Issues	Mean	% Change
Baseline	244	0.0
Hatchery introgression	266	6.3
CNFH 2: Steelhead integration	270	6.7
CNFH 4: High flow hatchery strays	252	3.5
CNFH 1: Diversion entrainment	245	0.2
CNFH 5: CNFH mortality (hatchery-route)	248	1.2
CNFH 5: CNFH mortality (trapping-route)	246	-2.9
Barriers	59	-75.8
CNFH least effects	272	8.3

5. Discussion

Due to limited data available for salmonid lifestages, traditional statistical estimation models are difficult to apply when attempting to predict outcomes of future management actions (Williams 2006). Unlike predictive models, simulation models can be useful for organizing existing knowledge and identifying gaps in understanding, even if the model predictions are imprecise (Williams 2006). Simulation models should be thought of as experimental systems or aids that are distinct from the “real world” in which the consequences of various sets of assumptions can be examined (Peck 2004). However, model usefulness is measured by how well it captures the interactions of the most important factors and leaves out unimportant ones (Ford 1999), thereby limiting model complexity that might otherwise make interpretation of results more difficult. More complex models can be too dataset specific and have poor predictive ability mainly due to estimation error, while more simplistic models can be too general and incorporate error due to system oversimplification (Astrup *et al*. 2008). Therefore, we attempted to model the influence of CNFH issues and BCRP effects on steelhead with adequate complexity to identify the importance of these effects, while limiting the inclusion of factors not useful for evaluating project effects or unsupported by existing scientific knowledge. In addition to the myriad modeling assumptions that are described previously in the model documentation, we discuss the major assumptions and limitations of this modeling approach below.

5.1 Major Model Assumptions and Limitations

Given that *O. mykiss* are not as well studied as Chinook salmon in Battle Creek, assumptions were made to allow model construction. While assumptions were made for a variety of reasons, most assume that data from other geographical regions are representative of Battle Creek *O. mykiss*. Also, when these data did not exist, we made choices or used TAC input to inform modeling decisions. Below we discuss these assumptions.

5.1.1 Availability of data

When local data are limited, which was the case for *O. mykiss* in Battle Creek, model relationships can often be informed by field data from outside the study region, by laboratory studies in controlled experimental settings, or by data from artificially raised (hatchery) surrogates. Where these information sources are absent, assumptions made by expert opinion are used.

5.1.2 Fish Movement

Spawning migration is greatly simplified in the model due to lack of mechanisms explaining more detailed movement behavior. In the wild, steelhead may choose to spawn in reaches with better habitat quality (*i.e.*, cooler water temperatures, more suitable substrate). However, due to lack of information to inform this behavior, we have steelhead return to their natal reach for spawning, with variability in spawning distribution developing only after years of differential reach survivals affecting their reach-specific return rates. Similarly, although spawners in the wild may move to a different reach as spawner density increases, without data to inform a mechanism for this behavior, density of spawners only affects productivity to the egg stage.

Fry behavior is also greatly simplified in the model, with fry rearing in the same reach where they emerged from the gravel. Many fry in Battle Creek likely make migrations of varying length throughout the rearing period for various reasons, such as searching for better quality habitat or avoiding intra- or inter-specific competition. However, no data are available to inform the mechanisms behind this movement behavior. Therefore, we chose to limit model complexity and not include highly uncertain movement behavior.

5.1.3 Redd Superimposition

Redd superimposition has been observed to occur in many Central Valley rivers, in some cases at high rates when spawner densities are high (Sommer *et al*. 2001). However, rates of superimposition in Battle Creek and the egg mortality rate incurred by redd destruction during superimposition is unknown. Therefore, we did not model superimposition, and instead simply limited the number of successful spawners in a given reach on a monthly basis due to the amount of suitable spawning habitat available.

5.1.4 Hatchery Introgression

Hatchery-origin fish that enter the restoration area are assumed to have a deleterious effect on natural spawner productivity. Although this has not been directly observed in Battle Creek, this type of interaction between hatchery and wild spawners has been documented in other watersheds. Therefore, we applied a relationship found from a meta-analysis of salmonid populations in the Pacific Northwest (Chilcote *et al*. 2013).

5.1.5 Reliance on data from different geographic regions

Given the dearth of quantitative information on *O. mykiss* in Battle Creek, we relied on data that were collected in different geographic regions:

- In other regions, there is evidence that anadromous *O. mykiss* produce resident offspring and vice versa (Thrower and Joyce 2004; Zimmerman *et al.* 2009). We term this "cross-life-history production" within the life-cycle model. Rather than attempting to model the complex genetic and physiological drivers of life-history choice, we took a simplified, empirically-based approach by assuming a fixed proportion of juveniles from each parental cross adopt anadromous and resident life-history pathways. Barring data specific to Battle Creek stocks, we assumed *O. mykiss* adopt life-history strategies proportional to observed values from Thrower and Joyce (2004). These smoltification rates were derived from a breeding study conducted in Sashin Creek, Alaska whereby resident and anadromous *O. mykiss* were spawned in a hatchery and the resulting offspring were monitored to determine life-history and sex (Table 7). By doing this, we assumed that spawning ratios from Alaska are representative of those in Battle Creek. Once similar studies are completed in Battle Creek, those data should be used.

- While we had estimates of fecundity for *O. mykiss* at CNFH that were mainly steelhead, we did not have estimates of fecundity for resident rainbow trout and steelhead that were spawning in the river. In the model, resident rainbow trout only produces 1,000 eggs. This was quantified by assuming that resident fish had no more fecundity than a 14-inch rainbow trout in the Yakima River. Therefore, we used the relationship of fecundity and size as identified for the Yakima River in Pearsons *et al.* (1993). Although fecundity is size-specific, we assumed that a single estimate of fecundity for anadromous and resident *O. mykiss* was sufficient for the model, and that the estimates are accurate.

- Given that *O. mykiss* are better studied in other geographic regions such as the Yakima River, we used data on maturity of resident *O. mykiss* from that river, since comparable data are not currently available for Battle Creek. Similarly, we used data from the Yakima River to determine the number of years that steelhead stayed in the ocean and the proportions of each.

- We estimated territory sizes for each of the different age classes by using a relationship derived by Grant and Kramer (1990), but this study did not include *O. mykiss*. Although the equation is not species- or region-specific, it is commonly used in a variety of salmonid life-cycle models to estimate similar parameters as those developed for this steelhead life-cycle model.

- Mortality of juvenile *O. mykiss* emigrating in Battle Creek is currently not available. Therefore, we used data from Pacific Northwest streams as estimates of mortality in Battle Creek (*e.g.*, Conley *et al.* 2009; Romer *et al*. 2013). Also, given the reach-specific spatial scale of the model, we estimated the distance smolts traveled from the midpoint of their home reach to the midpoint of each downstream reach, and then to the mouth of Battle Creek.

5.1.6 Assumptions Made by the Modeling Team

The modeling team also made simplifications to the model other than just using data from other geographic regions to make the model logistically feasible (*e.g.*, less computationally intensive). We recognize that some of the following are oversimplifications of the true population dynamics, but we think that they are worthwhile for maintaining a consistent, uncluttered model structure. For simplification, we decided and executed the following in the model:

- Other than that smolts leave the system and adults return, there is no movement of *O. mykiss* in the model. Also for simplification, the transition from and to the ocean is not modeled explicitly (*i.e.*, no transitions between age classes in the ocean). Also, the upstream movement of adult steelhead from the ocean to the CNFH barrier weir is not explicitly modeled, since no CNFH or BCRP effects are hypothesized in this lifestage and area. Given a lack of quantitative information currently available on certain impacts of CNFH operations, such as rates of delayed steelhead mortality, we assumed no delayed mortality as a result of handling and passing natural-origin steelhead through the hatchery or in the barrier weir trap. There is likely some effect resulting in reduced productivity in the natural environment, and this should be incorporated into future iterations of this model when the information becomes available. Finally, we assumed one hundered percent fidelity to natal reaches. Therefore, resident rainbow trout always remain in their natal reach.

- We assumed there is negligible contribution of reconditioned steelhead to future spawning events, so kelts do not need to be included in the model. This assumption is possibly invalid, especially during years of low survival of a cohort, but it was used due to the lack of Battle Creek-specific information. When this information becomes available, this assumption should be evaluated and removed in future versions of the model. Removing this assumption in the updated model, will necessitate incorporating into the model the releases of reconditioned fish that occur in March.

- Reconditioned hatchery fish were not released back into Battle Creek as currently occurs. This is a modeling simplification because there was not adequate Battle Creek specific information to incorporate this additional complexity into the model.
- Competition is only within an age class (*e.g.*, age 0-1) but not between age classes. This was done to decrease model complexity, but is probably not true in reality. Minimizing the number of transitions in the model greatly reduced how computationally intensive the model is. More computationally intensive models in the future can work on predictions without this assumption.
- Beverton-Holt transitions only occur between the following age classes: spawners, eggs, age 0-1, age 1-2, age 2-3, and age 3-4+. This transition was only conducted when the monthly cohort was transitioning between these lifestages. Although more transitions could be modeled, minimizing the number of transitions greatly reduced how computationally intensive the model is.
- We assumed that given a reasonable set of rules, we could use the presence and abundance of yolk-sac fry to estimate the timing of lifestages. This assumes that the rules created are appropriate, and that the Battle Creek rotary screw trap data from 2008 – 2014 detected the yolk-sac fry when they were present. Given the timing generated for steelhead in the model is within the timing of Central Valley steelhead as estimated by McEwan (2001), we think the timing is appropriate.
- For diversion loss, we made an assumption that could possibly overestimate diversion loss. We assumed that the diversion flow rate was always 64 cfs, which provides an overestimate of this effect as this is a maximum rate.
- The model works on a monthly time-step, and it is assumed that this time-step is appropriate to estimate the issue statements. While this made the model less computationally intensive, use of monthly data might not allow the model to best incorporate fine-scale temporal events like redd scour, or spawning. Further, we rely on water temperatures to estimate survival of in-river spawners, which may overestimate their survival.
- In the wild and hatchery, milt from a male *O. mykiss* can fertalize multiple females. Given this assumption, a male broodstock target was not incorporated into the model.
- We assumed that adult steelhead did not hold in Battle Creek, as we did not have data to incorporate this.
- In the model, excess eggs produced are culled, which occurs in the hatchery as needed. This assumption allows the model to better match the hatchery production. Also, we assumed that the hatchery staff were equally likely to cull eggs from all crosses because

hatchery operators do not know until after the fact how many of the hatchery broodstock were residents.

5.1.7 Assumptions Made by the TAC

Given the lack of Battle Creek-specific data, we often relied on the TAC to develop assumptions:

- Current and future passage estimates were provided by the TAC. The TAC determined what barriers impede the passage of steelhead, where the barriers are, and provided estimates of current and future steelhead passage.
- To estimate the SAR rates for steelhead propagated at CNFH and released as "yearling" smolts, we were provided with SAR data from Kevin Niemela (USFWS) to estimate SAR rates. These SAR estimates were based on the following assumptions: (1) all steelhead mature at age-3 and return to the hatchery. Thus, the estimates do not account for harvest. (2) There are no differences in male and female steelhead SARs. Therefore, these are not perfect estimates of SAR but the best estimates currently available.
- No mortality is assumed to occur when *O. mykiss* move up the fish ladder, and no trapping is occurring. While this seems plausible, empirical studies should be completed to confirm this assumption.
- Stray rates due to high flow events were capped at 5% and only occur between 800 – 4,500 cfs, given the current lack of data.
- In the model, fish are diverted at the unscreened Intake 2 in proportion to the flow.
- TAC input was used to change the proportion of steelhead smolts that leave Battle Creek each year, as the TAC advised these proportions were more appropriate for the model than the data that was quantified on Central Valley steelhead by Hallock *et al*. (1961).
- One percent of hatchery-origin *O. mykiss* are assumed to stay lower in the system, avoid detection at the barrier weir, and spawn in the Lower Reach. This proportion was assumed since there seems to be a low level of spawning but most do not spawn. The proportion is arbitrary, and more precise estimates are needed.

5.1.8 Environmental Input Data

We relied on simulated water temperature and fish habitat data to inform model relationships. Our ability to accurately model the trajectory of *O. mykiss* in Battle Creek is closely tied to the quality of the data that informs the model. Future field validation of the simulated environmental data could help evaluate the accuracy of the data used in the model, and help calibrate future temperature and hydrologic modeling efforts.

5.2 Information Gaps

During the model-building process, we identified multiple gaps in understanding of steelhead life-history in Battle Creek. Below we discuss the major gaps in knowledge and reference long-term monitoring (Appendix F) or short-term diagnostic studies (Chapter 4) that will attempt to address some of these knowledge gaps.

5.2.1 Life-History and timing of Battle Creek *O. mykiss*

Battle Creek *O. mykiss*-specific information is vital for accurately modeling what is occurring in Battle Creek. Yet, data on *O. mykiss* in Battle Creek is limited. Better data are needed on the distribution of resident rainbow trout and steelhead, and the age classes and sex ratios of each life-history as they vary across the different reaches. Also, refined information is needed on the timing of each lifestage, and determining exactly how spawning occurs (*e.g.*, extent of superposition of redds and eggs survival). Studies are needed to determine if assortative mating is occurring in Battle Creek, and what controls it (*e.g.*, size). Additionally, monitoring of spawning activity and egg survival could validate and refine estimates of redd scour. Finally, estimates of abundance and survival could also help to validate and refine the predictions in the model, which are quite important. Barrier passage monitoring is described in the Integrated Monitoring Plan (Appendix F) and would provide data on spatial and temporal distribution of steelhead. A plan for monitoring juvenile steelhead production and reach-specific resident *O. mykiss* abundance using rotary screw traps and snorkel surveys in Battle Creek is described in the Integrated Monitoring Plan (Appendix F).

5.2.2 Rates of Anadromy

For the offspring, we need to know how to best model anadromy and to execute this, we need to know what controls anadromy in Battle Creek *O. mykiss*. In the model, it is dependent on the sex and life-history of the parents and the survival of the offspring. While heritability and differential survival are important in determining rates of anadromy, other factors such as the environment, may also play a role (Satterthwaite *et al.* 2010). This is particularly important when trying to quantify the effects of environmental changes, such as those that occur following restoration actions, because life-history diversity and abundance are environmentally modulated. If researchers can document and quantify what factors affect anadromy, these can be built into partial anadromy models, thereby increasing the accuracy of their predictions.

5.2.3 Out-of-basin Data

The survival of juvenile steelhead in the ocean can vary due to many factors including entry timing, physical ocean conditions, trophic dynamics, and size or condition of fish upon entry. However, because the focus of the model was to evaluate the potential effects of CNFH operations and BCRP actions, we wanted to isolate the effects occurring in Battle Creek. As with any simulation tool, model usefulness is measured by how well it captures the interactions of the most important factors, while leaving out unimportant ones to limit model complexity as much as possible (Ford 1999). Therefore, like in the Sacramento River and San Francisco Estuary portions of the model, we only wanted to provide reasonable estimates of survival, not examine drivers of survival which would have only introduced greater model complexity and made result interpretation more difficult.

5.2.4 Battle Creek Mortality Data

Data were lacking to inform survival of *O. mykiss* life-history phases in Battle Creek. No data were available to inform overall egg mortality rates in Battle Creek, or more specific information on mortality due to redd scouring during high flow events. Instead, we relied on literature values or expert opinion to inform survival rates. Likewise, data were not available to help validate juvenile mortality rates applied in the model. Future field investigations examining egg and juvenile survival rates could help refine model relationships in the future. A plan for monitoring juvenile steelhead production using rotary screw traps in Battle Creek is described in the Integrated Monitoring Plan (Appendix F). Juvenile production estimates, along with estimates of steelhead spawner numbers would allow estimation of survival of steelhead during early lifestages in Battle Creek (egg and fry combined).

5.2.5 Barrier Passage

Current and future barrier passage estimates were provided by the TAC. The TAC determined what barriers impede the passage of steelhead, where the barriers are, and estimates of their current and future passability. While expert opinions are important, empirical data collected from properly designed mark-recapture studies, which aim to refine passage estimates could improve the accuracy of the estimates used in the model. Barrier passage monitoring is described in the Integrated Monitoring Plan (Appendix F).

5.2.6 Stray Rates

Stray rates due to high flow events were capped at 5% and only occur between 800 – 4,500 cfs, based on TAC input and very limited data. Quantifying stray rates under high flow conditions is challenging due to Battle Creek's flashy hydrology and the increased variability occurring under high flow conditions. Further empirical studies are needed to confirm that 5% is a maximum value and that passage of strays only occurs between 800 – 4,500 cfs. A diagnostic study (DS7) evaluating high-flow passage of hatchery-origin strays above the barrier weir is described in Chapter 4.

5.2.7 Sub-lethal Project Effects

With lack of data on indirect mortality effects, we were only able to evaluate the effect of direct mortality on migrating salmonids as they pass through the CNFH barrier weir. Future studies evaluating delayed impacts of stress incurred during passage through the barrier weir could support more complete evaluations of this effect in the model. A diagnostic study (DS1) evaluating the impact of stress during passage and handling at the barrier weir is described in Chapter 4.

5.2.8 Hatchery Introgression

As described above, no local data were available to inform the potential negative impact of hatchery-origin spawner introgression with natural-origin fish. Future studies evaluating the possible reduced fitness effect of Battle Creek steelhead due to the presence of hatchery-origin spawners could be conducted to evaluate this impact. For example, the USFWS is working on a study of relative reproductive success of hatchery and natural-origin steelhead spawning naturally upstream of the barrier weir in Battle Creek. The results from this and other studies of relative reproductive success of hatchery and natural-origin steelhead in Battle Creek can be used in future version of the models when the results are published and the data become available.

5.2.9 Environmental Data

Gaps in environmental data are briefly presented under the Major Modeling Assumptions and Limitations section. However, in developing this life-cycle model it became clear that a detailed understanding of spatial water temperature dynamics in Battle Creek, and the influence of hatchery operations on these dynamics is sorely lacking.

5.3 Model Revisions

During review of the draft AMP, multiple updates to model functionality were suggested by reviewers to best reflect the most recent life history or operational knowledge of Battle Creek. Below is a description of model updates that are expected to be made in future versions of the model.

6. Literature Cited

Astrup, R., Coates, K., and E. Hall. 2008. Finding the appropriate level of complexity for a simulation model: an example with a forest growth model. Forest Ecology and Management 256: 1659–1665.

Busby, P. J., Wainwright, T. C., Bryant, G. J., Lierheimer, L. J., Waples, R. S., Waknitz, F. W., and I. L. Lagomarsino. 1996. “Status review of west coast steelhead from Washington, Idaho, Oregon, and California.” National Marine Fisheries Technical Memorandum NMFSNWFSC-27. Seattle WA.

California Data Exchange Center (CDEC). http://cdec.water.ca.gov/. Last accessed on March 15, 2015.

Cech, J. J., and C. A. Myrick. 1999. Steelhead and Chinook Salmon Bioenergetics: Temperature, Ration, and Genetic Effects. Technical Completion Report for Project Number UCAL-WRC-885.

Chilcote, M. W., Leider, S. A., and J. J. Loch. 1986. Differential reproductive success of hatchery and wild summer-run steelhead under natural conditions. Transactions of the American Fisheries Society 115: 726–735.

Chilcote, M. W., Goodson, K. W., and M. R. Falcy. 2011. Reduced recruitment performance in natural populations of anadromous salmonids associated with hatchery-reared fish. Canadian Journal of Fisheries and Aquatic Sciences 68: 511–522.

Chilcote, M. W., Goodson, K. W., and M. R. Falcy. 2013. Corrigendum: reduced recruitment performance in natural populations of anadromous salmonids associated with hatchery-reared fish. Canadian Journal of Fisheries and Aquatic Sciences 70: 513–515.

Conley, A., Freudenthal, J., Lind, D., Mees, P., and R. Visser. 2009. Yakima Steelhead Recovery Plan. Yakima Basin Fish and Wildlife Recovery Board. Available from: http://www.ybfwrb.org/. Last accessed on July 21, 2014.

Courter, I. I. Frederiksen C. R., Teply, M. E., Cramer, S. P., Justice C., Temple G. M., and F. P. Thrower. *Unpublished* report. Influence of resident rainbow trout on abundance of steelhead in the upper Yakima River basin.

Courter, I. I., Child, D. B., Hobbs, J. A., Garrison, T. M., Glessner, J. J., and S. Duery. 2013. Resident rainbow trout produce anadromous offspring in a large interior watershed. Canadian Journal of Fisheries and Aquatic Sciences, 70(5): 701–710.

Creek, K. D., and S. Tu. 2001. Stream temperature model for the Battle Creek Salmon and Steelhead Restoration Project. Land and Water Quality Unit, Report No.:026.11-00.256 for Technical and Ecological Services.

Donohoe, C. J., and R. Null. 2013. Migratory history and maternal origin of rainbow trout (*Oncorhynchus mykiss*) returning to Coleman National Fish Hatchery in 2008. Contract report by Institute of Marine Sciences, University of California, Santa Cruz.

Ford, F. A. (1999). Modeling the environment: an introduction to system dynamics models of environmental systems. Island Press.

Gallagher, S. P., and C. M. Gallagher. 2005. Discrimination of Chinook and coho salmon and steelhead redds and evaluation of the use of redd data for estimating escapement in several unregulated streams in northern California. North American Journal of Fisheries Management 25: 284–300.

Grant, J. W. A., and D. L. Kramer. 1990. Territory size as a predictor of the upper limit to population density of juvenile salmonids in streams. Canadian Journal of Fisheries and Aquatic Sciences 47 (9): 1724–1737.

Hallock, R. J. 1989. Upper Sacramento River steelhead *Oncorynchus mykiss*, 1952 – 1988. A report to the U.S. Fish and Wildlife Service. September 15.

Hallock, R. J., Van Woert, W. F., and L. Shapovalov. 1961. An evaluation of stocking hatchery reared steelhead rainbow trout (*Salmo gairdnerii gairdnerii*) in the Sacramento River system. California Department of Fish and Game. Fish Bulletin 114. 74 pp.

HSRG (Hatchery Scientific Review Group). 2012. California Hatchery Review Group report. Prepared for the U.S. Fish and Wildlife Service, Sacramento, CA 102 p.

Interagency Ecological Program (IEP). 1998. Monitoring, Assessment, and Research on Central Valley Steelhead: Status of Knowledge, Review of Existing Programs, and Assessment of Needs.

Jones and Stokes. 2005. Battle Creek salmon and steelhead restoration project final environmental impact statement/environmental impact report. Volume I, Report. Sacramento, CA.

Kaczynski, W., Leemis, L., Loehr, N., and J. McQueston. 2012. Nonparametric random variate generation using a piecewise-linear cumulative distribution function. Communications in Statistics – Simulation and Computation 41: 449–468.

Killick, R., and I. A. Eckley. 2014. An R package for changepoint analysis. Journal of Statistical Software 58: 1–19.

McEwan, D. 2001. Central Valley steelhead. Calif. Dep. Fish Game Fish Bull. 179: 1–43.

McLean, J. E., Bentzen, P., and T. P. Quinn. 2003. Differential reproductive success of sympatric, naturally spawning hatchery and wild steelhead trout (*Oncorhynchus mykiss*) through the adult stage. Canadian Journal of Fisheries and Aquatic Sciences 60: 433–440.

McMillan, J. R., Katz, S. L., and G. R. Pess. 2007. Observational evidence of spatial and temporal structure in a sympatric anadromous (winter steelhead) and resident rainbow trout mating system on the Olympic Peninsula, Washington. Transactions of the AFS 136: 736–748.

Moyle, P. B. 2002. Salmon and Trout, Salmonidae - Rainbow Trout, (*Oncorhynchus mykiss*) in Inland Fishes of California. Los Angeles, California: University of California Press, 271–282.

National Marine Fisheries Service (NMFS). 2014. Recovery Plan for the Evolutionarily Significant Units of Sacramento River Winter-run Chinook salmon and Central Valley Spring-run Chinook Salmon and the Distinct Population Segment of California Central Valley Steelhead. California Central Valley Area Office. July 2014.

National Marine Fisheries Service (NMFS). 1998. Listing decision for Central Valley Steelhead (*Oncorhynchus mykiss*). 63 Federal Register 13347. March 19, 1998.

Null, R. E., Niemela, K. S., and S. F. Hamelberg. 2013. Post-spawn migrations of hatchery-origin *Oncorhynchus mykiss* kelts in the Central Valley of California. Environmental biology of fishes 96: 341–353.

Oroville F.E.R.C. relicensing (Project no. 2100). Interim report. SP-F3.2 Task 2, SP-F21 Task 1. 2003 Appendix A. Matrix of life history and habitat requirements for Feather River fish species. Literature review of life history and Habitat requirements for Feather River fish species: Steelhead.

Pearsons, T. N., McMichael, G. A., Bartrand, E. L., Fisher, M., Monahan, J. T., Leider, S. A., Strom (YIN), G. R., and A. R. Murdoch. 1993. Yakima Species Interactions Study, 1992 Annual Report. Washington Department of Wildlife, U. S. Department of Energy, Bonneville Power Administration, Division of Fish and Wildlife, Project Number 1989-105, Contract Number DE-BI79 1989BPO1483, 107 electronic pages (BPA Report DOE/BP-01483-3).

Pearsons, T. N., Phelps, S. R., Martin, S. W., Bartrand, E. L., and G. A. McMichael. 2007. Gene flow between resident and anadromous rainbow trout in the Yakima Basin: Ecological and genetic evidence *In* Redband Trout: Resilience and Challenge in a Changing Landscape, Oregon Chapter, AFS, 2007.

Peck, S. L. 2004. Simulation as experiment: a philosophical reassessment for biological modeling. Trends in Ecology and Evolution 19: 530–534.

Rich, A.A. 2000. Water Temperature Requirements for Chinook Salmon and Steelhead Trout. Testimony Submitted to the State Water Resources Control Board, Yuba River hearings, 1 May 2000 (Exhibit S-DFG-39). 12 p. in Contributions to the biology of Central Valley salmonids. Volume 1. R. L. Brown (ed.). Sacramento, California. CDFG, 1–297.

Romer, J. D., Leblanc, C. A., Clements, S., Ferguson, J. A., Kent, M. L., Noakes, D., and C. B. Schreck. 2013. Survival and behavior of juvenile steelhead trout (*Oncorhynchus mykiss*) in two estuaries in Oregon, USA. Environmental biology of fishes, 96(7): 849–863.

Satterthwaite, W. H., Beakes, M. P., Collins, E. M., Swank, D. R., Merz, J. E., Titus, R. G., Sogard, S. M., and M. Mangel. 2010. State-dependent life history models in a changing (and regulated) environment: steelhead in the California Central Valley. Evolutionary Applications 3: 221–243.

Scheuerell, M. D., Hilborn, R., Ruckelshaus, M. H., Bartz, K. K., Lagueux, K. M., Haas, A. D., and K. Rawson. 2006. The Shiraz model: a tool for incorporating anthropogenic effects and fish-habitat relationships in conservation planning. Canadian Journal of Fisheries and Aquatic Sciences 63: 1596–1607.

Sommer, T.R., McEwan, D., and R. Brown. 2001. Factors affecting Chinook salmon spawning in the lower Feather River. In: Brown R. (Ed.), Fish Bulletin 179. Contributions to the biology of Central Valley salmonids. Volume 1. Sacramento (CA): California Department of Fish and Game. p 269–297.

Terraqua. 2004. Draft Battle Creek salmon and steelhead restoration project adaptive management plan, prepared for the U.S. Bureau of Reclamation, Pacific Gas and Electric Company, National Marine Fisheries Service, U.S. Fish and Wildlife Service, and California Department of Fish and Game. Wauconda, Washington. 238 pp.

Thomas R. Payne and Associates. 1998. A 1989 Instream Flow Study: 1 of 8 Components. Prepared for California Department of Fish and Game.

Thrower, F. P., and J. E. Joyce. 2004. Effects of 70 years of freshwater residency on survival, growth, early maturation, and smolting in a stock of anadromous rainbow trout from southeast Alaska. Am. Fish. Soc. Symp. 44: 485–496.

U.S. Bureau of Reclamation (USBR). 2001. Hydrology of North and South Fork Battle Creek, Battle Creek Salmon and Steelhead Restoration Project.

U.S. Fish and Wildlife Service (USFWS). 1995. Working Paper on Restoration Needs: Habitat Restoration Actions to Double Natural Production of Anadromous Fish in the Central Valley of California. Vol. 2. Stockton, CA: Prepared for the U.S. Fish and Wildlife Service under the direction of the Anadromous Fish Restoration Program Core Group.

U.S. Fish and Wildlife Service (USFWS). 2011. Biological assessment of artificial propagation at Coleman National Fish Hatchery and Livingston Stone National Fish Hatchery: program description and incidental take of Chinook salmon and steelhead. U.S. Fish and Wildlife Service, Red Bluff, CA.

Ward, M. B., and W. M. Kier. 1999. Battle Creek salmon and steelhead restoration plan. Report by Kier Associates to Battle Creek Working Group.

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

Zimmerman, C. E., Edwards, G. W., and K. Perry. 2009. Maternal origin and migratory history of *Oncorhynchus mykiss* captured in rivers of the Central Valley, California. Transactions of the American Fisheries Society 138(2): 280–291.

7. Personal Communications

Carmichael, R. Oregon Department of Fish and Wildlife, Salem, Oregon. richard.w.carmichael@state.or.us. Personal communication in 2009.

Kock, T. US Geological Survey, Cook, WA. tkock@usgs.gov. Personal communication in 2014.

Temple, G. Washington Department of Fish and Wildlife, Olympia, WA. Gabriel.Temple@dfw.wa.gov. Personal communication in 2008.

Appendix F: Integrated Monitoring Plan

Prepared for:

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Table of Contents

I. Introduction

A monitoring plan structured to detect and diagnose meaningful changes in population performance is a critical element of an effective adaptive management plan.

Chapter 4 described the selection and implementation of initial actions, but this does not fulfill the input of new information to the adaptive management process. Rather, the implementation of management actions is paired with initiation of monitoring to allow for ongoing assessment of effectiveness of the selected actions. It is expected that additional data collected through the integrated monitoring plan, combined with interpretation and incorporation into the quantitative life cycle model, may lead to changes including:

- Adjustment of goals or objectives, or the setting of new goals or objectives.
- Identification of new issues, or redefining of existing issues.
- Identification of new or revised management actions.
- Conceptual model revisions reflecting the addition of new information.
- New information on environmental conditions necessary to support target species in the BCRP area, the Sacramento River, the San Francisco Estuary, or the Pacific Ocean.
- Life cycle model revisions, which quantifies and links issues, actions, habitat conditions, and population response.

Thus it is critical that the monitoring plan yield data that can inform scientifically defensible indicators (performance measures), which guide adaptive decision-making. In many cases, observations provided by the monitoring plan do not function as stand-alone success standards, but rather must be incorporated into the quantitative life cycle model in order to consider population-level impacts (see Chapter 4).

The monitoring plan described here is intended to provide a framework for data collection that will inform management decisions relevant to the BCRP, the CNFH, and diversions and hydroelectric facilities within the Battle Creek watershed. This includes (1) status and trends of salmon and steelhead populations in Battle Creek, (2) performance measures to evaluate the success or impacts of the BCRP, CNFH and Battle Creek diversions and hydroelectric facilities, (3) the effect of CNFH operations on natural-origin salmonids in Battle Creek and (4) information to update and improve the steelhead and Chinook salmon life cycle models.

Application and interpretation of biological data provided by this monitoring plan in many cases will require information on environmental attributes of the BCRP area. These factors include water quality (especially water temperature), and the physical extent and quality of habitat to support target species. Types of environmental data and performance triggers for collecting that data in the Battle Creek watershed are described in the BCRP-AMP and will not be repeated here. This monitoring plan is not intended to describe short-term diagnostic studies and experiments, which are needed to address specific CNFH/BCRP issues (see Chapter 4).

II. Recommended Monitoring

An integrated biological monitoring plan that satisfies the needs of CNFH and BCRP adaptive management, requires four major field monitoring elements: 1) BCRP area spawning escapement, 2) lower Battle Creek spawning escapement, 3) adult passage and spawning distribution, and 4) juvenile production. Each of these four monitoring elements is multi-faceted and interdependent. For example, failure to properly monitor adult spawning distribution will greatly limit the utility of juvenile production monitoring data. The fifth element of the monitoring plan requires the analytical integration and synthesis of collected data into population performance measures. Detailed attributes for each of the five monitoring plan elements are provided below.

M-SE1: BCRP Area Spawning Escapement

Informs

- BCRP AMP population objectives 1, 2, 3, 4
- BCRP AMP habitat objectives 1, 3,
- BCRP AMP passage objectives 1, 3
- CNFH AMP Issues 2, 3, 4, 5, 6, 7, 9, and 10
- BCRP Issues A, B, C, and D

Description

The barrier weir and fish ladder system is an essential component of CNFH operations, and for monitoring fish passage into the BCRP area. All fish entering the hatchery or the restoration area must pass through the fish ladder system when flows are lower than 800 cfs. Less is known about the effectiveness of the barrier above those flows but some functionality likely remains. As such, the fish ladder system and associated operations provide the ability to obtain the best possible data on adult escapement. Data collected at the barrier weir can be analyzed to inform a variety of key fish population metrics needed to evaluate the BCRP-AMP, and to evaluate the effects of the CNFH on natural-origin populations. This includes escapement estimates, tissue samples for genetic analysis, and collection of fish to be tagged for passage assessments and distribution in the restoration area. Data collected from the current barrier fish ladder system, may at times rely on manual trapping of fish within the ladder system, and at other times by video only monitoring. The adult escapement monitoring element requires that a large fraction of fish passing into the BCRP area be enumerated, measured for fork length, and sampled for DNA.

Methods

- During CNFH operations: direct capture and handling of Chinook salmon and steelhead.
- During barrier ladder operations: automated sorting of individual fish or other sorting method that allows staff to identify sorting category and obtain tissue samples.
- Non-target Chinook salmon and steelhead will not be allowed passage into the BCRP area.

Data to be collected

- Date and time of passage, fork length, species, race, HD lateral and dorsal images for potential image-based mark-recapture, and for identifying clipped fish.

- Tissue or DNA samples from each individual fish.

Data application

- Chinook salmon race verification (genetics).
- Escapement estimate by species and race.
- Construct genetic pedigree or potential spawners.
- Performance metrics identified in Performance Metrics (M-PM) section below.

Relation to other studies

Escapement monitoring will be an essential starting point for other studies including:

- Tagging to evaluate movements, spawning distribution, upstream barrier passage, and migration delay/mortality.

Options

- Tissue sampling
    1. All fish: Minimizes uncertainty in racial classification. Increases precision of population metrics. Reduces number of juveniles that must be collected for calculation of population metrics.
    2. Some fish: Greater uncertainty in racial classification. Lower precision of population metrics. Greater numbers of juveniles needed for population metrics. Greater difficulty in detecting population trends.
    3. No fish: Greatest uncertainty in racial classification. Poor precision of population metrics. Difficult to detect population trends due to poor precision.
- PIT tagging
    1. All fish: Greatest precision in estimating distribution of races and species between the south and north fork. Greatest precision for estimating passage efficiency at ladders and barriers.
    2. Some fish: Greater uncertainty in the metrics listed above. Potential unequal sample size by race if tagging is not equally distributed through the migratory windows of all races/species.
    3. No fish: High uncertainty regarding racial distributions. No quantitative information on migration delay or post-handling mortality. Separate study would be needed for passage efficiency at barriers/ladders.

Uncertainties and challenges

Less than 100% of adults entering BCRP area will be enumerated and sampled. This could occur as a result of high flow events, equipment failure, or regulatory sampling constraints. However, many important population metrics can still be calculated even if only a fraction of adult immigrants are sampled.

Currently, handling of salmonids at the barrier weir is constrained to periods when water temperatures are below 60 degrees. However, other monitoring projects in the Central Valley are permitted to handle anadromous salmonids at higher temperatures. CDFW, NMFS, and USFWS should consider handling salmonids at higher temperatures, to extend the period of tagging and genetic sampling. Alternatively, technology exists for automated sorting and sampling that could be implemented continually, or during periods of sub-optimal temperature. Automated sorting and sample collection would allow fish to be sampled without exposing them to additional handling stress, and would allow them to be included in estimation of reproductive success. The technology for automated sorting and data collection is still under development, although the methods assumed here are technologically feasible and available.

M-SE2: Lower Battle Creek Spawning Escapement

Informs

- BCRP AMP Population objective 3
- CNFH AMP Issue 8

Description

The number of fish entering lower Battle Creek is currently monitored by CDFW using video equipment. This monitoring is specifically designed for fall Chinook salmon. Although a side view camera permits identification of a subset of adipose clipped salmon that could provide an overall estimate of hatchery composition, the video monitoring does not permit identification (or selective passage) of other races that may spawn in this reach (e.g., late-fall Chinook) or out of basin hatchery strays.

Methods

A weekly survey during the fall and late fall spawning period to inspect all available "fresh" carcasses (not exceeding 100/week). The USFWS has performed these surveys in previous years. Data is needed to estimate composition of natural and hatchery-origin Chinook salmon in lower Battle Creek. This survey would not need to generate an estimate of population size; only estimate the proportion of fish that are of hatchery and natural-origin. Escapement to lower Battle Creek is expected to vary in response to natural influences on population demographics and hatchery practices (e.g. trucking smolts to the estuary). Thus the number of fresh carcasses that need to be examined each week may need to vary in response to escapement. Once there is an estimate of hatchery composition in lower Battle Creek, a power analysis should be performed to determine the number of fresh carcasses that should be examined to obtain a reasonable level of accuracy in the estimate.

Data to be collected

- Date of sample, fork length, sex, spawned/unspawned, marked/unmarked for each carcass inspected.
- Heads (containing coded wire tags) from all marked, "fresh" carcasses sampled.
- Tissue or DNA samples from all "fresh" carcasses sampled.

Data application

- Spawning escapement estimate by species, race and origin (natural and hatchery).
- Performance metrics identified in M-PM.

Relation to studies

- Additional to video monitoring currently conducted by CDFW.

Uncertainties and challenges

- Results from this monitoring may eventually suggest a need for selective passage of natural-origin fall Chinook salmon into lower Battle Creek.

Options

- A100% mark rate would allow hatchery fish to be identified by video monitoring, although lateral images would be needed. Hatchery fall Chinook could be excluded from spawning naturally in lower Battle Creek (if appropriate facilities for selective passage are provided).

M-SD: Spawner Distribution and Barrier Passage

Informs

- BCRP AMP population objectives 1, 2, 3, 4.
- BCRP AMP habitat objectives 1, 3.
- BCRP AMP passage objective 1, 3.
- BCRP Facilities objectives
- BCRP Issues A, B, C, and D

Description

Monitoring the distribution of spawners for each race and species among the north fork, south fork and main stem as well as passage over artificial and natural barriers will be essential for evaluating restoration objectives and to confirm and refine the life cycle models. Removal of migration barriers was identified by the lifecycle models as the primary limitation to the size of target populations. The assumption that fish will efficiently pass artificial and natural barriers must be confirmed with empirical data for target runs and species over a range of environmental conditions. The empirical data can then be integrated into the lifecycle model to provide more accurate predictions of population dynamics. Additionally, the distribution of spawners within the watershed needs to be empirically evaluated to evaluate if spatial habitat use by each race and species is being maximized and to confirm predictions of the models. This is particularly important because certain forks and reaches were identified by the model as being good habitat for certain races. If empirical estimates of spawner distribution do not match predictions, it may suggest further management actions are necessary (e.g. improved passage efficiency). Additionally the empirical estimates can be used to refine the lifecycle models.

Methods

Estimation of passage efficiency at natural and artificial barriers will be accomplished through strategic placement of PIT tag antennas. Fish tagged at the barrier weir can then be used for passage evaluations at relevant barriers. Antennas will need to be configured to estimate the number of fish approaching the passage obstacle, the number defeating the obstacle, and the number that defeated the obstacle and then "fell back". This would allow for calculation of passage efficiency and fall back at each obstacle.

Fish implanted with PIT tags detected at antenna arrays located near the confluence of each fork and at passage facilities also will make it possible to estimate spawning escapement by fork or by river segment. Combined with tissue samples collected during tagging, these data can be used to estimate race-specific escapement to each fork of Battle Creek.

PIT tag technology is a good fit for this application because the tags are low-cost, providing the ability to tag a large number of individuals. Additionally, tag implantation is less invasive than radio or acoustic tagging without the need for sutures or external antennas. PIT tags have been successfully used to assess passage of adult salmon in the Columbia River (Williams et al. 2004) where fish are constrained to certain passage routes, as will be the case in Battle Creek. It is possible that extreme high flow conditions could interfere with detections or allow fish to bypass PIT tag detectors. Although this is likely to be rare relative to typical passage conditions, radio or acoustic telemetry could be used if PIT tag technology proves to be ineffective.

The total number of spring and winter Chinook salmon and steelhead passing the fish barrier weir is expected to be low following the completion of the restoration project; however, passage numbers are expected to increase over the long term. The precision of estimates for population size and passage efficiency are dependent on both the number of fish tagged, and the probability of a fish being detected by an antenna (Krebs 1999). The number of fish available for tagging will be limited; thus, there should be a goal of 90% detection probability to ensure the greatest precision of each estimate.

Data to be collected

- Date and time of passage.
- Date and time obstacle is first encountered.
- Date and time obstacle is defeated.
- Date and time of "fall back".

Data application

- Spatial distribution of spawners in each fork.
- Spatial distribution of spawners within reaches.
- Estimates of escapement for each species and race in the North and South Forks of Battle Creek.
- Passage efficiency at barriers.
- Fall back rate at barriers.
- Performance metrics identified in M-PM.

Relation to other studies

- Evaluate delay/mortality from handling history.
- Evaluate ladder performance [BCRP Facilities Monitoring].
- Collect data for Central Valley-wide steelhead PIT tag study.
- Evaluation of winter Chinook reintroduction program.

Uncertainties/challenges

- Number of fish tagged must be sufficient to provide robust estimates of passage rates.
- Placement of detection arrays, and tagged fish reaching arrays needed to estimate detection probabilities and conduct mark-recapture statistical analyses.
- Few fish may attempt to defeat barriers.

Options

- Use video to monitor passage and fall back at fish passage facilities.
- Video might be complementary to PIT tagging, but would not provide a suitable replacement because of uncertainty and difficulty in identifying individual fish.

M-JP: Estimate BCRP Juvenile Production

Informs

- BCRP AMP population objectives 1, 2, 3, 4.
- BCRP AMP habitat objectives 1, 4.
- BCRP AMP passage objective 2.
- CNFH AMP Issues 2, 3, 4, 5, 6, 7, 9, and 10.
- BCRP Issues A, B, C, and D.

Description

Monitoring of juvenile production will be an essential component of evaluating the effectiveness of the restoration. Anadromous salmonids have been absent from much of the restoration area for many years and the capacity of these areas for juvenile production is unknown. The best areas for spawning of target species may not be the same areas that favor juvenile survival. Thus, it is essential to identify areas where juvenile production is good or poor relative to spawner density and to document how these relationships change in response to environmental variation and spawner density. These data can then be used to guide additional management actions in restoration targets are not being met. Additionally, trapping of juveniles will provide opportunities to obtain tissue samples that will be essential for calculating various population metrics described in the section on population metrics below.

Methods

Juvenile production will be estimated from monitoring conducted upstream of the CNFH fish barrier weir using rotary screw traps. The efficiency of capture at each location should be confirmed with regular efficiency trials. At a minimum, the capture efficiency of fry, parr, and smolt life stages should be evaluated. Target efficiencies should be developed based on differences that need to be detected among years. For example, in Figure 1, assuming that the true number of fish passing the trap is 1,000, and the trap is operating at 5% efficiency; the 95% confidence interval of the estimate would be 660-1,340. If the next year true passage is 500, and efficiency is 5% the 95% confidence interval is 300 – 700. These estimates would not be statistically indistinguishable despite the large difference in true passage. Thus, efficiency would need to be higher if a difference of that magnitude needs to be detected. Efficiency may be increased by changing the location and/or the configuration of the traps or by adding behavioral guidance devices at the screw trap location. Efficiencies are likely to be low during high flow periods, and this will need to be taken into consideration when making interannual comparisons of juvenile production.

When populations are small such as is expected in the short-term following completion of Battle Creek restoration, it will be difficult to determine what efficiency is best. It will also be difficult to detect differences between years because of the small number of fish captured, and because of the limitation of screw traps as a sampling device. As fish population size increases, more information will be available to determine the necessary efficiency.

Fork and reach specific production will be estimated based upon genetic parentage analysis from tissue samples collected from juveniles and adults (M-SE1). These estimates will be contingent on the tagging, detection, and genetic sampling of a sufficient proportion of spawners. Snorkel surveys will be used to estimate the number of *O. mykiss* juveniles (regardless of resident or anadromous origin) in the restoration area with sites selected using generalized random tessellation sampling. This type of design is advantageous, because it is composed of sites that are sampled every year to aid in trend analysis, and sites that rotate at various time intervals to maximize spatial coverage in the basin. This sampling design has been adopted for estimating juvenile steelhead and coho salmon abundance in California's coastal streams as part of the Coastal Monitoring Program (Adams et al. 2011).

Data to be collected

- Life stage specific (fry, parr, smolt) counts of each race and species through the outmigration period.
- Efficiency estimates of traps by species, life stage, flow and other important environmental covariates.
- Counts of O. mykiss juveniles in sample reaches.
- Tissue or DNA sample collected from a subsample of fish encountered.

Data application

- Juvenile production estimates for each race and species by life stage.
- Proportion of each race migrating as fry, parr and smolts.
- Abundance of juvenile O. mykiss in the restoration area.
- Other metrics identified in M-PM.

Relation to other studies

- Population context for evaluation of entrainment into unscreened diversions.
- Potentially provides specimens for tagging studies to estimate out migration survival.

Uncertainties/challenges

- Availability of fish for efficiency trials is unknown.
- Some metrics may not be calculated in some years if productivity/captures are low.
- Ability to achieve required sampling efficiency is unknown.
- Screw trap deployment may be difficult in the forks of Battle Creek.

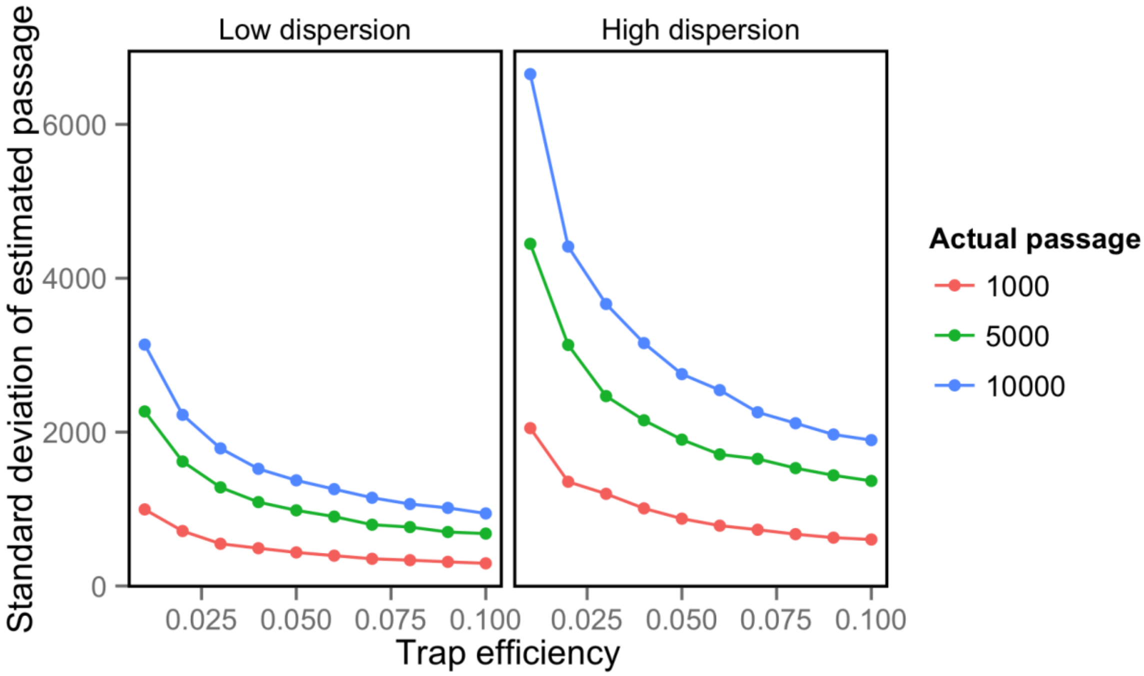

Figure 1. Changes in the standard deviation of passage estimates as a function of trap efficiency for three levels of daily passage. Dispersion in the data can be reduced by including covariates in efficiency models (i.e., fish size, flow, temperature), whereas higher dispersion can be problematic in simpler models without covariates.

(M-PM) Population Metrics

Informs

- BCRP AMP Population objectives 1, 2, 3, 4.
- BCRP AMP Habitat objective 1.
- CNFH AMP Issues 2, 3, 4, 5, 6, 7, 9, and 10.
- BCRP Issues A, B, C, and D.

Description

The monitoring activities described previously are required to obtain data for calculating population metrics that can be used to quantitatively evaluate impacts of the restoration project, hatchery operations and hydroelectric facilities on target populations. The metrics can be used to analyze population trends and to compare values obtained from Battle Creek to other populations/watersheds. These metrics also are integral to CNFH AMP success standards and performance metrics. Additionally, they are essential to inform population viability criteria specified by NOAA for endangered and threated salmonid populations (Crawford and Rumsey 2011).

Methods

Some metrics can be calculated with either genetic or traditional abundance data whereas others can only be estimated with genetic information, or the accuracy and precision of the metric is increased by incorporating genetic information. Samples of genetic material from adult fish passing the weir and out-migrating juveniles captured in screw traps will both be essential elements in this process. This is particularly important for racial classification. Estimation of metrics such as cohort replacement rate, smolt-to-adult rate and recruits-per-spawner can all be calculated with abundance data only; however, genetic information can increase both the precision and the accuracy of the metric. For example, the metric "recruits-per-spawner " can be calculated with adult and juvenile passage data; however, this method is biased by uncertainty in racial classification, and also in the number of spawners because not all fish passing the weir will spawn successfully. Incorporating genetic information provides a method to estimate the number of fish that actually spawned (Jones et al 2010; Luikart et al 2010) and allows the metric to be calculated separately for each race. Figure 2 describes how the estimated number of breeders varies as a function of the number of juveniles examined for different population estimators. The number of juveniles that will need to be examined will change with the number of breeders in the watershed. At very low population sizes such as would be expected in the short term post-BCRP completion, estimation with this method, as well as more traditional methods, will be difficult. However, in the long term post-BCRP completion, the relationship between the number of juveniles sampled and the precision of estimates will become better understood for each race (Figure 3).

Other metrics can only be calculated with genetic data. These include: the incidence of introgression (Rannala and Mountain 1997), number of breeders (Kohn et al. 1999; Eggert et al. 2003), effective population size, and relative reproductive success. For these metrics the tissue sampling rate will be important for precision and accuracy. If sampling rates are low or do not capture the full migration period for each race, the resulting metrics may be biased. As described above, when population sizes are small, calculating metrics with abundance and genetic data will be difficult and may only be calculated when sufficient sample sizes are available.

Metrics calculated

- Juvenile production estimates for each race and species by life stage.
- Incidence of non-target strays.
- Incidence of genetic introgression.
- Relative reproductive success (by reach; by passage/handling history).
- Cohort replacement rate.
- Smolt-to-adult rate.
- Recruits-per-spawner.
- Number of breeders.
- Effective population size.
- Proportion of resident *O. mykiss* contributing to steelhead smolt production.

Data application

- Informs success standards for most CNFH AMP Issues.
- Provides performance standards for most CNFH AMP issues.
- Provides basis for most performance measures identified in CNFH AMP.

- Informs population viability assessment.
    - Productivity
    - Diversity
    - Abundance
    - Spatial distribution
- Informs carrying capacity.

Uncertainties/challenges

- Small population sizes may prevent some metrics from being estimated, especially in the early years following BCRP completion. This will be a problem regardless if metrics are calculated with genetics or more traditional population data.
- Lack of tissue/DNA samples, or lack of fish available for capture would impede calculation of metrics.
- If too few tissue/DNA samples are collected, it may be difficult to detect population trends/differences.

Options

- Without PIT tagging component of M-SE1, estimate only total BCRP metrics (not fork or reach specific).
- Without tissue/DNA collection, estimate SAR and CRR, but no other metrics.

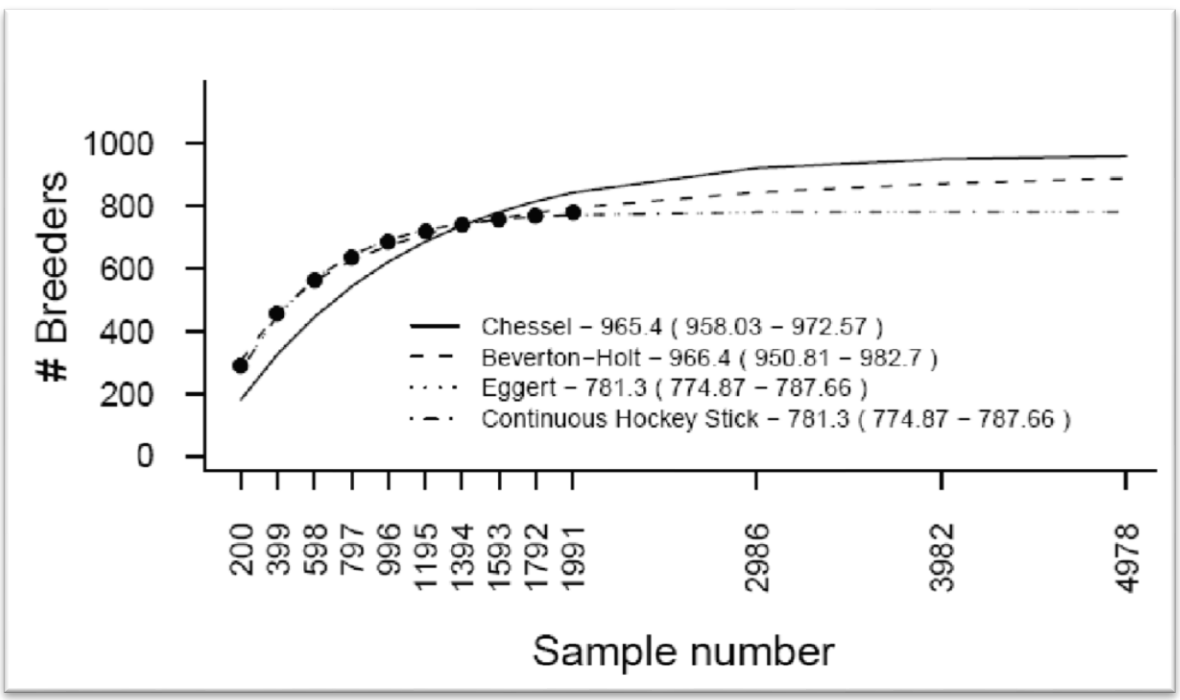

Figure 2. Relationship between the estimated number of breeders and the number of juveniles sampled for four different population estimators.

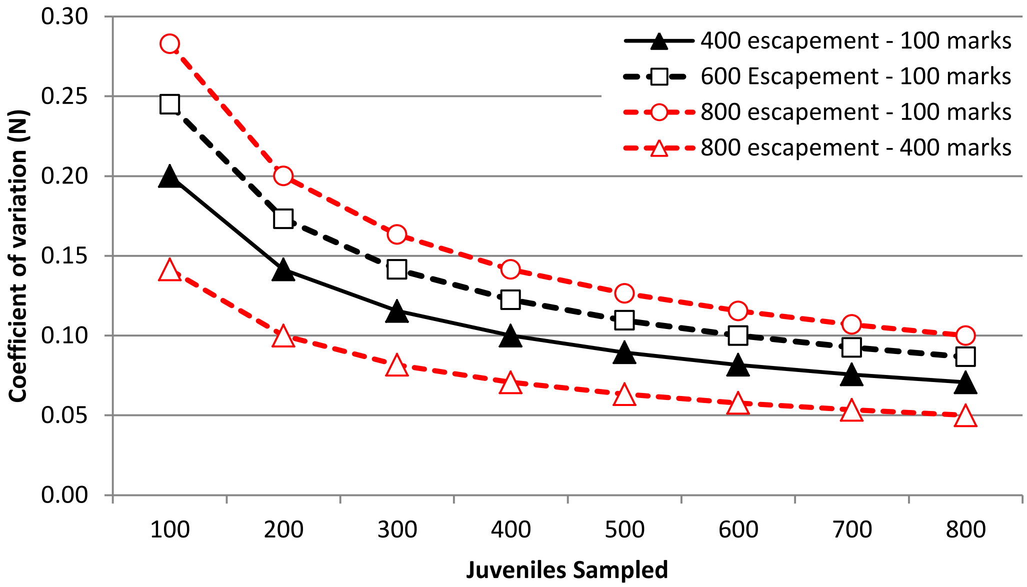

Figure 3. Relationship between the precision of estimates and the number of juveniles sampled for a range of values for the number of breeders.

III. Literature cited

Adams PB, Boydstun LB, Gallagher SP, Lacy MK, McDonald T, and Shaffer KE. 2011. California coastal salmonid population monitoring: strategy, design and methods. Fish Bulletin 180, California Department of Fish and Wildlife.

Crawford BA and Rumsey S. 2011. Guidance for monitoring recovery of Pacific Northwest salmon and steelhead listed under the federal Endangered Species Act. 125pp.

Eggert, L.S., J.A. Eggert, and D.S. Woodruff. 2003. Estimating population sizes for elusive animals: the forest elephants of Kakum National Park, Ghana. Mol. Ecol. 12:1389-1402.

Jones, A.G., C.M. Small, K.A. Paczolt, and N.L. Ratterman. 2010. A practical guide to methods of parentage analysis. Mol. Ecol. Res. 10(1): 6-30.

Kohn, M.H., E.C. York, D.A. Kamradt, G. Haught, R.M. Sauvajot, and R.K. Wayne. 1999. Estimating population size by genotyping feces. Proc. R. Soc. Lond. B 266: 657-663.

Krebs CJ. 1999. Ecological Methodology, 2nd edition. Benjamin/Cummings, Menlo Park, CA.

Luikart G., Ryman N, Tallmon DA, Schwartz MK and Allendorf FA. 2010. Estimating of census and effective population sizes: the increasingly usefulness of DNA-based approaches. Conser. Gen. 11:355-373.

Rannala, B., and J.L. Mountain. 1997. Detecting immigration by using multilocus genotypes. Proceedings of the National Academy of Sciences of the United States of America 94: 9197-13 9201.

Williams, J.G., Smith, S.G., Muir, W.D., Sandford, B.P., Achord, S., Mc Natt, R., Marsh, D.M., Zabel, R.W., Scheuerell, M.D. 2004. Effects of the federal Columbia River power system on salmon populations. National Marine Fisheries Service, Seattle Washington.