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Study of Physical Data Gaps to Inform the Implementation of Nur Rematriation Upstream of Shasta Dam
(AB 211 Drought Grant Agreement Number – Q2396040)

Background Compendium and Design Criteria Report for the Feasibility of Volitional Fish Passage above Keswick and Shasta Dams

Prepared for California Department of Fish and Wildlife

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ABBREVIATIONS

2009 BiOp	*Biological Opinion and Conference Opinion on the Long-Term Operation of the Central Valley Project and State Water Project*
7-DADM	7-day average of the daily maximum
ACID	Anderson-Cottonwood Irrigation District
ac-ft/year	acre-foot per year
AWS	auxiliary water supply
BiOS	Biogeographic Information and Observation System
Buliyum Puyuuk	Winnemem Wintu words for Mount Shasta
BY	brood year
CEC	California Energy Commission
CDEC	California Data Exchange Center
CDFW	California Department of Fish and Wildlife
cfs	cubic foot per second
CI	confidence interval
Consultant Team	team of engineering and fisheries science consultants consisting of Anchor QEA; HDR Engineering, Inc.; U.S. Geological Survey; and QEDA Consulting, LLC
CSA	County Service Area
CVP	Central Valley Project
CVSCS	Central Valley spring-run Chinook Salmon
DWR	California Department of Water Resources
ESA	Endangered Species Act
ESU	evolutionarily significant unit
eWRIMS	Electronic Water Rights Information Management System
Feasibility Study	Feasibility Study of Salmon Passage at Shasta and Keswick Dams
FEMA	Federal Emergency Management Agency
FERC	Federal Energy Regulatory Commission
FL	fork length
ft-lb/sec/ft^3	foot-pound per second per cubic foot
ft/s	foot per second
gpm	gallon per minute
IFPSC	Interagency Fish Passage Steering Committee
IPT	inclined plane trap
ITEK	Indigenous Traditional Ecological Knowledge
JSATS	Juvenile Salmon Acoustic Telemetry System
JSCS	Juvenile Salmonid Collection System

LiDAR	Light Detection and Ranging
LFA	limiting Factors analysis
LSNFH	Livingston Stone National Fish Hatchery
m	meter
m^2	square meter
mm	millimeter
NAVD88	North American Vertical Datum of 1988
NIR	near-infrared
NMFS	National Marine Fisheries Service
Nomtipom Waywaket	Winnemem Wintu words for Sacramento River
NTU	nephelometric turbidity unit
Nur	Winnemem Wintu word for Chinook Salmon
NWIS	National Water Information System
NZ	New Zealand
OHW	ordinary high water
PAD	California Fish Passage Assessment Database
PG&E	Pacific Gas & Electric Company
Pilot Program	fish passage pilot program
PNW	Pacific Northwest
Project	studies to gather data, compile information, and identify data gaps related to physical and biological conditions in the Study Area
RBDD	Red Bluff Diversion Dam
RCP	Representative Concentration Pathway
Reclamation	U.S. Bureau of Reclamation
RM	river mile
RST	rotary screw trap
sawalmem	Winnemem Wintu word for sacred water
SDFPE	Shasta Dam Fish Passage Evaluation
SFHA	Special Flood Hazard Area
SLWRI	Shasta Lake Water Resources Investigation
SRWCS	Sacramento River winter-run Chinook Salmon
SSTEMP	Stream Segment Temperature (model)
TAG	Technical Advisory Group
State Water Board	California State Water Resources Control Board
SWAMP	Surface Water Ambient Monitoring Program
TDM	temperature-dependent mortality
USEPA	U.S. Environmental Protection Agency

USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
V:H	vertical:horizontal (ratio)
Winnemem Waywaket	Winnemem Wintu words for McCloud River
WRLCM	Winter-Run Life-Cycle Model
WSE	water surface elevation

1 Introduction

A team of engineering and fisheries science consultants consisting of Anchor QEA; HDR Engineering, Inc.; U.S. Geological Survey (USGS); and QEDA Consulting, LLC, known herein as the "Consultant Team," received funding from the California Department of Fish and Wildlife (CDFW) to implement studies to gather data, compile information, and identify data gaps related to physical and biological conditions in the Study Area. These studies will be referred to within this report as the "Project." Results of the Project have been incorporated into a parallel study investigating the feasibility of providing volitional passage for fish, particularly Chinook Salmon (*Oncorhynchus tshawytscha*) above Keswick and Shasta dams on the Nomtipom Waywaket (also known as the Sacramento River) into the Winnemem Waywaket (also known as the McCloud River) in northern California (Feasibility Study of Salmon Passage at Shasta and Keswick Dams [Feasibility Study]). Providing passage would allow Chinook Salmon to spawn and rear in historical habitat off the floor of the Central Valley where conditions are more suitable. In this document, Chinook Salmon is used to generally describe the species because once connectivity is re-established through reintroduction, fish will adapt to the new environments and could display run timing consistent with multiple runs. It is inclusive of Nur, which the Winnemem Wintu Tribe uses for Chinook Salmon that have been raised by the Tribe. The formal, evolutionarily significant unit (ESU)-specific name (e.g., Sacramento River winter-run Chinook Salmon [SRWCS]) is used when discussing federal Endangered Species Act (ESA)-listed Chinook Salmon or steelhead (*O. mykiss*). The Feasibility Study may be used by the co-managers to inform fish passage alternative(s) that will move on to advanced levels of design.

Filling physical and biological data gaps is necessary to inform the formulation and evaluation of volitional fish passage alternatives and evaluate risks related to placing Chinook Salmon upstream of Shasta Dam. This report compiles and summarizes the results for each of the Project studies and describes the physical and biological setting and design criteria used in the Feasibility Study. The Project studies are incorporated into this report as appendices.

Throughout the course of implementing the Project studies, the Consultant Team had numerous opportunities to hear from Winnemem Wintu Tribe members and Chief Sisk about Indigenous Traditional Ecological Knowledge (ITEK) and Tribal priorities. The Consultant Team understands that ITEK is spatially based (e.g., flows and temperature are expressed uniquely at different places throughout the system), thus it would not be appropriate to describe ITEK using a watershed-wide approach. The Consultant Team further understands that obtaining an adequate understanding of ITEK will require in-person engagement with the Tribe as the alternatives are further developed. Nonetheless and because of its importance, the Consultant Team has sought to incorporate what we heard to be the following Tribal perspectives into this document and the appendices to the best of our ability: 1) prioritize salmon wildness; 2) minimize human intervention, but when human intervention is necessary, use systems that mimic nature as much as possible; 3) connect salmon with their historical habitat using volitional passage through natural tributaries; and 4) honor and respect the Wintu language by using Wintu names and language when available. We acknowledge that full incorporation of ITEK into this document has not been accomplished but emphasize the need to continue efforts to do so as project activities progress forward.

Readers should also understand that on December 12, 2025, the Consultant Team received an email stating that the Winnemem Wintu Tribe does not endorse these reports (referring to the Background Compendium and *Alternatives Formulation and Evaluation Report* [Anchor QEA and HDR 2026]).

This section of the report goes on to describe relevant background information, the Project goals and objectives, the Study Area, the Winnemem Wintu Tribe, salmon co-management arrangements, and drought emergency actions. The rest of the report accomplishes the following:

- Discusses what ITEK is and how it was incorporated into the Project and discusses additional coordination and outreach activities (Section 2)
- Provides a summary of the data and information compiled for the Project (Section 3)
- Describes the physical and biological setting for potential volitional passage alternatives (Section 4)
- Identifies and summarizes key design guidelines, and engineering and biological principles that influenced the development of design criteria (Section 5)
- Provides a discussion of key conditions and remaining data gaps (Section 6)
- Provides references used in this report (Section 7)
- Provides detailed information about each study completed as part of the Project (Appendices A through R)

1.1 Background

With the completion of Shasta Dam in 1945, three of the four historic populations of winter-run Chinook Salmon were extirpated from historical habitat in the upper river basin of the Nomtipom Waywaket above Shasta Dam. The historical populations included those in the Little Sacramento River; Pit, Fall, and Hat rivers; the Winnemem Waywaket; and Battle Creek (Lindley et al. 2004). Winter-run Chinook Salmon returning adults numbered approximately 120,000 fish in the 1960s and 40,409 fish in brood year (BY) 1970 but have declined to as low as approximately 200 to 400 fish in the early 1990s and are currently at 1, 367 fish for BY 2024 (Azat and Killiam 2025).

SRWCS were listed as "endangered" by the State of California in 1989 and by the federal government in 1994. Abundance, productivity, spatial structure, and diversity are all factors that influence extinction risk (McElhany et al. 2000). On June 28, 2005, the National Marine Fisheries Service (NMFS) issued a final listing determination that concluded that the SRWCS ESU is in danger of extinction due to risks to the ESU's diversity and spatial structure and, therefore, continues to warrant listing as an endangered species under the ESA (70 *Federal Register* 37160; NMFS 2014). The four historical, independent populations of Nomtipom Waywaket winter-run Chinook Salmon have been reduced to a single population below Keswick Dam that does not have access to historical spawning habitat and is subject to lethal temperatures in the Nomtipom Waywaket below the dam.

In its 2014 Recovery Plan, NMFS noted that meeting objectives for redundancy and spatial distribution of SRWCS will require introducing some populations to habitats that historically supported the species above Shasta Dam. Reintroduction of winter- and spring-run Chinook Salmon above Shasta Dam (via fish passage around the dams) will increase the abundance and productivity of the populations and expand their spatial structure to areas off the valley floor where habitat quality is higher. This is especially important given the potential for future droughts and climate change. Returning Chinook Salmon to the Winnemem Waywaket immediately provides access to over 24 miles of cold-water, mainstem habitat, and it meets NMFS's recovery goal of establishing at least one SRWCS population above Shasta Dam, greatly reducing extinction risk. The quality of the 24 miles of habitat depends on the run and life stage of Chinook Salmon under current conditions.

1.1.1 Past Shasta Dam Fish Passage Evaluation

The Shasta Dam Fish Passage Evaluation (SDFPE) was a previous effort by the U.S. Bureau of Reclamation (Reclamation) to determine the feasibility of reintroducing SRWCS, Central Valley spring-run Chinook Salmon (CVSCS), and steelhead to tributaries above Shasta Dam (Reclamation 2017). The SDFPE was part of Reclamation's response to the *Biological Opinion and Conference Opinion on the Long-Term Operation of the Central Valley Project and State Water Project* (2009 BiOp; NMFS 2009), which required Reclamation to evaluate fish passage over Shasta Dam.

The SDFPE included a pilot program, which was the first phase of reintroduction of SRWCS and CVSCS above Shasta Dam, as presented in the *Pilot Implementation Plan* (Reclamation 2017). NMFS and Reclamation focused the first stages of the pilot program on reintroducing SRWCS upstream of Shasta Dam based on the following: 1) the imperiled status of the run and the resulting urgency to move these fish back into their historical habitats as a means of reducing extinction risk; and 2) the good habitat conditions in tributaries entering Shasta Reservoir (Reclamation 2017). NMFS recommended that the pilot program focus on the Winnemem Waywaket due to instream habitat conditions that provide suitable spawning and rearing habitat. In addition, NMFS required the use of federally listed SRWCS from the wild in the Nomtipom Waywaket and/or the Livingston Stone National Fish Hatchery (LSNFH) broodstock program to meet the goals of the pilot program (NMFS 2016). As part of this effort, a broad range of fish passage alternatives were contemplated, but the focus of the pilot program was on collection, handling, transport and release of adults and juveniles for upstream and downstream passage, not volitional passage.

Reclamation stopped implementing the SDFPE in 2019 because the 2009 BiOp was replaced by the 2019 BiOp (NMFS 2019), which concluded that the proposed action would not jeopardize the continued existence of listed salmon species, thus the requirement for Reclamation to implement the SDFPE was no longer applicable.

1.1.2 Habitat Evaluations Above Shasta Dam

In 2013, Reclamation conducted a habitat evaluation consisting of an aerial video survey across the entire stretch of the Winnemem Waywaket below McCloud Dam with ground level field surveys at three locations as part of the SDFPE. Field survey sites covered 38% of the channel length in the upper study reach (river mile [RM] 23.2 to RM 19.8), 7% of the channel length in the middle reach (RM 19.8 to RM 9.5), and 0% in the lower reach (RM 9.5 to RM 0; Reclamation 2014). An overall habitat condition score was calculated based on channel morphology, substrate, and habitat scores to determine habitat suitability. Resulting spawning habitat condition scores indicated fair to good physical spawning habitat is available for Chinook Salmon throughout the Winnemem Waywaket between Shasta Reservoir and McCloud Dam under suitable water temperature conditions (Reclamation 2014). Spawning habitat condition scores in the upper and middle study reaches (McCloud Dam down to RM 9.5) were fair to good as determined from both the aerial video and field derived habitat inventories. Field surveys were not conducted in the lower 9.5 miles of the river, so no ground-truth measurements are available for comparison to the aerial video measurements for habitat conditions in this reach. Substrate size and other habitat conditions were difficult to determine from the video survey. As such, the frequency and extent of suitable Chinook Salmon spawning habitat observed at the field sites was considerably greater than that measured from the aerial video (Reclamation 2014).

There was a large range in estimated spawner capacity for the three reaches depending on the survey method. The field survey derived estimates ranged from 2,480 females (using a 10-square-meter [m^2] spawning territory, baseflow stage) to 4,155 females (6-m^2 spawning territory, ordinary high water [OHW] stage), whereas estimates based on the aerial video-derived estimates ranged from 200 females (10-m^2 spawning territory, baseflow stage) to 402 females (6-m^2 spawning territory, OHW stage; Reclamation 2014). Estimates of Chinook Salmon spawning capacity were determined based on the aerial video-based habitat inventory with incomplete verification of field sites for all reaches (Reclamation 2014). Therefore, the sources of error and bias associated with the aerial video interpretations result in a greater level of uncertainty in spawner capacity estimates. Additional field-based surveys are needed to confirm potential spawning areas and capacity to improve the level of certainty in these estimates.

NMFS's Southwest Fisheries Science Center conducted an evaluation of the habitat capacity of the lower, middle, and upper Winnemem Waywaket; the Nomtipom Waywaket Headwaters; Sulanharas Creek; and the Lower Pit River (FitzGerald et al. 2024). The study team used thermal and habitat criteria specific to each life stage, stream temperature, geomorphic channel types, and wetted area to quantify suitability and capacity throughout the freshwater component of the life cycle for each area of interest (FitzGerald et al. 2024). This study was a desktop study completed at a coarse scale that could not distinguish local fine-scale habitat features and biotic factors (e.g., cover, aquatic vegetation, substrate type) or subtleties in temperature, depth, and water velocity at finer scales than monthly averages or reach averages that were used in the study (FitzGerald et al. 2024). As such, the resulting capacity indices are not representative of actual capacity but are informative as relative measures (FitzGerald et al. 2024).

They found that hundreds of river kilometers of thermally optimal, productive habitat for all winter-run Chinook Salmon life stages exist upstream of Shasta Reservoir. The study team further found that the lower, middle, and upper Winnemem Waywaket areas had the most suitable habitat during the summer for embryos, which is the most sensitive life stage. The middle and upper Winnemem Waywaket are both upstream of the McCloud Dam. They also found that the Lower Pit River, Sulanharas Creek, and Nomtipom Waywaket Headwaters exceeded the optimum thermal threshold for incubation in mid-summer. The upper Winnemem Waywaket had the highest spawner and rearing capacity indices, but suitability and capacity varied by life stage, area, and season. In July, the upper Winnemem Waywaket had the highest spawner capacity index and Sulanharas Creek had the lowest. In September, the rearing capacity index was highest in the upper Winnemem Waywaket and lowest in Sulanharas Creek. The lower Winnemem Waywaket reach below McCloud Dam was found to be generally thermally suitable for all life stages; however, the reach had little ideal spawning habitat based on channel typing, which was done at a coarse resolution. The study team concluded that providing access to just one of the areas above Shasta Reservoir "could substantially increase winter-run abundance, productivity, habitat spatial structure, and, over time, genetic and life-history diversity, critical to helping this endangered species withstand future perturbations" (FitzGerald et al. 2024).

Overall, the studies concluded that there is an abundance of habitat above Shasta Dam that is suitable for spawning and rearing based on existing habitat data (e.g., temperature, flow, channel morphology, and substrate), particularly in the Winnemem Waywaket. However, more field-based surveys are needed to determine fine-scale habitat conditions over many sections of the river. For example, there is a need to better understand the amount of spawning substrate available and how it aligns with other suitable spawning habitat conditions, including temperature. Given these results, Fitzgerald et al. (2024) suggest that winter-run Chinook Salmon abundance would be maximized when access to a mosaic of connected habitats is available to the population so that each life stage can exploit habitat that maximizes its survival.

1.1.3 Winnemem Wintu Tribe

The Winnemem Waywaket (the Middle River), is the homeland of the Winnemem Wintu Tribe, a traditional Tribe whose ancestral territory ranges from Buliyum Puyuuk (Mount Shasta) down the Winnemem Waywaket watershed since time immemorial. Their name translates to English as "Middle

River People," and their identity is inextricably linked to the river and to the Nur that gave the Winnemem their voice at the time of creation. The Winnemem Waywaket and the Nur are sacred, and the Winnemem Wintu Tribe has responsibilities to care for sawalmem (sacred water) and speak for the Nur. Nur are more than a subsistence species to the Winnemem Wintu Tribe—they are a sacred relative, and the fate of the Nur and the Tribe are culturally and spiritually intertwined. The construction of Shasta Dam displaced both the Nur from their natal waters and the Winnemem Wintu Tribe from their homes, burial grounds, and other sacred sites. The Winnemem Waywaket is the center of the Winnemem Wintu Tribe's universe. Thus, returning Nur above Shasta Dam will ensure the Winnemem Wintu Tribe's health, wellbeing, and cultural continuity.

The spiritual leader of the Winnemem Wintu Tribe, Chief Caleen Sisk, has been actively working to bring Nur back to the Winnemem Waywaket for decades. In 2016, Chief Sisk started the Run4Salmon prayer journey to "restore our salmon runs, protect our waters, and our indigenous lifeways" (Run4Salmon 2025). The Run4Salmon is a 300 mile prayer journey that follows the volitional pathway Chief Sisk and the Winnemem Wintu Tribe want to see the salmon take to return home. Participants lay prayers down throughout the journey in an effort to return the Nur home (Run4Salmon 2025). Also, in 2016, the Winnemem Wintu Tribe prepared a Salmon Restoration Plan that included volitional passage concepts that would allow Nur to pass volitionally around Keswick and Shasta dams via tributary bypasses through Stillwater Creek, Churn Creek, and Cow, Little Cow, and Dry Creeks (Winnemem Wintu Tribe 2016). The Salmon Restoration Plan was submitted as part of the Winnemem Wintu Tribe's comments on Reclamation's SDFPE and draft *Pilot Implementation Plan*.

1.1.4 2023 Co-Management and Stewardship Agreements

In spring 2023, the Winnemem Wintu Tribe, CDFW, and NMFS entered into historic salmon management and stewardship agreements. These documents state the following:

> The purpose of this Agreement is to establish a co management framework that integrates Winnemem Wintu Tribe's traditional knowledge and cultural tribal values with CDFW's and NMFS' recovery responsibilities and research and management practices, toward the goal of restoring traditional cultural fisheries including State and federally listed winter-run impacted by loss of access to historical spawning grounds above Shasta Reservoir to the extent possible and consistent with Indigenous Rights and federal, state, and local laws and regulations. (CDFW and Winnemem Wintu Tribe 2023)

The Winnemem Wintu Tribe received funding from CDFW to collaborate and participate in the efforts to return Nur to their homeland as a salmon co-manager.

1.1.5 Early Reintroduction Efforts

The placement of SRWCS eggs into the Winnemem Waywaket has been occurring since the summer of 2022. To minimize the impacts of the continued drought on SRWCS, eggs from LSNFH were placed into the Winnemem Waywaket by the salmon co-managers in 2022, 2023, and 2024 as detailed in Sections 1.1.5.1 to 1.1.5.3. A total of approximately 80,000 eggs were also placed into the Winnemem Waywaket during four events in 2025 (two in July and two in August).

1.1.5.1 Transfer Winter-Run Chinook Salmon Eggs to the Winnemem Waywaket in 2022

As an urgent response to severe drought, in 2022, approximately 40,000 SRWCS eggs were transferred from LSNFH to the Winnemem Waywaket near the Ah-Di-Na Campground, where they incubated throughout summer 2022. This was the first time in 80 years since Shasta Dam was constructed that salmon eggs have been in the Winnemem Waywaket. The eyed eggs were placed in incubator tanks and heath trays that circulated river water through them. The eggs were placed in heath trays due to an unforeseen turbidity event associated with Mud Creek flows. Once the eggs hatched and the alevins developed into fry, they were released directly into the river or into temporary rock holding pools built by Winnemem Wintu Tribe along a downstream beach. The fry then migrated approximately 20 miles downstream to the McCloud Bridge Day Use Area, where rotary screw traps (RSTs), fyke nets, and weirs were set up by CDFW in consultation with the Winnemem Wintu Tribe. Fry collected in RSTs were loaded into coolers and driven to a release site in the Nomtipom Waywaket downstream of Shasta and Keswick dams. From there, the salmon continued their journey to the ocean. The 2022 egg release summary is as follows (Johnson 2023):

- 40,000 eggs were delivered in two batches of 20,000 and incubated at Ah-Di-Na Campground on the Winnemem Waywaket.
- Eggs/embryos were incubated from July 11 through September 28, 2022.
- 35,313 juvenile winter-run Chinook Salmon were released into the river between September 4 and 14 and between September 26 and 28, 2022.
- RSTs and fyke nets were operated near McCloud Bridge Day Use Area between September 6 and December 12, 2022.
- A total of 1,634 juvenile winter-run Chinook Salmon were collected; 27 of those were mortalities, and an additional 7 died during transport.
- A total of 1,600 juvenile winter-run Chinook Salmon were successfully released into the Nomtipom Waywaket in Redding.

1.1.5.2 Transfer Winter-Run Chinook Salmon Eggs to the Winnemem Waywaket in 2023

Similarly, in 2023, approximately 80,000 eyed eggs were delivered on three separate trips to Ah-Di-Na. Each of the three groups was divided among the two different incubation methods, including the Nur Nature Base incubator system developed by Winnemem Wintu Tribe and University of California, Davis, and the heath trays (a common salmon hatchery aquaculture incubation technology). The approach of a heath tray, or stacked incubation, system is that water enters a channel in the top tray, upwells through the egg tray, and flows over the front wall into a channel that feeds the next lower tray unit and onward to the last tray. The Nur Nature Base incubator is the first of its kind to use ITEK to better prepare early life stages of salmon for life in the river and their migration out to the ocean before returning to spawn. The Winnemem Wintu Tribe's ITEK indicates that fish reared in a more natural setting, including natal water flows, rocks, plants, and intrinsic medicines, will produce "fit fish" when compared to conventional fish hatchery tray systems (heath tray system) currently used alongside the Nur Nature Base incubator. Western science would articulate the concept of the Nur Nature Base incubator as "environmental enrichment," and the literature is replete with examples of the positive impact enrichment has for downstream outcomes of importance, including fitness and survival. The Nur Nature Base incubator system attempts to mimic a natural environment for rearing fish.

The Nur Nature Base incubator system received approximately 40,000 eggs, and the number of mortalities and fish released was not recorded. The heath tray system was supplied with approximately 40,000 eyed eggs. Of those eggs, 1,000 mortalities were recorded before release. An additional approximately 14,000 eggs were killed during a disinfection process. Therefore, in 2023, approximately 25,000 fry were released from the heath tray system, and an unknown number of juveniles were released from the Nur Nature Base incubator system into the Winnemem Waywaket.

An inclined plane trap (IPT) was installed on the Winnemem Waywaket and operated from September 14 to October 7, 2023 by CDFW in consultation with the Winnemem Wintu Tribe. A total of 6,922 juvenile salmon were collected. In addition, two efficiency trials were conducted, from which ITP collection efficiency was estimated at 19% and 53%. On October 8, 2023, the IPT was removed due to increased river flow and debris loading. RSTs were installed and continued to operate for the remainder of the sampling period. Two efficiency trials were conducted on October 11 and November 2, 2023, and collection efficiency was 14% and 11%, respectively.

The California Department of Water Resources (DWR) installed and operated the Juvenile Salmon Collection System (JSCS) in the McCloud Arm of Shasta Reservoir between the McCloud Bridge and Ellery Creek from September 18 through November 15, 2023, downstream of the IPT and RSTs. The JSCS is being operated as part of a pilot study to determine how best to capture juvenile fish at the head of Shasta Reservoir. Throughout the season, the JSCS captured 853 fish in total, including test fish released during JSCS capture efficiency trials. Average capture probability across the season was 22.3%, with a maximum recapture rate of 51.5% and a minimum recapture rate of 0.3% (DWR 2024). The JSCS operated at peak capture probability when reservoir depth at the collection site was between 10 feet and 12 feet and water velocity at the trap entrance was within the range of 1.3 feet per second (ft/s) and 2.1 ft/s feet per second (DWR 2024).

The number of juvenile fish collected, transported, and released into the Nomtipom Waywaket in Redding was 7,775 from the in-river traps and the JSCS in 2023.

1.1.5.3 Transfer Winter-Run Chinook Salmon Eggs to the Winnemem Waywaket in 2024

In 2024, approximately 80,000 eggs were planned for delivery to Ah-Di-Na. However, due to low adult returns, only 62,288 eggs were delivered. The eggs were divided among the two different incubation methods, including the Nur Nature Base incubator system and the heath tray system.

The Nur Nature Base incubator system received approximately 42,188 eggs, and the number of mortalities and fish released was not recorded. The heath tray system was supplied with approximately 20,100 eyed eggs. Of those eggs, 638 mortalities were recorded before release. Therefore, approximately 19,500 fry were released from the heath tray system, and an unknown number of juveniles were released from the Nur Nature Base incubator system into the Winnemem Waywaket.

An IPT and RST were installed on the Winnemem Waywaket and operated from August 27 to November 11 (IPT) and November 19 (RST). A total of 4,583 juvenile fish were collected in river. In addition, four efficiency trials were conducted on the IPT, and estimated collection efficiency ranged from 22.5% and 72.25%. On November 11, 2024, the IPT was removed due to increased flow and debris loading. RST operation continued until November 19, 2024. Two efficiency trials were conducted on the RST and estimated collection efficiency was between 0% and 3.47%.

DWR installed and operated the JSCS downstream of the IPT and the RST in the McCloud Arm of Shasta Reservoir between Pine Point and Ellery Creek from September 17, 2024, through January 19, 2025 (DWR 2025a). The JSCS captured 78 fish throughout the season, including efficiency trials. The average capture probability across the season was 1.5%, with a maximum recapture rate of 6% and a minimum recapture rate of 0% (DWR 2025a). The JSCS did not catch fish after December 5, 2024, when water depth at the trap entrance exceeded 15 feet. Predation may have significantly impacted survival and capture probability, and trap location and function likely contributed to low trap efficiencies (DWR 2025a).

The number of fish collected, transported, and released into the Sacramento River in Redding for 2024 was 4,661 juveniles from in-river collection and the JSCS.

1.2 Project Goal and Objectives

This Project builds on the previous work that has been completed to bring Chinook Salmon back to the Winnemem Waywaket, and the overarching goal of the Project is to collect data needed to inform and evaluate volitional fish passage alternatives. Specific Project objectives included the following actions:

- Reach out to and coordinate with key collaborators and landowners to communicate Project goals and objectives.
- Incorporate ITEK into data gaps studies, as possible, by collaborating with the Winnemem Wintu Tribe to learn about ITEK and the Winnemem Wintu Tribe's perspective on fish behavior, timing of life-history events (e.g., spawning and migration), and observed traits and characteristics.
- Provide support to USGS as it implements the biological data gaps project by providing expert knowledge on salmon behavior and ecology needed for fish passage and alternatives assessment.
- Organize and co-lead a tour of Pacific Northwest (PNW) fish passage facilities in 2025.
- Compile existing data or collect new data on the information needed for the formulation and evaluation of volitional passage alternatives.
- Describe the current trap and haul concept for Shasta Dam in sufficient detail to allow volitional passage alternatives to be compared to traditional trap and haul.

2 Indigenous Knowledge, Coordination, and Outreach

2.1.1 Indigenous Traditional Ecological Knowledge

The Winnemem Wintu Tribe is guided by ITEK, which is the knowledge and practices that describe the relationships of living beings with one another and with their physical environment (Berkes et al. 2000). ITEK has developed over many centuries and has been passed down from generation to generation through oral transmission. ITEK is place based and is formed from communal knowledge gained over time through practice and application. Western science is based on certain principles that have been determined using the scientific method to explain the natural world. A hypothesis (or question) is developed based on observations of the natural world and an experiment is designed to collect some type of data that helps to validate or invalidate the hypothesis. ITEK and Western science come from different perspectives. The differences between ITEK and Western science are summarized as follows from an article in *Science*.

> Although both Indigenous knowledge and Western science include observations and data collection, they differ in several key dimensions, Atalay explains. Indigenous knowledge is place-specific, whereas Western science tends to seek universal rules that apply everywhere. Indigenous knowledge is rooted in the relationship between humans and their environment rather than isolating study targets from their surroundings. And the knowledge gained through Indigenous science is managed by the community, in contrast to publishing all results and using patents to restrict access to certain information. (Mervis 2023)

Others have observed that defining ITEK and comparing it to Western science is difficult and commented on the role of ITEK as a collaborative concept as summarized in the following excerpt from an article by Whyte (2013) in *Ecological Perspectives*.

> I argue that the concept of TEK should be understood as a collaborative concept. It serves to invite diverse populations to continually learn from one another about how each approaches the very question of "knowledge" in the first place, and how these different approaches can work together to better steward and manage the environment and natural resources. Therefore, any understanding of the meaning of TEK is acceptable only so long as it plays the role of bringing different people working for different institutions closer to a degree of mutual respect for one another's sources of knowledge. The implication is that environmental scientists and policy professionals, indigenous and non-indigenous, should focus more on creating long term processes that allow for the implications of different approaches to

knowledge in relation to stewardship and management priorities to be responsibly thought through.

The Consultant Team's interpretation of knowledge shared by the Winnemem Wintu Tribe is that handling salmon impacts their ability to survive by reducing their wildness. The Consultant Team's interpretation of what we heard from the Winnemem Wintu Tribe is that the Tribe supports collecting data in ways that minimize touching of the fish or disturbing the fish's interactions with their environment and further supports hands-off, fully volitional passage of adult and juvenile fish between the Nomtipom Waywaket and the Winnemem Waywaket. This means that adult and juvenile fish can migrate upstream and downstream unassisted, under their own swimming capability, using timing and behavior they choose (i.e., they are not trapped, mechanically lifted or pumped, or transported).

This Project has been implemented from the Western science perspective, and the Consultant Team has coordinated with Winnemem Wintu Tribe since Project kickoff and has been learning about the Winnemem Wintu Tribe's ITEK and integrating the Consultant Team's interpretation of the Tribe's ITEK into the studies and this report, including the technical memoranda and the Feasibility Study, to the best of the Consultant Team's ability.

Members of the Project team were invited to and attended a Winnemem Wintu Tribe Egg Ceremony in August of 2024 and July of 2025. At each ceremony, the Winnemem Wintu Tribe and invited guests received winter-run hatchery eggs for incubation and introduction to the Winnemem Waywaket. Ceremony and prayers were conducted for the eggs prior to placement in the Nur Nature Base incubation systems.

Coordination calls with Winnemem Wintu Tribe occurred every other week throughout Project implementation and as needed to keep the Tribe informed of Project progress and results, answer questions, and provide opportunities for the Consultant Team to learn and integrate their interpretation of the Tribe's ITEK into the Project. In addition, the Consultant Team met in person with Winnemem Wintu Tribe staff and members to hear the Tribal and ITEK perspectives when conducting Project site visits.

2.1.2 Summary of Coordination and Feedback with Salmon Co-Managers and DWR

The Consultant Team convened monthly coordination calls on the first Wednesday of each month with a group called the Passage Partners that included the salmon co-managers (Winnemem Wintu Tribe, CDFW, and NMFS), DWR, and Pacific States Marine Fisheries Commission. The calls were informal, and not all organizations were represented on every call. The purpose of these calls was to keep the Passage Partners informed on the status of the physical and biological data gaps studies and the Feasibility Study, answer questions, and provide initial study results for discussion. Meeting summaries from the Passage Partner coordination calls is provided in Appendix A.

DWR administered the CDFW grant money for the Feasibility Study. In this role, DWR convened coordination calls with the Consultant Team every other week. On these calls, the Consultant Team provided updates on the status of the physical and biological studies and Feasibility Study and discussed any necessary topics with DWR staff.

2.1.3 Outreach

The Consultant Team participated in in-person and virtual outreach meetings with the Winnemem Wintu Tribe, CDFW, NMFS, key collaborators, and interested parties to present project updates and results. These outreach meetings included the following:

- Bay Delta Science Conference in Sacramento, California, in October 2024, where Anchor QEA and USGS presented an overview of the physical and biological data gaps studies
- In-person Technical Advisory Group (TAG) meeting in January 2025 in Sacramento, California, and a virtual TAG meeting in April 2025. During both meetings, the Consultant Team presented initial physical and biological data gaps results to the TAG. The TAG was convened to support the Feasibility Study and consists of representatives from the Tribe, CDFW, NMFS, Reclamation, U.S. Fish and Wildlife Service (USFWS), DWR, Trout Unlimited, and the Sacramento River Settlement Contractors.
- Sacramento River Science Partnership Science Subcommittee Meeting in July 2025, where Anchor QEA and USGS presented an overview of the physical and biological data gaps studies and initial results
- Workshop on Fish Reintroduction and Passage for High-Head Dams in September 2025 in Sacramento, California, where the Consultant Team presented on the physical and biological data gaps studies and results and the Feasibility Study

Additionally, the Consultant Team coordinated with landowners to obtain access to conduct the studies. Access was required in Dry Creek, Little Cow Creek, and Cow Creek for the temperature data collection study and the physical barrier study. Access was also required in the Winnemem Waywaket for the temperature data collection study. Based on the data collection needs, 34 parcels were selected for outreach. Landowner names and mailing addresses were obtained from the tax assessor's office. A standardized outreach letter (see Appendix B) was sent to each landowner, and additional contact was made via phone and/or email when that information was available. Several landowners reached out after receiving the letters and followed up with questions about the studies due to interest and were generally enthusiastic about helping. In total, 15 landowners granted access to their parcels. No letters were returned denying access. All landowners who granted access requested advance notification prior to any site visits. Some parcels requested further coordination due to landowner preference, reduced interference with business operations, or due to weather concerns. These landowners were contacted typically one month in advance and actively coordinated with through phone and email to accomplish Project goals.

2.1.4 PNW Fish Passage Facility Tour in 2025

The Consultant Team coordinated a tour of PNW fish passage facilities for the salmon co-managers, key project team members, and collaborators to see existing fish passage facilities and learn from the facility owners about the operation and maintenance of each facility.

The objective of the tour was to observe facilities that inform the feasibility of providing passage of Chinook Salmon from the Nomtipom Waywaket to the Winnemem Waywaket and facilitate engagement with reintroduction practitioners working for the Yakama Nation to discuss lessons learned from reintroduction programs conducted over the past 20 years. The itinerary for the tour and a list of participants is provided in Appendix C. Activities and outcomes from the tour include the following:

- Day 1: Lower and Upper Cushman Dam, Hoodsport, Washington
  - Objective: See how Tacoma Power and the Skokomish Tribe resolved the issue of how to lift adult fish collected at the base of a high-head dam to a handling facility
  - Potential application: Lifting juvenile fish collected in the Winnemem Waywaket up and into a flume to allow them to flow via gravity to Dry Creek and lifting adults over Shasta Dam
  - The group was able to view the operation of a fish elevator that travels from the base to the top of the dam approximately 150 feet and discussed facility performance and modifications with Tacoma Power representatives.
- Day 2: Cle Elum Cle Elum Dam, Roza Dam, and a nature-like passage channel on the Yakima River
  - Objective: Tour the Cle Elum downstream juvenile Sockeye Salmon (*Oncorhynchus nerka*) volitional passage facility (helix), view adult collection facilities at the dam, and discuss Sockeye Salmon reintroduction efforts (and visit the Cle Elum River immediately upstream of the reservoir) and program with the Yakama Nation
  - The group toured the helix and was able to see six multilevel ports that were constructed to address the range in surface water fluctuations in the Cle Elum Reservoir, which is similar to Shasta Reservoir.
  - The group discussed the reintroduction of Sockeye Salmon into the Cle Elum River with the Yakama Nation staff.
  - The group toured Roza Dam on the Yakima River and heard about how the fish passage facility is used to collect and transport adult salmon to support reintroduction programs run by the Yakama Nation.

  - The group toured the City of Yakima site of the former Nelson Dam, which is now a nature-like fishway. The dam was removed, and a grand control structure was constructed to provide water to the city while allowing adult and juvenile salmonids to freely pass through the reach. This is an example of how to potentially bifurcate water and have a potential tributary bypass enter the Winnemem Waywaket.
- Day 3: Yakima River fish passage facilities and reintroduction discussions with Yakama Nation at Prosser Dam
  - Objective: View multiple Yakama Nation facilities and programs; adult Sockeye Salmon can be collected and transported if lower river water temperature becomes too high; many aspects of the various Yakima River reintroductions are based out of the Prosser "hub."
  - The group met with the Yakama Nation/USGS Smallmouth Bass removal crew who were sampling in the reach below the dam.
  - The group viewed Prosser headgates and talked about flow management, water temperature issues, Pacific Lamprey reintroduction, summer-run and fall-run Chinook Salmon reintroduction efforts, and avian predation.
  - The Winnemem Wintu Tribe was introduced to Yakama Nation members working on fish passage and reintroduction efforts.
  - The group was able to hear lessons learned from reintroduction efforts that have been ongoing for 20 years or more on the Yakima River.

3 Overview of Data and Information Compiled and Collected

Information and existing data were compiled, or new data were collected, for each of the physical and biological data gaps studies and/or topics listed in Table 1. Information and data were compiled within the Study Area that encompasses the area where fish passage alternatives are currently being considered. A potential tributary bypass from Cow Creek to Little Cow Creek to Dry Creek and into the Winnemem Waywaket is the only fully volitional passage alternative and the only alternative the Winnemem Wintu Tribe supports. As such, there was a focus on collecting information and data to inform the evaluation of that potential swimway. The term "swimway" is hereto used throughout this document and related appendices and attachments to define the length of modified and/or constructed waterway intended to provide a hydraulicly continuous navigational pathway for migrating Chinook Salmon.

Desktop searches for existing publicly available information and targeted outreach were conducted to identify the existing characteristics of the Study Area and identify data gaps. Additional topographic and bathymetric Light Detection and Ranging (LiDAR), instream temperature, and physical barriers data were collected in the field to support the Feasibility Study. Data sources by topic are summarized in an excel spreadsheet provided in Appendix D, which includes the topic, a full citation for the data source, and a description of the importance of each source to the Feasibility Study.

Table 1
Summary of Physical and Biological Data Compiled and/or Collected for the Project

Data Category	Data Type	Description	Report Section with Details
Physical	LiDAR	Collected new topographic and bathymetric data along sections of Dry Creek, Little Cow Creek, and Cow Creek and the Winnemem Waywaket in Study Area to support Project studies	4.1.2
Physical	Transportation Corridors, Access, and Utilities	Compiled existing publicly available data and information within the Study Area and conducted a limiting factors analysis to identify site-specific challenges for the construction and operation of future fish passage elements	4.1.3
Physical	Water Infrastructure (dams, release structures, water pipelines, open-channel distributaries, diversion structures, storage tanks, water intake structures, and water crossings), Barriers, and Water Rights	Compiled existing publicly available data and information to describe the existing conditions within the Study Area that could impact implementation of fish passage alternatives	4.1.4
Physical	Hydrology	Compiled existing publicly available stream flow data in the Winnemem Waywaket and Cow Creek and calculated statistics to estimate current (regulated) flow exceedance conditions, current peak flow conditions, unregulated conditions, and potential future conditions with climate change on the Winnemem Waywaket and Cow Creek	4.1.5
Physical	Temperature	Compiled existing publicly available data and collected new instream data in the Winnemem Waywaket, Dry Creek, Little Cow Creek, and Cow Creek to fill a critical data gap and support the thermal accumulation evaluation of fish passage alternatives	4.1.6.1
Physical	Thermal Accumulation	Using existing instream temperature data, conducted preliminary assessment of thermal gains, water supply, and water temperature suitability for winter-run and spring-run Chinook Salmon for fish passage alternatives; identified preliminary recommendations and remaining data gaps that will be used to inform future fish passage facility siting and evaluation	4.1.6.2
Physical	Water Supply	Conducted an evaluation of water sources and supply needed for fish passage alternatives	4.1.7

Data Category	Data Type	Description	Report Section with Details
Physical	Physical Barriers	Compiled existing publicly available data and information on physical barriers; collected data in the field and conducted an evaluation of natural and anthropogenic barriers along the potential tributary bypass in Dry Creek, Little Cow Creek, and Cow Creek	4.1.8
Physical	Trap and Haul	Compiled existing information on trap and haul approach to fish passage at Keswick and Shasta dam, which was used to compare to the volitional passage alternatives in the Feasibility Study	4.1.9
Biological	Nomtipom Waywaket Chinook Salmon Life History	Compiled existing publicly available information on life-history diversity, timing, and environmental factors affecting various life stages of Chinook Salmon in the Nomtipom Waywaket to inform potential donor populations for reintroducing Chinook Salmon into the Winnemem Waywaket from local sources and the development of alternatives for passing adult and juvenile fish around Keswick and Shasta dams	4.2.1, 4.2.2
Biological	Juvenile Salmon Out-Migration from the Winnemem Waywaket – In-River Collection	Compiled and evaluated existing data on the in-river collection of juvenile Chinook Salmon in the Winnemem Waywaket using RSTs and an IPT	4.2.3.1
Biological	Juvenile Salmon Out-Migration from the Winnemem Waywaket – Head-of-Reservoir Collection	Compiled data and information on the operation of the head-of-reservoir JSCS that has been designed and operated by DWR since 2022	4.2.3.2
Biological	Life-Cycle Modeling	Used the existing winter-run Chinook Salmon life-cycle model to estimate juvenile fish collection efficiency targets that juvenile fish collection methods need to achieve to sustain a population of Chinook Salmon in the Winnemem Waywaket and to evaluate the fish passage alternatives in the Feasibility Study	4.2.5

4 The Physical and Biological Setting

This section provides the physical and biological setting for the Study Area where fish passage alternatives are currently being considered as part of this study effort. This information could influence the design of fish passage alternatives and is important to compile, collect, and document to support the formulation and evaluation of fish passage alternatives in the Feasibility Study. The physical setting (Section 4.1) describes the Study Area and the existing environmental and infrastructure characteristics within the Study Area. Key physical characteristics include topography/bathymetry, hydrology, water quality, natural and anthropogenic fish passage barriers, site access, transportation corridors, utilities, water-related infrastructure, water rights, and water supply and availability. The biological setting (Section 4.2) includes ecological and species-specific considerations, including target species and life stages, migration timing, homing characteristics, life-cycle considerations, reservoir conditions (fish movement and food web), reintroduction risk and benefits, fish health considerations, and conditions in the reintroduction/rematriation area.

4.1 Physical Setting

4.1.1 Study Area

The Study Area extends from the confluence of Cow Creek and the Nomtipom Waywaket and includes the Winnemem Waywaket from Shasta Reservoir to the McCloud Dam (Figure 1). It includes portions of the Winnemem Waywaket; Nomtipom Waywaket, including Keswick and Shasta dams and reservoirs; Dry Creek; Little Cow Creek; and Cow Creek. These water bodies vary in hydrology, geomorphology, and water quality, with seasonal fluctuations in temperature and flow; these parameters are being measured during this Project to evaluate habitat suitability and passage for salmonids. Understanding these physical conditions is essential to evaluating the feasibility of restoring fish passage to historical spawning and rearing areas upstream of the dams.

River miles used in this report and appendices are shown on Figure 2 for Dry Creek, Little Cow Creek, and Cow Creek and Figure 3 for the Winnemem Waywaket,

Figure 1
Study Area

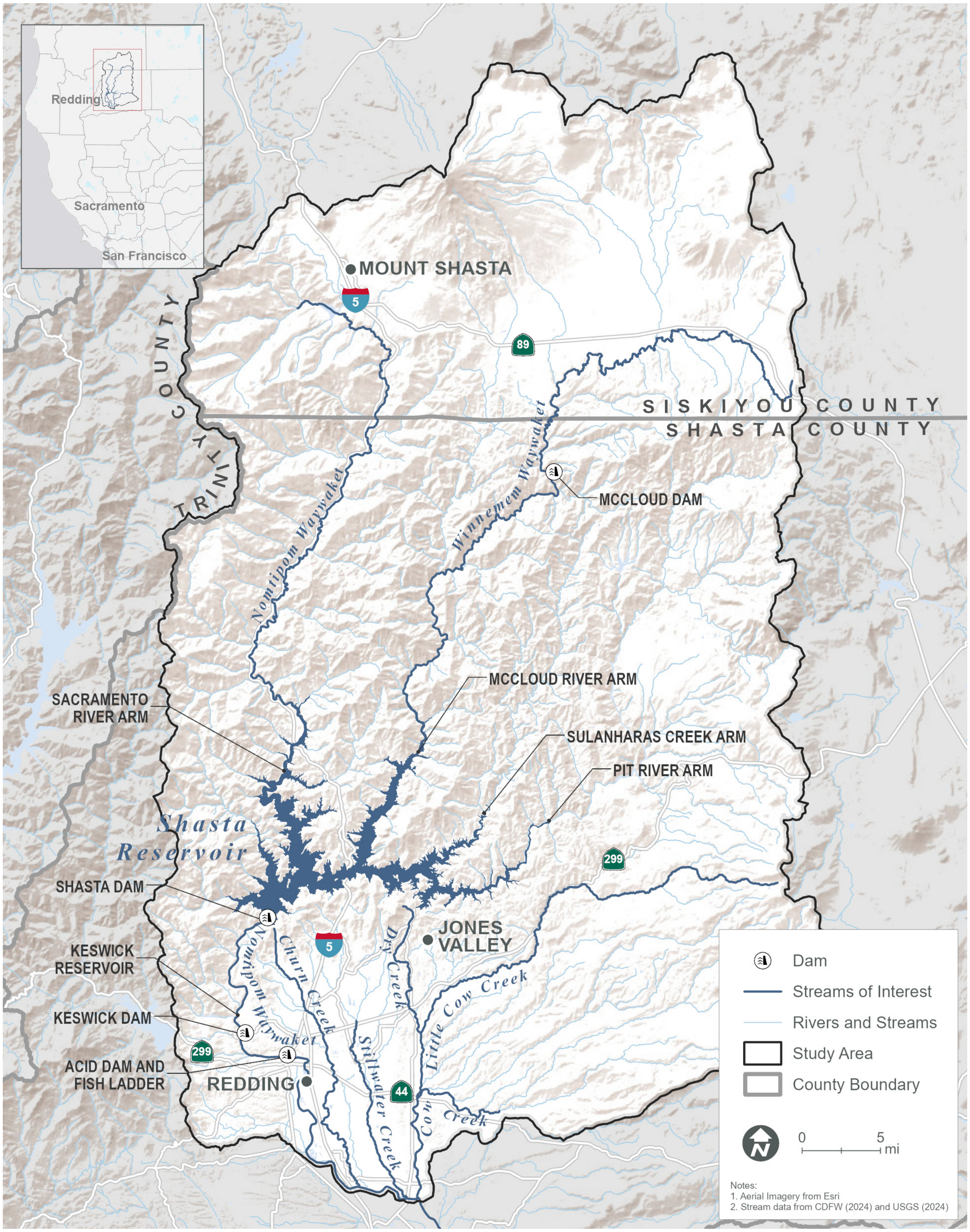


Figure 2
River Miles for Dry Creek, Little Cow Creek, and Cow Creek

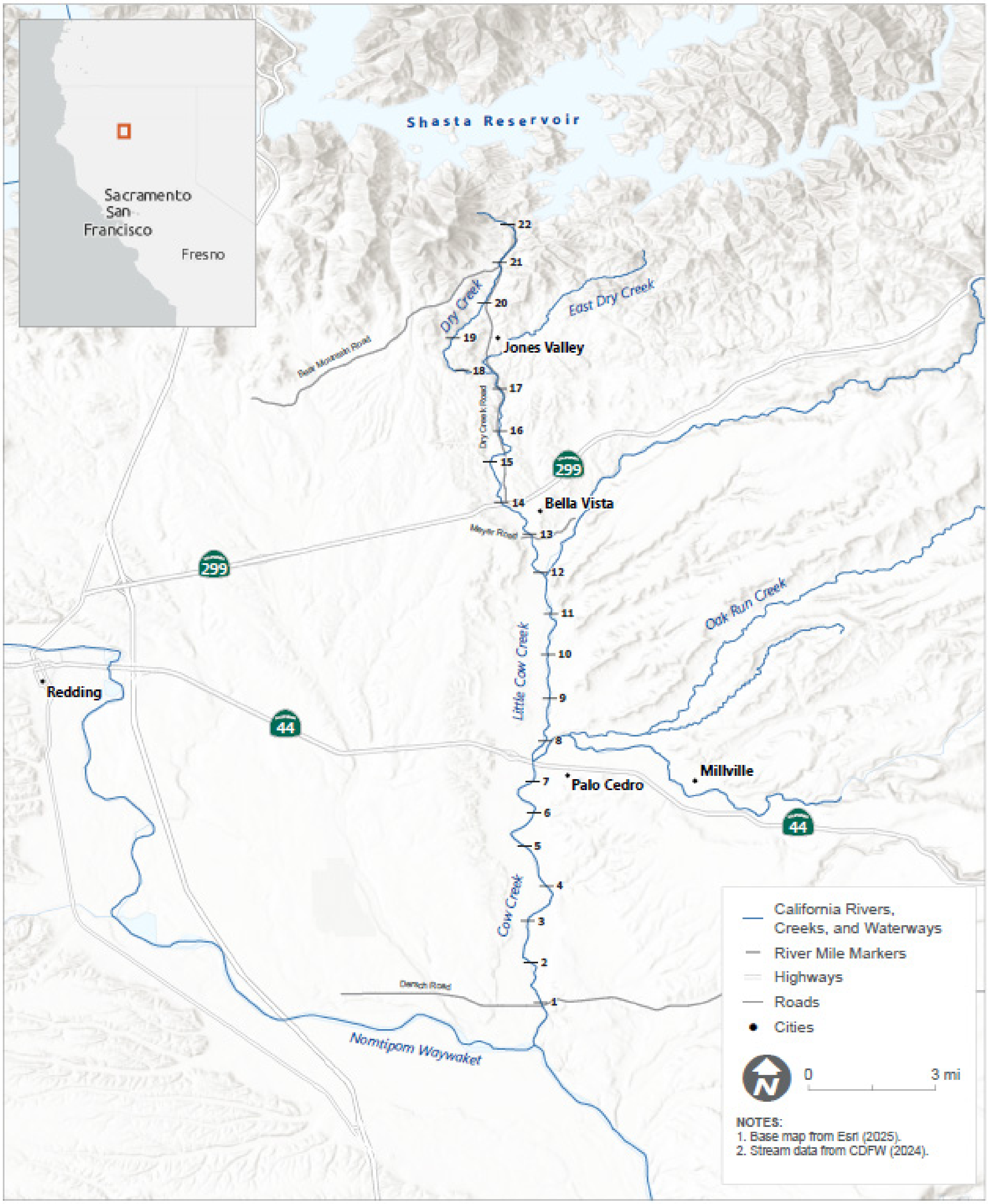
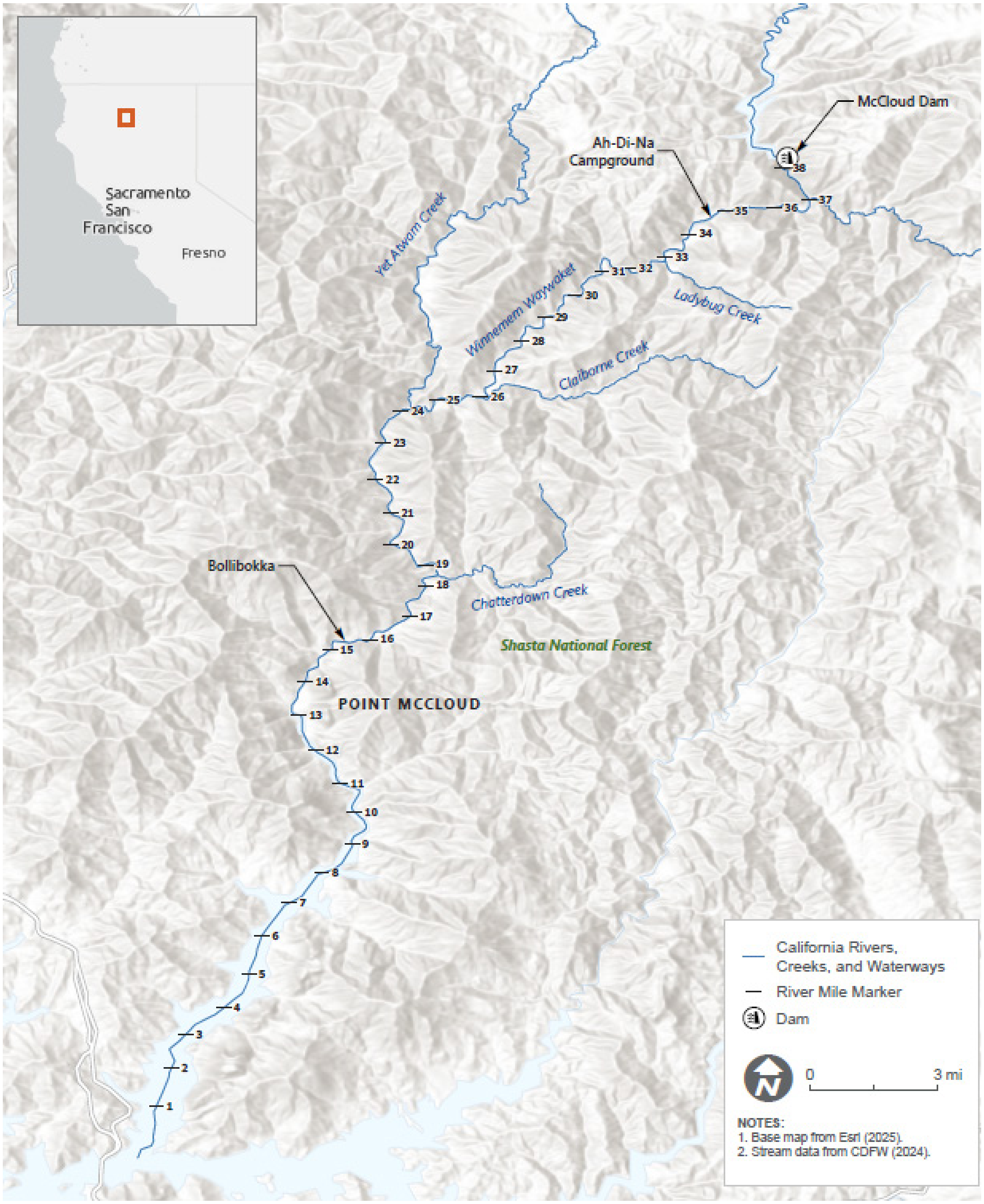


Figure 3
River Miles for the Winnemem Waywaket



4.1.2 LiDAR Data Collection

In the fall of 2024, NV5, under contract with Anchor QEA, conducted an airborne topographic and bathymetric LiDAR and digital imagery survey across 3,422 buffered acres in the Winnemem Waywaket, Dry Creek, Little Cow Creek, and Cow Creek watersheds. The data collection effort is summarized below and documented in a report provided in Appendix E, *2024 Topobathymetric Lidar and Imagery Technical Data Report*.

4.1.2.1 Purpose and Scope

The purpose of the LiDAR survey was to collect high-resolution topographic and bathymetric data and co-acquire digital imagery of the Winnemem Waywaket, Dry Creek, Little Cow Creek, and Cow Creek to support the physical data gaps studies as well as the fish passage alternatives formulation and evaluation. Topobathymetric data were collected along the Winnemem Waywaket and topographic data only were collected along Dry Creek, Little Cow Creek, and Cow Creek. Specifically, these data were used as part of the hydraulic analysis that was part of the natural barriers evaluation described in Section 4.1.8 and Appendix L, *Physical Barriers to Fish Passage Evaluation*, and identifying locations for siting future facilities and challenges associated with known preferred future facility locations access routes and potential locations for fish passage facilities as described in Section 4.1.3 and Appendix F, *Physical Considerations for Construction of a Volitional Swimway Around Keswick and Shasta Dams*. The existing topographic LiDAR data were not sufficient because no bathymetric data were available along the Winnemem Waywaket and parts of Dry Creek, Little Cow Creek, and Cow Creek, and higher-resolution data were needed in all areas.

4.1.2.2 Methods

LiDAR data are generally collected by emanating a pulsed laser light to the ground. The laser light bounces off the ground and back to a sensor. The sensor then measures the distance between the ground and the sensor (based on the time it took the laser light to bounce back) as well as the intensity of the light that was reflected. To collect topographic and bathymetric data, traditional near-infrared (NIR) LiDAR was fully integrated with green-wavelength return (bathymetric) LiDAR data to provide a seamless topographic and bathymetric dataset. A high-resolution topobathymetric dataset consisting of greater than or equal to 8 pulses/m^2 (on average) was prepared.

The survey utilized a Riegl VQ-880-GII LiDAR system mounted on a Cessna Grand Caravan to collect data integrating NIR and green-wavelength lasers. These enabled simultaneous mapping of land topography and submerged riverbeds. A PhaseOne iXM-RS150F digital camera captured co-acquired RGB imagery at 0.5-foot resolution. Ground control was achieved via real-time kinematic, post-processed kinematic, fast static, and Global Navigation Satellite System techniques, supported by multiple base stations and aerial targets to ensure spatial accuracy.

Upon completion of data acquisition, NV5 processing staff initiated a suite of automated and manual techniques to process the data and photographs into the deliverables. These data processing steps are described in detail in Appendix E.

Deliverables provided by NV5 included the following:

- Classified point clouds (LAS v1.4)
- Digital elevation models (bare earth), Digital Surface Models, intensity images (NIR and green), and a water surface model
- RGB orthophoto mosaics (GeoTIFF and compressed SID formats)
- Bathymetric coverage shapefiles and metadata compliant with Federal Geographic Data Committee standards
- A comprehensive technical report documenting methods and results

4.1.2.3 Key Findings

Data acquisition occurred on October 6 and 7, 2024, preceded by Secchi depth and turbidity measurements to assess water clarity. This was done to inform the collection of bathymetric data within the stream channel. Careful flight planning, including ≥60% flight line overlap, enabled thorough data coverage. Survey parameters targeted ≥8 points/m^2 average pulse density. NIR LiDAR was fully integrated with green-wavelength return (bathymetric) LiDAR data to provide a seamless topobathymetric LiDAR dataset.

Approximately 50.2% of bathymetric areas were successfully mapped, with limitations mostly in the Winnemem Waywaket attributed to the following:

- Terrain-driven flight elevation (up to 1,300 meters [m] above ground level)
- Stream depth and reflectivity affecting bathymetric return density

NV5 implemented post-processing steps, including bathymetric refraction correction (via proprietary LAS Monkey software), classification using American Society for Photogrammetry and Remote Sensing standards, and quality assurance against ground survey benchmarks.

4.1.2.4 Conclusions

NV5 delivered high-resolution, accurate topographic and bathymetric and imagery data products. These datasets provide information for understanding general topography, bathymetry (where possible), and river morphology along the Winnemem Waywaket, Dry Creek, Little Cow Creek, and Cow Creek. The collection of bathymetry data along the Winnemem Waywaket was challenging due to the required flight elevation and stream depth. As such, this remains a data gap. All methods, calibrations, and results were reviewed and certified by NV5’s professional land surveyor and project manager in accordance with national spatial data accuracy standards.

4.1.3 Physical Access Data Compilation and Analysis

Physical access data and information were compiled to support a limiting factors analysis (LFA) to inform ease of access, property use, and availability of services within areas where potential fish passage alternatives are currently considered. Data and information were acquired through a variety of public sources, such as Shasta County, the U.S. Department of Agriculture (USDA) Forest Service, the California Energy Commission (CEC), and PacifiCorp, among others. Detailed information about sources utilized can be found in Appendix D. A summary of the data compilation is provided below and full details are included as Appendix F.

4.1.3.1 Purpose and Scope

The purpose of this data compilation effort was to collect existing data, including, topography and bathymetry, transportation corridors, electrical service, parcel data (including property ownership, land use type, development, and flood zone), and stream access points within the Study Area. The data was used to inform an LFA for the design, access, construction, and operation of potential fish passage facilities associated with the volitional passage alternatives. Results of the LFA identified locations for siting future facilities and identified challenges associated with potential facility locations.

4.1.3.2 Methods

Data for existing physical conditions were sourced via desktop research and compiled into an online geospatial database and used in the LFA to support the development and evaluation of fish passage alternatives as part of the Feasibility Study process. A summary of the data and sources compiled for the LFA is shown in Table 2, while a complete record of data sources and metadata is included in Appendix D.

Table 2
Summary of Data Compiled

Data type	Data compiled	Source
Topography and bathymetry	LiDAR	OCM Partners (2024)
Transportation corridors	County/city/federal/private roads; National Forest System roads	Shasta County (2024); USDA Forest Service (2024); HDR (2024a)
Electrical service	CEC substations; electrical distribution systems owned by Pacific Power, City of Shasta Lake, City of Redding	CEC (2024); PacifiCorp (2024); City of Shasta Lake (2024); City of Redding (2024)
Parcel information	Parcel boundaries; ownership; land use; size; FEMA Flood Zone	LOVELAND Technologies (2024)
Stream access points	Aerial imagery review of improved or unimproved roadways leading to the OHW; site reconnaissance of water crossings	HDR (2024b); HDR (2024c)

Topographic data were available throughout the Study Area, which will allow the Consultant Team to initiate conceptual design and siting of key landward features of fish passage alternatives, including access roads, laydown areas, and fish passage facilities. In the Winnemem Waywaket, collection of green LiDAR data (i.e., bathymetric data) was challenging due to terrain-driven elevation of the LiDAR data collection flight and water depth. Bathymetric data were identified only in areas where the Dry Creek, Little Cow Creek, and Cow Creek were dry at the time of LiDAR collection because green LiDAR data were only collected in the Winnemem Waywaket. These data were used to inform the analysis of existing channel elevation and width to identify challenges for volitional passage.

Transportation corridors identified included county, city, federal, private, and National Forest Service roads. Two private roads, the Bollibokka Fly Fishing Club Private Road and the McCloud Fly Fishing Club Private Road, were hand-digitized using aerial imagery from Google Maps (HDR 2024a). The transportation corridor data were used to inform the "Access" factor as part of the LFA to determine challenges related to regular staffing, maintenance, or construction activities at different potential fish passage facility locations.

Electrical service data were sourced from the CEC, PacifiCorp, the City of Shasta Lake, and the City of Redding. Pacific Gas and Electric Company (PG&E) did not provide detailed electrical service linework for the Study Area; however, based on a review of electric service area maps, PG&E is the main provider of power for the residential homes and public buildings along the Winnemem Waywaket, Dry Creek, Little Cow Creek, and Cow Creek (PG&E 2014). Knowledge of the electrical services in the Study Area was used to inform the "Power Availability" factor in the LFA by identifying general areas without existing nearby power, which increases the difficulty and cost in constructing and operating a potential fish passage facility.

Parcel information included the boundaries and a full list of attributes for each parcel, such as Assessor Parcel Number, size, description of land use, zoning code, zoning description, and owner. Parcel ownership, use, and parcel size are important for determining the "Parcel Type" and "Parcel Size" factors in the LFA because they provide insight regarding anticipated level of difficulty for future efforts to acquire easements or property, as well as the number of acquisitions that may be required.

The Federal Emergency Management Agency (FEMA) has conducted detailed flood studies in Cow Creek, Little Cow Creek, and portions of Dry Creek and the Winnemem Waywaket. At this stage of fish passage alternative development, knowledge of the FEMA-identified flood zone within the Study Area informs the level of complexity needed for future permitting efforts and the resulting "FEMA Flood Zone" factor in the LFA.

Stream access data were gathered via aerial imagery and through field investigations. The aerial review and site reconnaissance confirmed locations of existing water crossings and existing improved or unimproved roadways leading to the approximate location of the stream's OHW line. The stream access data were used to inform the "Access" factor as part of the LFA.

The intent of the LFA was to provide a numerical ranking of all parcels based on key considerations common to all types of fish passage facilities. The results of the LFA can be used to evaluate possible facility locations and identify site-specific challenges at the location. Each parcel was assigned a score of 0 to 5 for each limiting factor, with 25 points as the maximum. A higher score is preferable, indicating fewer limitations for construction and operation of a future fish passage facility. A summary of the factors, their definitions, and an abbreviated version of the rating scale is provided in Table 3. Refer to Appendix F for the full definitions of each factor and rating scale.

Table 3
Limiting Factors and Scoring

Limiting Factor	Definition	Rate Scale
Access	The “Access” factor is intended to identify parcels that have either existing stream access, road access, or both. Fish passage facilities require both stream access and road access for everyday function and ongoing maintenance. Existing water crossings provide the simplest stream and parcel access, while improved or unimproved roadways leading to the OHW line may also serve as important features. Transportation corridor data and stream access data inform the “Access” factor score.	**Score of 5 (best):** A water crossing exists or a maintained (paved) roadway exists that leads to the existing OHW line; or there is a water crossing located on an adjacent right-of-way parcel. **Score of 0 (worst):** Roadways or crossings are more than 1 mile from the site.
Power Availability	The “Power Availability” factor is intended to identify parcels that have existing electrical service. Electrical service is the most critical need for a future fish passage facility to operate and maintain the facility. Electrical service data inform the Power Availability score.	**Score of 5 (best):** A commercial or industrial building exists on the site that most likely has three-phase power. **Score of 0 (worst):** Electrical service lines (excluding transmission lines) are more than 5 miles from the site measured along unimproved or improved roadways.
Parcel Type	The “Parcel Type” factor is intended to identify the ownership and whether a parcel had been previously developed for each of the parcels along the study streams. The parcels along the study streams vary between privately or publicly owned and developed or undeveloped. The state of ownership or development affects the difficulty of acquiring easements or property. Parcel ownership and use data inform the Parcel Type score.	**Score of 5 (best):** The parcel is publicly owned and without development. **Score of 0 (worst):** The parcel is owned by a private landowner or by a trust and is developed.
Parcel Size	The “Parcel Size” factor is intended to identify the relative size of each of the parcels. Depending on the selected facility, a future fish passage facility may require purchase of only one large parcel (approximately 3 acres minimum) or could necessitate the purchase of several smaller parcels (less than 3 acres), increasing Project costs and coordination needs.	**Score of 5 (best):** The parcel is 3 acres or more. **Score of 0 (worst):** The parcel is less than 0.5 acre.
FEMA Flood Zone	Depending on the FEMA Flood Zone, additional permitting effort may be needed for construction of facilities. Extra cost, coordination, or effort may be associated with properties that are adjacent to a stream channel designated as a SFHA.	**Score of 5 (best):** The parcel is Zone X (unshaded) – area of minimal flood hazard. No additional permitting required. **Score of 0 (worst):** The parcel is Zone A or AE – SFHA. Additional permitting required.

4.1.3.3 Key Findings

Table 4 provides a summary of the results of the LFA for all 455 parcels. Out of the possible 25 points, the maximum score achieved by any parcel was 23 points, and the minimum score was 9 points.

Table 4
Limiting Factors Analysis Results

Score (Points)	Rating	Number of Parcels
19–25	Optimal	14
16–18	Good	92
13–15	Fair	235
0–12	Poor	114

Figures 4 through 9 provide the existing data collected within the Study Area to inform the LFA and each parcel's resulting score.

Figure 4
Limiting Factors Analysis (Winnemem Waywaket, North)

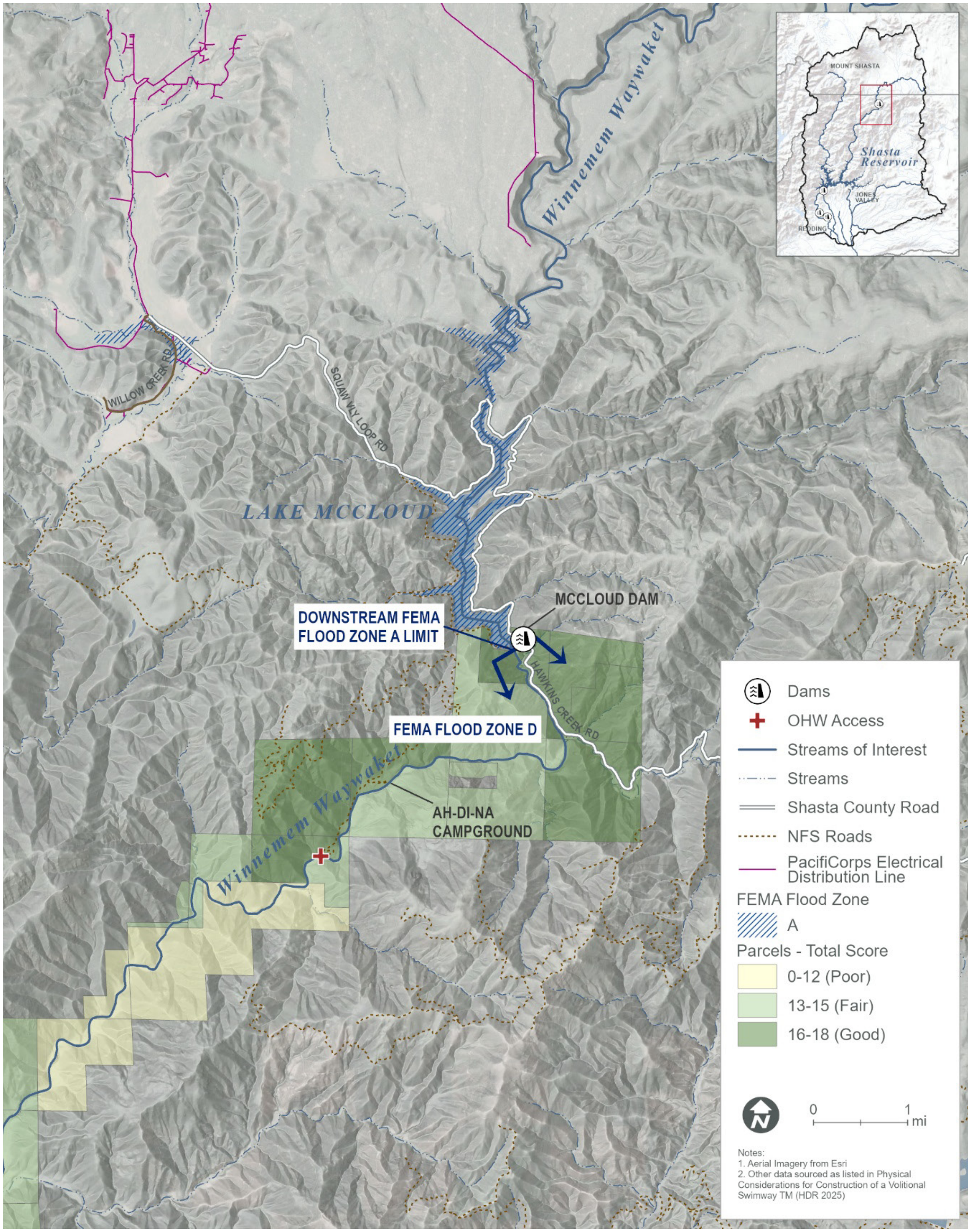


Figure 5
Limiting Factors Analysis (Winnemem Waywaket, South)

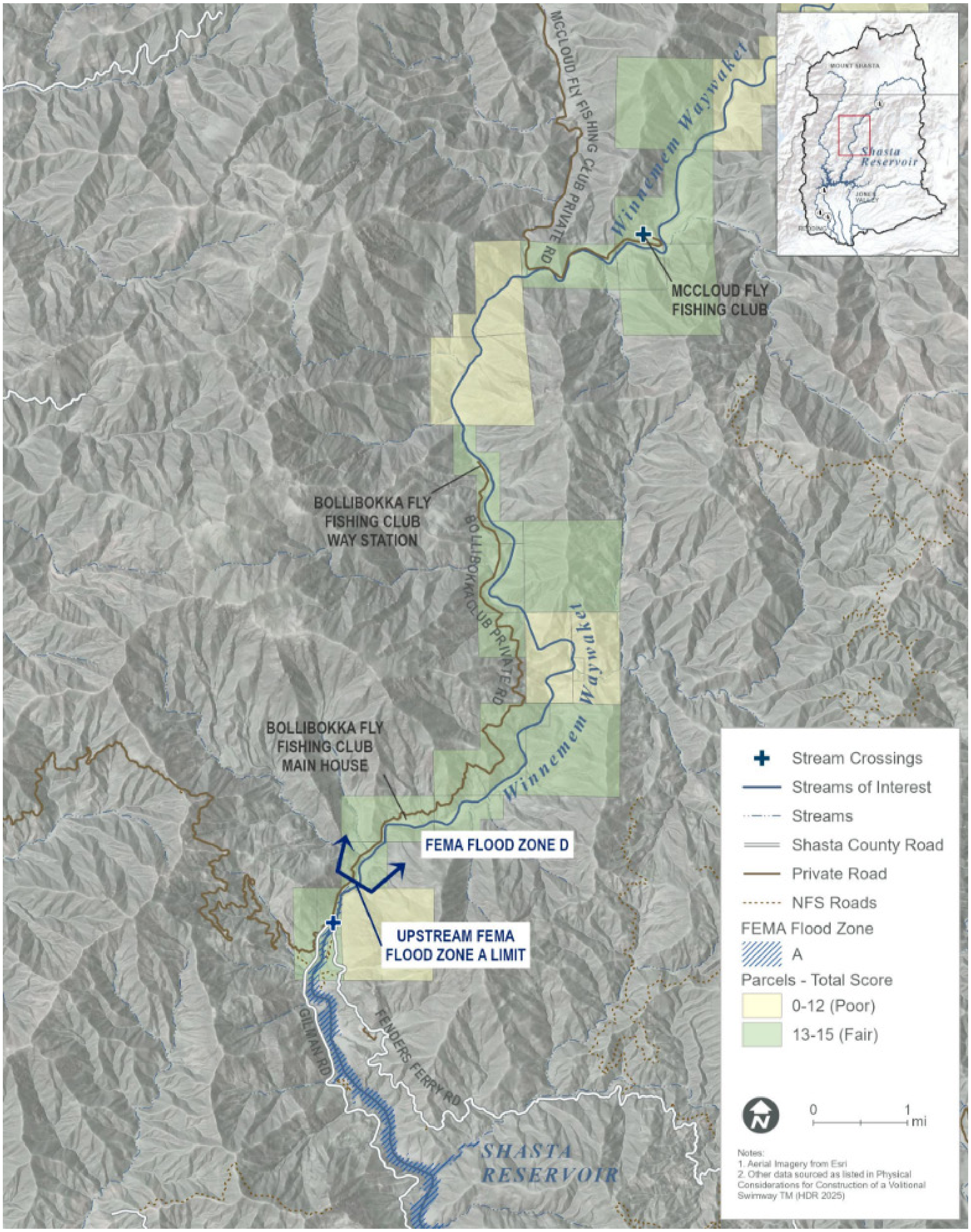


Figure 6
Limiting Factors Analysis (Dry Creek, North)

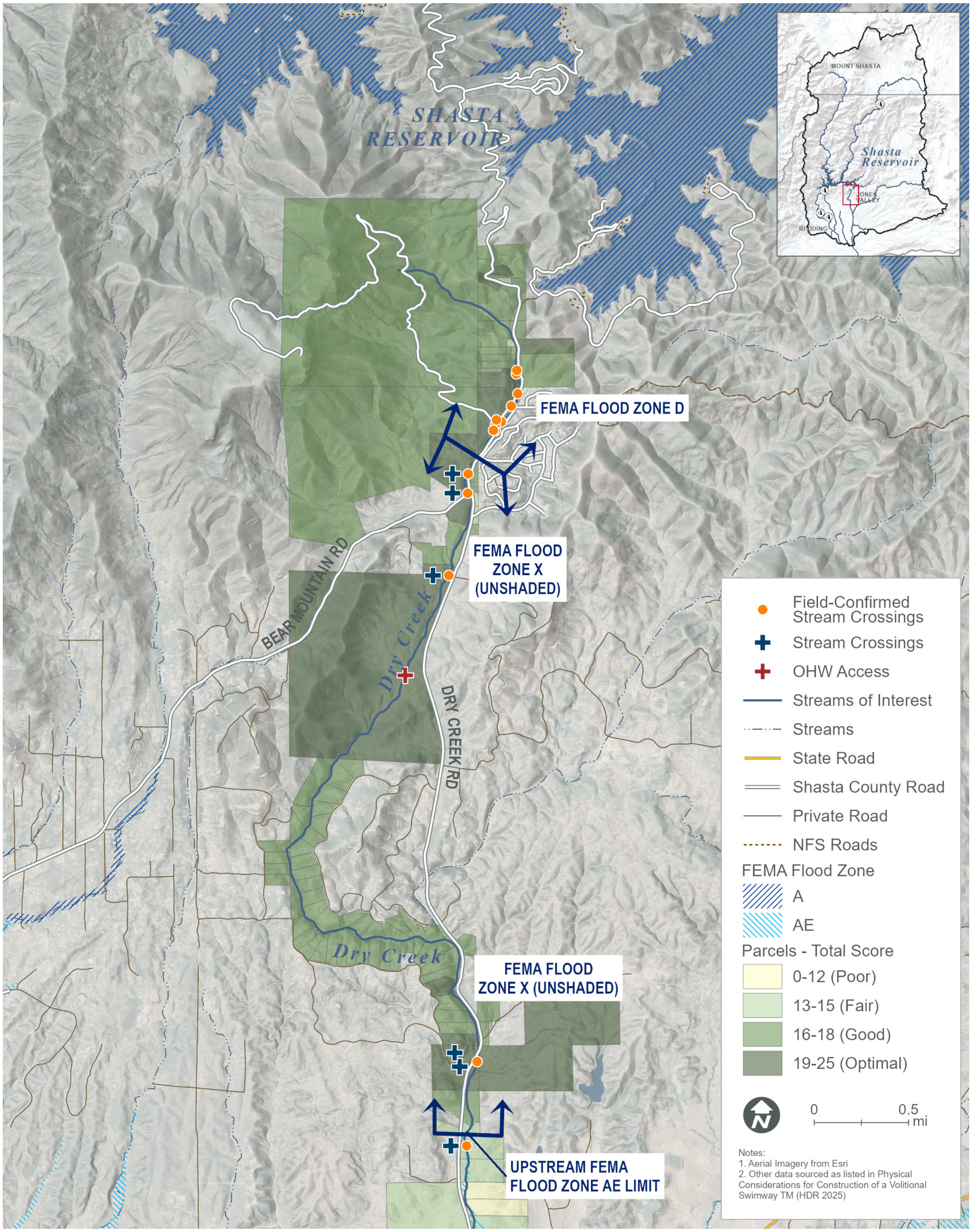


Figure 7
Limiting Factors Analysis (Dry Creek, South, and Little Cow Creek, North)

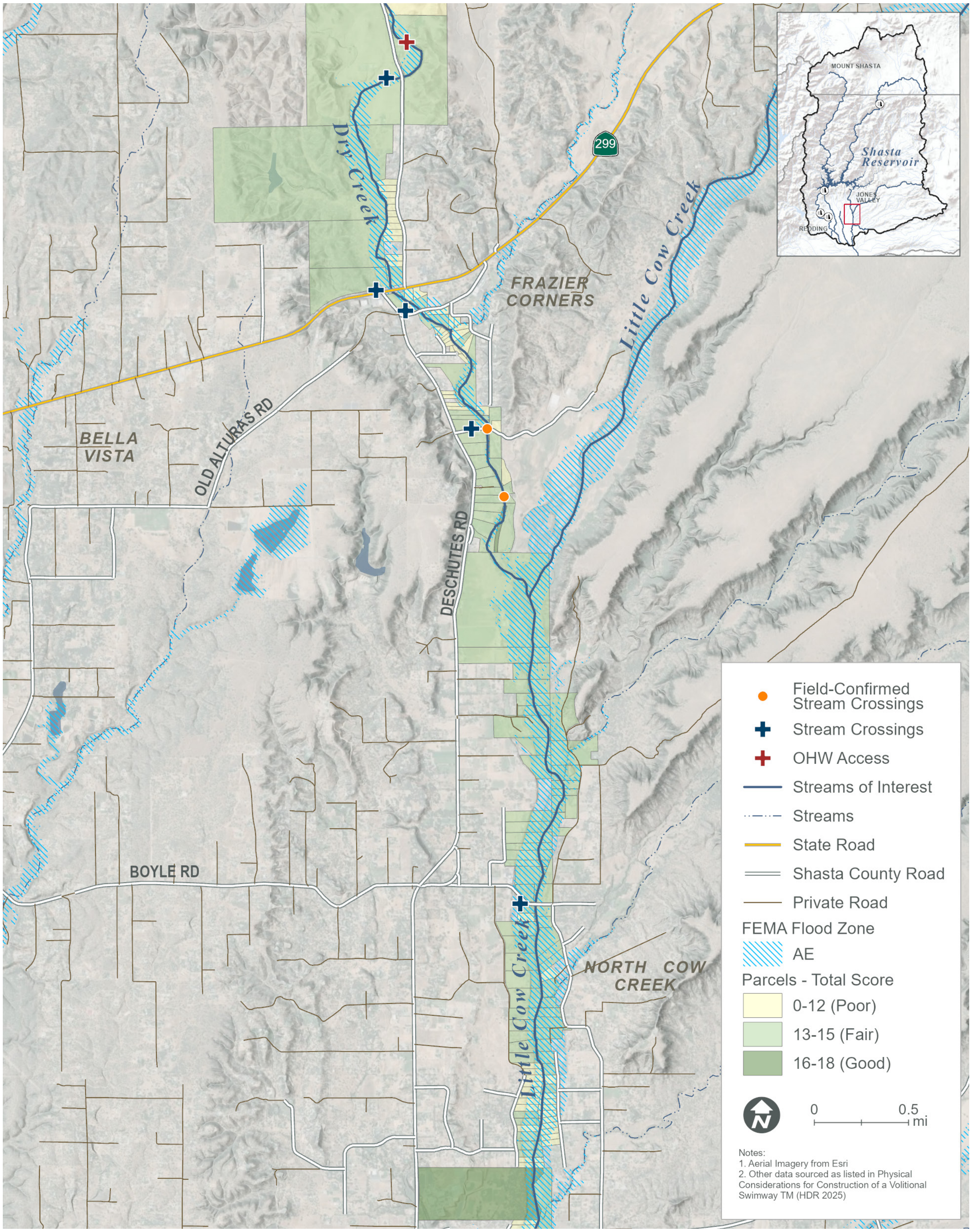


Figure 8
Limiting Factors Analysis (Little Cow Creek, South, and Cow Creek, North)

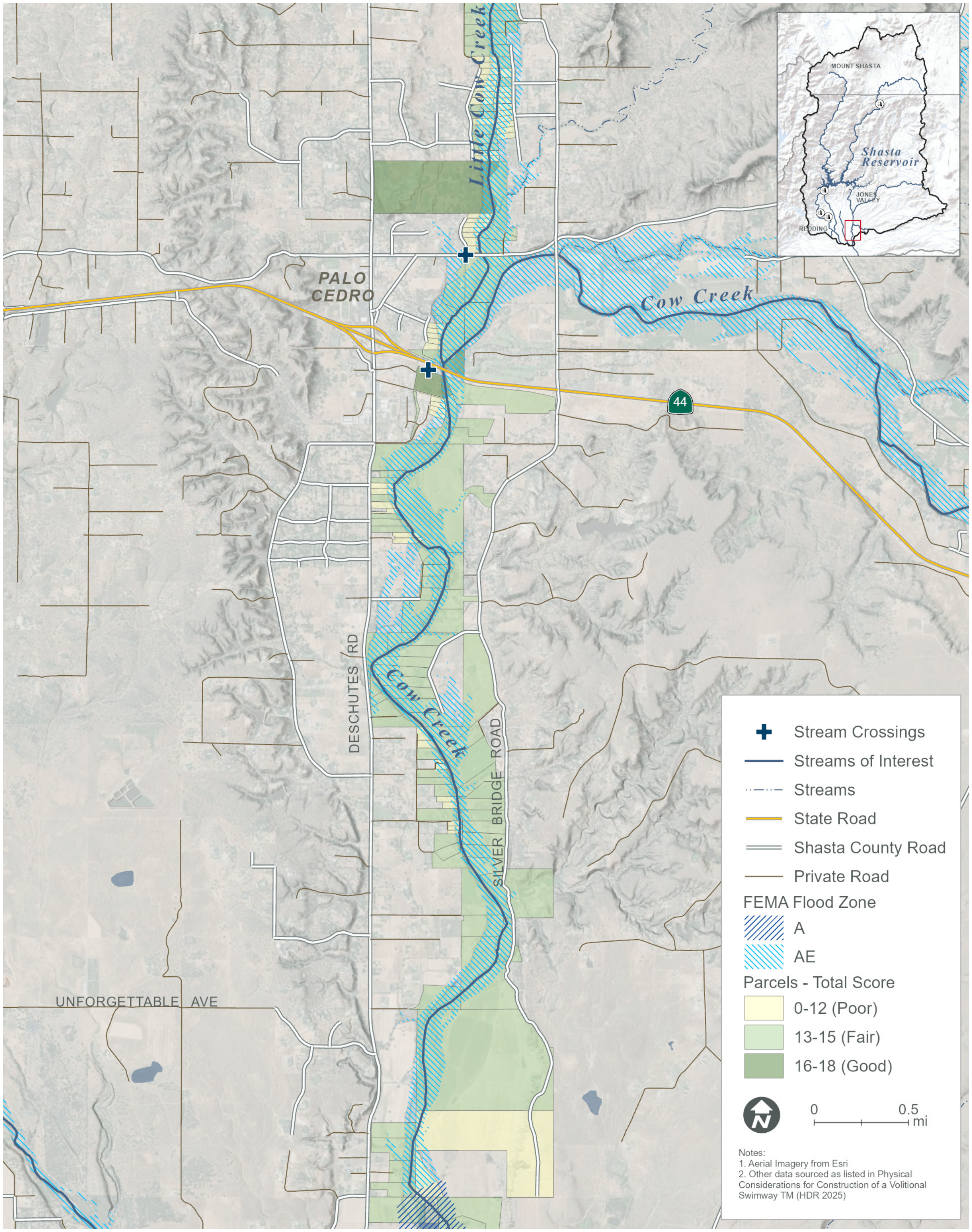
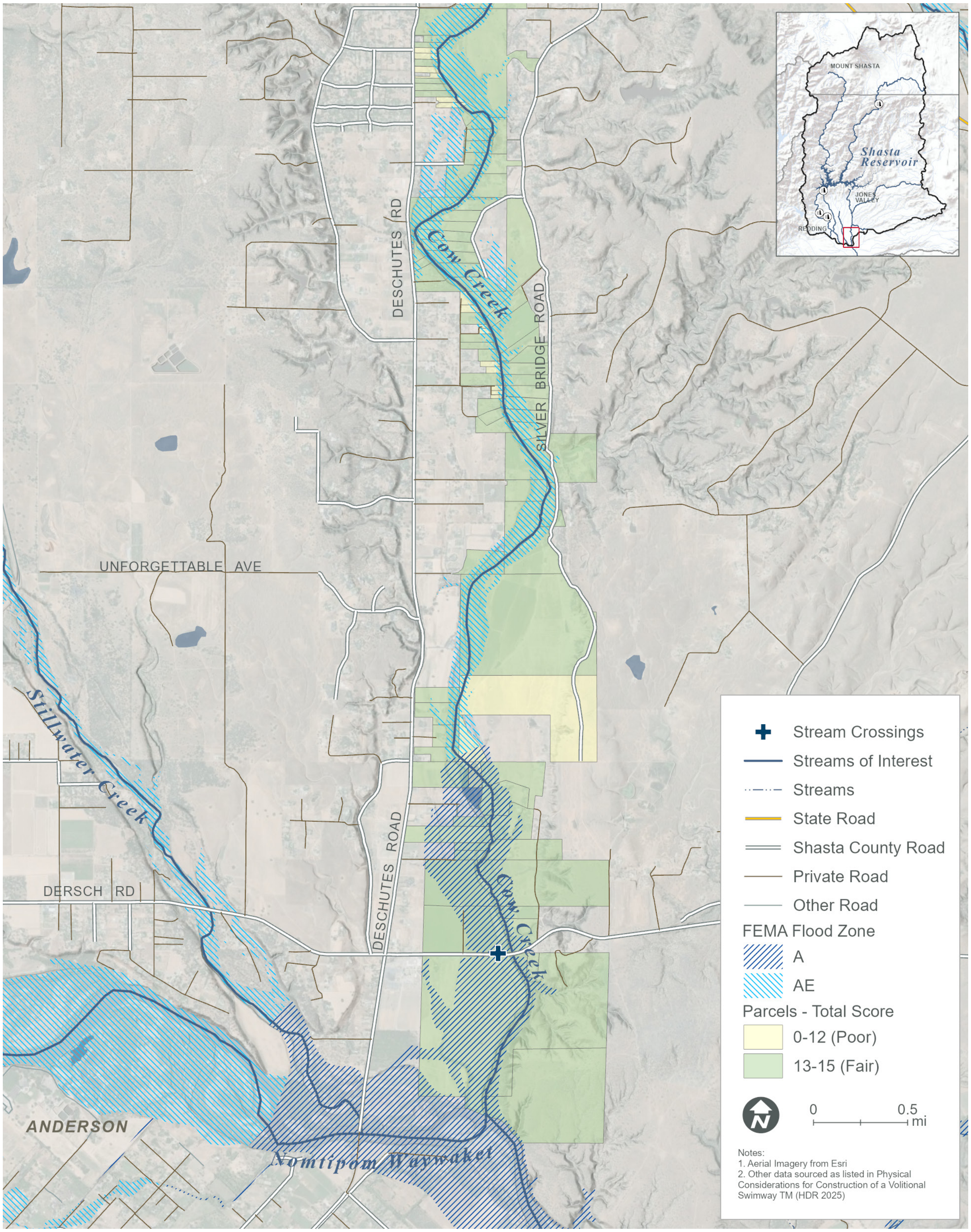


Figure 9
Limiting Factors Analysis (Cow Creek, South)



4.1.3.4 Conclusions

Overall, the 57 parcels located along the Winnemem Waywaket scored well in the "Parcel Size" and "FEMA Flood Zone" categories; however, the same parcels scored poorly in the "Power Availability" and "Access" categories. The closest existing known local electrical service to the Winnemem Waywaket is supplied by PacifiCorp to the City of Mount Shasta and is a minimum of 5 miles away from these parcels. Access to the river and existing roadways on the parcels is minimal, though the private roads of Bollibokka Fly Fishing Club and McCloud River Fishing Club provide road access to 12 parcels. Two of the most likely areas for future fish passage facilities along the Winnemem Waywaket are in the vicinity of the Bollibokka Fly Fishing Club and the head of Shasta Reservoir. In these locations, parcel scores are ultimately categorized as fair (ranging from 13 to 15 points). Fish passage facility construction on these parcels would require major road improvements, land acquisition, and electrical utility construction.

The 398 parcels located along Cow Creek, Little Cow Creek, and Dry Creek generally scored well in the "Access" and "Power Availability" categories but poorly in the "Parcel Type" and "Parcel Size" categories. Roads and electrical service are present throughout the stream corridor, but due to primarily residential land use, the parcels are generally small and privately owned. A third possible location for a future fish passage facility is between the upstream extents of Dry Creek (meeting the ridge line just east of Bear Mountain) and Shasta Reservoir. In the context of the volitional swimway, this area is the confluence between the existing waterway, and the constructed channel; access will be required for heavy machinery used for tunnel construction. Parcel scores between the upstream end of Dry Creek and Shasta Reservoir are ultimately categorized as good or optimal (16 to 25 points). The "Parcel Type" and "Parcel Size" scores are generally higher in this location because they are owned by the federal government as part of the Shasta Recreational Area. Fish passage facility construction would involve fewer challenges in this vicinity than anywhere else along the potential volitional tributary bypass.

4.1.4 Water-Related Infrastructure and Water Rights

Water-related infrastructure and water rights information and data used in the development of this document were acquired through federal and state agencies, counties, districts, and municipalities and publicly available reports and webpages. Water-related infrastructure and water rights information and data were compiled to understand how existing infrastructure and water rights impacts water use and availability in the Study Area. Detailed information about sources utilized in this document can be found in Appendix D. A summary of this data compilation effort and results are provided below and in more detail in Appendix G, *Existing Water Infrastructure, Barriers, and Water Rights Data*.

4.1.4.1 Purpose and Scope

The purpose of this effort was to obtain and summarize readily available information on existing water infrastructure, barriers, and water rights in the Study Area. Information data gaps and their recommended resolutions were documented for future fish passage alternatives evaluation and development.

Appendix G provides a multitude of information on facilities located within the Study Area, including their location, water use, operational requirements and considerations, and barrier status. Operational theory of identified water infrastructure and barriers is described to understand how each facility or barrier influences one another. This includes a description of how the system is operated per documented operation plans and demands but may differ from actual operations depending on real-time information, forecasts, or user/agency needs. The document also includes a summary of historical and present-day water right law in California as it pertains to surface and groundwater. This includes a description of the different processes for obtaining water rights, such as permitting, licensure, and registration, as well as water rights court decrees and adjudication. Water rights within the Study Area are detailed to understand water availability and authorization for evaluation and design purposes.

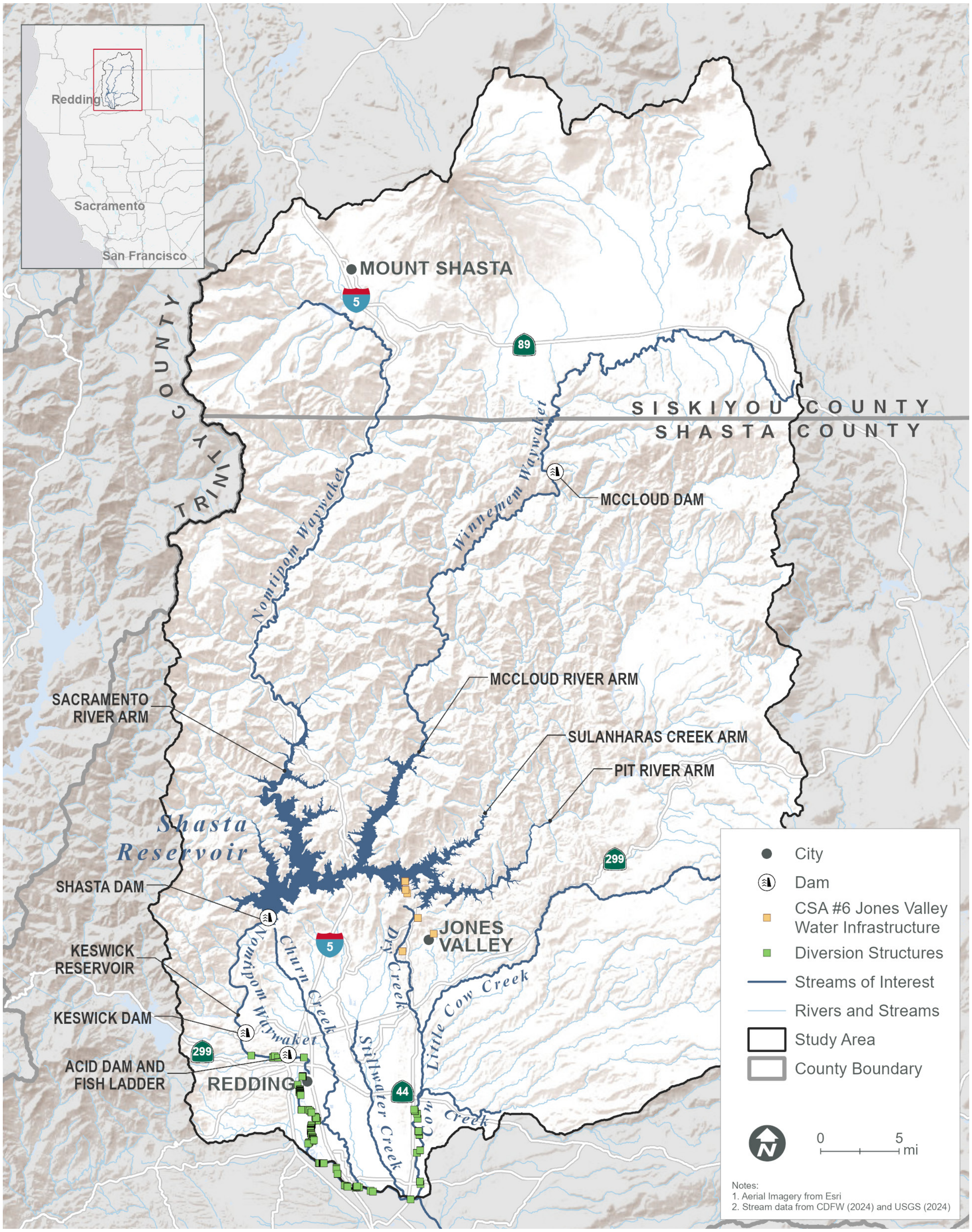
4.1.4.2 Key Findings

Key findings are summarized in the following subsections and broken into three categories as follows: 1) Existing Water Infrastructure and Barriers; 2) Operational Theory; and 3) Water Rights.

4.1.4.2.1 Existing Water Infrastructure and Barriers

Existing water infrastructure and barriers identified for this study included dams, release structures, water pipelines, open-channel distributaries, diversion structures, storage tanks, and water intake structures. Figure 10 shows the relative locations of identified water infrastructure and barriers.

Figure 10
Relative Locations of Identified Water Infrastructure and Barriers



Several dams are in the Study Area that influence river conditions and flood events, including McCloud Dam, Shasta Dam, Keswick Dam, and Anderson-Cottonwood Irrigation District (ACID) Diversion Dam. The following paragraphs summarize general information on these dams.

McCloud Dam is an earth- and rock-filled dam located at RM 38 of the Winnemem Waywaket built to divert up to 1,400 cubic feet per second (cfs) via McCloud Tunnel to Iron Canyon Reservoir and subsequently the Pit River for hydroelectric generation (State Water Board 2019). This facility is a part of PG&E's James B. Black Development, a major component of the McCloud-Pit Hydroelectric Project. Along the dam spillway crest, there are three radial gates used to discharge water via the spillway to the Winnemem Waywaket below the dam. Minimum instream flows of 40 cfs to 50 cfs must be maintained below McCloud Dam to sustain trout spawning.

Shasta Dam is a concrete gravity dam located at RM 311 of the Nomtipom Waywaket, operated to ensure water is available during dry years for urban, agricultural, and environmental purposes. Shasta Dam is operated by Reclamation as part of the Central Valley Project (CVP). The Shasta Division of the CVP includes both the Shasta Dam and Reservoir and the Keswick Dam and Reservoir and provides storage for flood control and irrigation of the Sacramento and San Joaquin valleys. The Shasta Division is also responsible for maintenance of navigation and fish conservation in the Nomtipom Waywaket, providing protection from saltwater intrusion in the Sacramento-San Joaquin Delta, water for municipal and industrial uses, and generation of hydroelectric energy (Reclamation 1992). The spillway face has 18 valves used to manage reservoir level and provide flood control downstream of the dam. Five penstocks connected to the reservoir deliver water to the seven generators in the powerplant (Reclamation 2004). A temperature control device was installed on the upstream face of the dam to manage river temperature downstream for fish habitat by pulling water from various depths within the reservoir (Reclamation 2012). LSNFH, operated by USFWS, is located at the base of Shasta Dam. The hatchery was established to partially offset habitat and fish losses resulting from the construction of the dam; raising endangered winter-run Chinook Salmon and maintaining a reserve population of Delta Smelt (*Hypomesus transpacificus*) population (CV Water Board 2023).

Potential future facility changes for Shasta Dam, related to Reclamation's Shasta Lake Water Resources Investigation (SLWRI), include raising the dam crest by 18.5 feet. The SLWRI concluded that an 18.5-foot dam raise would prioritize water supply reliability and support anadromous fish survival (Reclamation 2014). If implemented, the raise would result in potential periodic inundation of the Winnemem Waywaket basin. At the time of this document development, Congress has not appropriated funds or authorized construction of Shasta Dam raise (Reclamation 2022).

Keswick Dam, located at RM 302 of the Nomtipom Waywaket, is a concrete gravity dam constructed as an afterbay dam to control river fluctuations due to releases from the Shasta Dam and Powerplant and the Trinity River Diversion of the CVP (Reclamation 2004). The spillway contains four slide gates, used to regulate flows below the facility (USACE 2024). During flood events, Keswick Dam is operated in coordination with Shasta Dam so that flows do not exceed 79,000 cfs at the tailwater of Keswick Dam, and/or stage of the Nomtipom Waywaket does not exceed 39.2 feet approximately 40 RMs downstream. The powerplant on the west side of the dam facility has three generating units, operated depending on discharges from upstream facilities (Reclamation 2004). A fish trap is located at the base of Keswick Dam to capture upstream-migrating Chinook Salmon and steelhead and operates in conjunction with both LSNFH and Coleman National Fish Hatchery on Battle Creek (Reclamation 2004; CNFH 2024).

ACID Diversion Dam is located at RM 298.6 of the Nomtipom Waywaket and consists of a 450-foot-long flashboard dam, a screened diversion, and two fish ladders (a vertical slot fishway on the north side and a pool-and-chute fish ladder on the south side) for upstream passage. According to an investigation conducted in May of 2024, the ACID Diversion Dam's fish ladders do not provide safe and timely passage for upstream-migrating fish (Shasta County Grand Jury 2024). However, there is little available documentation or study results available that describe the specific level of passage effectiveness or cause of passage challenges. The flashboard dam is erected yearly to provide water to ACID customers during the irrigation season (April through October).

A number of diversion structures are located within the Study Area that may act as potential barriers to fish passage. Information about identified diversion structures, including location, prior assessments, status, and key features, are provided in this document. No diversion structures were identified within the Study Area portion of Winnemem Waywaket at the time of this analysis. Ninety-nine diversion structures were identified within the Study Area portion of the Nomtipom Waywaket using the CalFish-managed California Fish Passage Assessment Database (PAD) layer of the CDFW Biogeographic Information and Observation System (BiOS) online tool. Thirteen of these diversion structures were identified as screened, and a large majority were most recently surveyed in 2014 by CDFW. Three unscreened pump diversions are associated with the ACID (separate diversions for the ACID and not associated with the diversion dam), and four screened pump diversions are associated with the Bella Vista Water District.

Twelve diversion structures, consisting mainly of pump diversions and one pushup dam, were identified in the Study Area portion of the Cow Creek based on a 2015 report prepared by H.T. Harvey & Associates. Barriers and diversions were categorized in this report as "major" or "minor" according to their potential impact on fish and/or fish habitat, and all 12 diversion structures in the Cow Creek were categorized as minor (H.T. Harvey & Associates 2015). No diversion structures were identified within the Study Area portion of the Little Cow Creek and Dry Creek.

Numerous water supply systems exist and operate within the Study Area. The Shasta County Water Agency's special district County Service Area (CSA) No. 6, Jones Valley, was reviewed due to its potential role related to Project alternatives development and evaluation. The Jones Valley CSA provides domestic and commercial water to approximately 500 parcels in the unincorporated area of Jones Valley, utilizing two screened water intake structures with 60-horsepower submersible pumps in Shasta Reservoir, a water treatment plant with a 225,000-gallon storage tank, and three storage tanks and 25 miles of water pipeline throughout the district for distribution (Shasta LAFCO 2017: Shasta County Public Works 2024).

4.1.4.2.2 Operational Theory

Flows within the Study Area are impacted by the system of dams and diversions extending from McCloud Dam at the upstream limit of the Study Area to the confluence of Cow Creek with the Nomtipom Waywaket at the downstream limit of the Study Area. The Winnemem Waywaket flows for approximately 24 miles before reaching the McCloud Reservoir and the McCloud-Pit Hydroelectric Project. Figure 11 provides an overview of how water moves through the Study Area. Table 5 summarizes operational considerations for each of the identified facilities and provides a summary of where water moves once it passes through each facility.

Figure 11
Study Area Process Diagram

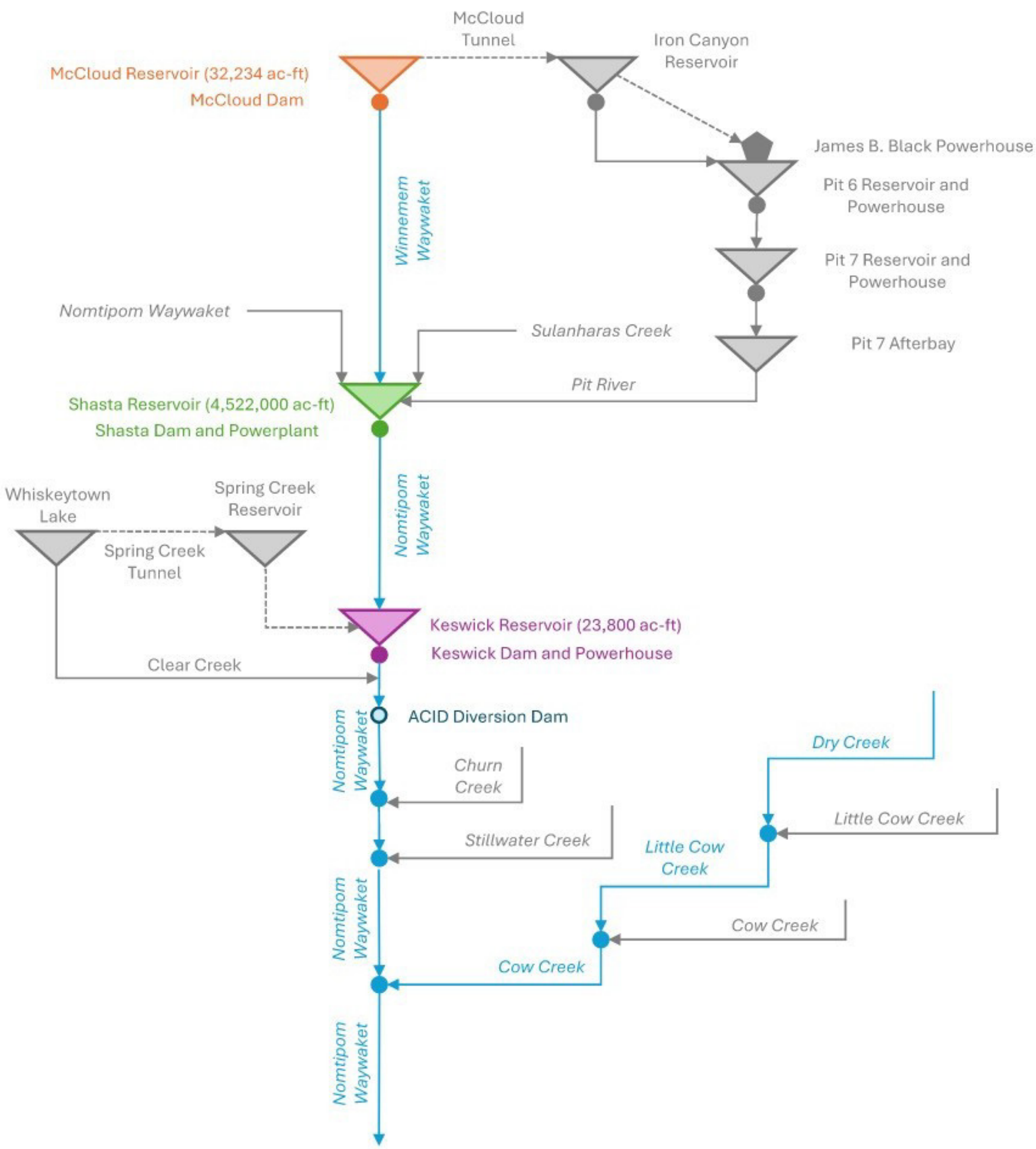


Table 5
Summary of Operational Considerations Throughout the Study Area

Facility	Operational Considerations						Flow Outlet
	Flood Control	Water Supply	Hydropower	Fish Conservation	Navigation	Recreation	
McCloud Dam		•	•	•		•	Winnemem Waywaket, Iron Canyon Reservoir/ Pit River
Shasta Dam	•	•	•	•	•	•	Shasta Powerplant, Nomtipom Waywaket
Keswick Dam			•	•	•		Keswick Powerplant, Nomtipom Waywaket
ACID Diversion Dam		•		•			Nomtipom Waywaket

Note:
"Operational Considerations" does not necessarily refer to the main purpose of the facility, but any consideration their operational strategy was made to accommodate.

4.1.4.2.3 Water Rights

Of note, this section does not provide detail on Aboriginal water rights; however, a definition is provided due to the concept's importance, Project relevance, and unresolved nature in the Study Area. An Aboriginal water right is one which was the first of its kind in a region, and is based on the use of water from the earliest days (Merrill 1980).

In California, water rights law is administered solely by the California State Water Resources Control Board (State Water Board) Division of Water Rights. The California Constitution requires all use of water to be reasonable, beneficial, and in accordance with the public trust doctrine. Beneficial uses are legally recognized and include municipal and industrial uses, irrigation, hydroelectric generation, livestock watering, recreational use, fish and wildlife protection, enhancement and aesthetic enjoyment, among others (State Water Board 2024a). The State Water Board must keep three major goals in mind when making water rights decisions, including "developing water resources in an orderly manner, preventing waste and unreasonable use of water, and protecting the environment" (State Water Board 2024a).

The water right law system for surface water utilizes both riparian (no permits, licenses, or government approval required) and appropriative rights (permits, licenses, or government approval required). In accordance with the "first in time, first in right" principal, the most recent right holder must be the first to discontinue water use during shortages. Pre-1914 appropriative water rights and riparian water rights do not require approval by the State Water Board. Riparian rights have a higher priority than appropriative rights, and priorities among riparian right holders are equal (State Water Board 2024a). A series of steps must be taken for a prospective appropriator to obtain a water right permit, including filing an application detailing the proposed project, environmental review, and public notice. After the permitted project is complete, a water right license can be issued.

Water rights in California for some waterbodies or portions of those waterbodies, and for some ground water basins, have been adjudicated through court decrees. The courts typically appoint a watermaster to administer court decrees for adjudications concerning surface or gound water. DWR, among many other entities that serve an official watermaster role, administers a state Watermaster Program for implementation and enforcement of established water right allocations in accordance with court adjudications.

The State Water Board maintains an Electronic Water Rights Information Management System (eWRIMS) to provide the public with water rights records, complaints, web mapping, decisions and orders, progress reports, application processing summaries, and petitions information (State Water Board 2024b). Using the eWRIMS portal, 17 water right applications were identified on the Study Area portion of the Winnemem Waywaket, accounting for approximately 2,720 cfs of direct diversion water and 39,300 acre-feet per year (ac-ft/year) of stored water (State Water Board 2024b). Beneficial uses of direct diversions and stored water include dust control, domestic, industrial, stock watering, fire protection, power, and irrigation. PG&E owns two water right applications on the Winnemem Waywaket that contain provisions for ensuring downstream minimum flow requirements during normal and dry water years.

Twenty-three water right applications were identified on the Study Area portion of the Nomtipom Waywaket, accounting for approximately 63,725 cfs of direct diversion water and approximately 45,299,103 ac-ft/year of stored water. Beneficial uses of direct diversions and stored water include power, stock watering, irrigation, recreational, municipal, industrial, fish and wildlife preservation and enhancement, domestic, fire protection, and milling. Reclamation is the owner of six water right applications on the Nomtipom Waywaket and ACID is the owner of four.

Thirteen water right applications were identified in the Study Area portion of the Cow Creek (none were identified on the Little Cow Creek or Dry Creek), accounting for approximately 12.3 cfs of direct diversion water and a small but unknown quantity of stored water. Beneficial uses of direct diversions and stored water include irrigation, stock watering, and fish and wildlife preservation and enhancement. The mainstem of the Cow Creek (along with the Old Cow Creek and South Cow Creek) was adjudicated by court decree under Decree No. 38577, dated August 25, 1969 (State Water Board 1969). Water rights under this decree are divided into four groups, and allotments in each group are broken into four priority classes to establish priority in the event of insufficient water supply. There are no established watermaster service areas in the Study Area portion of the Cow Creek watershed.

One water right application owned by Shasta County was identified for the Jones Valley CSA. The Shasta County Water Agency has a subcontract with Shasta County for this water right application through the CVP. This license provides water delivery at a rate of approximately $45 per acre-foot for municipal beneficial use and specifies that the diversion shall not exceed 0.7 cfs and 350 ac-ft/year (Shasta County Public Works 2024).

4.1.4.3 Conclusions

In addition to synthesizing and summarizing readily available information on existing water infrastructure, barriers, and water rights in the Study Area, findings in this document included identification and documentation of information data gaps and key findings for use in informing future fish passage alternatives evaluation. Table 6 provides a summary of data gaps and indicates their importance for completing the Project, along with recommendations on how the data gaps can be resolved and the difficulty of each recommendation. All identified data gaps are judged to be significant and a high priority to resolve to continue the development of fish passage alternatives evaluation, such as water availability, infrastructure operational changes, and fish passage navigational unknowns.

Table 6
Summary of Identified Data Gaps

Pertinent Section	Data Gap	Importance of Data Gap	Recommended Data Gap Resolution	Anticipated Difficulty of Resolution (Low, Medium, High)
Existing Water Infrastructure and Barriers	Minimum instream flow requirements at McCloud Dam	Influences water availability within the Winnemem Waywaket (upper end of Study Area) and may impact additional water supply needs in design.	Reach out to PG&E and/or FERC to determine whether any minimum instream flow requirements have been set.	Medium
Existing Water Infrastructure and Barriers	Specific water supply allocations of the CVP in future years and under a potential future 18.5-foot Shasta Dam raise	Unknown future impact to Shasta and Keswick reservoir storage	Reach out to Reclamation to determine whether any forecasts are available for water supply allocation that consider climate change and anticipated future supply and demand.	Medium
Existing Water Infrastructure and Barriers	Specific crest and infrastructure elevations at the ACID Diversion Dam	Influences range of operational water surface differentials at ACID Diversion Dam	Obtain as-built information for ACID Diversion Dam.	Low
Existing Water Infrastructure and Barriers	Inability to access portions of privately owned land on the Cow Creek and Little Cow Creek; lack of assessment on Dry Creek	There may be additional diversions within the Study Area in the Cow Creek watershed that have not yet been identified. This influences the total number of points of diversions to navigate when addressing passage and can impact water supply needs in design.	Obtain landowner permission for field survey or conducting boat survey of waterbody reaches previously inaccessible (Cow Creek and Little Cow Creek) and previously unassessed (Dry Creek) to identify and confirm existence, status, and location of potential diversions.	High
Existing Water Infrastructure and Barriers	Potentially outdated diversion status reported by the PAD layer of the CDFW BiOS online tool	There may be additional diversions within the Study Area in the Nomtipom Waywaket that are not accurately represented in the PAD. This influences the total number of points of diversions to navigate when addressing passage and can impact water supply needs in design.	Conduct field assessments and surveys within the Study Area stretches of Nomtipom Waywaket and Winnemem Waywaket to identify and confirm existence, status, and location of potential diversions.	High

Pertinent Section	Data Gap	Importance of Data Gap	Recommended Data Gap Resolution	Anticipated Difficulty of Resolution (Low, Medium, High)
Existing Water Infrastructure and Barriers	Discrepancy between PAD layer of the CDFW BiOS online tool and eWRIMS portal related to total number of diversions within Study Area portions of the Winnemem Waywaket, the Nomtipom Waywaket, and the Cow Creek watershed	There may be additional diversions within the Study Area that are not accurately represented in the PAD. This influences the total number of points of diversions to navigate when addressing passage and can impact water supply needs in design.	Field assessment and survey to identify and confirm the existence, status, and location of diversions on study waterbodies	High
Existing Water Infrastructure and Barriers	Lack of precise as-built drawings that describe the location of infrastructure in the Jones Valley CSA	Could impact design of future fish passage route alternative via Jones Valley area if precise locations of existing water infrastructure are unknown	Agency collaboration to obtain as-built drawings from the Jones Valley CSA for water infrastructure	Low
Operational Theory	Potential unknown diversions on Nomtipom Waywaket and Cow/Little Cow/Dry Creeks	May influence overall flows in Cow Creek watershed and/or Nomtipom Waywaket; may be additional diversions on these reaches not already identified	Collaborate with CalFish on any updates to the PAD within our Study Area, which is largely incomplete and relies on volunteered information.	High
Water Rights	Discrepancy between PAD layer of the CDFW BiOS online tool and eWRIMS portal related to total number of diversions within Study Area portions of the Winnemem Waywaket, the Nomtipom Waywaket, and the Cow Creek watershed	There may be additional diversions within the Study Area that are not accurately represented in the PAD. This influences the total number of points of diversions to navigate when addressing passage and can impact water supply needs in design.	Field assessment and survey to identify and confirm the existence, status, and location of diversions on study waterbodies	High

For a comprehensive and detailed summary of identified existing water infrastructure, barriers, and water rights in addition to operational theory of water infrastructure and barriers identified throughout the Project Study Area, refer to Appendix G. The information contained within this document represents the current basis of knowledge available for the Project, which will be developed further as this and other studies progress.

4.1.5 Hydrology Study in the Winnemem Waywaket and Cow Creek

Existing hydrology data from USGS gages and California Data Exchange Center (CDEC) on the Winnemem Waywaket and Cow Creek were compiled and analyzed for use in the *Alternatives Formulation and Evaluation Report* (Anchor QEA and HDR 2026). Hydrology information is limited to the existing USGS gage data available in the Winnemem Waywaket and Cow Creek near Millville. As such, there is a data gap for this type of information in Little Cow Creek and Dry Creek.

Detailed information about the hydrology data compilation and evaluation is provided in Appendix H, *Hydrology Study in the Winnemem Waywaket and Cow Creek*, and is summarized in the following subsections.

4.1.5.1 Purpose and Scope

The purpose of the hydrology study was to compile available data on hydrologic conditions in the Winnemem Waywaket and Cow Creek and analyze the compiled data. The scope of the study included the following:

- Summarizing available streamflow and hydrologic data
- Performing flow exceedance and peak flow analyses
- Assessing current and unregulated hydrologic conditions
- Evaluating future hydrologic scenarios under climate change conditions

4.1.5.2 Methods

The analysis draws on streamflow data from USGS and CDEC for 11 gage stations in the Study Area—10 from the Winnemem Waywaket and 1 from Cow Creek. Hydrologic modeling and statistical methods were applied to accomplish the following:

- Calculate flow exceedance probabilities using 5% and 95% daily flow percentiles. These data are being calculated because the NMFS's Fish Passage Guidelines (NMFS 2023a) require a fishway design and/or facility to allow for the safe, timely, and efficient passage of fish within a specific range of streamflow. The design streamflow range is bracketed by the designated fish passage design low flow and high flow. The design low flow for fishways is the average daily streamflow that exceeds 95% of the time during periods when migrating fish are normally present at a site. The design high flow for fishways is the average daily streamflow that exceeds 5% of the time during periods when migrating fish are normally present at the

site. Note that NMFS also released pre-design guidelines for projects in California that suggest project proponents consider using 1% daily exceedance values during the period from November 1 to May 15, conduct appropriate migration opportunity studies, and discuss the results with NMFS and develop fish passage design flows on a case-by-case basis (NMFS 2023b). Therefore, in future fish passage design efforts consideration will be given to the need to calculate the 1% flow exceedance probabilities (or other probabilities) for comparison of the different values and use of future design flow considerations.
- Estimate peak flows across recurrence intervals using the PeakFQ software and Expected Moments Algorithm.
- Simulate the removal of McCloud Dam by reconstructing unregulated flows for the Winnemem Waywaket based on McCloud Reservoir inflow/outflow and tunnel diversion data.
- Analyze climate change impacts using the CanESM2 Climate Model (a representative Global Circulation Model) and projections from tools like the Climate Toolbox and U.S. Forest Service hydrologic models under Representative Concentration Pathway (RCP) 8.5 scenarios for the late twenty-first century based on guidance provided in NMFS (2023c).

4.1.5.3 Key Findings

Current Conditions:

- The 5% and 95% flow exceedance estimates show high seasonal variability for the Winnemem Waywaket and Cow Creek gages.
- Cow Creek exhibits particularly high flow variability, with monthly 5% exceedances ranging from 82 cfs (September) to over 6,000 cfs (January).
- Peak flow estimates vary by USGS gage, with the McCloud River above Shasta Lake (USGS 11368000) gage offering the most robust dataset (77-year record).

Unregulated Conditions on the Winnemem Waywaket:

- Unregulated flows were reconstructed for the Winnemem Waywaket above Shasta Lake, revealing substantially higher flows compared to current regulated conditions.
- Estimated unregulated 95% exceedances (low flows) and 5% exceedances (high flows) indicate greater flow availability for fish passage design considerations.

Climate Change Projections:

- Climate change modeling using RCP 8.5 late-century projections indicates seasonal shifts:
  - Increased winter flows (e.g., +59% in January, +52% in February)
  - Decreased spring and summer flows (e.g.,−54% in May, -42% in June)
- The percentage change in future flow conditions predicted using CanESM2 Climate Model also indicates substantial seasonal shifts:

  - Increase in late summer, fall, and winter 5% exceedance high flows (e.g., +105% in August, +85% in November, +103% in February)
  - Decrease in spring and early summer 5% exceedance high flows (e.g., -28% in April; -32% in June)
- Peak flow estimates are also expected to change substantially:
  - The number of winter floods is projected to increase by 27%, with a 35% to 66% increase in peak flows for 1.5- to 25-year recurrence intervals.
  - Future 100-year flood flows for the Winnemem Waywaket are projected to increase by 37%, from approximately 53,920 cfs to approximately 73,870 cfs.

4.1.5.4 Conclusions

The hydrologic analysis demonstrates the following:

- Sufficient streamflow data are available for characterizing current conditions, though variability and some data gaps exist. Long-term continuous streamflow data gaps exist for Dry and Little Cow creeks given that the current period of record is short.
- Unregulated flow reconstructions for the Winnemem Waywaket offer valuable insights into the natural hydrology prior to reservoir influence.
- Climate change is expected to significantly alter flow timing and magnitude, particularly by increasing winter flows and decreasing spring and summer flows—implications that are critical for fish passage facility design.
- These findings support the need for flexible, climate-resilient fish passage infrastructure to restore access to historical salmonid habitats upstream of major dams.

4.1.6 Temperature

The Winnemem Wintu Tribe shared with the Consultant Team that they do not support the temperature studies because their ITEK does not rely on temperature thresholds. Temperature data within the Winnemem Waywaket, Dry Creek, Little Cow Creek, and Cow Creek, the Winnemem Wintu Tribe’s potential tributary bypass, are relatively sparse except for discrete data collections and two continuous temperature monitors on the Winnemem Waywaket and one on Cow Creek. Due to the length of these water bodies, there is limited resolution of spatial variability in water temperature, temperature gains and/or losses along the reaches of interest, and temperature impacts from major tributary inflows. Recovering higher-level resolution of the temperature data along the Winnemem Waywaket, Dry Creek, Little Cow Creek, and Cow Creek is critical to adult and juvenile fish management efforts, along with promoting an overall healthy ecosystem. To augment the limited existing data, temperature was collected in the Winnemem Waywaket, Dry Creek, Little Cow Creek, and Cow Creek between September 2024 and August 2025, and an analysis of thermal accumulation in the migratory corridors and channels was completed as described in the following subsections.

The key findings sections below provide a comparison of temperature data to optimal water temperatures, which have been developed and used for regulatory purposes. However, from a biological perspective, there is additional context to consider. Comparative water temperature analysis often represents conditions at a single point in the stream system. Water temperature varies throughout the Study Area and may be warmer or cooler than identified at other locations. There could be micro-habitat conditions that have lower temperature that Chinook Salmon would seek and find. Additionally, recent laboratory studies on hatchery-origin Chinook Salmon from along the Pacific Coast have identified population-specific thermal tolerances suggesting that fish evolve to survive in local thermal conditions (Zillig 2022; Zillig et al. 2023; Zillig et al. 2025). Therefore, it is difficult to generally apply thermal tolerances based on studies from a range of different conditions across broad areas. As such, comparisons of collected or compiled temperature data to thermal tolerances should consider these important factors when making conclusions.

4.1.6.1 Temperature Data Collection

Detailed information about temperature data collection is provided in Appendix I, *Temperature Data Collection Study*, and is summarized below.

4.1.6.1.1 Purpose and Scope

The primary focus was on characterizing water temperature along a potential tributary bypass, with opportunistic collection of additional temperature data and flow data.

4.1.6.1.2 Methods

Methods used for temperature data compilation and collection are described as follows; however, temperature data in Shasta Reservoir and flow data along the potential tributary bypass were also opportunistically collected:

- Existing temperature data were reviewed and categorized from multiple agencies and studies specific to the Study Area (CDEC, USGS, DWR, Surface Water Ambient Monitoring Program [SWAMP; State Water Board 2024c], PG&E, CDFW, and past Cow Creek studies).
- The data review identified deficiencies in continuous temperature coverage, especially in Dry Creek and Little Cow Creek, and areas with limited resolution for tributary impacts on mainstem temperature. The recommended high-priority locations to gather additional temperature data included the following:
  - Winnemem Waywaket:
    - Immediately upstream of Ladybug Creek
    - Immediately downstream of Ladybug Creek
    - Immediately upstream of Claiborne Creek
    - Immediately downstream of Claiborne Creek
    - Immediately upstream of Yet Atwam Creek

- Dry Creek
  - In Dry Creek upstream of the confluence with Little Cow Creek
  - In Little Cow Creek upstream of the confluence with Dry Creek
- Little Cow Creek
  - In Little Cow Creek upstream of the Cow Creek confluence
  - In Cow Creek upstream of the Little Cow Creek confluence
- Cow Creek
  - Near existing USGS Millville gage

- HOBO TidbiT temperature loggers were installed at the locations identified above in the Winnemem Waywaket and were also used in June 2025 to replace several HOBO U20L sensors lost over the duration of the study.
- HOBO U20L pressure transducers (recording temperature and depth) were installed at the locations identified above in Dry Creek, Little Cow Creek, and Cow Creek.
- Sensors were all placed in September 2024, with quarterly downloads and maintenance through August 2025.
- An opportunistic Shasta Reservoir temperature profile string was installed by the USGS to measure temperature stratification from September 2024 to May 2025.
- During temperature sensor installation, data download, and removal site visits, real-time water velocity was measured at each location (as possible) along the potential volitional pathway using a Swoffer Model 3000.
- Data analysis included calculating summary statistics, such as the mean, median, maximum, and minimum water temperature, and comparing these statistics across seasons. Additionally, daily average and daily maximum temperature readings from each data sensor were plotted over time to analyze seasonal and interannual variability as well as to compare to maximum optimal temperatures by life stage.

4.1.6.1.3 Key Findings

Winnemem Waywaket

As part of the reintroduction and rematriation of Chinook Salmon, the Winnemem Waywaket is expected to provide habitat for spawning, egg incubation, fry emergence, juvenile rearing, and juvenile migration. As such, temperature data collected as part of this study were compared to maximum optimal temperatures by life stage found in the literature for Chinook Salmon (*Nomtipom Waywaket [Sacramento River] Chinook Salmon Life History Summary* [Appendix N]). Key findings for the Winnemem Waywaket are provided as follows:

- Temperature consistently increased from upstream to downstream.
- Ladybug Creek had negligible influence on mainstem temperature; Claiborne Creek, and Yet Atwam Creek contributed slightly warmer water to the mainstem.

- The egg incubation and fry emergence maximum optimal temperature (53.5°F) was exceeded from late spring through August in some reaches; the adult spawning maximum optimal temperature (55°F) was also exceeded during this time. Juvenile rearing maximum optimal temperature (60.8°F) were exceeded by the daily maximum temperatures at the Claiborne Creek and Yet Atwam Creek Stations.
  - At Ladybug Creek (Winnemem Waywaket RM 32.9), the maximum temperature started to exceed the egg incubation and fry emergence maximum optimal temperature (53.5°F) at this station in late spring (i.e., May 2025) and continued through the data collection period at the end of August.
  - At Claiborne Creek (Winnemem Waywaket RM 26.3 and Winnemem Waywaket RM 26.1) and Yet Atwam Creek (Winnemem Waywaket RM 24.2), the maximum temperature started to exceed the egg incubation and fry emergence maximum optimal temperature (53.5°F) and the adult spawning maximum optimal temperature (55°F) in late spring (i.e., May 2025) and continued through the data collection period at the end of August.
  - At Claiborne Creek (Winnemem Waywaket RM 26.3 and Winnemem Waywaket RM 26.1) and Yet Atwam Creek (Winnemem Waywaket RM 24.2), the maximum daily temperature began to exceed the juvenile rearing maximum optimal temperature (60.8°F) briefly in mid-June and then consistently exceeded the tolerance limit in July. The juvenile rearing maximum optimal temperature was never reached at Ladybug Creek (Winnemem Waywaket RM 32.9), where the highest recorded temperature over the entirety of the Project was 59.4°F.

Shasta Reservoir

As part of the reintroduction and rematriation of Chinook Salmon, Shasta Reservoir is only being evaluated as migration habitat. Key findings for Shasta Reservoir are provided as follows:

- Temperature stratification was evident; surface layers were much warmer than deep water during the summer. Through the months of mid-November to mid-February, the temperature deviations across depths were minimal in comparison to the September through mid-November and mid-March through May periods. If the deployment had continued through the summer months, it is reasonable to presume that the differences in temperature across depths would be at their highest. As such, the period between March and October is likely when temperature differences between shallow and deep Shasta Reservoir water were highest.
- Adult migration through the top 20 m of the Shasta Reservoir and juvenile migration through the top 20 m to 40 m were thermally prohibitive, at least in the later-summer and early-fall months, making the deep water a critical thermal refuge during that time.

Other Shasta Reservoir temperature data have been collected as part of the biological data gaps study by USGS and as part of the JSCS pilot study by DWR (DWR 2024, DWR 2025a).

Dry Creek, Little Cow Creek, and Cow Creek

As part of the reintroduction and rematriation of Chinook Salmon, Dry Creek, Little Cow Creek, and Cow Creek (i.e., the potential tributary bypass) are expected to provide habitat for adult and juvenile migration. As such, temperature collected as part of this study were compared to the maximum optimal temperatures found in the literature for various life stages of Chinook Salmon. Key findings for Dry Creek, Little Cow Creek, and Cow Creek are provided as follows:

- Dry Creek was generally cooler than Little Cow Creek until late fall; thereafter, patterns reversed.
- In Dry Creek near the Little Cow Creek confluence, daily maximum and daily average temperature exceeded the juvenile rearing maximum optimal temperature (60.8°F; Appendix N) and juvenile out-migration maximum optimal temperature (64.4°F) from September until mid-October and then again starting in the spring prior to June. As such, water temperature is expected to exceed the juvenile rearing and out-migration maximum optimal temperature from the late spring through mid-October. The maximum temperature exceeded the adult migration maximum optimal temperature (68°F) in late September and then again starting in the spring prior to June, indicating that temperature is expected to exceed the tolerance limit from the spring through late September.
- Little Cow Creek was generally warmer than Cow Creek.
- In Little Cow Creek near the Cow Creek confluence, daily maximum and daily average temperature exceeded the juvenile rearing (60.8°F) and juvenile out-migration (64.4°F) maximum optimal temperatures from September until mid- to late October. Because Little Cow Creek was generally warmer than Cow Creek, it likely exceeded the juvenile rearing and juvenile out-migration maximum optimal temperatures again in late April. As such, the temperature is expected to exceed the juvenile rearing and out-migration upper tolerance limits from late April through mid- to late October. The maximum temperature exceeded the adult migration maximum optimal temperature (68°F) until mid-October and then again starting in mid-May, indicating that temperature is expected to exceed the upper tolerance limit from mid-May through mid-October.
- In Cow Creek near the Millville gage, daily maximum and daily average water temperature exceeded the juvenile rearing maximum optimal temperature (60.8°F) and out-migration maximum optimal temperature (64.4°F) from September until mid- to late October and then again starting in late April. As such, water temperature is expected to exceed the juvenile rearing and out-migration upper tolerance limits from late April through mid- to late October. The maximum water temperature exceeded the adult migration maximum optimal temperature (68°F)

from September until mid-October and then again starting in mid-May, indicating that water temperature is expected to exceed the upper tolerance limit from mid-May through mid-October.

- Several sensors were lost mid-Project (three of the five stations), likely due to flash weather events in early 2025, creating data gaps from December 2024 to June 2025.

4.1.6.1.4 Conclusions

The study confirmed significant seasonal and spatial variation in water temperature along the migration corridor, with multiple segments exceeding critical maximum optimal temperatures for Chinook Salmon at key life stages. Tributary influences vary, with some adding warmer water to mainstem flows. Shasta Reservoir's thermal stratification offers potential deep-water refugia for juvenile Chinook Salmon, but creates warm surface barriers during summer and early fall. Data gaps remain due to equipment loss and limited access, particularly in Dry Creek and Little Cow Creek.

4.1.6.2 Thermal Accumulation in Migratory Corridors and Channels

A preliminary thermal accumulation analysis was conducted to assess the ability of the proposed fish passage alternatives to maintain suitable water temperature for Chinook Salmon, including the necessary flow requirements to meet suitable water temperature. Data used in the development of the analysis were acquired from existing temperature records measured by PG&E, the CDEC, USGS, DWR, SWAMP, and the Central Valley Regional Water Quality Control Board, among others. The analysis is summarized below and detailed information about sources used and preliminary results. The full document can be found in Appendix J, *Thermal Accumulation in Migratory Corridors and Channels*.

4.1.6.2.1 Purpose and Scope

The purpose of this analysis was to summarize existing water temperature conditions in the Study Area, based on available gage or sensor data, and to evaluate how these trends align with the optimal water temperature requirements for Chinook Salmon. This analysis was completed as a preliminary assessment of thermal gains and the ability of the fish passage alternatives identified in Appendix K, *Water Quantity Requirements for Preliminary Fish Passage Alternatives*, to maintain suitable water temperature for Chinook Salmon, including the necessary flow requirements to meet suitable temperature.

4.1.6.2.2 Methods

Migratory thermal tolerances for Chinook Salmon as discussed in Appendix N are utilized throughout this analysis to determine the suitability of each waterway and fish passage alternative. A summary of these tolerances is provided below in Table 7.

Table 7
Summary of Migratory Thermal Tolerance by Life Stage

Life Stage	Maximum Optimal Temperature[1] (°F)	Source
Adult Migration (Summertime)[2]	68	USEPA (2003); Carter (2008)
Juvenile Non-Core Rearing[3] and Out-Migration (Summertime)[2]	64.4	USEPA (2003)

Notes:

1. Maximum optimal temperature indicates the temperature above which negative effects are expected to occur.
2. The USEPA (2003) temperature criteria shown here are recommended during summertime, when water temperatures are at their highest and cold-water salmonids are most vulnerable. USEPA recommends that non-summer criteria be established for cases when temperature-sensitive activities occur in spring/fall/winter. Otherwise, USEPA states qualitatively that "if the criterion is met at the summer maximum, then temperatures will be lower than the criterion during most of the year" to explain how these summertime criteria may still be protective in the off-season (USEPA 2003).
3. Non-core rearing describes rearing conditions of moderate to low density of juveniles. This use designation incorporates the fact that juveniles will use waters with high-than-optimal temperatures (USEPA 2003).

Available gage data compiled from Appendix I (summarized in Section 4.1.6.1) was used to characterize natural baseline thermal conditions in Cow Creek, Little Cow Creek, Dry Creek, and the Winnemem Waywaket. A full list of the gages and whether they were used in the thermal analysis is located within Appendix J. Additional water temperature data collected as part of the efforts described in Appendix I were used to supplement the analysis.

Using the existing information, data show the following:

- Nomtipom Waywaket temperature is below the maximum optimal temperature for adult Chinook Salmon migration and juvenile out-migration year-round and in all years (Figure 12).
- Cow Creek and Little Cow Creek temperature is generally above the maximum optimal temperature for Chinook Salmon adult migration from mid-April through mid-October and for juvenile out-migration from April through October (Figures 13 and 14).
- Although there are no flow data available for Dry Creek, it is known anecdotally and from LiDAR surveys that Dry Creek is dry in certain locations during summer and fall.
- Winnemem Waywaket temperature is below the maximum optimal temperature for adult migration year-round and in all years. Maximum optimal temperature for juvenile out-migration is exceeded in the months of June through mid-September (Figure 15).

Figure 12
Historical 7-DADM Water Temperature in the Nomtipom Waywaket below Keswick Dam for Calendar Years 1989 Through 2025

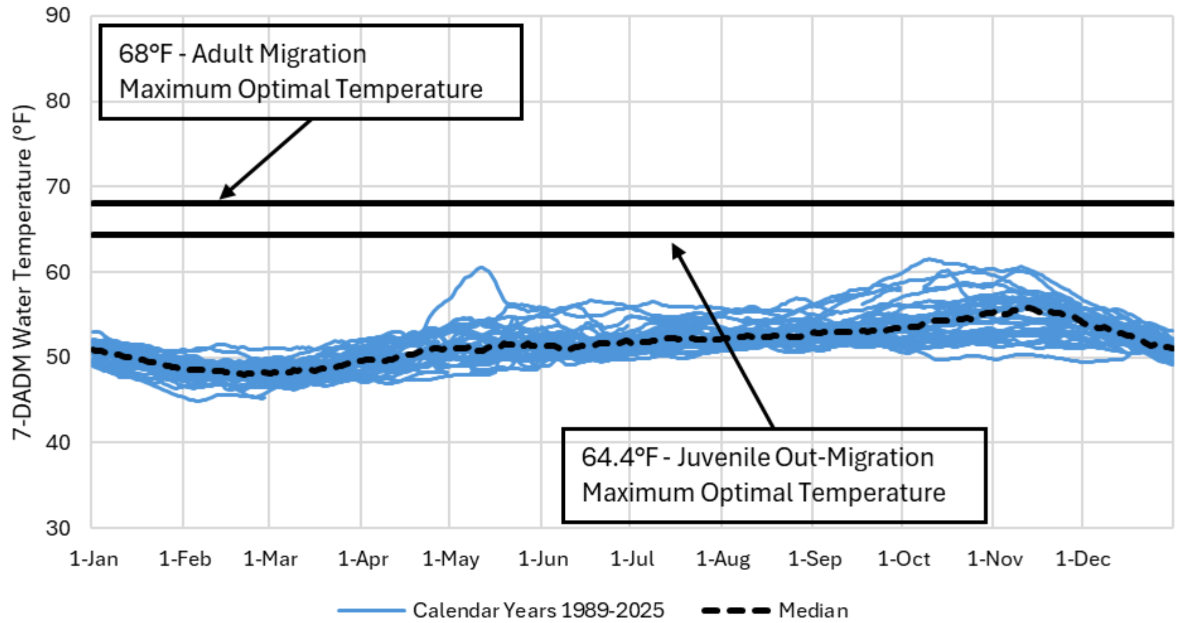


Figure 13
7-DADM Water Temperature in Cow Creek for Calendar Years 2008 Through 2023

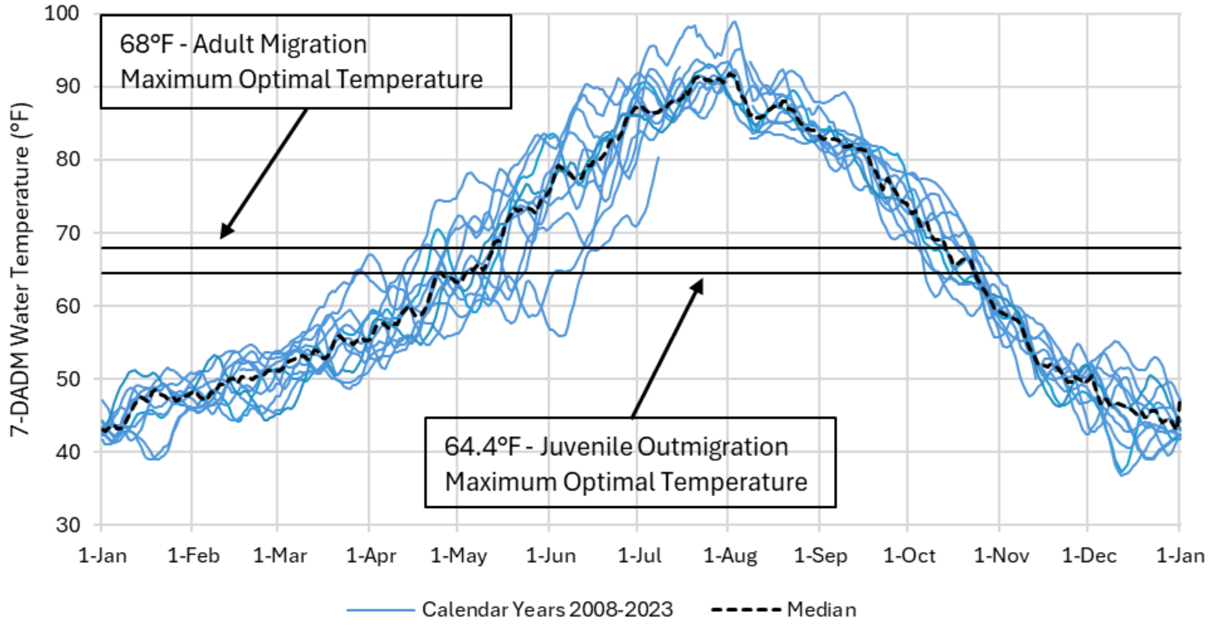


Figure 14
7-DADM Water Temperature in Little Cow Creek for Calendar Years 2003, 2020, 2021, 2024, and 2025

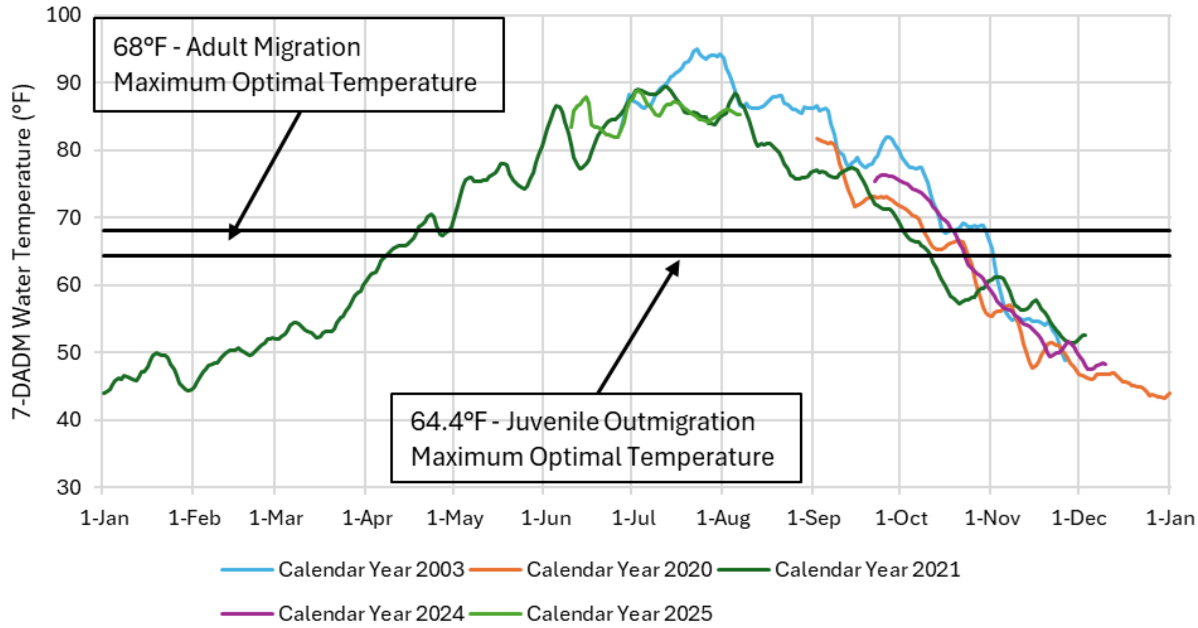
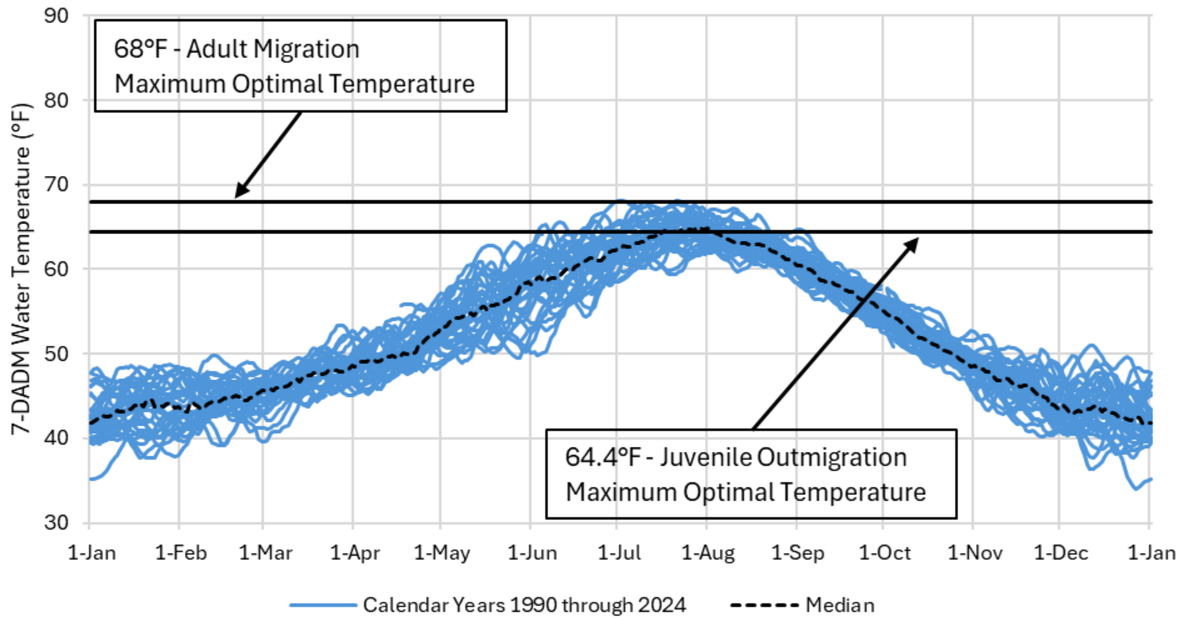


Figure 15
Historical 7-DADM Water Temperature in Winnemem Waywaket for Calendar Years 1990 Through 2024



For this analysis, thermal gain is defined as the rate of warming or cooling within a reach or channel. Using daily average water temperature data as compiled previously in the analysis, thermal gain is calculated as the relative temperature difference between two gages divided by the distance between the two gages, in RMs. Thermal gain can be used to estimate water temperature at any location within the reach based on static measure of the water temperature and the RM distance relative to that location.

Table 8 provides a summary of thermal gain and anticipated water supply needs in each location, which will be used to assess thermal accumulation in volitional passage corridors that are part of the fish passage alternatives.

Table 8
Existing Waterways Thermal Gain and Anticipated Water Supply Needs

Existing Waterway	Thermal Gain, Upstream to Downstream, Throughout the year (°F/RM)	Anticipated Water Supply Needs to Meet Temperature Suitability for Juvenile and Adult Chinook Salmon
Cow Creek	-0.2	Additional cold water is needed from approximately May through October.
Little Cow Creek	0.2–0.5	Additional cold water is needed from approximately April through October.
Dry Creek	No data	There is little to no natural flow in Dry Creek, except during storm events with active watershed runoff. It is assumed that imported water is needed throughout the entire year.
Winnemem Waywaket	0.1–0.3	Additional cold water is needed from approximately June through August.

4.1.6.2.3 Key Findings

A spreadsheet model was developed as a screening-level tool to estimate water temperature along the swimway in Alternative 1: Volitional Tributary Bypass from Cow Creek to the Winnemem Waywaket (see Appendix K for alternative descriptions). The spreadsheet model inputs included historical flow and water temperature data in the Winnemem Waywaket and Cow Creek and estimates of historical thermal gain previously calculated in this document. The spreadsheet model simulated water temperature in the potential tributary bypass assuming 50 cfs is diverted from the Winnemem Waywaket year-round for volitional passage of both juvenile and adult Chinook Salmon (see Appendix K for conceptual design of functional elements and the Alternative 1 nomograph analysis). Note that a flow rate of 50 cfs was selected for Alternative 1 because it is the smallest rate of flow that provides adequate flow depth and velocities for fish movement along all sections of the constructed channel portion of the swimway. Additional water or channel modifications may be required in Dry Creek, Little Cow Creek, and portions of Cow Creek to overcome depth barriers as discussed in Appendix L; this will be analyzed during later stages of design to determine the optimal water quantity and required construction activities to achieve adequate flow depth and velocities for fish movement throughout the entirety of the tributary bypass. Output from the spreadsheet model is presented in Section 5 of Appendix J.

Thermal accumulation of water temperature in the fish ladders at Shasta Dam and Keswick Dam for Alternative 3: Semi-Volitional Passage in the Nomtipom Waywaket Over Keswick and Shasta Dams to the Winnemem Waywaket was estimated using U.S. Department of Interior – USGS Stream Segment Temperature (SSTEMP) model version 2.0.8 (Bartholow 2002). SSTEMP can also simulate the special case of a dam at the upstream end of the stream reach with steady state releases (flow and temperature). Inputs to the model include stream geometry, reach inflow, reach accretion, and meteorology. The model predicts mean daily and maximum daily water temperature at the downstream end of the stream reach. Historical daily average water temperature data measured below the dam were used to estimate release temperature from Keswick Dam to the Keswick Dam fish ladder. At Shasta Dam, because it is unknown what the temperature will be at the inlet of the fish ladder due to reservoir stratification, a conservative assumption for incoming water temperature was used. Output from the SSTEMP models are presented in Section 7 of Appendix J.

Simulated 7-day average of the daily maximum (7-DADM) water temperature for Alternative 1 was compared to the optimal temperature for Chinook Salmon (Table 7) to estimate the suitability of the alternative for fish passage during migration periods. The assessment resulted in the following key findings:

- Analysis of turbulent heat transfer in the four tunnels within Alternative 1 found that the water would always exit at the same temperature as the rock wall temperature (58°F) regardless of water temperature entering the tunnel (Figure 18 of Appendix J).
- In general, imported water cools water temperature from May through September and warms temperature in October through December relative to the natural baseline in Cow Creek (Figure 21 of Appendix J) and Little Cow Creek (Figure 20 of Appendix J).
- 7-DADM water temperature in Cow Creek exceeds maximum optimal criteria for adult migration (68°F) from approximately May through mid-October (Figure 23 of Appendix J). This has the potential to negatively impact winter-run adult migration and holding (Figure 24 of Appendix J), and spring-run adult migration and holding (Figures 26 and 27 of Appendix J). Water temperature would decrease upstream of this location in Little Cow Creek and Dry Creek, providing more suitable temperature conditions for some life stages.
- 7-DADM water temperature in Cow Creek exceeds maximum optimal criteria for juvenile out-migration (64.4°F) from approximately May through October (Figure 23 of Appendix J). This has the potential to negatively impact winter-run and spring-run smolt out-migration (Figures 25 and 28 of Appendix J). Water temperature would decrease upstream of this location in Little Cow Creek and Dry Creek, providing more suitable temperature conditions for some life stages.
- Increasing flows from 50 cfs up to 150 cfs, the design criteria upper limit given in Appendix K to provide adequate flow depth and velocities along the potential tributary bypass constructed channel, did not significantly increase the amount of time 7-DADM water temperatures were less than the maximum optimal criteria for either adults or juveniles (Figure 29 of Appendix J).

A preliminary thermal assessment of Alternative 2 was not completed. Based on similarities between Alternative 1 and Alternative 2 it is likely that key findings would be similar to those of Alternative 1.

Simulated 7-DADM water temperature for Alternative 3 was compared to the optimal temperature for Chinook Salmon (Table 7) to estimate the suitability of the alternative for fish passage during migration periods. The assessment resulted in the following key findings:

- Thermal accumulation within the fish ladders was highest in July and lowest in December. The highest daily average total thermal accumulation in the Keswick Dam fish ladder was approximately 0.9°F (Figure 30 of Appendix J). The highest daily average total thermal accumulation in the Shasta Dam fish ladder was approximately 2.4°F (Figure 36 of Appendix J).
- 7-DADM water temperature in the Keswick Dam fish ladder never exceeded the maximum optimal criteria for adults (68°F; Figures 32 and 34 of Appendix J) or for juveniles (64.4°F) (Figures 33 and 35 of Appendix J), assuming water temperature in Keswick Reservoir is managed similarly in the future as they have in the past.
- 7-DADM water temperature in the Shasta Dam fish ladder is not expected to exceed the maximum optimal criteria for adults (68°F) as long as water temperature at the head of the fish ladder does not exceed 65.8°F for 7 continuous days.
- Proposed flows in the fish ladders are a minimum of 35 cfs (refer to Appendix K), as compared to much higher releases from Shasta Dam and Keswick Dam. The historical mean monthly flow below Keswick Dam in July is 12,500 cfs (USGS 11370500, July 1964 through July 2024). A small increase in water temperature from the fish ladders would not have any noticeable impact on water temperature in the Nomtipom Waywaket.

4.1.6.2.4 Conclusions

Based on observations from preliminary water temperature assessments for Alternative 1 and Alternative 3, Alternative 3 appears most suitable for fish survivability and Alternative 1 is the least suitable without additional cold-water inputs into Cow Creek. Refer to Appendix J for the full analysis, including detailed charts and figures, and to Appendix K for a discussion of the descriptions, conceptual functional elements designs, and water requirements for each alternative.

4.1.7 Water Quantity Requirements for Fish Passage Alternatives

Water quantity requirements were determined for each fish passage alternative. This section summarizes the assessment and more detailed information can be found in Appendix K. Data used in the development of the document were acquired through sources including NMFS, CDFW, and the California Department of Transportation, among others.

4.1.7.1 Purpose and Scope

The purpose of this document is to analyze and quantify water requirements for each of the preliminary fish passage alternatives. Water is a limited resource in the Study Area, and the required quantity of water for each alternative was a key factor in the alternatives evaluation.

This study provided information essential to establish water quantities for each functional element of the fish passage alternatives, including documentation of design criteria, target metrics, flow analysis, and the resulting conceptual design. The study synthesized the functional element conceptual designs and the thermal accumulation analysis in Appendix J to provide a water quantity estimate for each fish passage alternative.

4.1.7.2 Methods

The list of primary functional elements that use water as part of each alternative included modified natural channel, constructed channel, tunnel, water bridge, conduit, and fish ladder. A literature review was performed for each element to obtain design criteria and target metrics for use in developing conceptual designs. The list of sources was compiled as shown in Table 9, and detailed tables within Appendix K provide selected design criteria and metrics.

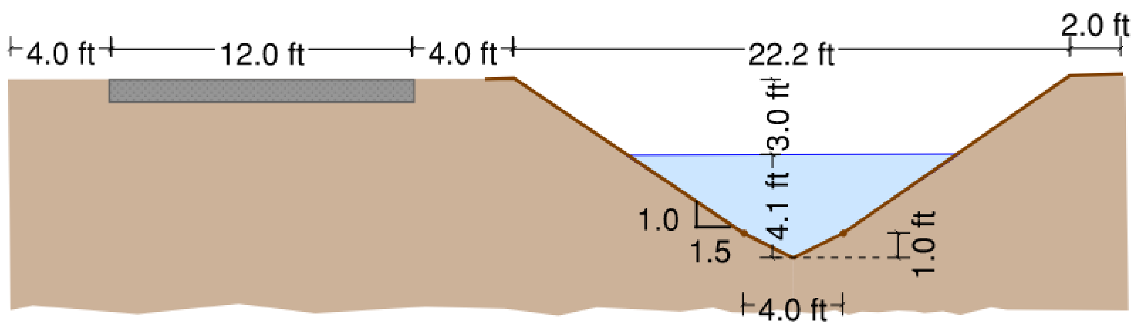
Table 9
Summary of Functional Elements and Water Quantity Requirements for Fish Passage Alternatives

Functional Element	Design Criteria or Target Metric Source
Modified natural channel	Keeley and Slaney (1996); Burner (1951); Chambers et al. (1955); Hamilton and Buell (1976); Allen (2000); CDFW (2017); NMFS (2023a)
Constructed channel	CalTrans (2020, 2025); NMFS (2023a)
Tunnel	CalTrans (2020, 2025); NMFS (2023a)
Water bridge	CalTrans (2020, 2025); NMFS (2023a)
Conduit	NMFS (2023a)
Fish ladder	NMFS (2023a)

During later stages of design, the design criteria would be further refined; however, the design criteria and target metrics identified by sources listed in Table 9 were used as the best available information to support the conceptual design of each functional element. Refer to Appendix K for a full description of each conceptual design.

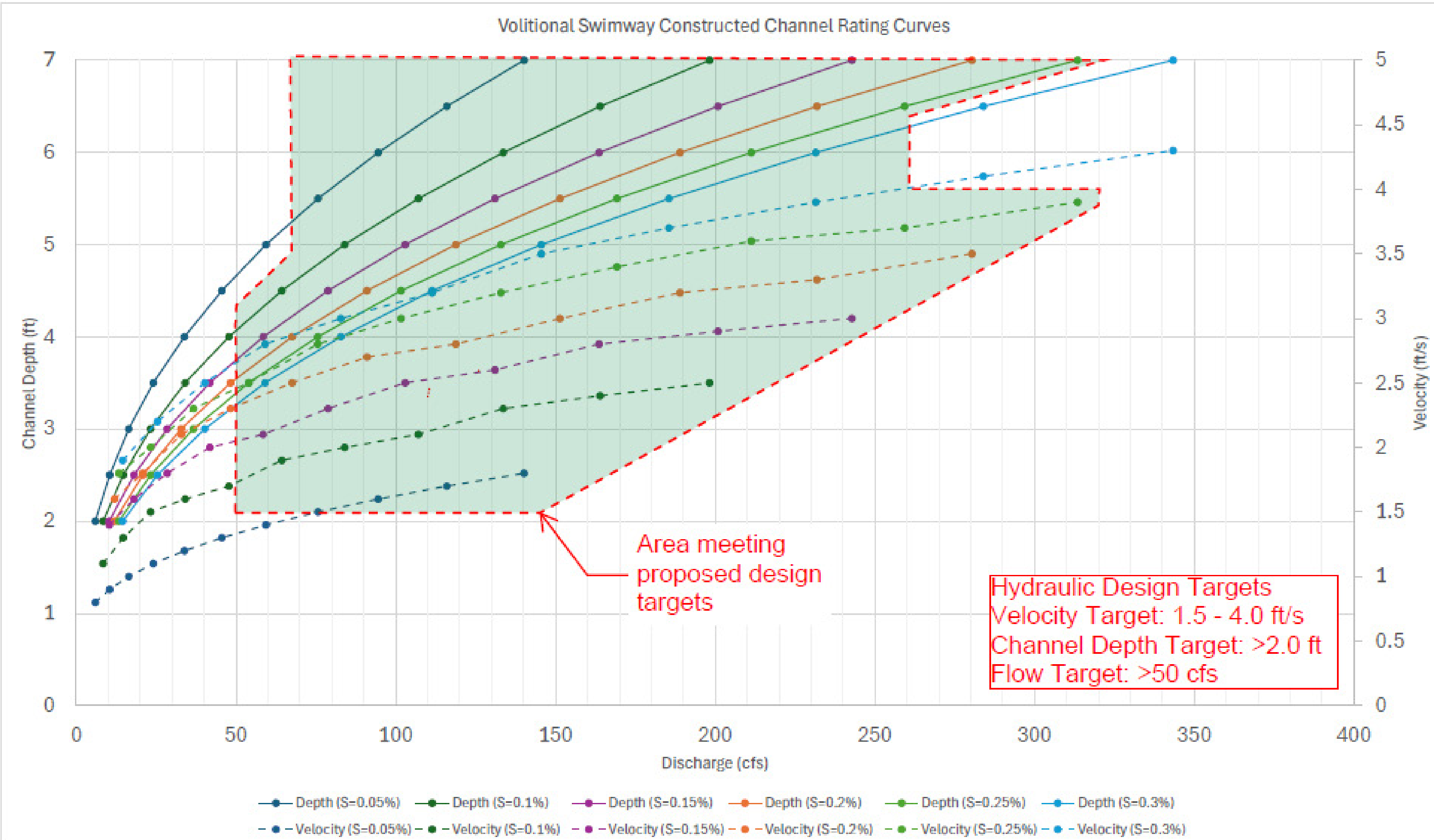
The most detailed analysis was performed to optimize the cross-sectional design of the constructed channel to meet identified target metrics while also minimizing the top width of the channel (Figure 16). Equipment access was considered in the maintenance road width and clearance from the channel.

Figure 16
Constructed Channel Design Cross Section



A series of nomographs for the constructed channel was developed utilizing inputs from the conceptual design such as the channel shape, Manning's n value of 0.04 to represent a clean, winding main channel with some pools and shoals (Chow 1959), slope, and depth to generate outputs including flow quantity and corresponding velocity. As a result, a range of potential design options meeting the target metrics is shown in Figure 17.

Figure 17
Nomographs for Constructed Channel Design Cross Section

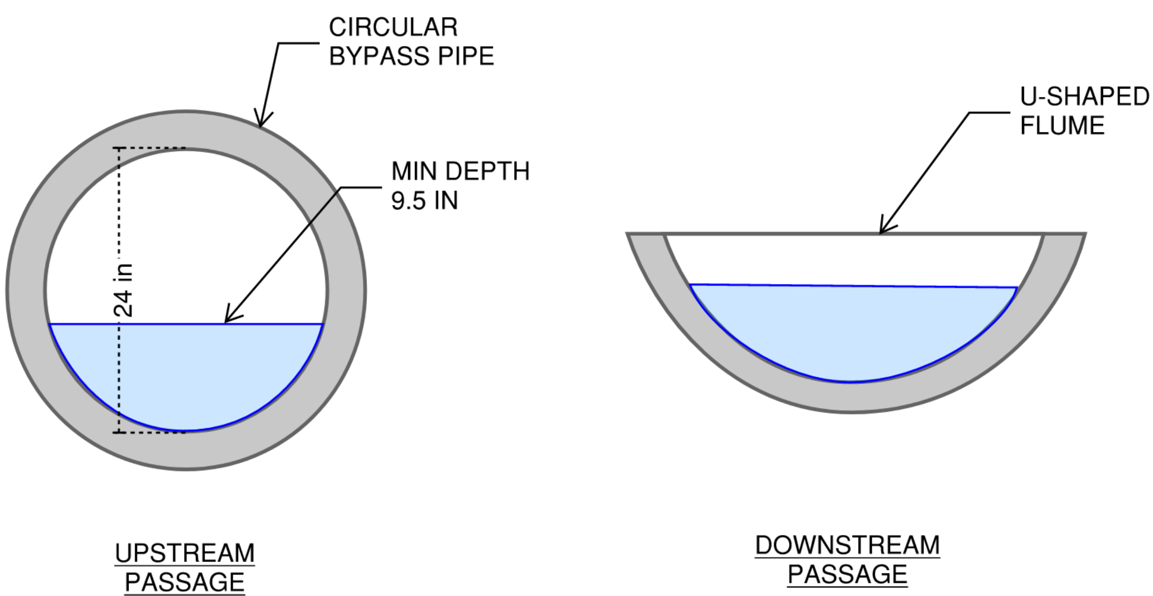


The area shaded green in Figure 17 can be used to select a constructed channel slope and flow rate that meets target metrics. For an option to meet all design criteria, the dashed line representing velocity criteria and the solid line representing depth criteria must both fall within the design target ranges. By selecting a slope and two separate data points along both the corresponding colored dashed and solid lines within the green area, the corresponding flow rate can be found on the x-axis.

The tunnel and water bridge use the same constructed channel cross section and maintenance road design as shown in Figure 16; refer to Appendix K for additional figures depicting these conceptual designs.

A conduit may be used to convey fish in both upstream and downstream passage applications. For upstream passage applications, a round, 12-inch-diameter conduit meeting design criteria (NMFS 2023a) would likely attach to the upstream end of a volitional passage structure to accommodate a wide range of water surface elevations (WSEs) at the fishway exit, called an adult return flume. For downstream passage applications, a bypass conduit meeting design criteria (NMFS 2023a) would likely be a U-shaped flume that would convey fish from the upstream side of a barrier to the downstream side. Figure 18 presents a potential cross section for an upstream passage conduit (left) and a downstream passage conduit (right).

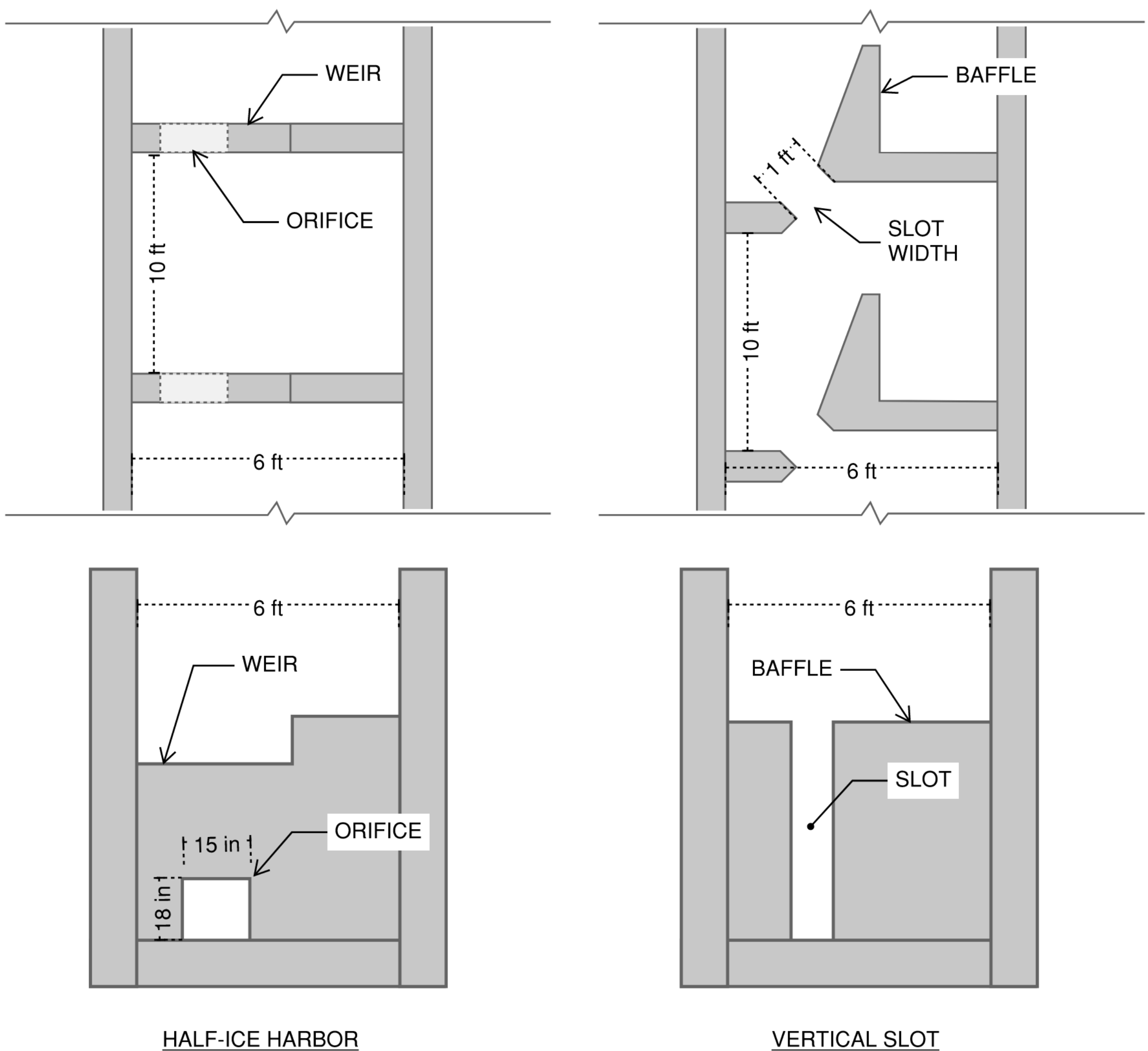
Figure 18
Potential Conduit Geometry



Note: Not drawn to scale

A Half-Ice Harbor–style fish ladder may be implemented at Keswick and/or Shasta dams to provide volitional or semi-volitional passage routes for upstream-migrating fish. Total length and entrance and exit configurations will vary for each site and each potential alternative, but the configuration shown in Figure 19 provide general design elements that are anticipated for each ladder.

Figure 19
Potential Fish Ladder Geometry



Notes: Not drawn to scale
Top panels are plan views; bottom panels are cross-section views

Appendix K also provides a summary of attraction flows for each potential fish ladder at Keswick and Shasta dams, calculated through analysis of daily average outflow data from CDEC and USGS's

National Water Information System (NWIS). Keswick Dam daily outflows were obtained from the Reclamation-operated CDEC KES gage, while Shasta Dam daily outflows were calculated as the total inflow into Keswick Reservoir with subtraction of flows from Spring Creek Debris Dam and Spring Creek Powerhouse. A summary of the daily discharge data and its source is provided in Table 10.

Table 10
Daily Average Discharge Data Sources

Gage Name	Gage ID	Description	Operating Agency	Period of Record	Source
Keswick Reservoir	KES (sensor 76)	Daily average inflows into Keswick Reservoir	Reclamation	01/01/1994 to 05/15/2025	CDEC
Keswick Reservoir	KES (sensor 23)	Daily average outflows from Keswick Reservoir (including powerhouse flows)	Reclamation	10/02/1993 to 05/15/2025	CDEC
Spring Creek Debris Dam	SPC	Daily average outflows from Spring Creek Debris Dam	Reclamation	12/25/2001 to 05/15/2025	CDEC
Spring C PH A Keswick CA	11371600	Daily average outflows from Spring Creek Powerhouse	USGS	01/01/1964 to 09/30/2024	NWIS

The daily average discharge values were used to calculate flow duration statistics and evaluate seasonality of flows downstream of each of the dams, which could later be used to analyze fish passage design flows. Section 5.3 provides figures showing the 95% exceedance, 50% exceedance, and 5% exceedance flows throughout the water year with an overlay of the Chinook Salmon upstream migration window for Shasta Dam and Keswick Dam.

Based on the NMFS (2023a) criteria for attraction flows, the high fish passage flows at Shasta Dam and Keswick Dam result in attraction flow ranges of 1,710 cfs to 3,420 cfs and 1,807 cfs to 3,614 cfs, respectively (refer to Table 11). Due to the difficulty of designing a fish ladder entrance that can effectively convey flows of this magnitude while maintaining favorable hydraulics, attraction flows conveyed through the entrances are anticipated to be on the order of 400 cfs. The use of lower, more practicable, attraction flows would also require additional elements that would improve guidance, hydraulic preference, and attraction to the ladder entrance such as a barrier/guidance dam, adjustable weir sections, and hydraulic guidance features that improve overall attraction to a ladder entrance. Refer to Appendix K for the full analysis, including monthly and annual duration statistics for both Shasta and Keswick dams.

Table 11
Fish Passage Design Flows

Location	Low Fish Passage Design Flow[1] (cfs)	High Fish Passage Design Flow[2] (cfs)	Low Attraction Flow[3] (cfs)	High Attraction Flow[4] (cfs)	Selected Attraction Flow[5] (cfs)
Shasta Dam	1,263	34,195	1,710	3,420	400
Keswick Dam	2,974	36,140	1,807	3,614	400

Notes:

1. Calculated as the minimum 95% average daily flow exceedance value during months which the adult Chinook Salmon migration period, based on NMFS (2023a) criteria
2. Calculated as the maximum 5% average daily flow exceedance value during months which the adult Chinook Salmon migration period, based on NMFS (2023a) criteria
3. Calculated as 5% of the high fish passage design flow based on NMFS (2023a) criteria
4. Calculated as 10% of the high fish passage design flow, based on NMFS (2023a) criteria
5. Modified based on anticipated capacity of fish ladder entrance in combination with other fish guidance features

4.1.7.3 Key Findings

The conceptual design of each functional element provided a basis for the thermal accumulation analysis performed in Appendix J (see to Section 4.1.6.2) and for the water quantity requirements for each alternative. A summary of each alternative, its water-related functional elements, and the resulting anticipated water quantity requirement is shown in Table 12. Note that for Alternative 1, a flow rate of 50 cfs was selected because it is the smallest rate of flow that provides adequate flow depth and velocities for fish movement along all sections of the constructed channel portion of the swimway. Additional water or channel modifications may be required in Dry Creek, Little Cow Creek, and portions of Cow Creek to overcome depth barriers as discussed in Appendix L; this will be analyzed during later stages of design to determine the optimal water quantity and required construction activities to achieve adequate flow depth and velocities for fish movement throughout the entirety of the tributary bypass.

Note that full descriptions of each alternative are provided in Appendix K, and that detailed analysis was not performed on Alternative 2 because the long stretches of constructed channels, water bridges, and tunnels throughout its alignment are anticipated to be similar to Alternative 1.

Table 12
Summary of Functional Elements and Water Quantity Requirements for Preliminary Fish Passage Alternatives

Alternative or Approach	Functional Elements	Water Quantity Requirement (cfs)
Alternative 1: Volitional Tributary Bypass from Cow Creek to the Winnemem Waywaket	Modified channel; constructed channel; tunnel; water bridge	50
Alternative 2: Semi-Volitional Tributary Bypass from ACID Dam to the Winnemem Waywaket via Railroad Grade	Fish ladder with attraction flow and adult return flume; constructed channel; tunnel; water bridge	N/A
Alternative 3: Semi-Volitional Passage in the Nomtipom Waywaket Over Keswick and Shasta Dams to the Winnemem Waywaket	Two fish ladders with attraction flow and adult return flumes; one surface flow outlet	1,700
Trap and Haul Approach	Two fish ladders with attraction flow and adult return flumes; one surface flow outlet; one holding facility	1,720
Downstream Fish Migration Guidance and Collection	Juvenile collection and transport facility	20

4.1.7.4 Conclusions

As shown in Table 12, Alternatives 1 and 2 are expected to require the least amount of water. However, based on information provided in Appendix J, the tunnels used as functional elements in Alternatives 1 and 2 undergo a turbulent heat transfer with the constructed channel flow, which limits the amount of cooling the imported water can provide. This limited cooling coupled with the high temperature in Cow Creek during the summer and fall causes water temperature to be unsuitable for Chinook Salmon in Cow Creek for 3.5 to 6 months during the adult Chinook Salmon migration and holding periods and for 4 to 7 months during the smolt out-migration period. Increasing the quantity of water within the channel does not affect the results of the thermal accumulation analysis. Though Alternatives 1 and 2 require the least water to function, data show the water temperature will vary throughout the year and will periodically be unsuitable for Chinook Salmon adult migration or holding and smolt out-migration. Increasing flows from 50 cfs up to 150 cfs, the design criteria upper limit given to provide adequate flow depth and velocities along the potential tributary bypass constructed channel, did not significantly increase the amount of time 7-DADM water temperatures were less than the maximum optimal criteria for either adults or juveniles (Figure 29 of Appendix J).

Alternatives 3 and 4 consider the most conservative assumptions (highest-flow requirement) to include worst-case scenario water requirements and are anticipated to require the most water to function (Table 12). Based on the analysis described in *Thermal Accumulation in Migratory Corridors and Channels* (Appendix J), the temperature within the Keswick Dam and Shasta Dam fish ladders are always suitable for adult Chinook Salmon migration and smolt out-migration. Therefore, while Alternatives 3 and 4 require a significantly increased quantity of water over Alternatives 1 or 2, the water temperature will remain suitable for Chinook Salmon throughout the migration and out-migration periods.

4.1.8 Physical Barriers to Fish Passage

Physical barriers to fish passage were evaluated along a potential tributary bypass around Keswick and Shasta dams, which goes from the Nomtipom Waywaket to Cow Creek to Little Cow Creek to Dry Creek. This pathway is the Winnemem Wintu Tribe's preferred routing around Keswick and Shasta dams. Natural and anthropogenic barriers were evaluated to fill data gaps using a mix of desktop and field-based data collection. Detailed information about the evaluation is provided in Appendix L and is summarized below.

4.1.8.1 Purpose/Scope

The purpose of this assessment was to compile available existing data on potential natural and human-made fish passage barriers in Dry Creek, Little Cow Creek, and Cow Creek to identify data gaps and then collect new data and perform analyses to fill those data gaps. The assessment focused on adult and juvenile Chinook Salmon migration, with emphasis on adults. Barriers were classified using the *Fish Passage Inventory, Assessment, and Prioritization Manual* (WDFW 2019) and the *Standard Operating Procedure for Critical Riffle Analysis for Fish Passage* (CDFW 2017), and then defined in terms of upstream migration obstruction under specified flow conditions.

4.1.8.2 Methods

Methods are described in the following list for the natural barriers and anthropogenic barriers evaluations for adult Chinook Salmon. Data collection addressed critical data gaps, particularly missing bathymetric information from post-2019 Carr and Hirz Delta Fire LiDAR datasets and missing potential natural and anthropogenic barrier information for Dry Creek and potential natural barrier information for Little Cow and Cow Creeks.

- Topobathymetric LiDAR was flown in October 2024 for target creeks in Shasta County, though some voids remained, requiring interpolation.
- Barrier assessment was categorized by feature type (natural, bridge, ford, or culvert) and followed established fish passage protocols, including passage criteria (WDFW 2019; CDFW 2017).
- Natural Barrier Evaluation
  - Field observations were collected along Dry Creek to better understand the roughness features of the channels, fine-scale features of previously identified natural waterfalls, and the effects of geology on channel morphology and channel features. Observations were used to adjust the 2D HEC-RAS model and to interpret the model results.

- Hydraulic modeling using a 2D HEC-RAS model incorporated criteria for water depth, velocity, water surface drop, and slope. The criteria are based on adult Chinook Salmon's swimming ability, leaping height capability, and minimum water depth criteria.
- Anthropogenic Barrier Evaluation
  - Field data were collected for culverts, bridges, and fords identified along Dry Creek. This information, along with GIS analyses confirming lengths and slopes, was used for this evaluation.
  - The evaluation included whether each feature could pass the augmented flows that would be required to get fish upstream when natural flows are low (e.g., approximately >160 cfs).
    - For culverts, water discharge and velocity at full-pipe (i.e., no head) were calculated using both Manning's equation for water flow in a circular pipe and the Darcy-Weisbach equation. The two equations assumed hydraulic roughness values provided an approximate range of values.
    - For calculating discharge through the bridges, Manning's equation for water flow in an open trapezoidal channel was used and channel dimensions were modified as necessary to fit a trapezoidal channel. The hydraulic calculations were completed using the R (ver. 4.5) hydraulics package (Maurer and Embry 2024).
  - If a feature either met the culvert and bridge barrier criteria, or was determined to not pass the required discharges, it was considered a partial or total barrier.
  - Fords were evaluated using a combination of the depth in/over structure criteria and discharge.

4.1.8.3 Key Findings

Key findings for the natural barrier and anthropogenic barrier evaluations are listed below.

Natural Barrier Observations

- Dry Creek headwaters show steep drops and narrow canyons that may act as natural barriers. Three natural waterfalls/cascades that are considered partial and temporal barriers exist along the upper portion of Dry Creek.
- Critical riffles for Chinook Salmon (<0.9-foot depth) and high-velocity reaches limit passage at low flows and high flows.
  - The hydraulic model results show that with increased flow augmentation, the number of critically shallow riffles decreases. Critical riffles are limited, to an extent, at 160 cfs and are unlikely to be complete barriers, but critically shallow depths would likely still be encountered in a few locations even with 200 cfs of flow augmentation in Dry Creek.
  - The hydraulic model results demonstrate that flow augmentation of up to 200 cfs into Dry Creek has little effect on depth in the larger Cow Creek drainage below Little Cow

Creek and that low-flow conditions in Cow Creek create critical riffle barriers that limit upstream migration of adult Chinook Salmon in summer and fall.

  - The hydraulic model also indicates that sustained high velocities are present in upper Dry Creek, and velocity generally increases with increased flow. Increased flow augmentation may also decrease pool-type habitats that provide resting areas for upstream-migrating adult Chinook Salmon by washing the pools out.
  - The combination of critically shallow depths at flows less than 160 cfs and sustained high velocities at flows of 160 and 200 cfs in Dry Creek indicates that hydraulics alone would present at least a partial barrier under current channel conditions. The modeling results suggest that channel modification and habitat improvement would likely be required along with flow augmentation to provide upstream passage for adult Chinook Salmon.

Modeling Notes

- High roughness values used for Dry Creek may underestimate velocity during high flows.
- Hydraulic results for Cow and Lower Cow Creeks incorporated variable roughness based on land cover.
- No model calibration was done for this evaluation because the scale at which inferences were made (i.e., 22 RMs) made model calibration impracticable. If this portion of the Project moves forward to more advanced levels of design, the 2D HEC-RAS model should be used to target areas for model refinement and calibration using field data across a range of flows.

Anthropogenic Barriers

- All assessed culverts were slope/velocity barriers at the discharges each was able to pass. None of the culverts were sized large enough to pass 160 cfs, which is the likely amount of flow needed to allow adult Chinook Salmon to pass based on the critical depth assessment that was part of the natural barrier evaluation.
- Two improved fords are partial barriers and will likely require removal or improvement.
- Most bridges are passable except Bear Mountain Road Bridge, which has a velocity risk.

4.1.8.4 Conclusions

4.1.8.4.1 Adult Chinook Salmon Considerations

When considering natural barriers, passage through Dry Creek is only feasible with a minimum of 160 cfs to 200 cfs flow augmentation between December and April when natural flows are highest. Even with flow augmentation, habitat modifications are likely still needed in upper Dry Creek for sustained passage. Low flows in Little Cow Creek and Cow Creek limit the benefit of Dry Creek flow augmentation in the summer and fall (i.e., May through November) because there are still critical depth barriers to passage during this low-flow period. As such, additional channel modifications are required for Chinook Salmon passage during these months.

Flow augmentation of 160 cfs to 200 cfs into Dry Creek during December to April provides the conditions most conducive to adult Chinook Salmon migration from Cow Creek to Little Cow Creek and up through Dry Creek. Winter-run Chinook Salmon would encounter the least amount of barriers, which are limited to Dry Creek because most of the migration occurs in the winter between January and March. Even with these favorable flows, there are likely channel areas that require modification to facilitate unimpeded passage. Spring-run Chinook Salmon are expected to encounter more barriers in Dry Creek, Little Cow Creek, and Cow Creek than winter-run Chinook Salmon due to their later migration timing when flows are lower, and fall-run and late-fall-run Chinook Salmon are expected to encounter the most barriers because they are migrating mostly during the fall when flows are lowest. Extensive channel modifications are likely required to facilitate unimpeded passage for adult spring-run, fall-run, and late-fall-run Chinook Salmon.

The anthropogenic barriers pose partial and total barriers to adult Chinook Salmon migration. The potential anthropogenic barriers to migration are mostly at the head of the watershed, in and around Jones Valley, which could be avoided by placing the constructed channel lower down in the Dry Creek natural channel and starting the flow augmentation downstream of Jones Valley.

All the culverts in the evaluation would be barriers to Chinook Salmon migration based on slope or velocity at the discharges the pipes can pass. However, none of the culverts can pass 160 cfs, which is the augmented discharge that would likely be required to move adult Chinook Salmon up through Dry Creek. Because of this, the culverts are all considered to be barriers that would need to be removed or fixed. The number of culverts that would need to be replaced depends on the route that is considered for fish passage. If the constructed channel starts in Bear Valley, as opposed to upper Dry Creek above the Jones Valley Community, fewer anthropogenic barriers would need to be fixed. Fish passage through Jones Valley would likely be difficult to implement because development has occurred along the ephemeral channel without consideration for the need to pass perennial flow or provide fish passage.

The two anthropogenic improved fords would likely need to be removed or improved because they would be overtopped at 160 cfs and vehicle traffic through a ford is not conducive to fish passage.

The bridges do not appear to represent barriers to migration, except for the Bear Mountain Road Bridge, which might require some maintenance to pass high flows without becoming a potential velocity barrier. All the remaining bridges appear to be able to convey current flood flows without issue and do not appear to have any features that would make them a barrier to migration.

4.1.8.4.2 Juvenile Chinook Salmon Considerations

Passage of juvenile Chinook Salmon should also be considered along the Dry Creek, Little Cow Creek, and Cow Creek pathway. Movement of juvenile Chinook Salmon can potentially be affected by natural and anthropogenic barriers.

- Juvenile Chinook Salmon that are fully smolted, including yearlings, are expected to orient to the highest-velocity cross section of the stream (thalweg) and readily pass through stream reaches if the amount of water in the channel provides sufficient depth relative to their body size. Sub-yearling juveniles exhibit migration behaviors that are less directed than fully smolted fish and more influenced by streamflow pulses that occur during rainstorms.
- Barriers that form a drop or waterfall/cascade should be easily passed by downstream-migrating smolts without injury as long as the plunge pool is deep enough so that the fish do not hit the substrate and impact velocities are within criteria.
- When the three waterfall/cascade barriers, culverts, and fords in Dry Creek, Little Cow Creek, and Cow Creek are modified to address adult Chinook Salmon passage, the design should ensure plunge pool depths and impact velocities for juvenile Chinook Salmon migrating downstream are addressed.
- There are 12 unscreened water diversions in the Cow Creek watershed that will need to be screened according to NMFS's guidelines (NMFS 2023a) to protect juvenile Chinook Salmon.
- Existing culverts, bridges, and fords along Dry Creek that were evaluated in this document for adult passage and found to require upgrading to meet adult passage criteria will also need to consider juvenile passage criteria (NMFS 2023d).

4.1.9 Trap and Haul Fish Passage Strategy Description

Previous efforts developed a trap and haul passage alternative for passing fish above Keswick and Shasta dams. The Feasibility Study is required by the CDFW grant agreement to compare volitional fish passage alternatives to the trap and haul strategy. Because of this, the data gaps study includes compiling existing information on the trap and haul passage strategy. This section summarizes the trap and haul strategy, and Appendix M, *Summary of Previous Development and Evaluation of Trap and Haul Passage Alternative*, provides additional details. Sources used to develop this trap and haul description were obtained from documents provided by Reclamation. Information relevant to the development of upstream and downstream trap and haul concepts from sources such as Reclamation, DWR, Winnemem Wintu Tribe, and Environmental Science Associates was compiled and summarized in this document. Detailed information about sources utilized for this alternative description can be found in Appendix D.

4.1.9.1 Purpose and Scope

The purpose of this task is to review and synthesize information from documents provided by Reclamation on existing trap and haul concepts for Chinook Salmon reintroduction above Shasta.

4.1.9.2 Key Findings

Key findings are summarized in the following subsections and broken into two categories: 1) Previously Considered Upstream Trap and Haul Concepts; and 2) Previously Considered Downstream Trap and Haul Concepts.

4.1.9.2.1 Previously Considered Upstream Trap and Haul Concepts

In 2010, Reclamation formed the Interagency Fish Passage Steering Committee (IFPSC) to evaluate feasibility for fish passage at Shasta Dam and inform decisions regarding long-term reintroduction strategies in response to the NMFS-prescribed series of actions required for continued operation of the CVP and State Water Project in compliance with the federal ESA (IFPSC 2017). One of the NMFS-prescribed actions was to evaluate reintroduction of winter-run and spring-run Chinook Salmon upstream of Shasta Dam and implement a fish passage pilot program (Pilot Program) on the Sacramento River. In 2013, the Fish Passage Technology Subcommittee (a subcommittee of the IFPSC) developed and evaluated a matrix of potential upstream and downstream passage alternatives for consideration in both the Pilot Program and long-term reintroduction (Reclamation 2013). Three trap and haul options considered for passage above Shasta Dam are detailed in Table 13 as described in an excerpt from the alternative matrix included as Attachment 1 of the meeting minutes from the December 2023 bimonthly Fish Passage Technology Subcommittee meeting.

Table 13
Excerpt from "Matrix of Upstream and Downstream Fish Passage Alternatives at Shasta Dam"

Alternative	Description	Pros	Cons	Worth Further Evaluation for Long Term ?	Potential Use in Pilot Program?
Trap and Haul at Keswick Dam	Uses existing fish collection facility at Keswick Dam. Includes fish ladder, trap, braille-lift, elevator, and trucking or barging to release site upstream of Shasta Dam	Uses existing facilities. Does not alter current project operations. Releases adults directly into tributaries or at head-of-reservoir location. Low cost.	Non-volitional passage. Requires handling and trucking.	Yes	Yes
Trap and Haul at Shasta Dam	Requires new construction of fish collection facility at Shasta Dam. Will include trapping, lifting, and trucking or barging to release site upstream of Shasta Dam.	Takes advantage of 9 miles of habitat between Keswick and Shasta dams. Potential to use LSNFH as collection location. Releases adults directly into tributaries or at head-or-reservoir location	Non-volitional passage. Requires new construction. Requires handling at Keswick Dam and handling and trucking at Shasta Dam. Habitat in Keswick Reservoir is not suitable for spawning.	No	No
Trap and Haul from Coleman Hatchery	Use exiting hatchery facilities (barrier, trap, holding area) to collect adults, hold as needed, and truck to desired tributary.	Uses existing facilities. Does not alter current project operations. Releases adults directly into tributaries or at head-of-reservoir location. Low cost.	Desirable broodstock may not be present in Battle Creek for initial pilot study. Availability of fall and late-fall runs only. Fish brought over from Battle Creek may wander from desired tributary. Requires handling. Would only apply to the initial pilot studies.	No	Yes

Source: Reclamation (2013)

Because LSNFH does not have a water treatment system in place, and Shasta Reservoir is the water source for the hatchery, the current strategy for pilot reintroduction above Shasta Dam is to transport winter-run Chinook Salmon eggs from the LSNFH captive broodstock program to incubation stations in the McCloud Arm of Shasta Reservoir (Reclamation 2023). Without water treatment at LSNFH, letting adult fish pass upstream (above the hatchery water supply/intake corridor) materially increases the risk of introducing pathogens upstream and to the hatchery water supply. The design and construction of a new hatchery facility in a new location is being considered to meet program goals, which could include the construction of trapping facilities.

4.1.9.2.2 Previously Considered Downstream Trap and Haul Concepts

One of the objectives of the NMFS-prescribed Pilot Program was to evaluate feasibility of collection and downstream transport of juvenile fish, which led to the implementation of the JSCS Pilot Study. Refer to Section 4.2.3.2 for details regarding JSCS program development and results.

4.1.9.3 Conclusions

Three trap and haul alternatives were initially considered by the IFPSC for upstream passage of adult salmonids. Trap and haul at Shasta Dam was initially removed from consideration as an upstream passage alternative by Reclamation due to higher anticipated costs and potential for disrupting existing dam operations associated with construction of new facilities. As required by CDFW’s grant, the strategy is now being compared to volitional passage alternatives. A modernization of LSNFH is required to support hatchery management goals because the current demands and future production targets of the captive broodstock program and its other objectives exceed the capacity of the existing LSNFH facilities. A trap and haul facility could be incorporated into the proposed new LSNFH site on the riverbank opposite the existing hatchery downstream of Shasta Dam, which would help consolidate efforts for fish passage and hatchery goals and allow program managers to strategically use Keswick Reservoir as cold-water refuge for adult Chinook Salmon during warmer years. If this strategy is further considered, pilot testing is recommended to inform design of a permanent trap and haul facility. Prior to upstream passage pilot testing, a water treatment system would need to be installed at LSNFH to minimize risk of biohazards from adult fish in Shasta Reservoir impacting fish health at LSNFH.

If a juvenile collection system is carried forward for alternative analysis, further investigation into facility siting may be needed to optimize hydraulics and promote entrance into the trap. In-river facilities may also be considered in addition to head of reservoir. The effects of predation on collection efficiency will also need to be taken into consideration when siting and designing the facility. If progressed to design, efficacy of juvenile transport following collection would need to be assessed, including transport mortality rates, release facility siting, and predation management at the release site.

4.2 Biological Setting

4.2.1 Target Fish Species and Life Stages

Target fish species and life stages for the development of alternatives for passing fish around Keswick and Shasta dams, include the adults and juveniles from the four runs of Chinook Salmon (winter, spring, fall, and late fall) that could occupy the Winnemem Waywaket. This naming convention is based on adult migration periods and is useful for Western science purposes but is very general and understates the variability in run timing of different populations in large river systems. Additional life-history information about each of the four runs of Chinook Salmon are provided in Appendix N.

4.2.2 Fish Migration Timing

Table 14 combines the timing of occurrence of each run of Chinook Salmon by life stage in the Nomtipom Waywaket. The timing included in Table 14 confirms that the four runs of Chinook Salmon will migrate during a large portion of each calendar year. As such, adult and juvenile passageways and facilities contemplated as volitional passage alternatives would all need to operate year-round except for annual maintenance periods. Planning for year-round operation allows for fish passage into the Winnemem Waywaket when we understand it might occur now, and when it might occur in the future, as the four runs adapt to the Winnemem Waywaket environment. This will result in the design of facilities and passageways that will allow the four runs of salmon (and other species) to adapt as needed to environmental conditions in the Winnemem Waywaket, which is best supported by broad, nonrestrictive, facility and passageway operational periods.

Table 14
In-River Timing of Winter-Run, Spring-Run, Fall-Run, and Late-Fall-Run Chinook Salmon by Life Stage

Run	Life Stage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Reference
Winter-Run	Adult Migration and Holding													Historical data: Azat (2023), Killam (2023), and Fisher (1994)
	Spawning													Carcass and redd survey data: Azat (2023) and CDFW (2024)
	Fry Emergence													Estimated from model results (SacPAS 2024a), genetic summaries of out-migrating juveniles (Anchor QEA 2024), and historical data (Fisher 1994).
	Smolt Stream Residency													Passage at RBDD: SacPAS (2024b) and Poytress et al. (2014)
	Smolt Out-Migration													Passage through RBDD and Chipps Island Trawls: SacPAS (2024b). Peak timing of RBDD passage is shown.
	Smolt Ocean Entry													Fisher (1994) and passage through Chipps Island Trawls (SacPAS 2024b)
Spring-Run	Adult Migration													Historical data: Fisher (1994)
	Adult Holding													Cordoleani et al. (2020)
	Spawning													Fisher (1994), Moyle (2002), and Killam (2023)
	Fry Emergence													Fisher (1994), Moyle (2002), and Cordoleani et al. (2020)
	Juvenile Stream Residency													Fisher (1994), Moyle (2002), and Cordoleani et al. (2020)
	Smolt Out-Migration													Cordoleani et al. (2020) indicates peak passage as December through March. RBDD passage from Poytress et al. (2014) and Voss and Poytress (2017, 2018, 2019, 2020, 2022a, 2022b, 2023) and Chipps Island passage from SacPAS (2024b) indicate peak passage as December through April.
	Yearling Out-Migration													Cordoleani et al. (2020)
	Smolt Ocean Entry													Fisher (1994) and IEP (2023)
Fall-Run	Adult Migration													Fisher (1994), Moyle et al. (2017), and FitzGerald et al. (2021)
	Spawning													Fisher (1994), Moyle et al. (2017), and FitzGerald et al. (2021)
	Fry Emergence													Fisher (1994), Williams (2006), and Moyle et al. (2017)
	Juvenile Stream Residency													Fisher (1994), Williams (2006), Moyle et al. (2017), and FitzGerald et al. (2021)
	Juvenile Out-Migration													Fisher (1994), Poytress et al. (2014), and FitzGerald et al. (2021)
	Juvenile Ocean Entry													Fisher (1994) and FitzGerald et al. (2021)

Run	Life Stage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Reference
Late-Fall-Run	Adult Migration													Fisher (1994), Williams (2006), Moyle et al. (2017), and FitzGerald et al. (2021)
	Spawning													Fisher (1994), Williams (2006), Moyle et al. (2017), and FitzGerald et al. (2021)
	Fry Emergence													Fisher (1994), Moyle et al. (1997), and FitzGerald et al. (2021)
	Juvenile Stream Residency													Fisher (1994), Williams (2006), and FitzGerald et al. (2021)
	Juvenile Out-Migration													Fisher (1994), Williams (2006), and Moyle et al. (2017)
	Juvenile Ocean Entry													Fisher (1994) and FitzGerald et al. (2021)

Note:
Shading within each group indicates temporal range and darkening in shading and addition of cross-hatching indicates peak timing.

4.2.3 Juvenile Out-Migration from the Winnemem Waywaket

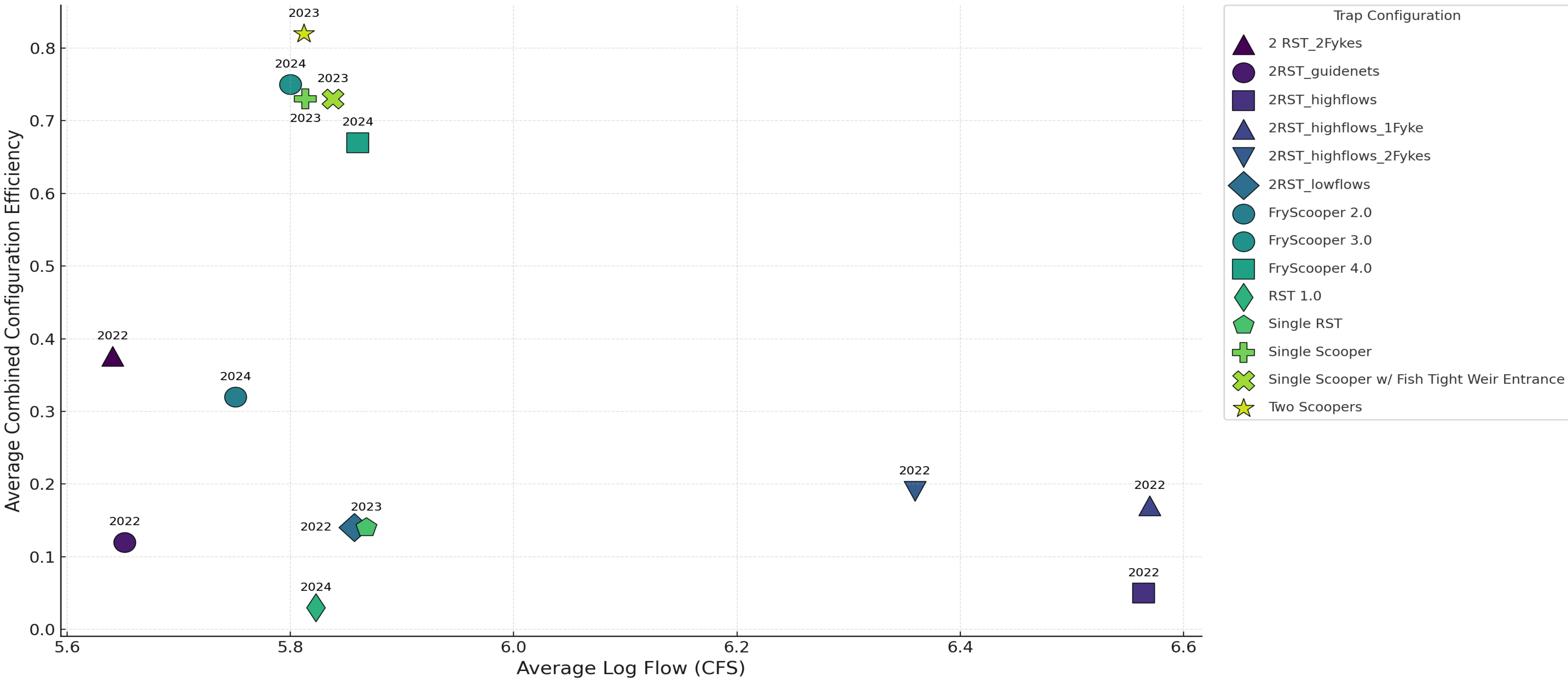
Attempts to capture juvenile Chinook Salmon migrating from their rearing areas in the Winnemem Waywaket have occurred since 2022 both in river and at the head of reservoir. The intent is to capture the juveniles migrating downstream before they reach Shasta Reservoir so they can be transported around the Shasta and Keswick dams and placed into the Nomtipom Waywaket near Redding, California. The outcome of the different in-river collection methods and head-of-reservoir methods are described below.

4.2.3.1 In-River Collection

The in-river collection of juvenile Chinook Salmon out-migrating from the Winnemem Waywaket incubation site near Ah-Di-Na Campground has occurred since eggs were first placed back into the river in 2022. Between 2022 and 2024, 14 distinct in-river salmon trap configurations of RSTs and IPTs (collectively referred to as scooper configurations), were deployed. Capture data were collected and tracked. Each deployment event involved a single, unique trap configuration and was evaluated for efficiency using a constant efficiency metric, the proportion of recaptured juveniles related to the number released.

To preliminarily explore trap performance, average reported efficiencies from each configuration were plotted against river flow during the respective deployment periods. Despite data constraints, emerging patterns indicate that the scooper configuration, including single and double scoopers and the various FryScooper designs (excluding FryScooper 2.0), generally outperformed traditional RST configurations (Figure 20). While the overall flow ranges for the scooper deployments tended to be narrower, some RST configurations (such as RST 1.0, single RST, and 2RST_lowflows) were deployed in similar discharge conditions but yielded lower efficiencies.

Figure 20
Juvenile Chinook Salmon Trap Configuration Efficiency Versus Average Log Flow (cfs)



Although there was a trend of higher efficiency from the scooper configuration, strong inferences cannot be drawn from the current dataset. Each trap configuration was deployed only once and not replicated across varying flow regimes, seasons, or abiotic conditions. To this extent, the 2RST_lowflows configuration was tested over the largest range of flow (cfs), and the two scooper configurations were tested during a very narrow range of flows. As such, observed differences in performance may be attributed to flow-dependent dynamics, configuration-specific characteristics, or other uncontrolled environmental and biological variables. To better assess trap effectiveness and optimize deployment strategies, future efforts should incorporate replicated trap configurations across a spectrum of environmental conditions and include comprehensive release and recapture metadata to enable more robust statistical analysis.

4.2.3.2 Head-of-Reservoir Collection

Out-migrating juvenile salmon were collected at the head of reservoir from fish that hatched in the Winnemem Wintu Tribe's Chinook Salmon Nature Based incubation system and CDFW's heath trays near Ah-Di-Na Campground as part of the drought emergency action. Data used in the development of this document were obtained from sources such as DWR, Environmental Science Associates, and the Winnemem Wintu Tribe. Detailed information about sources utilized in this document can be found in Appendix D and the full summary of head-of-reservoir collection is provided in Appendix O, *Summary of Juvenile Salmonid Collection System Pilot Study*.

4.2.3.2.1 Purpose and Scope

As part of a separate reintroduction study, DWR deployed and operated a JSCS on the McCloud Arm of the Shasta Reservoir in 2022, and 2023., and 2024/2025. The purpose of head-of-reservoir collection summary is to collect and synthesize information from the JSCS pilot deployment. This summary will help inform the formulation of Project volitional fish passage alternatives and related feasibility studies.

4.2.3.2.2 Key Findings

Key findings are summarized in the following subsections and broken into two categories: 1) JSCS Background; and 2) JSCS Deployment and Results.

4.2.3.2.2.1 JSCS Background

The JSCS program was implemented to evaluate the feasibility of passive collection of juvenile winter-run Chinook Salmon in the Upper McCloud Arm of Shasta Reservoir. As a result of brainstorming among agency experts, a head-of-reservoir system was chosen and the pilot program was designed to accommodate challenges such as cost-effectiveness, system passivity and utilization of fish behavior instead of pumps, high collection efficiency, low risk of predation, safety for operators and the public, movability, and adaptability to varying flow conditions. The JSCS consists of a 15-foot-long passive trap on a 40-foot by 24-foot platform with guidance that relies on induced velocity and fish behavior for attraction. Components were fabricated between 2018 and 2023, and the system was deployed in the fall of 2022, 2023, and 2024.

4.2.3.2.2.2 JSCS Deployment and Results

The JSCS was deployed over three seasons to assess different features of the system. Each deployment location was selected based on hydrology, water level forecasts, and Reclamation anchoring requirements.

In 2022, the JSCS was installed at the river to reservoir transition (head of reservoir). Due to the fluctuation of WSE of Shasta Reservoir, the head-of-reservoir location can vary greatly from season to season. The purpose of this deployment was to assess the system's overall engineering feasibility. The JSCS was operational between September 19 and November 12, 2022, at a WSE of 930 feet North American Vertical Datum of 1988 (NAVD88). The 2022 system included a debris boom, guidance net, notch with six docks on each side, and a temperature curtain. Because the goal of this deployment was to evaluate system function, rather than collection performance, no trap was included in the system and no fish were collected. Water and environmental data were collected and recorded, and there were two main findings: 1) water temperature was stratified and the temperature curtain helped moderate temperatures but only at depths below 10 feet; and 2) water was too deep to provide velocity through the trap at deployment location. These findings led DWR to relocate the 2023 JSCS several miles upstream closer to the river-reservoir interface.

In 2023, the JSCS was deployed in a narrower portion of the reservoir between Ellery Creek Campground and the McCloud Bridge Campground. The purpose of this deployment was to assess JSCS collection efficiency and juvenile salmon survival. Deployment took place at two specific locations: the downstream location operated from September 20 to October 25, and when operation ceased due to inadequate water depths, and the upstream location operated from November 1 through November 15. The 2023 system included a fish trap, platform, guidance nets, debris booms, temperature curtain, and boat gates. The fish trap included a 15-foot-long stainless-steel and aluminum passive trap set into the notch of the JSCS platform. Similar to the 2022 deployment, water and environmental data were collected and recorded. DWR used mark-recapture efficiency trials: a known number of dual-marked fish are released a set distance upstream from the JSCS trap. For 5 weeks, 300 juvenile winter-run Chinook Salmon were released and the trap was sampled at least once a day with all species in the trap identified and counted. Collection efficiencies of released Chinook Salmon averaged 22.3%. Captured winter-run Chinook Salmon predator species (Black Bass) were euthanized and examined. Results showed that 11% of these predators contained juvenile Chinook Salmon in their stomachs. Poor performance of the JSCS was attributed in part to suboptimal water depths and velocities at the trap entrance as well as predation and unsuitable temperature conditions.

For the 2024/25 deployment, the JSCS was located between Ellery Creek Campground and the Pine Point Campground to target the reservoir/river interface and was deployed at three different locations during the season. Similar to the 2023 season, the purpose of this deployment was to assess JSCS collection efficiency. The duration of the 2024/2025 deployment extended from September 3, 2024, to January 28, 2025. Installation of the JSCS began on September 3, 2024. Fishing at Site 1 occurred from September 17 through October 28, 2024, when it was determined that water depths at the site were too shallow. The JSCS was moved to Site 2, where operations began on October 31. The JSCS operated at Site 2 from November 21 through December 3, 2024, but paused due to storm conditions. Operations resumed after conditions were determined to be safe; however, the storm resulted in a significant increase in reservoir WSE, and operations at Site 2 ceased on December 19. The JSCS was then moved back upstream to Site 3, approximately 100 feet upstream of Site 1 between December 20, 2024, and January 1, 2025. Debris loading during and following storm events became a significant obstacle because the debris boom and JSCS is not currently configured to handle large amounts of debris, and trap operation was delayed during debris removal.

The 2024/25 system components were similar to 2023; however, a trap wrap was utilized in place of the temperature curtain. Water and environmental data were collected and recorded similar to previous deployments. Collection efficiencies averaged 1.42% for the 2024/2025 deployment. Poor performance of the JSCS was attributed in part to suboptimal water depths and velocities at the trap entrance.

Table 15 summarizes the collection efficiency and associated velocity and water depth for the 2023 deployment. The JSCS operated at peak collection efficiency when reservoir depth at the trap site was between 10 feet and 12 feet and water velocity at the trap entrance was within the range of 1.3 ft/s to 2.1 ft/s (DWR 2024).

Table 15
Summary of 2023 Capture Efficiency Trials

Efficiency Release No.	JSCS Site	Fish Released	Number Recaptured	Collection Efficiency (%)	Water Depth at Trap Entrance (feet)	Velocity Magnitude at Trap Entrance (ft/s)	Velocity Magnitude in Fry Box (ft/s)
1	1	300	129	43.0	13	1.3	0.1
2	1	299	154	51.5	10	2.1	0.2
3	1	299	27	9.0	9	3.1	1.5
4	2	299	23	7.7	28	0.7	0.4
5	2	300	1	0.3	28	0.7	0.4
	Total	1,497	334	22.3 (Average)	--	--	--

Source: DWR (2024)

For the 2024/2025 deployment, trap efficiency trials were divided into paired releases (“standard” and “near”) to assess the impact of predation upstream of the structure versus in the immediate trap vicinity. The “standard” release group consisted of approximately 150 dual-marked fish that were released 0.5 kilometer upstream of the JSCS. The “near” release group consisted of 50 to 150 fish marked only with Bismarck Brown-Y dye that were released 300 feet upstream of the JSCS. A total of nine trap efficiency trials were conducted with a total of 2,147 fish released.

Capture efficiencies during the 2024/2025 deployment were significantly lower than during the 2023 deployment. Table 16 summarizes the collection efficiency for the “standard” and “near” release groups during 2024/2025 capture efficiency trials. As shown in Table 16, the highest collection efficiencies were observed at Site 1, with a maximum collection efficiency of 6.0% and an average site collection efficiency of 3.5%. Collection efficiencies declined over the remainder of the deployment with minimum collection efficiency of 0.0% at Site 3. The average trap efficiency across all capture efficiency trials was 1.4%. Most juvenile Chinook Salmon were captured when flow velocities through the trap were 0.25 ft/s to 1.5 ft/s and water depths were less than 15 feet, with depth being a stronger indicator of capture (DWR 2025a).

In addition to the juvenile Chinook Salmon capture efficiency trials, NMFS and USGS released passive integrated transponder-tagged and Juvenile Salmon Acoustic Telemetry System (JSATS)-tagged yearling late-fall-run Chinook Salmon upstream of the JSCS and monitored their movement. Detections indicated that the JSCS did not effectively intercept yearling Chinook Salmon, because a significant portion of yearlings out-migrated during winter pulse flows while trap operations were suspended and only 2 (or approximately 1%) of 186 yearlings detected at the trap were captured (DWR 2025a).

Table 16
Summary of 2024/2025 Capture Efficiency Trials

Site	Efficiency Trial Release Date	Release Group	Number of Fish Released by Release Group	Number Recaptured by Release Group (%)	Collection Efficiency by Release Group (%)	Total Efficiency by Release Date (%)	Total Efficiency by Site (%)
Site 1	09/24/2024	Standard	149	2	1.3	4.52	3.52
		Near	50	7	14		
	10/01/2024	Standard	149	0	0	0.00	
		Near	49	0	0		
	10/25/2024	Standard	150	3	2	6.00	
		Near	50	9	18		

Site	Efficiency Trial Release Date	Release Group	Number of Fish Released by Release Group	Number Recaptured by Release Group (%)	Collection Efficiency by Release Group (%)	Total Efficiency by Release Date (%)	Total Efficiency by Site (%)
Site 2	11/05/2024	Standard	150	6	4	2.33	0.92
		Near	150	1	0.06		
	11/12/2024	Standard	150	3	2	1.00	
		Near	150	0	0		
	12/05/2024	Standard	150	0	0	0.03	
		Near	150	1	0.06		
	12/10/2024	Standard	150	0	0	0.00	
		Near	150	0	0		
Site 3	01/07/2025	Standard	150	0	0	0.00	0.00
		Near	150	0	0		
	01/14/2025	Near	150	0	0	0.00	
Total	--	--	2,246	32	--	--	1.42

Source: DWR (2025a)

4.2.3.2.3 Conclusions

In 2022, the JSCS was set up in a very wide portion of the reservoir, which resulted in a large angle between and greater pressure on the guidance nets and docks causing deformation. The 2023 locations allowed for the siting of the JSCS in narrower and shallower portions of McCloud River Arm, which corrected this issue. Other issues noted during the 2022 deployment included guidance net anchoring challenges, cold-water passage under the guidance net, and the temperature curtain not providing enough cooling for juvenile collection until after a week of deployment. Other issues noted during the 2023 deployment included difficulty opening boat gates, beaching of docks as water levels dropped, and billowing guidance nets due to high velocities. During the 2024/2025 deployment, debris loading during and following storm events also became a significant obstacle because the debris boom and JSCS is not currently configured to handle large amounts of debris, and trap operation was delayed during debris removal.

Per the JSCS study, facility siting plays a key role in the performance of a collection facility. If Project alternatives include a downstream juvenile collection facility similar to the JSCS system, care should be taken to site the facility in a location with appropriate water depths, velocities, and channel width to maximize the collection efficiency. This may include the option to reconfigure the JSCS to operate at the riverine-reservoir interface as opposed to the head of reservoir, or inclusion of active hydraulic controls (e.g., attraction pumps) to create more favorable hydraulics at the trap entrance and reduce likelihood of fish bypassing the trap. In addition, a portable facility may be more suitable compared to a fixed facility because the water levels may fluctuate substantially throughout the collection season and redeployment of a juvenile collection facility may be required. Modifications to the configuration to handle larger debris loads should also be considered. Once additional research into predation of Chinook Salmon has been completed, the findings should also be taken into account for the design and location of a Project juvenile collection facility, if carried forward during the alternatives analysis.

4.2.4 Pacific Salmon Olfactory Imprinting and Homing Considerations

This section summarizes key insights from a review of scientific literature on Pacific salmon olfactory imprinting, relative to the rematriation/reintroduction of winter-run Chinook Salmon to the Winnemem Waywaket. The review was authored by Dr. Thomas P. Quinn (University of Washington, School of Aquatic and Fishery Sciences) and outlines the biological processes supporting salmon homing behavior and evaluates how transportation and water diversion may influence the success of reintroduction efforts. A summary of the review, including the purpose and scope and key findings is provided below, and the entire review is provided as Appendix P, *Notes on Pacific salmon Olfactory Imprinting, and the Effects of Transportation and Water Diversion on Homing as They May Pertain to McCloud River Winter-Run Chinook Salmon*.

4.2.4.1 Purpose and Scope

The document reviews scientific literature on how juvenile and adult Pacific salmon imprint on and later respond to chemical cues in their migratory environment. The implications of transportation, attraction flows and conditions, and diverted water pathways are considered in the context of ongoing and proposed reintroduction efforts above Shasta Dam in the Winnemem Waywaket.

4.2.4.2 Key Findings

Key findings of the literature review include the following:

- Olfactory Imprinting and Homing Behavior: Pacific salmon imprint on the chemical composition of their natal waters during key life stages, including early emergence and downstream smolt migration. These olfactory memories are used to navigate back to spawning grounds as adults. Scientific evidence indicates the following:
  - Imprinting is a sequential process that occurs during multiple ecologically important time periods corresponding to migrations.
  - Migration itself appears essential to successful imprinting.
  - Salmon typically use a sign-stimulus response, swimming upstream upon detecting familiar odors rather than following gradients.
- Transportation Effects on Imprinting: Transporting juveniles prior to or during migration can disrupt natural imprinting processes. The effects vary based on the timing and nature of transport as follows:

  - Fish transported before initiating migration often return to the release site rather than the natal stream.
  - In contrast, fish captured mid-migration and transported downstream show improved rates of natal homing, though some straying may still occur.
  - Volitional passage, when feasible, remains preferable to preserve natural imprinting.
- Impacts of Water Diversion on Homing: Diversion of Winnemem Waywaket water to the Pit River is expected to present significant challenges for fish returning to the Winnemem Waywaket as follows:
  - Altered flow and odor profiles can cause "false attraction," whereby returning adults are misdirected.
  - Studies from British Columbia (e.g., Seton Creek system) demonstrate that adult salmon can distinguish even diluted concentrations of natal water and prefer less mixed or more chemically familiar flows.
  - The degree to which diverted Winnemem Waywaket water maintains its original odor signature—once mixed or altered—is uncertain and may affect homing fidelity.
- Implications for Chinook Salmon Reintroduction/Rematriation: Effectively returning winter-run Chinook Salmon to the Winnemem Waywaket will require the following:
  - Evaluating the tradeoffs between volitional passage and transportation through or around Shasta Reservoir.
  - Ensuring that returning adults encounter hydrologic and chemical cues that match those imprinted during their juvenile migration.
  - Considering seasonal temperature, flow conditions, and adult density—factors that also influence homing and straying.

4.2.4.3 Conclusions

While infrastructure design and water management strategies play a vital role in salmon rematriation/reintroduction, biological factors—especially olfactory imprinting—are critical. The unpredictability of salmon behavior under modified conditions emphasizes the need for caution and adaptive management strategies. Ultimately, the success of the rematriation/reintroduction efforts depends not only on human engineering but also on the behavioral responses of the fish themselves.

4.2.5 Summary of Life-Cycle Modeling

4.2.5.1 Phase 1

Phase 1 life-cycle modeling was conducted as described in the following subsections.

4.2.5.2 Purpose and Scope

The purpose of this analysis is to identify the level of passage success and survival that adult and juvenile Chinook Salmon would need to achieve under reintroduction scenarios to have an equivalent adult spawner abundance to the historical average (1995 to 2020).

This type of analysis necessitates the use of a model to evaluate hypothetical scenarios of reintroduction. The Consultant Team used the Winter-Run Life-Cycle Model (WRLCM), which incorporates temperature-dependent mortality (TDM) into a function that defines egg-to-fry survival. The TDM is itself a model that incorporates spawning distribution and the subsequent temperatures experienced by redds to calculate a monthly thermal mortality rate (Martin et al. 2017). The objectives of this analysis are as follows:

- Evaluate the ability of reintroduction to the Winnemem Waywaket to improve egg-to-fry survival by reducing the TDM being experienced by winter-run Chinook Salmon that currently spawn in the mainstem Nomtipom Waywaket.
- Utilize the WRLCM and the TDM models to evaluate what levels of passage success and survival would be needed for the reintroduction scenarios to be equivalent to the baseline historical conditions. That is, perform the reintroduction action and evaluate the survival and passage rates that would have to occur to match the historical (1995 to 2020) average abundance of winter-run Chinook Salmon.

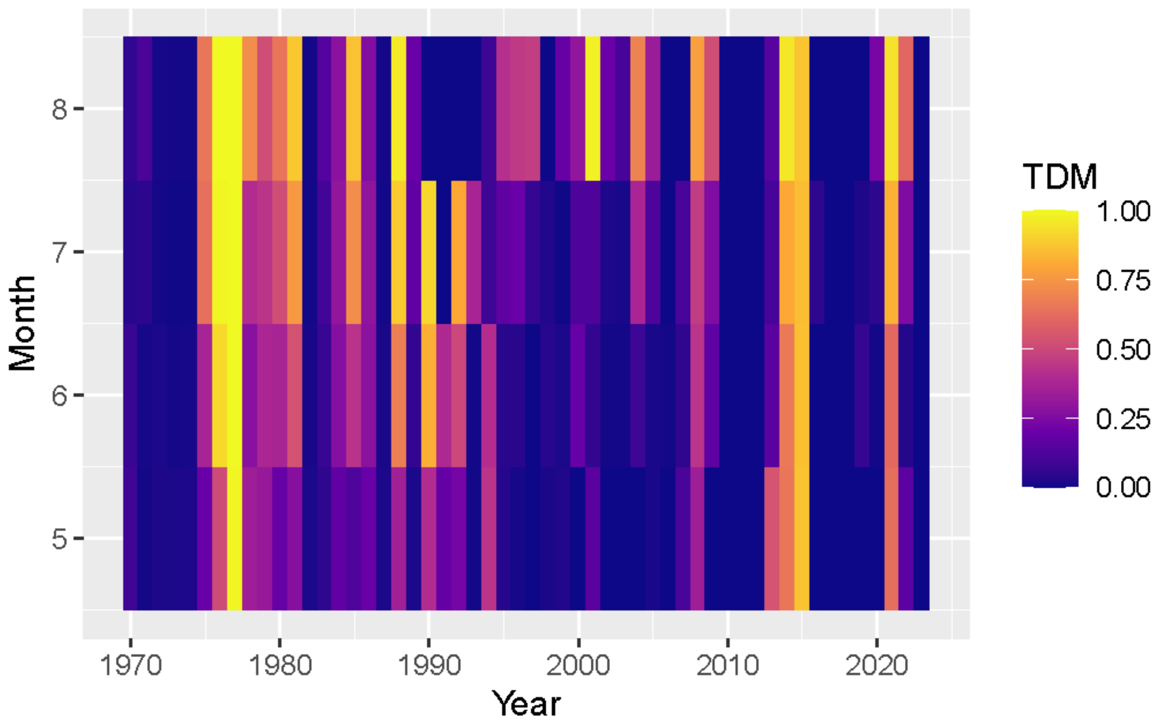
4.2.5.3 Methods

A counterfactual analysis, in which the WRLCM was run under a set of historical conditions from 1995 to 2020 was developed along with a set of scenarios with different levels of survival and passage rates for a hypothetical reintroduction to the Winnemem Waywaket. It was assumed that the amount of TDM was 5% and that it only occurred in August in the Winnemem Waywaket. This assumption was based on historical temperature records on the Winnemem Waywaket that were collected from 2000 to 2010 from a gage near The Nature Conservancy fishing camp. In contrast, the TDM in the Sacramento River below Keswick Dam was variable among years historically (Figure 21). In some years, the TDM values were greater than 0.5, indicating that the majority of eggs deposited in that month succumbed to TDM (e.g., 1977 and 2015). Several scenarios were developed with the following characteristics:

- The reintroduction scenarios start with the adult life stage below Keswick Dam and end with juveniles below Keswick Dam.
- The survival and passage rates over these life stages corresponded to levels of 0.70, 0.75, 0.80, 0.85, and 0.90.
- The WRLCM was run over 1,000 Monte Carlo simulations drawing from the parameter uncertainty.

- For each iteration of the 1,000 simulations, the pairwise differences between the reintroduction action at the specified level and baseline was calculated as 100% x (action - baseline)/baseline.

Figure 21
Temperature-Dependent Mortality in the S Nomtipom Waywaket Below Keswick Dam for Spawning Initiated in Months 5 to 8 (May to August)



Note: Data based on model described in Martin et al. (2017)

4.2.5.4 Key Findings

The model simulation results can be summarized by the percent differences in average abundance (1995 to 2020). Under the reintroduction scenarios, the levels of passage and survival for adults below Keswick Dam to juveniles below Keswick Dam would need to be approximately 0.80 to match the historical abundance levels of winter-run spawners in the Nomtipom Waywaket. Passage and survival rates of 0.9 would increase average abundance by 30% over baseline (Table 17).

Table 17
Results of Running Reintroduction Scenarios Under Varying Levels of Adult to Juvenile Passage and Survival Rates

Level	Median Difference from Baseline (95% Interval)
0.70	-18% (-21%, -15%)
0.75	-8.7% (-11%, -6.1%)
0.80	2.0% (0.0%, 4.0%)
0.85	15% (14%, 16%)
0.90	30% (30%, 31%)

Note:
The scenarios were run in the WRLCM and average abundance under each level was compared to baseline (historical) average abundance (1995 to 2020).

4.2.5.5 Conclusions

- A reintroduction scenario in which winter-run Chinook Salmon were allowed to access the Winnemem Waywaket with passage and survival rates of 0.8 (i.e., adult to juvenile passage and survival rate) would lead to a spawner abundance that was approximately equivalent to the historical spawner average (1995 to 2020). Greater levels of passage and survival would lead to increases in the average abundance over baseline average abundance.
- There are a few caveats to the current analysis that are worth identifying, as follows:
  - It was assumed that the TDM levels in the Winnemem Waywaket were constant across all years with a value of 0.05 in August only. If the TDM values in the Winnemem Waywaket are higher than assumed, greater levels of survival and passage rates would be required to match the historical spawner averages.
  - The results of this analysis are dependent on the TDM from 1995 to 2020 that defined the baseline scenario. A different set of hydrologic and thermal conditions could result in different levels of survival and passage rates to match the baseline average abundance.
- Future work to evaluate reintroduction scenarios includes the following efforts:
  - Evaluation of specific passage and survival rates defined by reintroduction alternatives (e.g., Alternatives 1,3, and 4)
  - Modeling a longer historical time series—1970 to 2020 to expand the environmental conditions over which the alternatives can be evaluated
- Calculations of population productivity under additional metrics such as cohort replacement rate—e.g., spawner to returns (escapement + harvest) $\geq$1, and a sustainable population given the fall-run Chinook Salmon fishery, e.g., spawner to escapement $\geq$1.

4.2.5.6 Phase 2

Phase 2 life-cycle modeling was conducted as described in the following subsections to evaluate the alternatives developed and described in the *Alternatives Formulation and Evaluation Report* (Anchor QEA and HDR 2026).

4.2.5.7 Purpose and Scope

Developing reintroduction alternatives to achieve specific population-level targets, such as increased long-term abundance and sustainability under ocean fisheries, requires a better understanding of how the reintroduction will affect the adult and juvenile life-history stages. The purpose of the Phase 2 analysis is to explicitly model the reintroduction rates of adult attraction from the Nomtipom Waywaket, adult survival to the Winnemem Waywaket, juvenile collection in the Winnemem Waywaket, and juvenile survival to the Nomtipom Waywaket to understand how these rates affect the abundance and productivity of the Keswick and Winnemem Waywaket populations. Finally, two volitional alternatives have been modeled, and it is important to understand how their design elements translate into the four reintroduction rates and thus the probability of achieving the population-level targets.

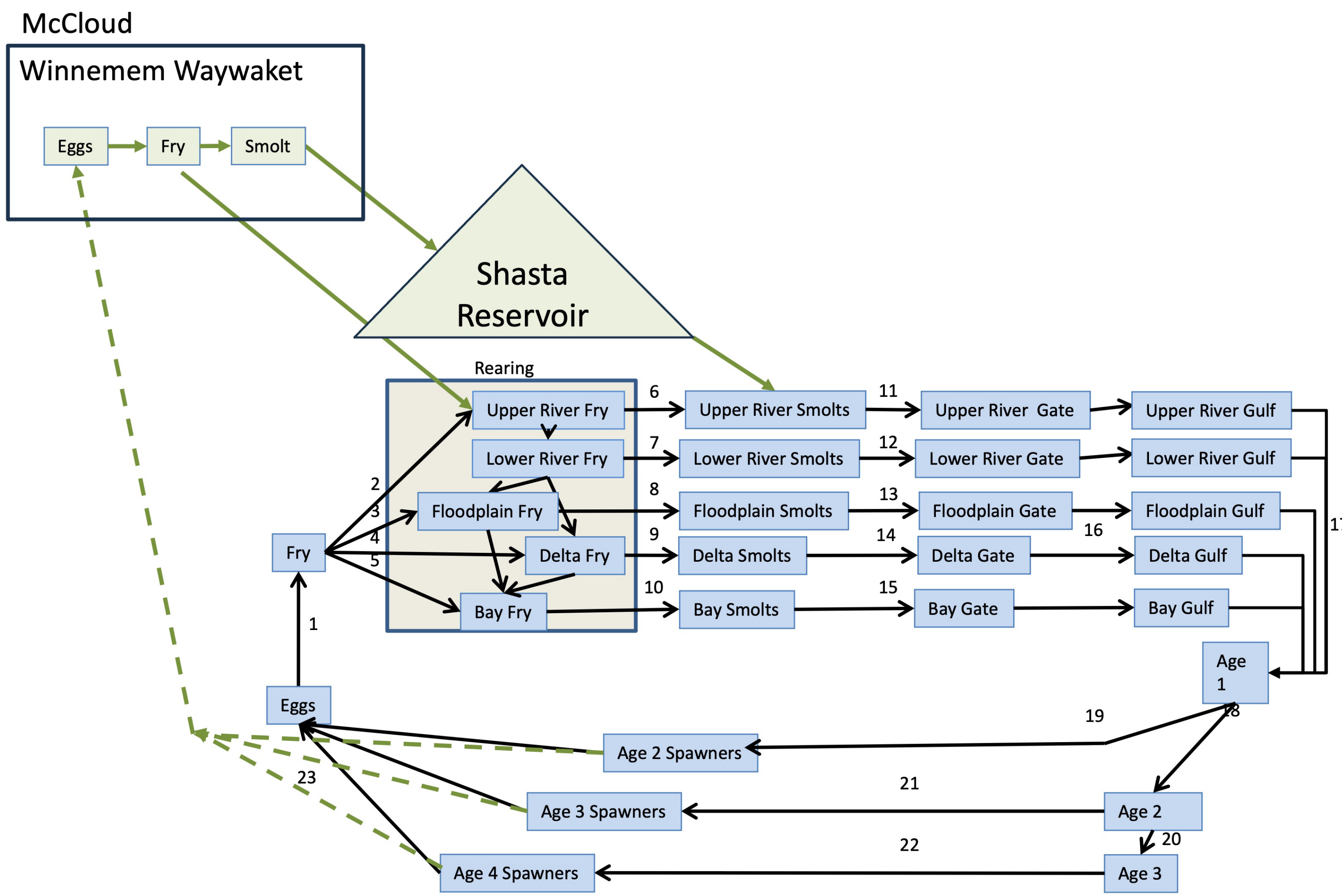
The objectives of the Phase 2 analysis are as follows:

- Evaluate the reintroduction to the Winnemem Waywaket by winter-run Chinook Salmon that currently spawn in the lower mainstem Nomtipom Waywaket. Conditions in the Winnemem Waywaket can increase egg-to-fry survival, yet adult attraction, adult survival, juvenile guidance/collection, and juvenile survival are also required to complete the life cycle of fish into the Winnemem Waywaket. Utilize the WRLCM with reintroduction to evaluate these tradeoffs for varying levels of reintroduction rates.
- Identify which combination of reintroduction rates would lead to a population that is equivalent to the baseline historical conditions.
- Identify which combination of reintroduction rates would be sustainable given current levels of bycatch of winter-run Chinook Salmon in the ocean fishery.
- Map the reintroduction rates that lead to equivalent population abundance and that may be sustainable under ocean fishery bycatch to the specific design elements under the two volitional alternatives modeled (a fully volitional passage route via Cow Creek, Little Cow Creek, and Dry Creek (Feasibility Study Alternative 1) and a semi-volitional passage route over Keswick Dam and to the crest of Shasta Dam (Feasibility Study Alternative 3).

4.2.5.8 Methods

The Phase 2 approach used the WRLCM with reintroduction to simulate the population trajectory from 1970 to 2020. The role of the WRLCM with reintroduction is to complete the remainder of the life cycle from juveniles in the Nomtipom Waywaket to adults returning to spawn. The reintroduction process provides pathways for adults to reach the Winnemem Waywaket, for spawning to occur, and for juveniles to rear and move from the Winnemem Waywaket to the Nomtipom Waywaket (Figure 22). Spawning to juvenile production, egg-to-fry survival, and fry survival functions from the WRLCM are used to model these life-cycle processes in the Winnemem Waywaket.

Figure 22
Winter-Run Chinook Salmon Life-Cycle Model Flow Chart



Note: WRLCM that includes passage for adults to reach the Winnemem Waywaket (dashed green lines), adults to produce juveniles, and for juveniles to return to the Nomtipom Waywaket through, or around, the Shasta Reservoir as fry or smolts (solid green lines).

The WRLCM runs were based on conditions from 1970 to 2020, which lead to a 51-year time series for evaluating the performance of the reintroduction alternatives. There are four reintroduction rates that are required to run the reintroduction analyses, and they are defined as follows:

- Adult attraction: The rate at which adult Chinook Salmon heading for Winnemem Waywaket can enter the pathway to that spawning area
- Adult survival: For those Chinook Salmon that are attracted, the proportion that survive through the pathway to the Winnemem Waywaket
- Juvenile guidance: The proportion of juvenile Chinook Salmon that enter the pathway to the Nomtipom Waywaket from the Winnemem Waywaket
- Juvenile survival: For those Chinook Salmon that enter the pathway, the proportion that survive from the entrance point to the Nomtipom Waywaket.

4.2.5.9 Key Findings

We evaluated two bookend scenarios that reflected baseline conditions without a reintroduction and a perfect reintroduction in which the reintroduction rates were set to values of 1.0. Under the baseline (lower bookend scenario) model run (Figure 23) the following patterns in population dynamics occurred:

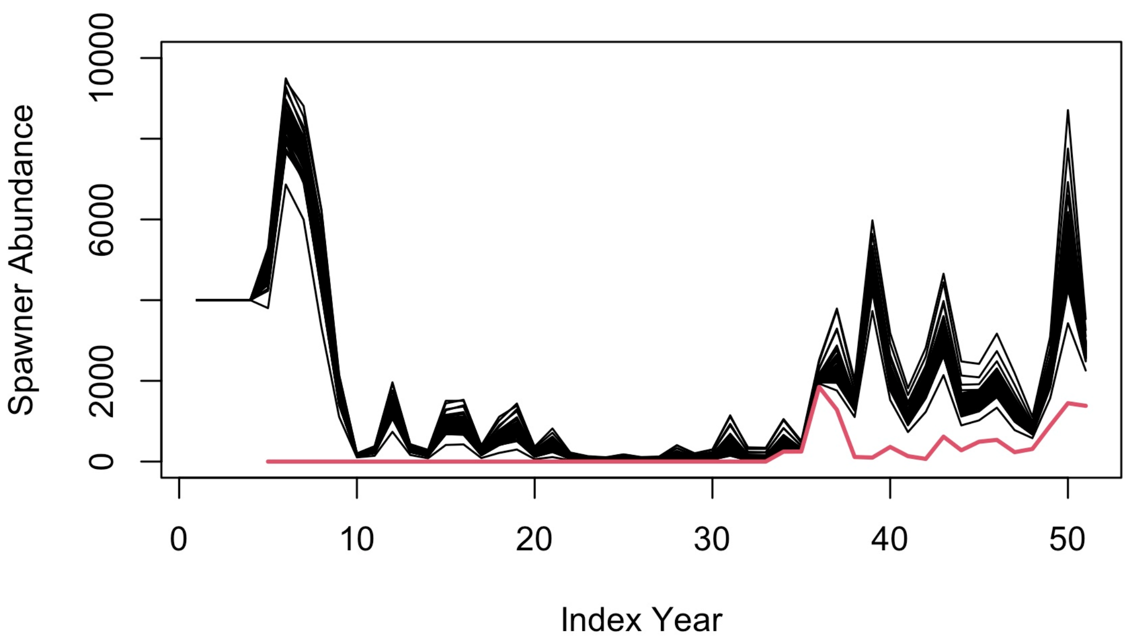
- In the initial 8 model index years, the initial population increased for the first several years after the initial abundance of 4,000 spawners
- In model index years 9 and 10, the population declined rapidly due to TDM, reducing survival in the egg-to-fry stage (corresponding to drought conditions in the late 1970s).
- In model index years 11 through 35, the population remained below 1,000 spawners
- In model index year 32 and thereafter, hatchery supplementation began and population abundance began to recover and remained greater than 1,000 spawners beginning in year 35

Under the perfect reintroduction (upper bookend scenario) model run (Figure 24) the following patterns in population dynamics occurred:

- The population that spawns below Keswick Dam had a similar trajectory as the baseline.
- In model years 9 and 10, the Winnemem Waywaket population remained stable because it does not experience the same thermal conditions as the population spawning in the reach below Keswick Dam.
- In model years 10 to 35, the Winnemem Waywaket population remained at an abundance higher than the population spawning in the reach below Keswick Dam.
- In model index year 35, the population spawning in the reach below Keswick Dam surpassed the Winnemem Waywaket population when the hatchery began producing spawners that returned to the population and spawned below Keswick Dam.
- In model years 36 to 51, the Winnemem Waywaket population declined, driven in part by a reduction in later life stage survival (e.g., smolt and early ocean life stages).

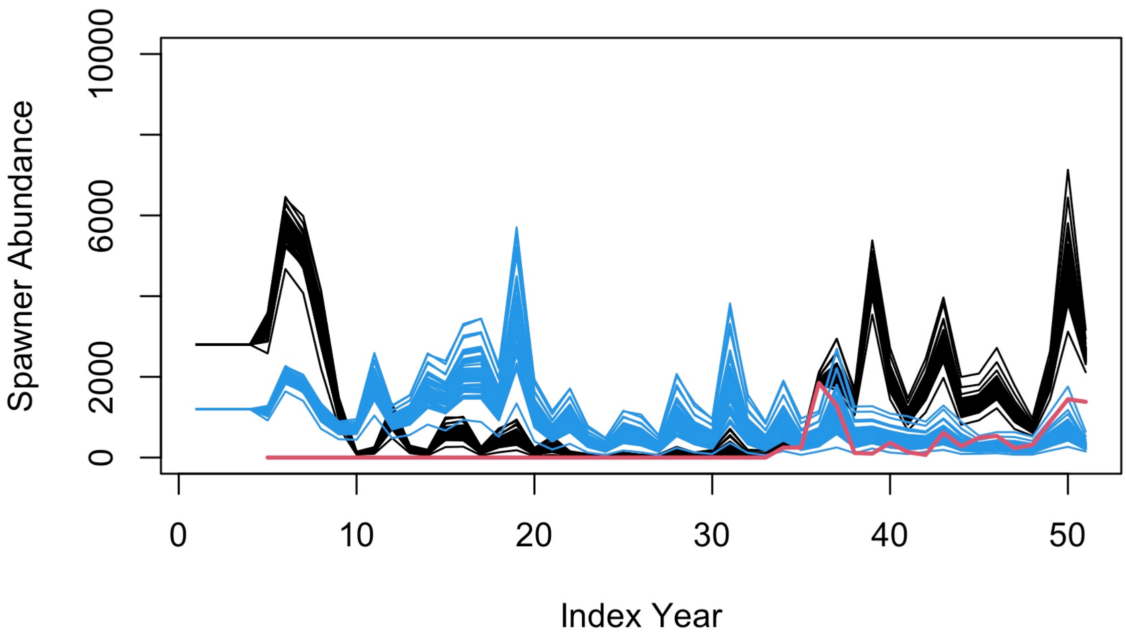
The time series of abundance values shows how the Winnemem Waywaket population and population spawning below Keswick Dam covary over the modeled time period. For much of the time series, the Winnemem Waywaket and below Keswick Dam populations are moving out of phase with each other (Figure 24). The two subpopulations are varying asynchronously due to the low correlation in productivities of each subpopulation. The result is a more resilient population overall; therefore, it is encouraging to see the potential for these dynamics with reintroduction to the Winnemem Waywaket.

Figure 23
Baseline Winter-Run Life-Cycle Model Run



Notes: Baseline (lower bookend scenario) WRLCM run, based on 50 trajectories of the spawner abundance over the 51 years of the modeled time series. Spawner abundance for the spawning reach below Keswick Dam for 50 iterations (black lines) and hatchery-origin spawners (red line).

Figure 24
Perfect Reintroduction Winter-Run Chinook Salmon Life-Cycle Model Run



Notes: All collection and survival levels are set to 1.0. Below Keswick spawner abundance (black lines) for 50 simulations and hatchery-origin spawners (red line). Winnemem Waywaket spawner abundance (blue lines) for 50 simulations of the WRLCM with reintroduction.

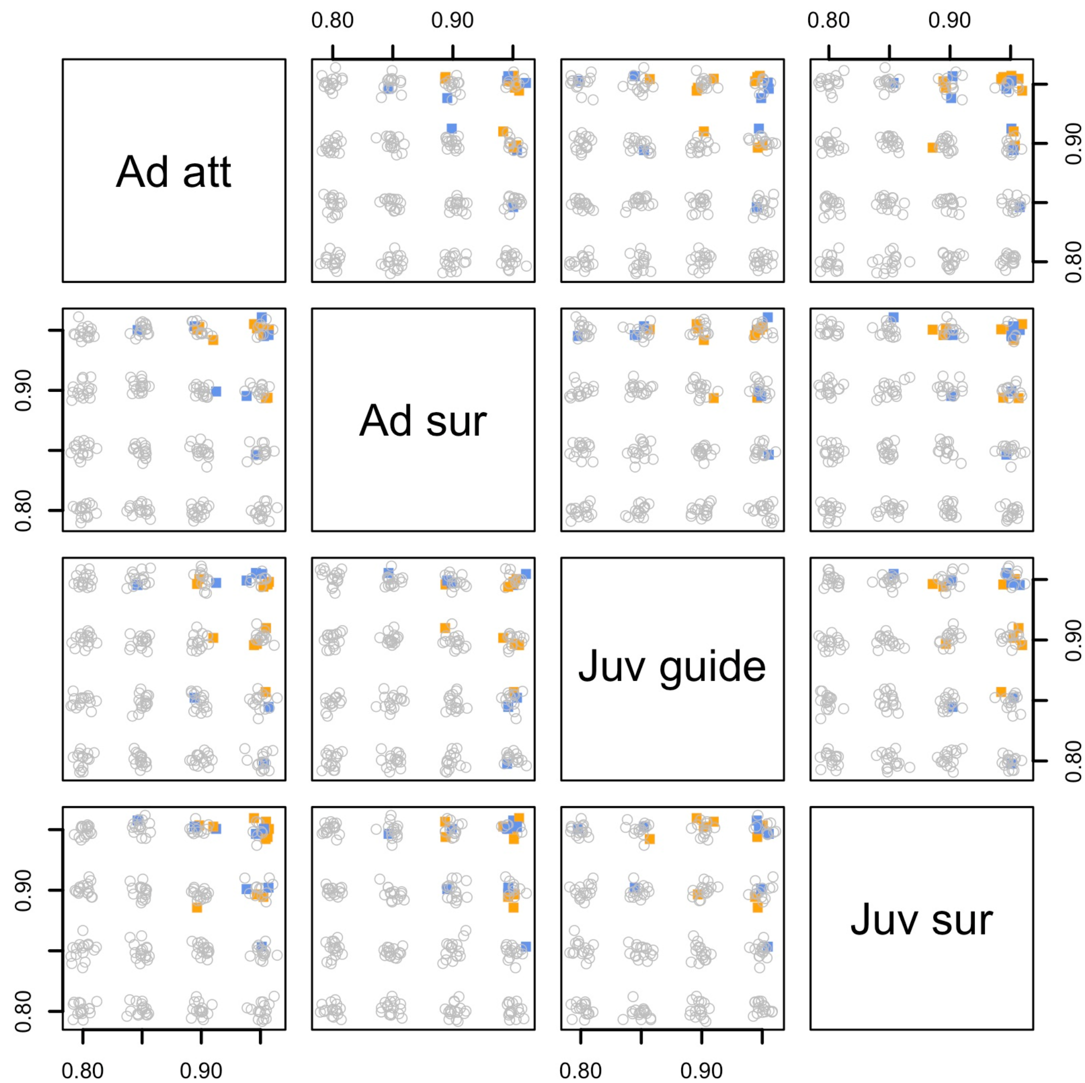
To evaluate reintroduction rates, the WRLCM with reintroduction was run under multiple possible combinations of adult attraction, adult survival, juvenile guidance/collection and juvenile survival. The approach was to build all combinations of these four reintroduction rates at the levels of 0.8, 0.85, 0.9, and 0.95. This approach resulted in 256 ($4^4 = 256$) combinations and thus 256 distinct runs of the WRLCM with reintroduction.

The following tiers were constructed to place each of the scenarios into one of the following tiers:

- Tier 1: The average abundance of the reintroduction was less than or equal to the average baseline abundance with a probability of $\leq$0.5.
- Tier 2: The average abundance of the reintroduction was greater than the average baseline abundance with a probability of >0.5.
- Tier 3: All scenarios in Tier 1 and in addition the population has the potential to be sustainable under the ocean fishery.

Many of these runs resulted in combined abundance levels that were below the baseline on average, i.e., Tier 1 (Figure 25).

Figure 25
Evaluation of 256 Combinations of the Reintroduction Rates of Adult Attraction, Adult Survival, Juvenile Guidance/Collection, and Juvenile Survival (Variation 1)



Notes: Evaluation of 256 combinations of the reintroduction rates of adult attraction (Ad att), adult survival (Ad sur), juvenile guidance (Juv guide), and juvenile survival (Juv sur). Gray circles indicate Tier 1 combinations, blue squares indicate Tier 2 combinations, and the orange squares indicate Tier 3 combinations. Combinations at design points (0.80, 0.85, 0.90, and 0.95) have been jittered to facilitate the visualization.

To evaluate the range of reintroduction rates more fully, we reran the WRLCM with reintroduction under a new set of combinations for the four reintroduction rates at four levels in the range of 0.90 to 0.95 (0.905, 0.920, 0.935, and 0.950). The second set of values provided a better view of the regions in which Tier 2 and Tier 3 results diverge (Figure 26). Generally, values of the reintroduction rates greater than 0.92 resulted in sustainability under ocean fisheries (Tier 3), whereas values between 0.90 and 0.92 resulted in abundances that were Tier 1 and Tier 2.

Figure 26
Evaluation of 256 Combinations of the Reintroduction Rates of Adult Attraction, Adult Survival, Juvenile Guidance/Collection, and Juvenile Survival (Variation 2)

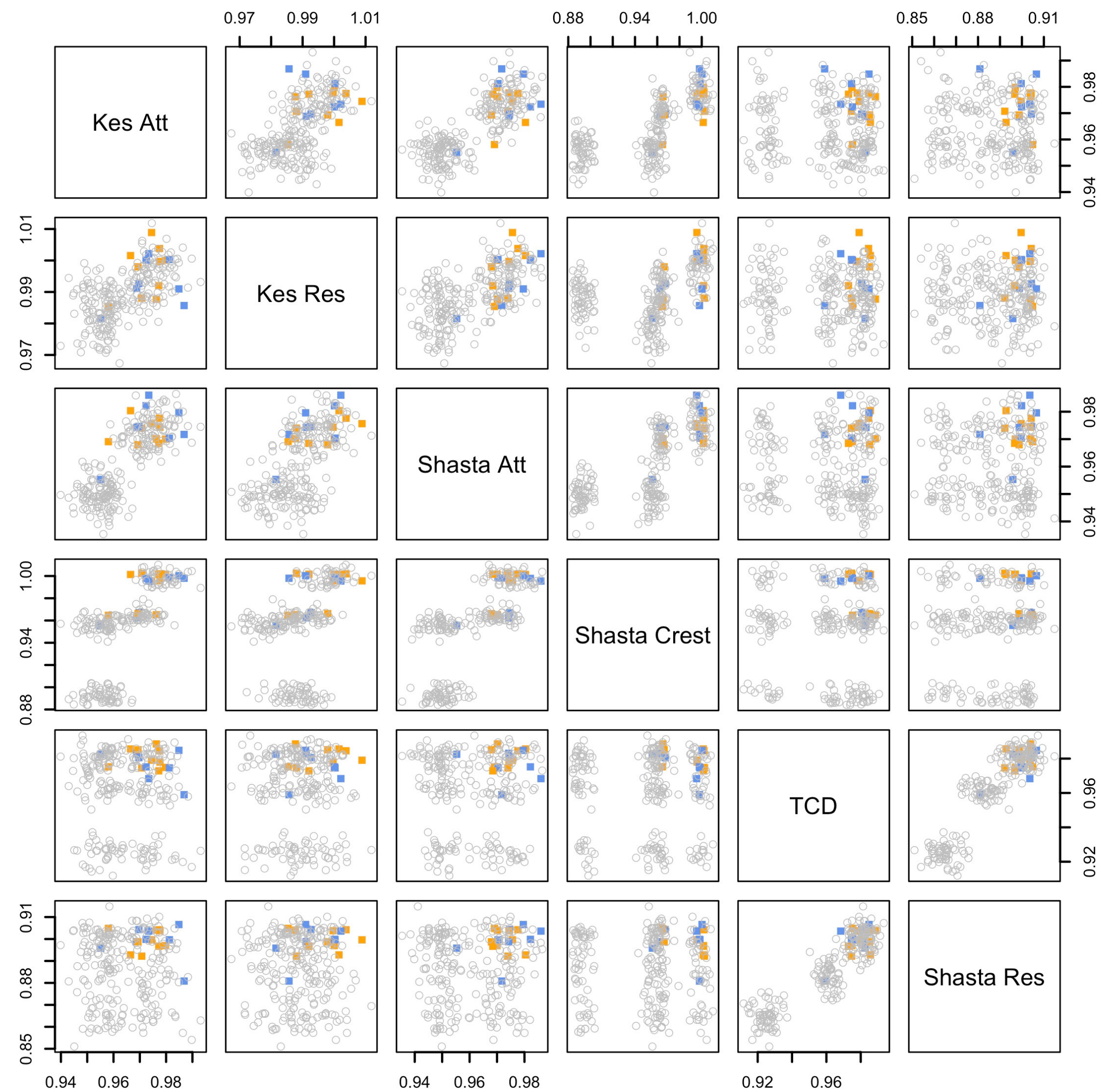
Notes: Evaluation of 256 combinations of the reintroduction rates of adult attraction (Ad att), adult survival (Ad sur), juvenile guidance (Juv guide), and juvenile survival (Juv sur). Gray circles indicate Tier 1 combinations, blue squares indicate Tier 2 combinations, and the orange squares indicate Tier 3 combinations. Combinations at design points (0.905, 0.920, 0.935, and 0.95) have been jittered to facilitate the visualization.

Finally, we mapped the design elements under each of the two volitional alternatives to the reintroduction rates (Table 18). This allowed us to evaluate what level of the design elements were most likely to lead to each of the 256 combinations of reintroduction rates and their associated population response. These were then plotted for each of the alternatives, and the results for Alternative 1 are provided in Figure 27.

Table 18
Mapping of Design Components to Reintroduction Rates in Alternatives 1 and 3 and Trap and Haul

Reintroduction Rate	Alternative 1	Alternative 3	Trap and Haul
Adult Attraction	• Proportion of adults into Cow Creek	• Percent of adults through the Keswick fish ladder • Percent through Keswick Reservoir • Percent into guidance structure • Percent to Shasta Dam crest	• Percent of adults through the Keswick fish ladder • Percent through Keswick Reservoir • Percent into guidance structure • Percent through ladder at Shasta Dam
Adult Survival	• Percent of adults to top of natural channel • Percent of adults through constructed channel into the Winnemem Waywaket	• Percent through temperature control structure • Percent through Shasta Reservoir	• Percent through sorting facility • Percent survive trucking
Juvenile Guidance	• Percent through guidance structure into constructed channel	• Percent through collection facility on the Winnemem Waywaket	• Percent through collection facility on the Winnemem Waywaket
Juvenile Survival	• Percent of juveniles through constructed channel and into the Nomtipom Waywaket	• Percent survive trucking to Shasta Dam • Percent survive sorting facility • Percent to Keswick Dam • Percent through surface flow outlet	• Percent survive trucking to Shasta Dam • Percent survive sorting facility • Percent to Keswick Dam • Percent through surface flow outlet

Figure 27
Mapping of 256 Combinations of the Design Elements Related to Adult Reintroduction Rates Under Alternative 3



Notes: Gray circles indicate Tier 1 combinations, blue squares indicate Tier 2 combinations, and the orange squares indicate Tier 3 combinations. Combinations at design points related to reintroduction rates of (0.80, 0.85, 0.90, and 0.95) have been jittered to facilitate the visualization. Kes Att is the percent of adults that make it through the Keswick fish ladder; Kes Res is the precent of adults that travel through Keswick Reservoir; Shasta Att is the percentage of adults that go into the guidance structure; Shasta Crest is the percent of adults that make it to Shasta Dam crest; TCD is the percent that make it through the temperature control structure; and Shasta Res is the percentage of fish that make it through Shasta Reservoir.

4.2.5.10 Conclusions

Conclusions of the Phase 2 analysis include the following:

- Development of the WRLCM with reintroduction allows a more accurate depiction of the reintroduction dynamics by explicitly incorporating the rates of adult attraction, adult survival, juvenile guidance, and juvenile survival.
- Under a perfect reintroduction in which all collection and survival rates are 1.0, the Winnemem Waywaket population growth rates and abundance show independent population trends from the Keswick population for much of the 1970 to 2020 time series. This result suggests that there is considerable value in establishing a population in the Winnemem Waywaket to improve the overall resilience of winter-run Chinook Salmon in the Central Valley.
- When all reintroduction rates were greater than 0.92, most of the model runs resulted in the potential for sustainability under harvest, whereas when all rates were in the 0.9 to 0.92 range, higher population abundances could be achieved under the reintroduction relative to the baseline.
- By mapping design elements under each of the volitional alternatives to the reintroduction rates, the population-level outcomes can be associated with the design element values. Each design element maps to a reintroduction rate. Using an optimization algorithm, the design levels can be identified for a given reintroduction rate, and the levels of the design elements can be associated with a specific population objective, such as increasing overall population abundance or population sustainability under harvest. Under this approach, target passage or survival rates can be identified for each of the design elements to achieve the population objectives.
- The results of the life-cycle modeling study provide an initial analysis of the target passage and survival rates that could lead to sustainable populations of Chinook Salmon in the Winnemem Waywaket; however, the specific rates identified in this analysis are conditional upon the many assumptions used to run the WRLCM under reintroduction. In particular, the hydrologic sequence used in the counterfactual analyses may not be indicative of future hydrology, and the level of refuge from TDM in the Winnemem Waywaket may both affect modeling results. Furthermore, other population-level metrics could be evaluated (e.g., variability in spawner population size, covariation in population productivity, and probability of quasi-extinction) in future studies. These analyses may lead to identifying other combinations of reintroduction rates and therefore design element target rates to achieve those population metrics.

4.2.6 Fish Movement in the Reservoir

Understanding juvenile Chinook Salmon migration and survival through the McCloud Arm of Shasta Reservoir and Shasta Reservoir is critical for re-establishing a viable population upstream of Shasta

Dam. Previous acoustic telemetry studies in 2017 revealed inconsistent survival estimates, highlighting the need for further research. To address these gaps, USGS conducted a multi-season acoustic telemetry study in 2024, capturing a range of environmental conditions to better characterize downstream migration behavior and survival in Shasta Reservoir (Stockwell et al. 2026).

4.2.6.1 Purpose and Scope

The purpose of this study was to evaluate the movement and survival of juvenile Chinook Salmon during out-migration through the McCloud Arm of Shasta Reservoir and Shasta Reservoir and evaluate behavior near Shasta Dam as it relates to downstream passage. The scope of the study included the following:

- Assessing movement downstream of Shasta and Keswick dams
- Collecting vertical temperature profiles throughout the Winnemem Waywaket and Shasta Reservoir
- Analyzing environmental and operational data as they relate to movement and behavior

4.2.6.2 Methods

Environmental and operational data were obtained from DWR (2025b) and Reclamation, as well as in-situ vertical water temperature profiles. Data were used to accomplish the following:

- Evaluate survival and behavior of juvenile Chinook Salmon in Shasta Reservoir
- Describe behavior and passage patterns in the Shasta Dam forebay
- Relate these metrics to environmental covariates and dam operations

USGS used the JSATS to evaluate migration behavior and survival of juvenile Chinook Salmon. This applied to the telemetry study as follows:

- A total of 656 hatchery-origin juvenile late-fall-run Chinook Salmon, provided by Coleman National Fish Hatchery, were tagged and released from September to December 2024 over 7 release days.
- A total of 55 acoustic telemetry receivers were deployed for this study in early September 2024 to monitor fish movement from the McCloud Arm of Shasta Reservoir downstream through Shasta Reservoir, at Shasta and Keswick dams, and into the Sacramento River to San Francisco Bay. 55 receivers were placed to create the following gates:
  - Nosoni Creek
  - Upper McCloud Arm
  - Middle McCloud Arm
  - Lower McCloud Arm
  - East Shasta Reservoir
  - West of I-5 Bridge
  - Shasta Dam

    - Keswick Dam
- An additional six gates were leveraged on the Sacramento River from NMFS and were used to track movement downstream of Keswick Dam at the following locations:
    - Red Bluff
    - Meridian Bridge
    - Tower Bridge
    - Walnut Grove
    - Below Georgiana Slough
    - Benicia Bridge.

Telemetry records were compiled and proofed before being integrated with fish tagging, release, and environmental data. These data were used to complete the following activities:

- Describe general movement patterns in the Winnemem Waywaket, Shasta Reservoir, and near Shasta Dam
- Estimate reach-specific and release group-specific apparent survival using Cormack-Jolly-Seber model as follows:
    - Migration was divided into five reaches: Nosoni Creek to Upper McCloud Arm (Reach 1), Upper McCloud Arm to Middle McCloud Arm (Reach 2), Middle McCloud Arm to Lower McCloud Arm (Reach 3), Lower McCloud Arm to West of I-5 bridge (Reach 4), and West of I-5 bridge to Shasta Dam (Reach 5).
    - East Shasta Reservoir was excluded because these detections represented upstream movements.
    - The reach from release to Nosoni Creek was treated as an acclimation reach to reduce bias due to potential effects of in-river traps above the first detection gate and the potential non-migratory behavior of hatchery fish.
    - The reaches were grouped into two regions: Region 1 was Nosoni Creek to Lower McCloud Arm, and Region 2 was Nosoni Creek to Shasta Dam.
- Travel and residence times were also calculated to characterize movement dynamics.
    - Travel time calculated from release to Shasta Dam and from Lower McCloud Arm to Shasta Dam.
    - Total residence time at Shasta Dam forebay was calculated by grouping individuals by month of arrival at Shasta Dam.
- Diel patterns in fish movement at Shasta Dam were assessed based on first and last detection by hour of day.
- To assign passage routes at Shasta Dam, USGS used last detection records and dam operations for all fish that were confirmed to have passed the dam, based on downstream detections.

4.2.6.3 Key Findings

Environmental Conditions and Dam Operations

- Several large rainstorms resulted in periodic increases in inflow at Shasta Dam and increasing reservoir elevations in Shasta Reservoir.
  - Flows in the McCloud Arm of Shasta Reservoir were very low (<10 cubic meters per second) during most of the study with streamflow peaks on seven occasions.
  - Turbidity generally followed changes in river flow with increases in flow corresponding to higher turbidity (ranging 1 nephelometric turbidity unit [NTU] to 68 NTU)
- Vertical water temperature profiles, collected at three locations, ranged from 6°C at the reservoir bottom to 25°C at the surface during the warmest period in September 2024.
  - At all three locations, surface waters were warmest from September to October 2024, averaging 25°C, and subsequently cooled with surface temperatures ranging from 10°C to 12.5°C from late December 2024 through January 2025.
  - At all three sampling locations, temperatures from September through late November were stratified, after which the water column became homogenous and continued to cool through January 2025.
  - First detections of tagged fish at all three locations increased as mixing occurred.
- Reservoir elevation, outflow, and inflow reached their peak in February 2025.
  - Shasta Reservoir surface elevation ranged from 300 m to 320 m.
  - River outlets 259 m and 290 m were open for 11 and 17 days, respectively, during the February peak.

Acoustic Telemetry

- In total, 76.7% of the 656 juvenile Chinook Salmon that were tagged were detected downstream at Nosoni Creek.
  - Percent of downstream detections varied by release period.
- 21.2% were detected at Lower McCloud Arm gate and 10.4% were detected at Shasta Dam.
- Survival probabilities were lowest between Nosoni Creek and Upper McCloud Arm (0.443; 95% confidence interval [CI]: 0.400 to 0.487) and highest between Upper McCloud Arm and Middle McCloud Arm (0.803; 95% CI: 0.745 to 0.850).
- The lowest survival probabilities were observed for fish released October 15, 2025, in both Regions 1 (0.072; CI: 0.027 to 0.178) and 2 (0.018; 95% CI: 0.002 to 0.118), and highest for fish released on November 19, 2025 (Region 1: 0.575; 95% CI: 0.476 to 0.669; Region 2: 0.353; 95% CI: 0.265 to 0.452).
- Cumulative survival for non-release group pooled in Region 1, Nosoni Creek to Lower McCloud Arm, was 0.276 (95% CI: 0.239 to 0.317) and in Region 2, Nosoni Creek to Shasta Dam, was 0.135 (95% CI: 0.108 to 0.168).

- There were 60 fish detected in East Shasta Reservoir and 46 fish that did not enter East Shasta Reservoir that exhibited upstream travel, mainly between the Lower McCloud Arm and Middle McCloud Arm.
  - 11 fish arrived at Shasta Dam and traveled back upstream, and only 3 returned.
- Median travel time from release to first detection at Shasta Dam was 66.4 days (11.4 to 124.8 days)
- Median reservoir travel time (Lower McCloud Arm to Shasta Dam) was 15.9 days (2.5 to 114.0 days)
- Fish arrived mainly during daylight hours (between 6:00 a.m. and 6:00 p.m.), with a peak for arrivals and last detections at 10:00 a.m.
- Fish that arrived in December had the longest residence time at Shasta Dam, with a median time of 29.4 days
- Eight individuals were detected passing Shasta Dam, and two were trucked downstream passed Shasta Dam.
  - Four fish were assigned passage via the temperature control device, and four fish assigned passage via river outlets.
  - Three fish survived downstream migration to Benicia Bridge.
- Median forebay residence time was 11.9 days (0.1 to 104.6 days)

4.2.6.4 Conclusions

The 2024 study found that juvenile Chinook Salmon exhibited limited downstream movement from the McCloud Arm of Shasta Reservoir to Shasta Dam, with low survival rates consistent with previous research. Fall and winter migration was minimal, likely due to Shasta Reservoir physical characteristics and high predation risk. Movement was primarily triggered by storm-driven flow increases and the breakdown of thermal stratification. Behavioral data near the dam provided valuable insight into how fish responded to flow conditions and passage opportunities. These findings enhance USGS’s understanding of juvenile Chinook Salmon survival and behavior in the McCloud Arm of Shasta Reservoir and Shasta Reservoir that may ultimately contribute to designing downstream fish passage strategies for juvenile salmon produced above Shasta Dam.

4.2.7 Food Web and Reservoir Ecology

4.2.7.1 Purpose and Scope

The purpose of the reservoir ecology study was to characterize the existing food web structure in Shasta Reservoir as it may relate to reintroduced juvenile Chinook Salmon. Specifically, USGS sought to understand the current growing environment and predation risk in the reservoir (Johnson et al. 2026). Key questions included the following:

- What is the seasonal and spatial availability of prey?

- Are temperatures conducive to growth?
- Which species are the key predators? What is their monthly and annual consumption demand (biomass) on fish prey?
- How does the thermal structure of the reservoir influence seasonal predator-prey interactions and habitat overlap?

4.2.7.2 Methods

USGS conducted seasonal fish sampling in Shasta Reservoir in September and November 2024 and April 2025. Fish were collected with depth-stratified sinking gillnets that ranged in mesh size from 1.5- to 3.5-inch stretched mesh (small mesh) and 3.5- to 6-inch stretched mesh (large mesh) to target a wide range of fish sizes and depths. Discrete depths were sampled from the surface down to about 40 m, depending on the season and thermal structure of the reservoir. Pelagic fish, such as trout and Chinook Salmon, are not as susceptible to the benthic gillnets, so guided trips were taken in August and November 2024 and April 2025 to target these species with hook and line. Fish were identified to the lowest taxa possible, measured for length and weight, and sampled for diet contents, scales, otoliths, and fin tissue. All samples were placed on ice and then frozen. Zooplankton tows and temperature profiles were conducted monthly by CDFW staff between June 2024 and April 2025 at two sites: one in the main arm and one in the Lower McCloud Arm. At each site, two replicate samples were collected from the target depth to the surface for target depths of 10 m, 20 m, 30 m, and 40 m to estimate zooplankton densities for discrete 10-m depth bins. USGS also conducted a hydroacoustics survey over 3 nights in September 2024 to estimate density and abundance of the primary forage fish population in the reservoir (threadfin shad).

Stable isotope analysis was conducted on a subset of fish fin tissue samples and whole bodies of representative primary consumers in the reservoir (e.g., zooplankton, bivalves, and other benthic invertebrates) to map the food web. Bayesian stable isotope mixing models were used to estimate proportional diet contribution of major prey sources (zooplankton, fish prey, and benthic invertebrates) to key fish consumers. Scales were used to age and back-calculate size at annulus for a subset of individual fish from key species: Spotted Bass (*Micropterus punctulatus*), Smallmouth Bass (*Micropterus punctulatus*), Sacramento Pikeminnow (*Ptychocheilus grandis*), Rainbow Trout (*Oncorhynchus mykiss*), Brown Trout (*Salmo trutta*), kokanee, and Chinook Salmon. Tissue samples from all Chinook Salmon sampled were submitted to Cramer Fish Sciences to undergo genetic analysis. Densities of key zooplankton taxa (identified to genera for cladocerans and order for copepods) were estimated by enumerating individuals in a subset of aliquots for each sample. A subset of individuals were measured for body length to estimate individual weights and population biomass.

Wisconsin-style bioenergetics model simulations were used to estimate per capita and population-level consumption rates by key consumers in the reservoir to quantify species interactions. Inputs to these simulations included annual growth rate (from back-calculated size at age), diet proportions (from stable isotope mixing models), prey energy content (from the literature), and thermal experience (inferred from reservoir temperature profiles). Predator population-level consumption on fish prey was estimated for size-structured unit-populations of 1,000 individuals to characterize predation risk for fish in the reservoir because total population abundances are unknown.

4.2.7.3 Key Findings

Stable isotope analysis identified Chinook Salmon as the top predator in the Shasta Reservoir food web, estimated to rely more heavily on fish prey than any other consumer. Moderate-level predators included pikeminnow, large- and medium-sized bass, Brown Trout, Rainbow Trout, and catfish. Threadfin Shad (*Dorosoma petenense*) were estimated to consume a mix of zooplankton and benthic resources but relied more heavily on zooplankton than any other fish species examined in the reservoir.

Daphnia (the preferred zooplankton prey for juvenile salmonids in lakes and reservoirs) were highly abundant in the surface waters (0 m to 20 m deep) during their spring bloom at the beginning of April, and continued to be moderately abundant (two to five individuals per liter) through July, before they dropped to very low levels (less than 1 individual per liter) until February, when densities began to increase again. Once the reservoir stratified and the epilimnion warmed, *Daphnia* became more available in deeper waters and disappeared from the surface waters. Virtually no zooplankton were available from 0 m to 20 m deep in August and September.

Threadfin Shad densities at night varied across regions of the reservoir and were highest in the Pit River Arm and lowest in the main basin near the dam. Fish were distributed throughout the top 18 m of depth, with the highest densities observed in the top 12 m. The preliminary estimate of reservoir-wide abundance is around 600 million individuals, most of which were assumed to be newly recruited young-of-year based on initial target-strength analysis.

Out of 19 Chinook Salmon sampled in the reservoir, 5 were genetically identified as belonging to the reintroduced winter-run population from BY 2023. Four of these fish were sampled in November 2024 (fork length [FL] range: 249 millimeters [mm] to 280 mm), and one was sampled in April 2025 (FL: 371 mm). Analysis of back-calculated size at annulus suggests that the reintroduced winter run experienced a much faster growth rate in their first year of life compared to the stocked Chinook Salmon. Stable isotope analysis on the four winter-run Chinook Salmon that were sampled in 2024 (August and November) suggests that they relied primarily on Threadfin Shad as forage (>80% of their diet) for a period of time before capture in the reservoir.

Bioenergetics analysis indicated that size-structed unit-populations (1,000 individuals each) of pikeminnow consumed the highest biomass of fish prey, followed by Rainbow Trout, Brown Trout, and Chinook Salmon. Unit-populations of Smallmouth Bass and Spotted Bass consumed the lowest biomass of all key predators modeled. Notably, estimates of unit-population consumption do not account for large differences in total abundance of the predator populations. Biomass of fish consumed by the unit-populations is expected to be high from May through October and then steadily decrease to a minimum in February. Analysis of species-specific thermal optima for growth suggests that salmonid predators (i.e., Chinook Salmon, Rainbow Trout, and Brown Trout) would be most likely to overlap in habitat with juvenile Chinook Salmon in the reservoir for most of the year due to stratification and the very warm epilimnion and would thus be the primary predator of concern. Uncertainty in predator population abundance limits the ability to fully quantify predation demand by these piscivores.

4.2.7.4 Conclusions

Foraging opportunity and predation risk for juvenile Chinook Salmon in the reservoir will depend on their timing of and size at entry. Moderate zooplankton densities beginning in February suggest that zooplankton foraging should be available from February until July, with peak zooplankton foraging during the bloom in April. The hydroacoustic survey in September suggested ample availability of Threadfin Shad at this time, including abundant larval shad, which could offer foraging opportunities for juvenile Chinook Salmon large enough to feed on them. However, the size at which juvenile Chinook Salmon would begin to feed on larval shad is unknown. Seasonal availability of the shad population is currently unknown.

Predation risk for juvenile winter-run Chinook Salmon will be highest in October, when predator population consumption is at its highest and juveniles are still very small in size. Predation risk will decrease through the fall and winter due to several different mechanisms: 1) as prey weight increases, the number of individual fish needed to fulfill the consumption demand (biomass) of predators declines; 2) as prey length increases, the number of predators large enough to successfully capture them declines; and 3) as temperatures decrease through the winter, predator consumption demand declines with it. Over-winter temperatures in the reservoir are not low enough to fully dial back consumption rates by the salmonid predators (Chinook Salmon and trout), so these predators could still be important sources of predation mortality on juvenile Chinook Salmon during the winter. However, uncertainty in population abundance of these predators, access to alternative prey (e.g., Threadfin Shad), and probability of encountering juvenile Chinook Salmon limits USGS's ability to fully quantify this risk.

4.2.8 Ecological Considerations for Reintroducing Chinook Salmon Upstream of Shasta Dam

4.2.8.1 Purpose and Scope

As co-managers advance efforts to rematriate and reintroduce Chinook Salmon in the Winnemem Waywaket, a detailed understanding of potential ecological impacts may help to inform reintroduction planning and post-reintroduction monitoring. In this assessment, USGS synthesized existing literature to assess the ecological risks, benefits, and uncertainties associated with Chinook Salmon rematriation and reintroduction (Couch et al. 2026a). Key considerations included population viability, disease, and species interactions.

4.2.8.2 Methods

USGS conducted a targeted review of peer-reviewed literature and reports to identify key ecological benefits, risks, and uncertainties associated with Chinook Salmon rematriation and reintroduction. These considerations were evaluated for two potential source populations (New Zealand [NZ] Nur and winter-run Chinook Salmon), as well as for the target NZ Nur and winter-run Chinook Salmon populations that would result from rematriation and reintroduction in the Winnemem Waywaket. The researchers also assessed potential ecological effects on the recipient ecosystem.

4.2.8.3 Key Findings

The primary ecological benefits included the enhancement of spatial diversity and access to cold-water refuge for winter-run Chinook Salmon. Additionally, the return of marine-derived nutrients may benefit native species in the Winnemem Waywaket. Primary risks included the potential to deplete source populations, and the potential for disease transmission from NZ and the mainstem Nomtipom Waywaket into the Winnemem Waywaket. Predation or competition between reintroduced Chinook Salmon and resident fish in the Winnemem Waywaket is also possible. There are many uncertainties regarding how winter-run Chinook Salmon and NZ Nur may interact with each other and with other species in the Winnemem Waywaket, which largely depends on how life-history timing manifests for each target population.

4.2.8.4 Conclusions

Rematriation and reintroduction provides opportunities to enhance winter-run Chinook Salmon population viability and restore the spiritual and cultural connections between NZ Nur and the Winnemem Wintu Tribe. Several important ecological risks and areas of uncertainty were identified in this assessment, which may be addressed through additional research, monitoring, and mitigation efforts. For example, to mitigate the risks of importing pathogens from NZ, managers may choose to implement biosecurity and pathogen testing protocols. Genetic monitoring of rematriated NZ Nur and winter-run Chinook Salmon during the reintroduction process could clarify the extent of introgression between these two target populations and the relative risks and benefits of mixing, in addition to supporting potential genetic management plans. Similarly, the risks and uncertainties associated with predation and competition among NZ Nur, winter-run Chinook Salmon, and resident fish species could be in part addressed by studying the distributions and behavior of these species in the Winnemem Waywaket and developing predictive models to explore the potential effects of interactions.

4.2.9 New Zealand Pathogen Assessment

4.2.9.1 Purpose and Scope

The purpose of this assessment was to evaluate the relative risks posed by pathogens that are known to affect fish, particularly salmonids, and that may be of concern in the context of rematriating Nur from NZ to the Winnemem Waywaket. This assessment also outlines potential mitigation strategies that managers could implement to reduce the risk of pathogen introduction during the reintroduction process (Couch et al. 2026b).

4.2.9.2 Methods

USGS conducted a targeted review of peer-reviewed literature and reports to evaluate the risks associated with the 29 pathogens currently targeted for testing in NZ prior to potential reintroduction. These included 12 viral, 12 bacterial, and 5 parasitic organisms. Risk level for each pathogen was evaluated based on its ability to infect salmon, vertical transmissibility, virulence, and geographic distribution. For the purposes of this assessment, the researchers assumed that eggs would be the transported life stage.

4.2.9.3 Key Findings

Of the 29 pathogens evaluated, USGS identified 10 moderate-risk and four high-risk pathogens. High-risk pathogens included NZ rickettsia-like organisms, pilchard orthomyxovirus, infectious pancreatic necrosis virus, and *Yersinia ruckeri*. To mitigate the risk of introducing these pathogens into the Winnemem Waywaket, a suite of biosecurity and testing measures may be employed. These measures include testing of 100% of parents prior to egg transport; iodophor disinfection of eggs; quarantine, monitoring, and testing of juveniles prior to release; and pathogen surveillance of the source population.

4.2.9.4 Conclusions

While the importation of Nur eggs from NZ presents notable pathogen risks, these risks could be reduced with appropriate mitigation strategies. Managers may choose to implement the risk reduction measures outlined in this assessment during the reintroduction process to reduce risk to an acceptable level.

4.2.10 Reintroduction Review

Reintroduction of Pacific salmon into historically important habitat has occurred in western North America since 1947. These efforts have been integral to restore connectivity, ecological function, and to recover imperiled salmon and steelhead populations. An extensive body of expertise has been accrued by reintroduction practitioners working in various systems, thus, opportunities to compile and distill best practices and lessons learned can benefit newly implemented and future programs.

4.2.10.1 Purpose and Scope

This review is intended to update the existing state-of-knowledge on Pacific salmon reintroduction and to identify best practices and lessons learned to benefit new and future programs. The objectives were addressed by soliciting participation from an experienced group of reintroduction practitioners and via literature review.

4.2.10.2 Methods

USGS conducted a comprehensive review to identify all locations where Pacific salmon reintroductions have occurred in western North America and to gather as many publications and reports, as well as other literature, as possible. USGS also convened an expert group of co-authors representing federal, state, Tribal, and private entities that are well-versed in salmon reintroduction. During this process, USGS acquired annual count data for returning adults at all projects where that data were available and project partners were willing to provide them. This information was then analyzed and distilled to provide updates to a similar effort conducted more than a decade ago (Anderson et al. 2014).

4.2.10.3 Key Findings

USGS identified a total of 47 Pacific salmon reintroductions that have been implemented in western North America since 1947. General observations from these reintroduction efforts are described as follows:

- Reintroduction has occurred in the following states/provinces: Oregon (38%), Washington (34%), California (11%), Idaho (9%), and British Columbia (9%).
- Implementation primarily occurred during the 1990s to 2010s (74%), but also during the 2020s (11%), 1980s (2%), 1960s (4%), and 1940s (2%). Additionally, USGS identified three new programs that will be implemented in the next several years.
- Implementation methods included: trap and haul (52%), dam removal (15%), other (13%), streamflow improvements (11%), and fishway development (9%).
- Chinook Salmon were included in 72% of the programs, followed by Coho Salmon (*Oncorhynchus kisutch*; 33%), steelhead (22%), Sockeye Salmon (20%), Pink Salmon (*O. gorbuscha*; 4%), and Chum Salmon (*O. keta*; 2%).
- Approximately 80% of the reintroduction programs that had annual adult return data available exhibited positive (increasing) trends in adult abundance.

4.2.10.4 Conclusions

Pacific salmon reintroduction is one of many management tools that are currently available to recover imperiled salmon populations throughout western North America. These programs have proven to be durable; 95% of the implemented reintroductions remain active today, many of which were initiated more than 20 years ago. Most programs have resulted in long-term increases in annual adult returns and some programs have returned tens of thousands to hundreds of thousands of adults each year. While these results are encouraging, USGS emphasizes that reintroduction must be implemented in conjunctions with other management actions (e.g., habitat restoration, predator management, and improved biological flows) to effectively recover imperiled salmon populations.

4.2.11 Fish Responses to Tunnels and Lighting Literature Review Summary

4.2.11.1 Purpose and Scope

A comprehensive literature review on lighting influences and effects on migrating Chinook Salmon was conducted and the results were synthesized to inform the Feasibility Study. The synthesized information included summaries of available literature, applicability of previous studies to fish migration pathways being considered in the Feasibility Study and application of guidelines and theory to lighting requirements in future fish passage alternatives.

The scope of this review focuses on smaller-scale or short-duration studies with very few directly addressing the long, enclosed tunnel environments most relevant to fish passage alternatives in the Feasibility Study. Sources for this review were concentrated on empirical studies as well as reviews and agency guidance documents.

4.2.11.2 Methods

This report compiled and synthesized peer-reviewed literature, research studies, and data regarding the influence of light on salmon behavior. It then summarized findings that helped fill knowledge gaps regarding the behavior of salmon in ambient and artificially lit navigational pathways. Finally, it identified applications and guidelines that can be used in the formulation and development of conceptual fish passage designs in long tunnels.

Target species for passage at Keswick and Shasta dams centered on historically extirpated winter-run Chinook Salmon, alongside the conservation of other runs of Chinook Salmon, steelhead (anadromous form), resident Rainbow Trout (resident form), and Pacific Lamprey (*Entosphenus tridentatus*).

4.2.11.3 Key Findings

There are no studies documenting long tunnel-lighting effects with which to incorporate into the literature review. Collective findings from culvert, flume, and bypass studies support the benefits of ambient lighting, characterized by low-intensity, diffuse illumination that mimics natural conditions.

For long tunnels, lighting should be designed as a neutral environmental feature, one that minimizes disruption and supports natural movement, mimicking natural ambient lighting (moonlight, starlight, or diffuse sunlight). Artificial lighting schemes that rely on bright, direction or strobe illumination risk creating ecological traps, altering predator-prey dynamics.

4.2.11.4 Conclusions

There is a body of evidence from empirical research to suggest positive benefits and describe a need for fishway lighting. Ambient fishway lighting can be considered within the design process, with an integrated monitoring plan to assess the effectiveness of lighting. Ambient lighting should be evaluated at the specific fishway site.

5 Summary of Preliminary Design Criteria and Considerations that Influence Development of Potential Fish Passage Alternatives

This section compiles and summarizes preliminary design criteria and considerations relevant to the development of potential fish passage alternatives. For additional details on all design criteria, standards, and references, refer to the appendices noted in each subsection.

5.1 Focal Fish Species and Life History

Guidelines and criteria developed to inform the formulation of potential alternative concepts are based upon the life-history requirements of all run-types of Chinook Salmon currently present within the Nomtipom Waywaket. While other fish species are present within the Nomtipom Waywaket, the requirements of winter-run and spring-run Chinook Salmon are emphasized when considering facility design and operational requirements occurring above Shasta Dam. Table 19 indicates the periods of migration and peak migration for Chinook Salmon.

Table 19
Migration Periods for Chinook Salmon

Run	Life Stage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Winter and Spring	Upstream												
	Downstream												
All	Upstream												
	Downstream												

Note:
Shaded areas identify periods of migration with darker, cross-hatched areas indicating peak periods of migration.

5.2 Reservoir Operations

Reservoir operations at Shasta Dam and Keswick Dam are summarized in the following subsections. Refer to Appendix G for additional details. Note that reservoir elevations are reported directly from various data sources and have not been explicitly converted to a common datum for the purposes of this report (e.g., CDEC stations do not report a specific datum, whereas USGS gages are reported in NAVD88).

5.2.1 *Shasta Reservoir Water Level Fluctuation*

Water levels in Shasta Reservoir fluctuate seasonally based on precipitation, irrigation demands, power-generation demands, and flood storage requirements. WSEs recorded at the CDEC Station SHA between February 2000 and August 2024 indicate the reservoir typically fluctuates between a high operating pool elevation of 1,065.4 feet (0.1% exceedance) and a low operating pool elevation of 885.2 feet (99.9% exceedance). This represents the elevations the reservoir is typically operated between, rather than the absolute maximum and minimum WSEs that could occur.

To increase water supply and water supply reliability, Reclamation evaluated the potential of raising Shasta Dam in the SLWRI. Reclamation transmitted to Congress the Final Feasibility Report and Environmental Impact Statement for the SLWRI in July 2015 that investigated the potential effects of raising Shasta Dam by 6.5 feet, 12.5 feet, and 18.5 feet. The SLWRI evaluates the potential for increasing water supply, water supply reliability, and survival of anadromous fish populations in the upper Nomtipom Waywaket (Reclamation 2020). For the purposes of alternative evaluation, the 18.5-foot Shasta Dam raise scenario is assumed for future conditions, with no change to the minimum operating pool elevation.

5.2.2 *Shasta Dam Tailrace Water Level Fluctuation*

Downstream of Shasta Dam is Keswick Reservoir, therefore, WSEs are controlled by operations at Keswick Dam. Refer to Section 5.2.3 for Keswick Reservoir water level fluctuations.

5.2.3 *Keswick Reservoir Water Level Fluctuation*

Water levels in Keswick Reservoir do not fluctuate as widely as in Shasta Reservoir. WSEs recorded at the CDEC Station KES between February 1985 and November 2024 indicate the reservoir typically fluctuates between a high operating pool elevation of 586.5 feet (0.1% exceedance) and a low operating pool elevation of 576.2 feet (99.9% exceedance).

5.2.4 *Keswick Tailrace Water Level Fluctuation*

Downstream of Keswick Dam, WSEs in Nomtipom Waywaket fluctuate based on releases from Keswick Dam. The closest gage to the Keswick Dam tailrace is USGS gage ID 11370500 SACRAMENTO R A KESWICK CA, located approximately 5,000 feet downstream of the dam. While data within the tailrace are most ideal for this analysis, these values provide an order of magnitude estimate. WSEs (NAVD88) recorded at USGS gage 11370500 between May 2022 and May 2025 indicate Nomtipom Waywaket typically fluctuates between a maximum water surface elevation of 512.5 feet (0.1% exceedance) and a minimum WSE of 490.4 feet (99.9% exceedance).

5.2.5 Summary of Water Surface Elevations Selected for Alternative Formulation and Development

Table 20 details the WSEs that were selected for the purpose of alternative development.

Table 20
Summary of Water Surface Elevation Design Criteria

Design Criteria	Minimum WSE (feet)	Maximum WSE (feet)
Existing Shasta Reservoir	885.2	1,065.4
Future Shasta Reservoir	885.2	1,083.9
Shasta Dam Tailrace	576.2	586.5
Keswick Reservoir	576.2	586.5
Keswick Dam Tailrace	490.4	512.6

Source: Appendix G

5.3 Anticipated Flows During Periods of Migration

Per NMFS (2023a), fish passage facilities should be designed to provide safe and efficient passage for target species for the range of flows expected to occur during the Chinook Salmon migration period. This range is defined by the 95% average daily flow exceedance value (low fish passage design flow) and the 5% average daily flow exceedance value (high fish passage design flow). The fish passage flows are intended to bracket streamflows at which migrants are expected to be present, migrating, and dependent on the proposed fishway for safe passage. This guidance is intended to ensure that the passage facilities are designed to maintain favorable hydraulics (e.g., depths, velocities, and turbulence) while the facility is utilized by target species. Additionally, NMFS (2023b) recommends that attraction flow used to encourage upstream-migrating fish into passage facilities be 5% to 10% of the high fish passage design flow.

Adult winter-run and spring-run Chinook Salmon migration timing is shown above in Table 19. The following subsections describe the anticipated flows during this peak migration period (December through July) at several key locations: Winnemem Waywaket, Nomtipom Waywaket at Shasta Tailrace, Nomtipom Waywaket at Keswick Tailrace, Cow Creek, Little Cow Creek, and Dry Creek.

5.3.1 Winnemem Waywaket

Average daily flow exceedance values at three stream gage locations on Winnemem Waywaket were collected and analyzed, as described in Appendix H. The three different gages are listed in the following bullets, in order of upstream to downstream:

- USGS Gage ID 11367800 MCCLOUD R A AH-DI-NA NR MCCLOUD CA
- USGS Gage ID 11368000 MCCLOUD R AB SHASTA LK CA

- CDEC Gage MSS: McCloud River Above Shasta Reservoir

Tables 21, 22, and 23 present mean daily exceedance values from these gages, which are used to inform the high and low fish passage design flows. Fish passage design flows for a given facility should be chosen based on proximity to the gages. In the tables below, the Chinook Salmon migration window of December through July (refer to Section 4.2) is shaded green, and the fish passage low and high design flows within the migration window are bolded. The fish passage design flows at each gage location on the Winnemem Waywaket are listed in the following bullets:

- At the CDEC McCloud River Above Shasta Reservoir (MSS) gage, the low fish passage design flow (95% exceedance) is 237 cfs and the high fish passage design flow (5% exceedance) is 5,853 cfs.
- At USGS Gage ID 11368000 MCCLOUD R AB SHASTA LK CA, the low fish passage design flow is 221 cfs and the high fish passage design flow is 5,801 cfs.
- At USGS gage 11367800, the low fish passage design flow is 175 cfs and the high fish passage design flow is 1,631 cfs.

Table 21
Mean Daily Flow Exceedance – McCloud River Above Shasta Reservoir (MSS)

Month		95% Exceedance (cfs)	5% Exceedance (cfs)
1	January	263	4,060
2	February	373	**5,853**
3	March	367	4,131
4	April	365	3,588
5	May	292	2,266
6	June	254	1,022
7	July	**237**	574
8	August	223	470
9	September	230	472
10	October	230	869
11	November	269	868
12	December	269	2,492

Notes:
Period of Record Analyzed: 10/01/1997 to 09/30/2023
Missing Data: 11/22/1998 to 12/10/1998; 9/2/2010 to 1/23/2011

Table 22
Mean Daily Flow Exceedance – McCloud River Above Shasta Lake (USGS 11368000)

Month		95% Exceedance (cfs)	5% Exceedance (cfs)
1	January	270	4,010
2	February	280	**5,801**
3	March	357	4,018
4	April	327	3,521
5	May	288	2,078
6	June	260	1,020
7	July	239	506
8	August	227	396
9	Septembe r	241	368
10	October	258	832
11	November	280	884
12	December	**221**	2,720

Notes:
Period of Record Analyzed: 10/01/1997 to 09/30/2023
Missing Data: 10/01/2007 to 9/30/2008

Table 23
Mean Daily Flow Exceedance – McCloud River at Ah-Di-Na (USGS 11367800)

Month		95% Exceedance (cfs)	5% Exceedance (cfs)
1	January	179	681
2	February	187	1,561
3	March	193	1,053
4	April	188	**1,631**
5	May	179	1,220
6	June	**175**	560
7	July	180	269
8	August	181	263
9	September	203	271
10	October	203	469
11	November	200	338
12	December	185	520

Notes:
Period of Record Analyzed: 10/01/1997 to 09/30/2023
Missing Data: 10/01/2021 to 11/08/2021

5.3.2 *Nomtipom Waywaket at Shasta Tailrace*

The 95% and 5% average daily flow exceedance values for outflows from Shasta Dam presented in Table 24 were calculated for each month as part of the duration analysis described in Appendix K, Section 2.8.2. The Chinook Salmon migration window of December through July is highlighted green, and the selected fish passage low and high design flows are bolded. At the Shasta Dam tailrace, the low fish passage design flow is 1,263 cfs and the high fish passage design flow is 34,195 cfs.

NMFS (2023a) recommends that attraction flow be calculated as a range from 5% to 10% of the high fish passage design flow. This results in an attraction flow range of 1,710 cfs to 3,420 cfs. Due to the difficulty of designing a fish ladder entrance that can effectively convey flows of this magnitude while maintaining favorable hydraulics, attraction flows conveyed through the entrances at Shasta Dam are anticipated to be on the order of 400 cfs. Attraction may be enhanced by strategic design and operation of other proposed facility components (e.g., barrier/guidance structures) to augment attraction flows, or strategic siting that considers existing facility features (e.g., spillway, outlets, powerhouse tailrace) and fish behavior (e.g., milling patterns). Additional studies and pilot testing will be required at later stages of design to determine optimal entrance siting and attraction flows.

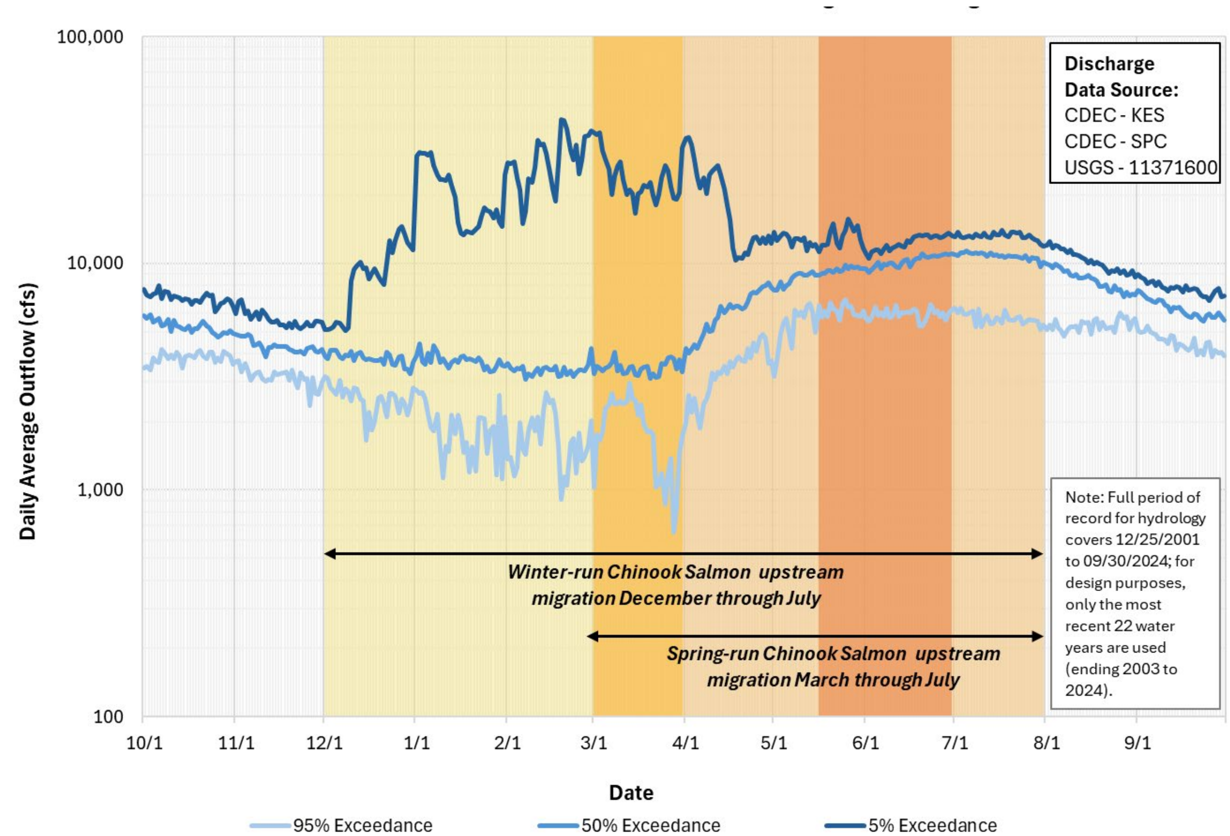
Table 24
Mean Daily Flow Exceedance – Outflows from Shasta Dam

Month		95% Exceedance (cfs)	5% Exceedance (cfs)
1	January	1,921	19,602
2	February	**1,263**	**34,195**
3	March	1,596	28,546
4	April	2,334	26,879
5	May	4,153	13,053
6	June	5,525	12,956
7	July	5,356	13,581
8	August	4,918	12,013
9	September	4,289	8,844
10	October	3,786	7,291
11	November	3,214	5,995
12	December	2,440	9,729

Notes:
Period of Record Analyzed: Water Years 2003 through 2024

Figure 28 illustrates seasonal variation in mean daily outflows from Shasta Dam and the 95% exceedance, 50% exceedance, and 5% exceedance flows throughout the water year. Outflows are most variable throughout winter and early spring, remaining below 5,000 cfs approximately 50% of the time but experiencing periodic large magnitude releases on the order of 20,000 cfs to 70,000 cfs to address flood control needs. As shown in Figure 28, this period of high flow variability coincides with the majority of the winter-run Chinook Salmon migration window, including peak migration during the month of March. The beginning of the spring-run Chinook Salmon migration window also overlaps with this period of high flow variability. Peak migration occurs during the months of May and June when flows are more consistent, generally remaining between 5,000 cfs and 15,000 cfs 90% of the time.

Figure 28
Seasonal Variation of Outflows from Shasta Dam Outflows Versus Chinook Salmon Migration



5.3.3 *Nomtipom Waywaket at Keswick Tailrace*

The 95% and 5% average daily flow exceedance values for outflows from Keswick Dam presented in Table 25 were calculated for each month as part of the duration analysis described in Appendix K, Section 2.8.2. The Chinook Salmon migration window of December through July is highlighted green, and the selected fish passage low and high design flows are bolded. At the Keswick Dam tailrace, the low fish passage design flow is 2,974 cfs and the high fish passage design flow is 36,140 cfs.

NMFS (2023a) recommends that attraction flow be calculated as a range from 5% to 10% of the high fish passage design flow. This results in an attraction flow range of 1,807 cfs to 3,614 cfs. Due to the difficulty of designing a fish ladder entrance that can effectively convey flows of this magnitude while maintaining favorable hydraulics, attraction flows conveyed through the entrances at Shasta Dam are anticipated to be on the order of 400 cfs. Attraction may be enhanced by strategic design and operation of other proposed facility components (e.g., barrier/guidance structures) to augment attraction flows, or strategic siting that considers existing facility features (e.g., spillway, outlets, and powerhouse tailrace) and fish behavior (e.g., milling patterns). Additional studies and pilot testing will be required at later stages of design to determine optimal entrance siting and attraction flows.

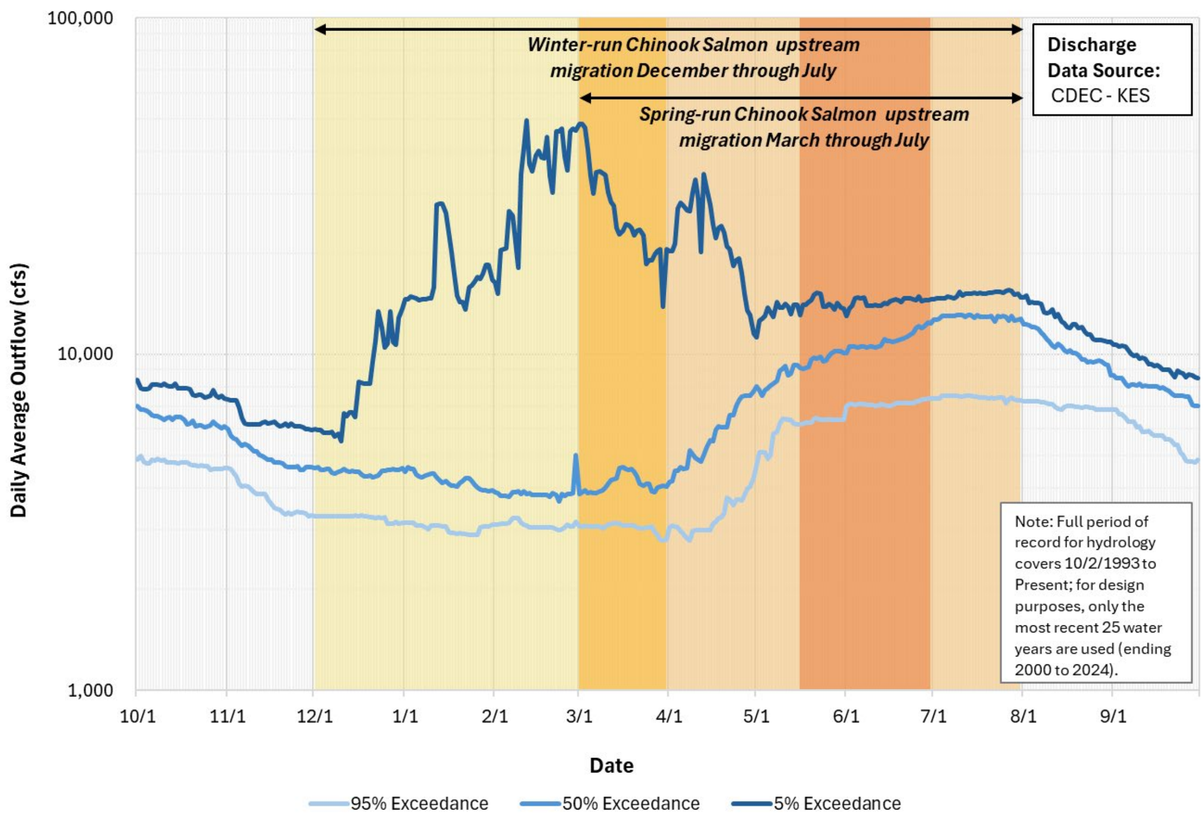
Table 25
Mean Daily Flow Exceedance – Outflows from Keswick Dam

Month		95% Exceedance (cfs)	5% Exceedance (cfs)
1	January	**2,974**	19,456
2	February	3,040	**36,140**
3	March	3,017	33,754
4	April	3,045	26,592
5	May	5,093	14,279
6	June	6,929	14,502
7	July	6,951	15,190
8	August	6,834	13,706
9	September	4,960	9,588
10	October	4,450	7,977
11	November	3,483	6,993
12	December	3,261	9,894

Notes:
Period of Record Analyzed: Water Years 2000 through 2024

While outflows show a relatively consistent annual pattern of ramping up outflows in late spring for irrigation and tapering off at the end of fall, flows throughout winter and early spring exhibit more variation from year to year, reflecting the natural variability the wet season. Wet season flows remain between 5,000 cfs and 10,000 cfs approximately 50% of the time but experience periodic large magnitude releases on the order of 20,000 cfs to 70,000 cfs to address flood control needs. As can be observed in Figure 29, this period of high flow variability coincides with the majority of the winter-run Chinook Salmon migration window, including peak migration during the month of March. The beginning of the spring-run Chinook Salmon migration window also overlaps with this period of high flow variability; however, peak migration occurs from May through June when flows are more consistent, generally remaining between approximately 5,000 cfs and 15,000 cfs 90% of the time.

Figure 29
Seasonal Variation of Outflows from Keswick Dam Outflows Versus Chinook Salmon Migration Timing



5.3.4 Cow Creek

The 95% and 5% average daily flow exceedance values at USGS stream gage 11374000 on Cow Creek are presented in Table 26. The Chinook Salmon migration window of December through July is highlighted green, and the selected fish passage low and high design flows are bolded. At USGS gage 11374000, the low fish passage design flow is 4 cfs and the high fish passage design flow is 6,088 cfs.

Table 26
Mean Daily Flow Exceedance – Cow Creek near Millville (USGS 11374000)

Month		95% Exceedance (cfs)	5% Exceedance (cfs)
1	January	105	**6,088**
2	February	159	5,708
3	March	161	4,680
4	April	141	2,362
5	May	44	1,525
6	June	11	730
7	July	**4**	200
8	August	2	95
9	September	5	82
10	October	18	202
11	November	59	1,022
12	December	82	5,353

Note:
Period of Record Analyzed: 10/01/1997 to 09/30/2023

Attraction of Chinook Salmon into Cow Creek from the Nomtipom Waywaket is an important consideration for success of reintroduction concepts, specifically the tributary bypass. For in-river fish passage facilities such as a fish ladder at a dam, NMFS (2023a) recommends attraction flow be provided at 5% to 10% of the high fish passage design flow. However, Cow Creek is an unregulated system with its own seasonal fluctuation in flow while the Nomtipom Waywaket is regulated by Shasta and Keswick dams, so the actual percentage of the Nomtipom Waywaket flow at any given time will vary. Table 27 compares the monthly 95% and 5% exceedance flows in Cow Creek to the same exceedance flows in the Nomtipom Waywaket to demonstrate this fluctuation seasonally. This does not consider the additional 50 cfs[1] of flow from the Winnemem Waywaket that would augment Cow Creek year-round under the tributary bypass concept. During some periods of the migration window, especially during wet years, Cow Creek may experience flows that are more likely to attract Chinook Salmon purely from a hydraulic perspective. It should be noted that other factors beyond hydraulics add nuance to Chinook Salmon attraction to Cow Creek, including olfactory imprinting to natal streams as discussed in Section 4.2.4.

[1] Note that for Alternative 1, a flow rate of 50 cfs was selected because it is the smallest rate of flow that provides adequate flow depth and velocities for fish movement along all sections of the constructed channel portion of the swimway. Additional water or channel modifications may be required in Dry Creek, Little Cow Creek, and portions of Cow Creek to overcome depth barriers as discussed in Appendix L; this will be analyzed during later stages of design to determine the optimal water quantity and required construction activities to achieve adequate flow depth and velocities for fish movement throughout the entirety of the tributary bypass.

Table 27
Cow Creek Flow as a Percentage of Nomtipom Waywaket Flow at 95% and 5% Exceedance

Month		Cow Creek Flow as a Percentage of Nomtipom Waywaket Flow at 95% Exceedance	Cow Creek Flow as a Percentage of Nomtipom Waywaket Flow at 5% Exceedance
1	January	3.5%	31.3%
2	February	5.2%	15.8%
3	March	5.3%	13.9%
4	April	4.6%	8.9%
5	May	0.9%	10.7%
6	June	0.2%	5.0%
7	July	0.1%	1.3%
8	August	0.0%	0.7%
9	September	0.1%	0.9%
10	October	0.4%	2.5%
11	November	1.7%	14.6%
12	December	2.5%	54.1%

5.3.5 Little Cow Creek

The calculated 95% and 5% average daily flow exceedance values for Little Cow Creek are presented in Table 28. The Chinook Salmon migration window of December through July is highlighted green, and the selected fish passage low and high design flows are bolded. Because Little Cow Creek is not gaged, the values presented in Table 28 were determined by scaling the flow duration analysis from USGS stream gage location 11374000 on Cow Creek based on Little Cow Creek's percentage of the total contributing watershed area of 34.5%. As a result of this method, low fish passage design flow is 1 cfs and the high fish passage design flow is 1,644 cfs. However, this method may underestimate low flows because it does not account for losses and diversions on Cow Creek, downstream of the Little Cow Creek confluence. Because of the lack of suitable gage data on Dry Creek, the low fish passage design flow should be set to 3 cfs for the purposes of alternatives development.

Table 28
Mean Daily Flow Exceedance – Little Cow Creek

Month		95% Exceedance (cfs)	5% Exceedance (cfs)
1	January	58	846
2	February	25	493

Month		95% Exceedance (cfs)	5% Exceedance (cfs)
3	March	6	230
4	April	2	62
5	May	**1**	33
6	June	2	36
7	July	7	93
8	August	21	609
9	September	29	1,897
10	October	36	2,478
11	November	54	2,159
12	December	65	**1,644**

Notes:
Period of Record Analyzed: 10/01/1949 to 6/12/2025
Values are scaled based on 34.5% of the flow reported at Cow Creek near Millville (USGS 11374000)

5.3.6 Dry Creek

The calculated 95% and 5% average daily flow exceedance values for Dry Creek are presented in Table 29. The Chinook Salmon migration window of December through July is highlighted green, and the selected fish passage low and high design flows are bolded. Because Dry Creek is not gaged, the values presented in Table 29 were determined by scaling the flow duration analysis from USGS stream gage location 11374000 on Cow Creek based on Dry Creek's percentage of the total contributing watershed area of 4.6%. As a result of this method, the low fish passage design flow is 0 cfs and the high fish passage design flow is 213 cfs. Similar to Little Cow Creek and because of the lack of suitable gage data on Dry Creek, the low design flow should be set to 3 cfs for the purposes of alternatives development.

Table 29
Mean Daily Flow Exceedance – Dry Creek

Month		95% Exceedance (cfs)	5% Exceedance (cfs)
1	January	8	110
2	February	3	64
3	March	1	30
4	April	**0**	8
5	May	**0**	4
6	June	**0**	5
7	July	1	12

Month		95% Exceedance (cfs)	5% Exceedance (cfs)
8	August	3	79
9	September	4	246
10	October	5	322
11	November	7	280
12	December	8	**213**

Notes:
Period of Record Analyzed: 10/01/1949 to 6/12/2025
Values are scaled based on 4.6 percent of the flow reported at Cow Creek near Millville (USGS 11374000)

5.3.7 Summary of Flows Selected for Alternative Formulation and Development

The low and high fish passage design flows selected for alternative formulation and development are presented in Table 30.

Table 30
Summary of Selected Fish Passage Design Flows

Location	Low Fish Passage Design Flow (cfs)	High Fish Passage Design Flow (cfs)
Winnemem Waywaket (MSS)	237	5,853
Winnemem Waywaket (USGS 1136800)	221	5,801
Winnemem Waywaket (USGS 11367800)	175	1,631
Nomtipom Waywaket at Shasta Tailrace	1,263	34,195
Nomtipom Waywaket at Keswick Tailrace	2,974	36,140
Cow Creek	4	6,088
Little Cow Creek	3	1,644
Dry Creek	3	213

Note:
Low design flows for Little Cow Creek and Dry Creek are increased to 3 cfs because the estimated low design flows are below the minimum recommended by NMFS.

5.4 Technical Engineering and Design Guidance for Fish Passage Projects

There are numerous guidelines and design criteria available which provide the engineering and ecohydraulic design principles for the development of downstream juvenile fish collection facilities.

Typical reference documentation used in the design of such facilities includes but is not limited to the following:

- *Fisheries Handbook of Engineering Requirements and Biological Criteria* (Bell 1991)
- *Fish Screening Criteria* (CDFW 2000)
- *NOAA Fisheries West Coast Region Anadromous Salmonid Passage Design Manual* (NMFS 2023a)
- *NOAA Fisheries West Coast Region Guidance to Improve the Resilience of Fish Passage Facilities to Climate Change – 2022* (NMFS 2023c)
- *Fisheries Pre-Design Guidelines for California Fish Passage Facilities* (NMFS 2023b)

5.5 Key Hydraulic Design Parameters Selected for Concept Formulation

5.5.1 Auxiliary Water Supply Diffusers

Auxiliary water supply (AWS) diffusers serve to dissipate energy from pumped or gravity AWS systems to maximize attraction and minimize fish injury. The maximum clear spacing between bars is 1 inch between diffusers bars for adult salmonids and 0.75 inch where Pacific Lamprey may be present (NMFS 2023a).

Orientation of flat bar stock should maximize the open area of the diffuser panel. If a smaller species or life stage of fish is present, smaller clear spacing between bar stock may be required (NMFS 2023a). Specific criteria related to AWS diffusers is provided from NMFS is included as follows:

- Material: The bars and picket panels used as part of AWS diffuser systems should be made of aluminum, stainless steel, or epoxy-coated carbon steel. The use of submerged galvanized steel should be minimized or eliminated, especially when used in close proximately to fish (i.e., fishways; NMFS 2023a).
- Velocity and Orientation: The maximum AWS diffuser velocity should be less than 1 ft/s for wall diffusers and 0.5 ft/s for floor diffusers based on the total submerged diffuser panel area (Bell 1991). Wall diffusers should only be used when the orientation can be designed to assist with guiding fish within the fishway. Diffuser velocities should be nearly uniform, which may require the use of porosity control panels. The face of the diffuser panels (i.e., the surface exposed to the fish) should be flush with the wall or floor (NMFS 2023a).
- Porosity Control Baffles: Similar to juvenile fish screens, diffusers should include a system of porosity control baffles located just upstream of the diffuser pickets to ensure that average velocities at the face of the diffuser are uniform and can meet velocity and orientation criteria (NMFS 2023a).
- Debris Removal: The AWS design should include access for personnel to remove debris from each diffuser unless the AWS intake is required to be equipped with a juvenile fish screen (NMFS 2023a). For debris rack criteria, see Section 5.5.7.

- Edges: All flat bar diffuser edges and surfaces exposed to fish should be rounded or ground smooth to the touch, with all edges aligning in a single smooth plane to reduce the potential for contact injury (NMFS 2023a).
- Lamprey Passage: At sites where Pacific Lamprey are present, horizontal diffusers should not extend the complete width of the floor of the fishway or entrance pool. A solid surface, approximately 1.5 feet wide, should be located along the floor between the lateral sides of the diffuser panels and the base of either wall.
- Elevation: Wall AWS diffusers should be submerged throughout the range of operation (i.e., the top elevation of the wall diffuser should be below the lowest WSE that will occur based on the fishway design; NMFS 2023a).
- Bedload Removal Devices: At locations where bedload may cause accumulations at the AWS intake, sluice gates or other simple bedload removal devices should be included in the design (NMFS 2023a).

5.5.2 Transport Channels

Transport channels are a functional element that may be used for some of the alternatives to provide volitional passage. Transport channels provide a route for fish to pass by conveying flow between different sectors of an upstream passage facility. The design criteria selected for transport channels based on NMFS (2023a) guidance is presented in Table 31.

The design parameters identified in Table 31 are utilized to establish a base concept for transport channels to represent average characteristics. Transport channels should target a channel depth of 5 ft/s per NMFS (2023a) guidance. However, the Consultant Team selected a concept design parameter of 4 feet for concept development, primarily for the tributary bypass alternative, which has a significant length (24 miles) of constructed channel. Reducing the design parameter for channel depth by 1 foot is not expected to adversely impact effectiveness of the channel but is expected to decrease implementation cost at the scale of the tributary bypass concept. This parameter represents the average hydraulic conditions within a typical transport channels design cross section for evaluation purposes. In practice, a transport channel will vary in cross-sectional area, depth, and velocity depending on the intended biological function of the reach. Refer to Appendix K for additional detail and discussion on constructed channel design criteria.

Table 31
Design Parameters for Constructed Channels

Element	Design Criteria	Source
Channel Depth	5 feet	NMFS (2023a)
Minimum and Maximum Velocity	1.5 to 4.0 ft/s	NMFS (2023a)
Minimum Width	4 feet	NMFS (2023a)

Element	Design Criteria	Source
Minimum Flow	50 cfs[1]	Nomograph analysis (Appendix K)
Freeboard to top of bank	3 feet	NMFS (2023a)

Note:

1. Note that for Alternative 1, a flow rate of 50 cfs was selected because it is the smallest rate of flow that provides adequate flow depth and velocities for fish movement along all sections of the constructed channel portion of the swimway. Additional water or channel modifications may be required in Dry Creek, Little Cow Creek, and portions of Cow Creek to overcome depth barriers as discussed in Appendix L; this will be analyzed during later stages of design to determine the optimal water quantity and required construction activities to achieve adequate flow depth and velocities for fish movement throughout the entirety of the tributary bypass.

5.5.3 Fishway Criteria

Upstream fish passage designs at dams use widely recognized fishway design guidelines and references and are traditionally designed for the adult fish life stage. There are three major components to a fishway: the fishway entrance, fish ladder, and fishway exit. The fishway entrance's primary objective is to maximize fish attraction. The fish ladder's primary objective is to provide hydraulic conditions that promote fish passage up and around a passage barrier. The fishway exit's primary function is to maintain hydraulic conditions suitable for fish passage for the range of forebay or reservoir WSEs. The design criteria specific to each component are presented in the following subsections.

5.5.3.1 Fishway Entrance

Fishway entrances should be located based on specific operations and stream flow characteristics, and in a location where fish can easily locate attraction flow (NMFS 2023a). The design criteria selected for fishway entrances is presented in Table 32.

Table 32
Design Parameters for Fishway Entrances

Element	Design Criteria	Source
Entrance Geometry	4 feet wide and 6 feet deep	NMFS (2023a)
Entrance Head Differential	1.0 to 1.5 feet	NMFS (2023a)
Attraction Flow	400 cfs	Section 5.3.2

5.5.3.2 Fish Ladder Design

Fish ladders may be implemented at Keswick and/or Shasta dams to provide volitional or semi-volitional passage routes for upstream-migrating fish. The design criteria selected for fish ladders is presented in Table 33. The maximum anticipated flow requirement for fish ladders at Shasta and/or Keswick Dams is 50 cfs.

Table 33
Design Parameters for Fish Ladders

Element	Design Criteria	Source
Maximum Head Differential	1 foot	NMFS (2023a)
Minimum Pool Dimensions	8 feet long, 6 feet wide, 5 feet deep	NMFS (2023a)
Energy Dissipation Factor	4 ft-lb/sec/ft^3	NMFS (2023a)
Minimum Depth Over Weirs	1 foot	NMFS (2023a)
Minimum Turning Pools Dimensions	2 times the standard pool length	NMFS (2023a)
Minimum Orifice Dimensions	15 inches high and 12 inches wide	NMFS (2023a)
Minimum Freeboard	3 feet at the high design flow	NMFS (2023a)
Lighting	Ambient lighting preferred. No abrupt lighting changes within fishway.	NMFS (2023a)

5.5.3.3 Fishway Exit

Fishway exits should be located along the shoreline where depths are similar to those within the fishway and sufficiently upstream of spillways, sluiceways, and powerhouses to minimize risk of fish being swept downstream (NMFS 2023a). Coarse trash racks should also be installed at the fishway exit; debris rack criteria are presented in Section 5.5.7. The design criteria selected for fishway exits is presented in Table 34. The maximum anticipated flow requirement for adult return flumes at Keswick and/or Shasta dams is 25 cfs.

Table 34
Design Parameters for Fishway Exits

Element	Design Criteria	Source
Head Differential[1]	0.25 to 1.0 foot	NMFS (2023a)
Minimum Length	2 times the standard pool length	NMFS (2023a)
Maximum Velocity	4 ft/s	NMFS (2023a)

Note:
1. In order to accommodate forebay fluctuations, this may require the use of adjustable weirs, multiple exits at different elevations, or other engineered solutions that accommodate forebay fluctuations.

5.5.3.4 Adult Lamprey Fishway Considerations

While Chinook Salmon are the target fish species for the Project, as discussed in Section 4.2, lamprey may be considered at passage facilities. Lamprey passage technologies are relatively new, and few facilities exist in the western United States that target lamprey for passage or collection and transport above dams. Where applicable, readily available best practices, lessons learned from experimental facilities on the Columbia River, and interviews with researchers who specialize in the understanding of lamprey behavior and navigational capabilities were used to inform lamprey passage facility requirements and anticipated performance. Preliminary upstream passage criteria for adult lamprey that may be considered are summarized in Table 35.

Table 35
Preliminary Lamprey Passage Design Criteria for Discussion and Consideration

Element	Design Criteria	Source
Maximum flow velocity	6 ft/s	USDA Natural Resources Conservation Service (2010)
Minimum ramp width	1.0 foot	Stevens et al. (2015)
Maximum distance between resting pools	20 feet	Stevens et al. (2015)
Minimum water depth in ramp	3 inches	Stevens et al. (2015)
Wetted surface finish	Smooth	Stevens et al. (2015)

Note:
Additional design characteristics have shown to be effective as part of retrofitting existing fish ladders on the Columbia River, including rounded corners, ramps to elevated orifices, and attachment plating around floor-oriented AWSs, among others.

5.5.4 Fish Passage – Natural Channels, Natural Features, and Modified Channels

Natural channels are those that utilize natural materials, such as boulders and woody material, to simulate natural riverine conditions. Within a natural channel, flow variability is inherent, and natural complexity features within the channel that may increase or decrease velocities or depth are common; therefore, strict design criteria for natural channels does not exist. Modified channels are natural channels that have been modified to meet certain design targets. The selected design criteria for modified natural channels are presented in Table 36. If a natural stream already meets design targets, modifications are not necessary. Additional details on the design criteria for natural channels, natural features, and modified channels can be found in Section 2.2 of Appendix K.

Table 36
Design Parameters for Modified Natural Channels

Element	Design Criteria	Source
Minimum Channel Depth	0.9 foot	Appendix K
Minimum Width	4 feet	NMFS (2023a)
Minimum Flow Capacity (added to existing flow)	50 cfs[1]	Appendix K

Note:
1. Note that for Alternative 1, a flow rate of 50 cfs was selected because it is the smallest rate of flow that provides adequate flow depth and velocities for fish movement along all sections of the constructed channel portion of the swimway. Additional water or channel modifications may be required in Dry Creek, Little Cow Creek, and portions of Cow Creek to overcome depth barriers as discussed in Appendix L; this will be analyzed during later stages of design to determine the optimal water quantity and required construction activities to achieve adequate flow depth and velocities for fish movement throughout the entirety of the tributary bypass.

5.5.5 *Fish Screen Criteria*

Specific criteria relative to adequate screen area, maintenance features, and facility hydraulics must be met to assure compliance with regulatory requirements. Fish screens are designed using NMFS (2023a). The intent of the fish screening criteria is to provide design guidelines and criteria that protect juvenile fish from entrainment or impingement and to guide juveniles to a collection and/or bypass system. Fish screens should be oriented parallel to river flow and minimize eddies. In a reservoir, screens should be located best for fish attraction and accommodate the full range of reservoir fluctuations (refer to Section 5.2). The selected design criteria for fish screening is presented in Table 37. While not required, it is common practice to oversize screen area for maximum diversion by a factor of 1.2 to 1.3.

Table 37
Design Parameters for Fish Screens

Element	Design Criteria	Source
Minimum Screen Area	Maximum screened flow divided by allowable approach velocity	NMFS (2023a)
Minimum Approach Velocity	0.33 ft/s (actively cleaned) 0.2 ft/s (passively cleaned)	NMFS (2023a)
Sweeping Velocity	0.8 to 3.0 ft/s	NMFS (2023a)
Maximum Travel Time	60 seconds	NMFS (2023a)
Multiple Bypass Entrances	Required if travel time exceeded	NMFS (2023a)
Screen Openings	1.75 mm	NMFS (2023a)
Minimum Open Area	27%	NMFS (2023a)
Screen Cleaning Interval	5 minutes, or when head differential exceeds 0.1 foot	NMFS (2023a)

Note:
Minimum approach velocity for active screens per NMFS (2023a) may be up to 0.4 ft/s where exposure time is limited to less than 60 seconds; however, CDFW (2000) guidance is 0.33 ft/s where fry are present.

5.5.6 *Fish Bypass Criteria*

Bypass systems are designed to facilitate both juvenile and adult fish downstream passage back to the river system, typically around a diversion or fish screen system, in a manner that minimizes risk of injury and delay. Fish bypass systems typically contain three major components: the bypass entrance, conduit, and exit.

5.5.6.1 Bypass Entrance Criteria

Bypass entrances should be provided with independent flow control systems. The selected design criteria for fish bypass entrances are presented in Table 38.

Table 38
Design Parameters for Fish Bypass Entrances

Element	Design Criteria	Source
Travel Time	Enter a bypass within 60 seconds of screen exposure	NMFS (2023a)
Maximum Velocity	110% of maximum screen sweeping velocity	NMFS (2023a)
Acceleration	No deceleration; maximum acceleration of 0.2 ft/s per foot of travel	NMFS (2023a)
Minimum Dimensions	18 inches wide	NMFS (2023a)
Minimum Depth over Weirs	1 foot	NMFS (2023a)
Minimum Juvenile Capture Velocity	8 ft/s	NMFS (2023a)

5.5.6.2 Bypass Conduit Criteria

Bypass conduits should be open channels; if open channels are not permittable by site conditions, a bypass pipe may be used provided pressure within the pipe is equal or greater than atmospheric pressure (NMFS 2023a). All interior surfaces should be smooth to minimize turbulence and the potential for fish injury. The selected design criteria for fish bypass entrances are presented in Table 39.

Table 39
Design Parameters for Fish Bypass Conduits

Element	Design Criteria	Source
Bypass Flow	Approximately 5% of total screened flow	NMFS (2023a)
Velocity	6 to 12 ft/s	NMFS (2023a)
Geometry	Sized to meet other criteria	NMFS (2023a)
Bends	Ratio of centerline to pipe diameter of 5 times or greater	NMFS (2023a)
Minimum Depth	40% of bypass pipe diameter	NMFS (2023a)
Hydraulic Jump	Not allowed within pipes	NMFS (2023a)

5.5.6.3 Bypass Exit Criteria

Bypass exits should be designed to avoid attraction from upstream migrants that could leap at the outfall and cause fish injury. The location of bypass exits should be located where strong downstream currents of a minimum of 4 ft/s exist and are free of eddies, reverse flow, or predation risk. Additionally, depth at the bypass exit should be sufficient to avoid fish injuries (NMFS 2023a).

5.5.6.4 Combination Velocity and Vertical Drop Barrier Criteria

A combination velocity and drop barrier consists of a weir and concrete apron. Upstream passage is prevented by a shallow, high-velocity flow on the apron with an impassable vertical jump over the weir upstream of the apron. A fish that negotiates the apron and reaches the base of the weir is unable to pass the weir due to insufficient water depth needed to reorient its position and the lack of a pool needed to accelerate to leap over the weir sill (NMFS 2023a). The selected design criteria for combination velocity and vertical drop barriers are presented in Table 40.

Table 40
Design Parameters for Combination Velocity and Vertical Drop Barriers

Element	Design Criteria	Source
Minimum Weir Height	3.5 feet (relative to max apron elevation)	NMFS (2023a)
Minimum Apron Length	16 feet from downstream base of a weir	NMFS (2023a)
Minimum Apron Slope	1V:16H	NMFS (2023a)
Maximum Weir Head	2 feet	NMFS (2023a)
Apron Elevation (downstream end)	Greater (higher) than tailrace WSE at the high design flow (Section 5.2)	NMFS (2023a)
Flow Venting over Weir	Fully vented along length to allow fully aerated nappe to develop between weir crest and apron	NMFS (2023a)
Minimum Flow Depth on Apron	0.5 foot	NMFS (2023a)
Minimum Velocity over Apron	16 ft/s	NMFS (2023a)

5.5.7 Debris Rack Criteria

Debris racks are commonly used to exclude large debris from entering fish passage facilities. Debris rack openings should be a minimum of 8 inches clear, or 10 inches clear if adult Chinook Salmon are present. NMFS (2023a) criteria state that approach velocity should be less than 1.5 ft/s. Debris racks should be oriented at a minimum deflection angle of 45 degrees relative to river flow. Debris racks should be sloped at 1V:5H or flatter to assist with manual cleaning. In systems with coarse floating debris, debris booms or other provisions must be incorporated into the debris rack design (NMFS 2023a).

5.5.8 Fish Trapping and Holding Criteria

Fish trapping and holding criteria aim to minimize stress and injury to fish when they must be trapped, held, and handled as part of a semi-volitional design element. Fish handling should be done with extreme care by trained individuals. NMFS guidance recommends anesthetization of fish prior to handling (NMFS 2023a), though juvenile traps in the Winnemem Waywaket do not currently anesthetize fish per the Winnemem Wintu Tribe’s request. The use of nets should be minimized or eliminated. The maximum daily fish return and typical species size expected at a trap should be used to inform the poundage of fish within a trap or holding structure. The selected design criteria for fish trapping and holding are presented in Table 41.

Table 41
Design Parameters for Fish Trapping and Holding

Element	Design Criteria	Source
Minimum Holding Pool Volume (durations <72 hours)	0.25 cubic foot per pound of fish	NMFS (2023a)
Minimum Holding Pool Volume (durations >72 hours)	0.75 cubic foot per pound of fish	NMFS (2023a)
Temperature	Less than 50°F; reduce poundage of fish held by 5% for each degree above 50°F	NMFS (2023a)
Dissolved Oxygen	6 to 7 parts per million	NMFS (2023a)
Minimum Water Supply	0.67 gpm	NMFS (2023a)
Frequency of Removal from Traps	1 day maximum, or as required to prevent overcrowding and adverse water quality	NMFS (2023a)
Adult Jumping Provisions	Freeboard of 5 feet or greater; covering or sprinkling the holding pool	NMFS (2023a)
Fish Species Segregation	As required	NMFS (2023a)

6 Discussion and Considerations

Target fish species and life stages for the development of alternatives for passing fish around Keswick and Shasta dams include the adults and juveniles from the four runs of Chinook Salmon (winter, spring, fall, and late fall) that exist in the Nomtipom Waywaket. This naming convention is based on adult migration periods and is useful for Western science purposes but is very general and understates the variability in run timing of different populations in large river systems. Additional life-history information about each of the four runs of Chinook Salmon are provided in Appendix N.

Table 14 combines the timing of occurrence of each run of Chinook Salmon by life stage in the Nomtipom Waywaket. The timing included in this table confirms that the four runs of Chinook Salmon will migrate during a large portion of each calendar year. As such, adult and juvenile passageways and facilities contemplated as volitional passage alternatives would all need to operate year-round except for annual maintenance periods. Planning for year-round operation allows for fish passage into the Winnemem Waywaket as we understand it might occur now, and when it might occur in the future, as the four runs adapt to the Winnemem Waywaket environment. This will result in the design of passage solutions that will allow the four runs of salmon (and other species) to adapt as needed to environmental conditions in the Winnemem Waywaket, which is best supported by broad, nonrestrictive, facility and passageway operational periods.

The studies described in this report were implemented to identify and evaluate the physical and biological data gaps relevant to developing volitional fish passage alternatives for Chinook Salmon. There are three focal areas that could be included as part of the fish passage alternatives to allow Chinook Salmon to reach the Winnemem Waywaket:

- Nomtipom Waywaket to Keswick and Shasta dams and Shasta Reservoir
- Cow Creek, Little Cow Creek, and Dry Creek
- Winnemem Waywaket

Each focal area presents distinct physical and biological conditions that must be considered when developing and evaluating fish passage alternatives. The following discussion outlines these considerations by focal area. Additional data collection and refinement will be needed as the fish passage alternatives are more fully developed, evaluated, and advanced to more detailed design phases.

6.1 Nomtipom Waywaket to Keswick and Shasta Dams and Shasta Reservoir

The Study Area includes the Nomtipom Waywaket to Keswick and Shasta dams and Shasta Reservoir, which is a focal area that could be part of a fish passage solution. Key physical and biological existing conditions in this focal area that are important to consider for the development and evaluation of fish passage alternatives are described in this section.

6.1.1 Existing Physical Conditions

Keswick and Shasta dams are owned and operated by Reclamation under federal authorizations that include water supply, flood control, hydropower, fish conservation, navigation, and recreation, but not fish passage. That is, fish passage is not a congressionally authorized purpose for the dams. However, it is recognized that the existing trap at Keswick Dam is currently used as the collection point for brood stock for the LSNFH for conservation purposes. Therefore, new congressional authorization and funding would be required to implement any future fish passage solutions. The design of any fish passage solution must account for the potential 18.5-foot raise of Shasta Dam and the corresponding 3,550-foot increase in inundation of the Winnemem Waywaket, as described in Appendix G.

There are narrow channels downstream of each dam that could be used for technical fish ladder entrances. Fish ladder operation is expected to require up to 1,700 cfs, though flow optimization may reduce ladder entrance flow to about 400 cfs while using hydraulic guidance structures to maintain attraction flows. A conservative thermal analysis assumed a minimum flow of 35 cfs. Thus, water requirements range between 35 cfs and 400 cfs, subject to refinement during design. Thermal accumulation modeling suggests that ladder temperature conditions at both dams would not impede year-round adult migration, provided current water management at Keswick Reservoir is maintained and Shasta Dam ladder inflows remain below 65.8°F for 7 consecutive days. Additional modeling may be required to confirm these results for a long fish ladder design exceeding 500 weirs.

6.1.2 Existing Biological Conditions

From a biological perspective, this focal area presents both opportunities and challenges if fish ladders are used as a fish passage solution. Adult Chinook Salmon would migrate through two technical fish ladders and two reservoirs, requiring consistency between hydrologic and chemical cues to avoid disrupting the migratory pathways to the Winnemem Waywaket. Altered flow of Winnemem Waywaket water to the Pit River and resulting mixing and odor signals in the reservoir may cause false attraction to the Pit River, reducing adult return success to the Winnemem Waywaket. Juveniles would not experience the same migration route as adults because they would be transported downstream from the Winnemem Waywaket to below Shasta Dam, potentially disrupting natural imprinting processes critical for adult homing. This is because of the existing conditions in Shasta Reservoir not supporting passage of juvenile fish as described in the next section.

6.1.3 Shasta Reservoir

Juvenile passage through Shasta Reservoir would be challenging, especially in summer and fall. Acoustic telemetry data from test fish released (656 fish) in the McCloud Arm of Shasta Reservoir in 2024 indicated that only 27.6% reached the main reservoir and 13.5% reached Shasta Dam (Stockwell et al. 2026). Migration was largely storm driven, with high predation and thermal constraints.

Reservoir temperatures often exceed optimal ranges for both juvenile and adult migration. Predation risk depends on timing and fish size; dominant predators include Chinook Salmon, large bass, trout, and pikeminnow, with up to 85% of predator diet composed of juvenile fish (Johnson et al. 2026). Seasonal foraging opportunities vary, with zooplankton abundant from February to July and Threadfin Shad peaking in September. Predation risk peaks in October when predators are most active and juveniles are smallest, but declines through winter as prey size increases, predator consumption decreases, and temperatures cool (Johnson et al. 2026).

6.2 Cow Creek, Little Cow Creek, and Dry Creek

The Study Area also includes Cow Creek, Little Cow Creek, and Dry Creek that could be a part of a volitional fish passage solution. Key physical and biological existing conditions in these creeks that are important to consider for the development and evaluation of fish passage alternatives are described in this section.

6.2.1 Existing Physical Conditions

Dry Creek typically runs dry in summer and fall, so significant flow augmentation and channel modification would be necessary for year-round passage of Chinook Salmon. Water rights would also need to be secured with a permit or transfer from the State Water Board for the flow augmentation. Modeling in Appendix K suggests that approximately 50 cfs from the Winnemem Waywaket would be the minimum amount of water needed to sustain a constructed bypass channel from the top of Dry Creek at Jones Valley to the Winnemem Waywaket with a 0.1% slope, 2.2-foot depth, and 1.8 ft/s velocity. However, the natural channel along Dry, Little Cow, and Cow creeks will likely require modification or additional flows to allow year-round fish passage. Additional analysis of the barriers is needed to determine the optimal water quantity and required construction activities to achieve adequate flow depth and velocities for fish movement throughout Cow Creek, Little Cow Creek, and Dry Creek.

There are partial natural migration barriers for Chinook Salmon at three waterfall features, and large portions of upper Dry Creek feature critically shallow riffles that would impede adult Chinook Salmon passage. The model results show that with increased flow augmentation, the number of critically shallow riffles decreases. Critical riffles are limited to an extent at 160 cfs and are unlikely to be complete barriers, but critically shallow depths would likely still be encountered in a few locations even with 200 cfs in Dry Creek.

Water velocity in the steep section of upper Dry Creek may pose a barrier to adult migration as the modeling indicates sustained high velocities are present in upper Dry Creek, and velocity generally increases with increased flow. The modeling also suggests in the upper portions of Dry Creek, in the Pit Formation shales, plane-bed and braided channel morphologies are present and natural pools are limited. As such, increased flow augmentation may further decrease pool-type habitats that provide resting areas for upstream-migrating adult Chinook Salmon by washing the pools out with high velocity. It is unlikely that high velocities, as indicated by the modeling, would represent a complete barrier to upstream migration because adult Chinook Salmon use small-scale features that are not reflected in these hydraulic models as resting areas.

The combination of critically shallow depths below 160 cfs and sustained high velocities at flows of 160 and 200 cfs in Dry Creek indicates that hydraulics alone would present at least a partial barrier to passage under current channel conditions. The modeling results suggest that channel modifications and habitat improvements would likely be required along with flow augmentation to provide upstream passage for adult Chinook Salmon.

Hydraulic modeling also demonstrates that flow augmentation of up to 200 cfs into Dry Creek has little effect on depth in Cow Creek below Little Cow Creek. Low-flow conditions in Cow Creek create critical riffle barriers that limit upstream migration of adult Chinook Salmon in summer and fall. This further suggests that channel modifications may be necessary in Cow Creek for passage of adult Chinook Salmon year-round.

Existing anthropogenic barriers, including culverts near Jones Valley, do not meet fish passage criteria. The lack of fish exclusion screens on irrigation diversions also pose entrainment risks for juveniles.

Temperatures in Cow Creek, Little Cow Creek, and Dry Creek are within optimal conditions for adult and juvenile migration except for the time period from late spring through mid-fall. However, this is from a Western science perspective. The Consultant Team’s interpretation of ITEK shared by the Winnemem Wintu Tribe indicates that Chinook Salmon historically tolerated and adapted to these temperatures by seeking cooler microhabitats. The Consultant Team’s interpretation is that temperature limits are not a part of the Winnemem Wintu Tribe’s ITEK. The temperature data are compared to optimal water temperatures, which have been developed and used for regulatory purposes. However, from a biological perspective, there is additional context to consider. Comparative water temperature analysis often represents conditions at a single point in the stream system. Water temperature varies throughout the Study Area and may be warmer or cooler than identified at other locations. There could be micro-habitat conditions that have lower temperature that Chinook Salmon would seek and find. Additionally, recent laboratory studies on hatchery-origin Chinook Salmon from along the Pacific Coast have identified population-specific thermal tolerances suggesting that fish evolve to survive in local thermal conditions (Zillig 2022; Zillig et al. 2023; Zillig et al. 2025). Therefore, it is difficult to generally apply thermal tolerances based on studies from a range of different conditions across broad areas. As such, comparisons of collected or compiled temperature data to thermal tolerances should consider these important factors when making conclusions.

Road and power access vary along Dry Creek, Little Cow Creek, and Cow Creek, with the most feasible construction site located between upper Dry Creek and Shasta Reservoir on federally owned land. Construction access for tunneling and channel work would be least constrained in this vicinity. Easements and access agreements from numerous landowners would have to be acquired to access the channel for modifications and habitat restoration.

6.2.2 Existing Biological Conditions

If Dry Creek, Little Cow Creek, and Cow Creek are part of a fish passage solution, there are biological considerations regarding the migration cues necessary for successful homing and migration of adult fish into Cow Creek from the Nomtipom Waywaket. There is a diversion of Winnemem Waywaket water into the Pit River that goes into Shasta Reservoir and eventually discharges into Keswick Reservoir and into the Nomtipom Waywaket below Keswick Dam. The presence of Winnemem Waywaket water in the Nomtipom Waywaket below Keswick Dam may cause adults from the Winnemem Waywaket to continue migrating in the Nomtipom Waywaket to Keswick Dam rather than turning right into Cow Creek. However, this is from a Western science perspective. The Consultant Team’s interpretation of the Winnemem Wintu Tribe’s knowledge is that ceremonies, songs, and prayers will guide the fish back to their ancestral waters, aligning biological and spiritual dimensions of migration.

Thermal conditions within the pathway are most favorable in winter and early spring, offering optimal migration windows for most of the adult winter-run and late-fall-run Chinook Salmon and the early migrating spring-run adults. Optimal thermal migration conditions are also present for late migrating winter-run and late-fall-run juveniles and most of the spring-run and fall-run juveniles. Summer and fall conditions remain above optimal temperature ranges, posing potential challenges for most of the spring-run and fall-run adults and most of the winter-run and late-fall-run juveniles. However, as described above in Section 6.2.1, it is difficult to generally apply thermal tolerances based on studies from a range of different conditions across broad areas. As such, comparisons of collected or compiled temperature data to thermal tolerances should consider these important factors when making conclusions.

6.3 Winnemem Waywaket

The Winnemem Waywaket is the historical spawning grounds for winter-run Chinook Salmon and serves as the ultimate cold-water habitat destination for the fish. The Winnemem Waywaket provides year-round cold water from springs bringing water into the river. Average temperatures within the Winnemem Waywaket near Ladybug Creek (RM 32) were found to be optimal for adult spawning year-round and optimal for egg incubation and fry emergence year-round except for the month of July. Average temperatures were also found to be optimal for these life stages near Claiborne Creek (RM 26) and Yet Atwam Creek (RM 24) all year except from approximately mid-May through September. Average temperatures were found to be optimal for juvenile rearing, juvenile migration, and adult migration year-round at all locations. This is from a Western science perspective. The Consultant Team's interpretation of Winnemem Wintu Tribe's ITEK is that salmon historically thrived in these waters year-round, using microclimates as needed for spawning, egg incubation, and fry emergence.

As mentioned in Section 6.2, the temperature data are compared to optimal water temperatures that have been developed and used for regulatory purposes. However, from a biological perspective, there is additional context to consider. Comparative water temperature analysis often represents conditions at a single point in the stream system. Water temperature varies throughout the Study Area and may be warmer or cooler than identified at other locations. There could be micro-habitat conditions that have lower temperature that Chinook Salmon would seek and find. Additionally, recent laboratory studies on hatchery-origin Chinook Salmon from along the Pacific Coast have identified population-specific thermal tolerances suggesting that fish evolve to survive in local thermal conditions (Zillig 2022; Zillig et al. 2023; Zillig et al. 2025). Therefore, it is difficult to generally apply thermal tolerances based on studies from a range of different conditions across broad areas. As such, comparisons of collected or compiled temperature data to thermal tolerances should consider these important factors when making conclusions.

Spawning habitat assessment results indicated fair to good physical spawning habitat is available for Chinook Salmon throughout the Winnemem Waywaket between Shasta Reservoir and McCloud Dam under suitable water temperature conditions (Reclamation 2014). Spawner capacity was estimated to be approximately 4,155 females (assuming 6-m^2 spawning territory, OHW stage) with a high level of uncertainty. Additional field-based surveys are needed to confirm potential spawning areas and capacity to improve the level of certainty in these estimates. Another desktop habitat study (FitzGerald et al. 2024) completed at a coarse scale found that the lower, middle, and upper Winnemem Waywaket areas had the most suitable habitat during the summer for embryos, which is the most sensitive life stage. The lower Winnemem Waywaket is below McCloud Dam, while the middle and upper Winnemem Waywaket are both upstream of the dam. Overall, the two existing habitat studies (FitzGerald et al. 2024 and Reclamation 2014) concluded that there is an abundance of habitat above Shasta Dam that is suitable for spawning and rearing based on existing habitat data (e.g., temperature, flow, channel morphology, and substrate), particularly in the Winnemem Waywaket. However, more field-based surveys are needed to determine fine-scale habitat conditions over many sections of the river. For example, there is a need to better understand the amount of spawning substrate available and how it aligns with other suitable spawning habitat conditions, including temperature.

Existing life-cycle modeling indicates that the Winnemem Waywaket could support a sustainable Chinook Salmon population if passage and survival rates reach approximately 80% or greater (i.e., 80% passage and survival from the adult life stage in the Nomtipom Waywaket to juveniles in the Nomtipom Waywaket). Greater survival would yield higher abundances, though results depend on assumptions regarding TDM and hydrologic variability. Pilot studies showed wide variation in juvenile collection efficiency. The JSCS, located in the McCloud Arm of Shasta Reservoir, capture rates ranged from 0% to 51.5%, while IPT, located in the Winnemem Waywaket, collection efficiency of marked test fish varied from less than 5% to more than 80% depending on configuration. Recent improvements to IPT configurations achieved 70% to 80% efficiency. Based on these findings, in-river collection of juveniles is more effective on the Winnemem Waywaket. Integrating ITEK with modern fish passage design may enhance biological performance by recognizing the resilience and adaptive behaviors of the Chinook Salmon population.

Access to lands for fish passage construction is limited, with potential sites near Bollibokka Fly Fishing Club and the head of Shasta Reservoir. However, these areas would require substantial infrastructure development, including road, power, and utility extensions.

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