January 2026
Study of Physical Data Gaps to Inform the Implementation of Nur Rematriation Upstream of Shasta Dam
(AB 211 Drought Grant Agreement Number – Q2396040)

HDR ANCHOR QEA

Appendix K
Water Quantity Requirements for Preliminary Fish Passage Alternatives

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ABBREVIATIONS

7-DADM	7-day average of the daily maximum
ACID	Anderson-Cottonwood Irrigation District
Background Compendium	*Background Compendium and Design Criteria Report for the Feasibility of Volitional Fish Passage Above Keswick and Shasta Dams*
°C	Celsius
CDEC	California Data Exchange Center
cfs	cubic feet per second
Consultant Team	Anchor QEA; HDR Engineering, Inc.; U.S. Geological Survey; and QEDA Consulting, LLC
°F	Fahrenheit
ft/s	feet per second
HDR	HDR Engineering, Inc.
LSNFH	Livingston Stone National Fish Hatchery
NMFS	National Marine Fisheries Service
NWIS	National Water Information System
Nomtipom Waywaket	Winnemem Wintu words for Sacramento River
Nur	Winnemem Wintu word for Chinook Salmon
QEDA	QEDA Consulting, LLC
RM	river mile
USBR	U.S. Bureau of Reclamation
USGS	U.S. Geological Survey
Winnemem Waywaket	Winnemem Wintu words for McCloud River

1 Introduction

A team of engineering and fisheries science consultants consisting of Anchor QEA; HDR Engineering, Inc. (HDR); U.S. Geological Survey (USGS); and QEDA Consulting, LLC (QEDA) known herein as the "Consultant Team," has 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 document as the "Project." The results of the Project will support an investigation of 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) and into the Winnemem Waywaket (also known as the McCloud River) in northern California. 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) is used when discussing federal Endangered Species Act (ESA)-listed Chinook Salmon or steelhead (*O. mykiss*). This document is an appendix to the overarching report documenting the results of the Project, which is called the *Background Compendium and Design Criteria Report for the Feasibility of Volitional Fish Passage Above Keswick and Shasta Dams* (Background Compendium). This larger report contains additional background information for the Project and this document should be considered within this context.

The Project 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; the Nomtipom Waywaket, including Keswick and Shasta dams and reservoirs; Cow Creek; Little Cow Creek; and Dry 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.

This document provides a summary of preliminary alternatives, conceptual design of their functional elements, and resulting anticipated water quantity requirements for each. Information collected and compiled during the Project will be used to support a volitional passage feasibility study that will be reviewed by the salmon co-managers (Winnemem Wintu Tribe, CDFW, and National Marine Fisheries Service [NMFS]) and used to inform fish passage decisions.

The objectives of this document are to:

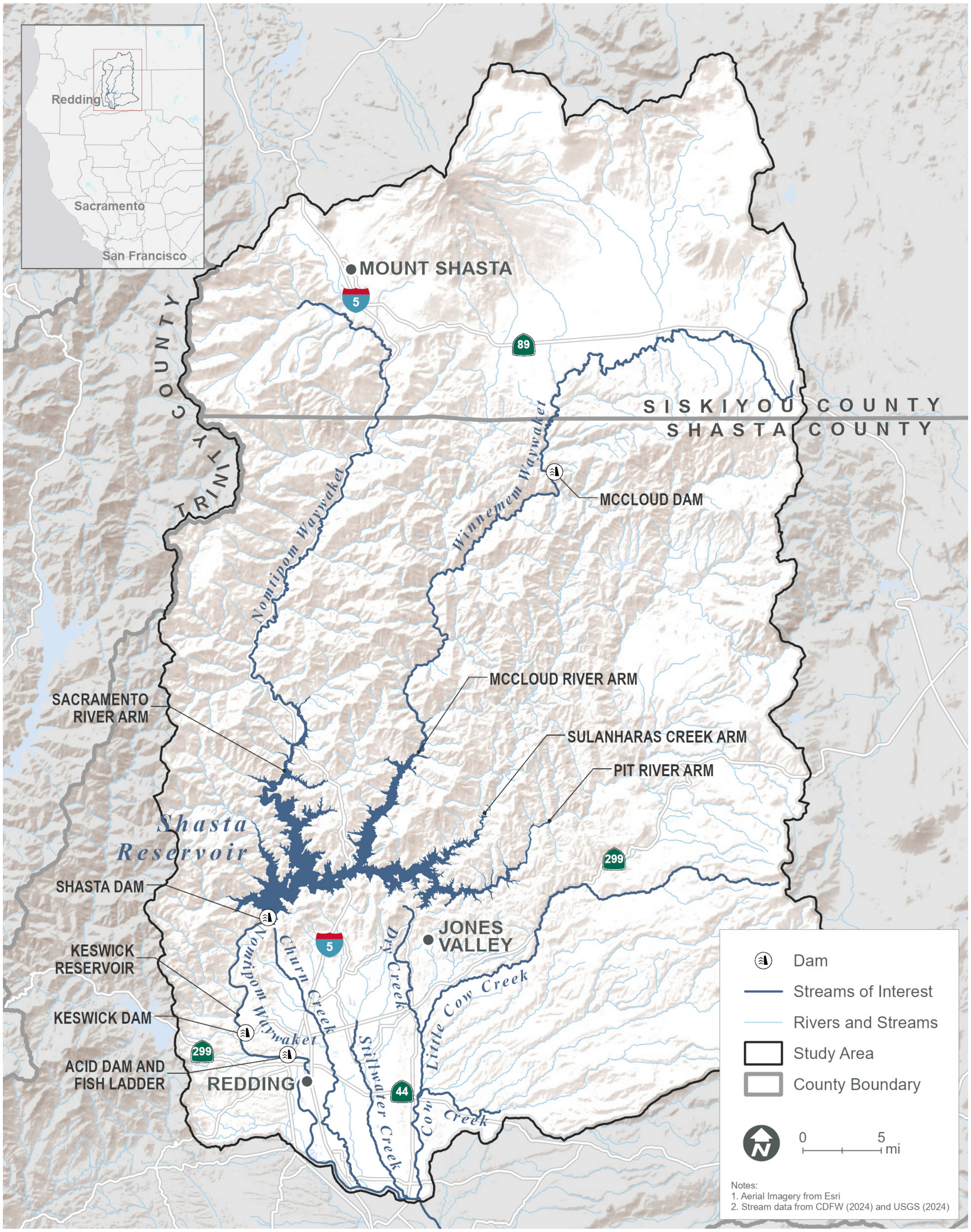
- Summarize design criteria used in preliminary alternative development

- Describe preliminary hydraulic design of functional elements in the alternatives
- Identify the basic water quantity requirements for alternatives using the preliminary hydraulic design of functional elements and the thermal accumulation analysis and conclusions from *Thermal Accumulation in Migratory Corridors and Channels* (Appendix J of the Background Compendium).

By utilizing the design criteria within Section 2 to develop preliminary designs in Section 3, the design team created a thermal accumulation model for each alternative which analyzes the suitability of water temperature for Chinook Salmon both under existing conditions and potential alternatives. See *Thermal Accumulation in Migratory Corridors and Channels* (Appendix J) for additional details regarding the thermal accumulation analysis. Thermal gain is defined as the rate of warming or cooling per river mile (RM) within a reach or channel, and thermal accumulation is defined as the measure of water temperatures along a reach or channel. The overall results of the thermal gain analysis provide information as to whether additional water supply is needed for cooling purposes for each of the alternatives, thereby informing the water quantity requirements in Section 4 of this document.

Readers should 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 appendices and *Alternatives Formulation and Evaluation Report* [Anchor QEA and HDR 2026]).

Figure 1
Study Area, Key Features, and Project Vicinity



2 Design Criteria

Section 2 summarizes key design criteria used to develop preliminary designs for the functional elements of proposed alternatives. The criteria and designs will be refined and further detailed as the Project progresses. At this time, the preliminary information was used to inform the analysis for water requirements for the various functional elements associated with each alternative. The selected design criteria within each section are optimized for Chinook Salmon, though the criteria will accommodate passage for a broad range of fish species.

2.1 Temperature Suitability Criteria

Migratory thermal tolerances for Chinook Salmon are summarized in Table 1 and discussed in detail in Section 3 of the *Nomtipom Waywaket (Sacramento River) Chinook Salmon Life History Summary* (Appendix N of the Background Compendium). This information provides the foundation to analyze temperature suitability and identify additional water needs to support fish use.

The threshold of 68 degrees Fahrenheit (°F) (20 degrees Celsius [°C]) as a maximum 7-day average of the daily maximum (7-DADM) is recommended for waterbodies that are used almost exclusively for adult migration during the summer maximum temperatures (Table 1, USEPA 2003). The metric of 7-DADM is generally protective of acute effects to fish, as it reflects the weekly average maximum temperature (USEPA 2003).

Table 1
Summary of Migratory Thermal Tolerance by Life Stage

Life Stage	Maximum Optimal Temperature[1] (°F)	Description	Reference
Adult Migration (summertime)[2]	68	Maximum 7-DADM thermal threshold for physical harm, passage barrier, and increased predation.	USEPA (2003), Carter (2008)
Juvenile Out-Migration (Summertime)[2]	64.4	Recommended 7-DADM to protect against lethal conditions for juveniles and adults, provide optimal or near-optimal growth under limited food conditions during most of the summer, protects against temperature-induced diseases.	USEPA (2003)

Notes

1. Maximum optimal temperature indicates the temperature above which negative effects or non-optimal conditions 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. EPA 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).

The thermal tolerances provided in Table 6 of Appendix N are mostly used for regulatory purposes. However, from a biological perspective, there is additional context to consider. It is important to note that comparative water temperature analysis often represents conditions at a single point in the stream system. Water temperature varies throughout a reach and may be warmer or cooler than shown at other locations. As such, the temperature data that are compared to the thermal tolerances provided in Table 1 do not account for the presence of micro-habitat conditions that could 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.

2.2 Modified Natural Channel Criteria

Within the Study Area, Cow Creek, Little Cow Creek, and Dry Creek may be utilized as an element of upstream volitional passage for Alternative 1 (see Section 4.1). Some of these creeks experience periods of drought or reduced flow throughout the year, thereby limiting their ability to provide fish passage during migratory periods. Because of this, flow augmentation will be required to allow passage (see Section 4.1). These natural channels may also need to be modified to meet design targets or prevent flooding as discussed below.

Within a natural channel, flow variability is inherent and natural complexity within the channel that may increase or decrease velocities or depth are common; therefore, strict design criteria for natural channels does not exist. A literature review of existing habitat metrics provided a range of water depths and velocities required for Chinook Salmon adult spawning and juvenile rearing habitat types (Table 2).

Table 2
Summary of Spawning and Rearing Metrics for Chinook Salmon

Habitat Type by Life Stage	Preferred Range of Depth (feet)	Preferred Range of Velocity (feet per second)
Spawning[1,2,3,4]	0.7 – 6.6	0.7 – 3.6
Rearing[1,5]	0.5 – 2.5	0.0 – 0.7

Notes:

1. Keeley and Slaney 1996
2. Burner 1951
3. Chambers 1955
4. Hamilton and Buell 1976
5. Allen 2000

For simplicity, the spawning and rearing habitat were combined into one target metric to inform preliminary channel design. During later steps of the Project, the channel design may be altered based on specific spawning or rearing metrics depending on the intended use of the reach.

Based on the metrics in Table 2, the depth of the natural channel should fall between 0.5 and 6.6 feet. Natural channels experience a variety of hydraulic diversity depending on the biological function of the reach. A variety of depths and velocities will be present for spawning areas, rearing areas, and navigational areas throughout Dry, Little Cow, and Cow Creeks as the flow regime, and the channel characteristics shift. In the future, as the design is further developed, the natural channels will be further investigated to determine the main biological goals throughout each reach and the resulting hydraulic metrics that will be needed to meet those goals.

The Study Area is water-limited with Cow Creek and Little Cow Creek experiencing stream temperature exceeding the maximum optimal thermal tolerances intermittently for 6 months throughout the year, and there is little to no natural flow in Dry Creek during this period except during high storm runoff events (*Thermal Accumulation in Migratory Corridors and Channels* [Appendix J). Therefore, a minimum target depth is required for design of a modified natural channel to facilitate fish passage. Based on relevant literature such as the *Standard Operating Procedure for Critical Riffle Analysis* (CDFW 2017), critical riffles need to be evaluated to determine if the natural channel should be modified because they are "particularly shallow and sensitive to changes in stream flow" (CDFW 2017). Based on the guidance, depths less than 0.9 foot can potentially inhibit the upstream navigation of adult migrating fish and are considered the lower bound for design depth. This represents a target minimum depth, as natural pathways commonly have refugia, resting pools, and runs with depths that exceed this selected value.

NMFS recommends a width of 4 feet for constructed channels in its salmonid passage channel guidelines (NMFS 2023). The natural channel will also vary in width due to natural variation within the stream. Based on the NMFS guidelines, the minimum channel target width is 4 feet.

The minimum flow capacity for the natural channels may change as design progresses. Flow augmentation is necessary for all alternatives, so for Alternative 1 that involves modified natural channels (Section 4.1), the amount of flow within the downstream natural channels may increase beyond their current capacity in reaches higher in the watershed that experience more groundwater seepage than surface runoff, such as Dry Creek. At this step of the Project, the flow requirement for the upstream constructed channel is set as a minimum of 50 cubic feet per second (cfs), but this may be altered as the alternative is refined. The current capacity of Dry Creek, Little Cow Creek, and Cow Creek should be carefully considered to verify that flow augmentation will not result in flooding that could harm infrastructure or public safety. Should the flow requirement for the upstream constructed channel (Section 3.2) be increased, the minimum flow capacity for the downstream natural channels must also be increased.

Minimum metrics identified for modified natural channels are presented in Table 3. Within a natural channel, variability is inherent, and habitat complexity within the channel that may increase or decrease velocities or depth are common. The metrics in Table 3 are intended to be a minimum to be met, as different sections of the natural channel may have higher values than the targets presented in the table. If the natural channels already meet metrics, no modifications are necessary; natural channel modification will only occur if metrics for identified biological goals are not met.

Table 3
Selected Metrics for Modified Natural Channels

Element	Design Criteria	Source
Minimum Channel Depth	0.9 foot	Table 2
Minimum Width	4 feet	NMFS 2023
Minimum Flow Capacity (added to existing flow)	50 cfs[1, 2]	Section 3.2, 4.1

Notes:

1. Should the flow requirement for the upstream constructed channel be increased (Table 5), the minimum flow capacity for the modified natural channel must increase correspondingly.
2. 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 *Physical Barriers to Fish Passage Evaluation* (Appendix L of the Background Compendium); 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.

2.3 Constructed Channel Criteria

Constructed channels are a functional element that may be used for some of the alternatives to provide volitional passage. Metrics for constructed channels, based on a literature review of constructed channel criteria and fish ladder criteria, are provided in Table 4. Criterion for freeboard (height above a designed flood level) was also included in the table to prevent flow from overtopping the banks and causing flooding.

Table 4
Design Targets for Constructed Channels

Element	Design Criteria	Source
Depth	5 feet	NMFS 2023
Velocity	1.5 – 4 feet per second	NMFS 2023
Width	4 feet	NMFS 2023
Freeboard to top of bank	3 feet	NMFS 2023

The preliminary design of the constructed channel requires the selection of target metrics to determine its hydraulic performance during concept development. Metrics identified in this section are utilized to establish a base concept for the constructed channel to represent its average characteristics. In future stages of design, the constructed channel will vary in cross-sectional area, depth, and velocity depending on the intended biological function of the reach. Biological goals and expectations for spawning, rearing, and navigational reaches may be refined as part of future alternative development efforts which may also influence the selection of final design criteria.

Per Table 4, transport channels should target a depth of 5 feet. However, taking into consideration the water-limited environment and the additional cost of an increased channel depth in a 24-mile constructed channel, the Consultant Team selected a concept depth metric of 4 feet to represent the average hydraulic conditions for fish within constructed channels. This represents a maximum depth in situations where a non-uniform channel geometry is used (e.g. a channel with a low flow notch). A future constructed channel will possess similar refugia, resting pools, and complexity elements that the natural channels possess and so will experience hydraulic diversity and varied depths. Within the constructed channel, elements such as flat sections or baffles will also be included to help increase depths throughout the channel.

The velocity metric for a constructed channel ranges from 1.5 to 4 feet per second (ft/s) based on the literature review (Table 4). The design will incorporate nature-like features such as resting pools, refugia, and flat sections to emulate the complexity of natural habitats. These elements help mitigate the higher velocities expected in narrower channels. By integrating wider fringe areas and strategically placed low-velocity zones, the constructed channel aims to provide functional habitat continuity and volitional passage similar to that found in natural systems.

Selected metrics are presented in Table 5. The constructed channel will also include a maintenance road and shoulders, with design criteria presented in Table 6.

Table 5
Selected Metrics for Constructed Channels

Element	Design Criteria	Source
Channel Depth[1]	4 feet	Adjusted from NMFS 2023
Minimum and Maximum Velocity	1.5 – 4.0 feet per second	NMFS 2023
Minimum Width	4 feet	NMFS 2023
Minimum Flow	50 cfs[2]	Nomograph analysis (Section 3.2)
Freeboard to top of bank	3 feet	NMFS 2023

Notes:

1. Represents the maximum depth of the channel when non-uniform channel geometry is used.
2. 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 *Physical*

Barriers to Fish Passage Evaluation (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.

Further information is provided in Section 3.2 about the preliminary design of the constructed channel and how it meets the selected metrics.

2.4 Tunnel Criteria

Tunnels may be used as a functional element for some of the fish passage alternatives to shorten the overall length of an alternative. For Alternative 1, tunnels would be used to optimize the swimway route by avoiding a winding path along the shore of Shasta Reservoir and instead tunneling through the hillside to shorten the overall length by over one mile. The tunnel's minimum width consists of three components: a width for the constructed channel (Section 2.3), a shoulder area for clearance from the channel to the tunnel wall, and an added minimum maintenance corridor width. A minimum maintenance corridor vertical clearance is also specified to allow the appropriate equipment to maintain the constructed channel. The required equipment to maintain the channel will be identified at a later stage of design; at this time, it is anticipated that a maintenance corridor width of 12 feet, height of 14 feet, and shoulders of 4 feet will be sufficient to maintain the constructed channel. An additional 2 feet of clearance is provided between the channel and the wall. This cross section will also meet standards for frontage roads (CalTrans 2020) and accommodate maintenance vehicles with a maximum width of 8.5 feet and maximum height of 14 feet within the tunnel without a need for an oversize vehicle annual transportation permit (CalTrans 2025). The maintenance road design will also be utilized for the constructed channel and the water bridge.

Final selected design criteria is presented in Table 6.

Table 6
Selected Design Criteria for Tunnels

Element	Design Criteria	Source
Minimum tunnel height	14 feet (measured from edge of maintenance corridor)	CalTrans 2025
Minimum maintenance corridor width	12 feet	CalTrans 2020
Minimum shoulder width	4 feet	CalTrans 2020
Lighting	Ambient lighting preferred; if artificial, blue-green lighting is required	NMFS 2023

Further information is provided in Section 3.3 about the preliminary design of the tunnel and how it meets the selected criteria.

2.5 Water Bridge Criteria

Similar to tunnels, water bridges may also be used as a functional element to shorten the overall length of an alternative. For Alternative 1, water bridges would be used to cross Shasta Reservoir and to cross other larger streams or inlets along the eastern bank of Shasta Reservoir and the Winnemem Waywaket. The water bridge's minimum width consists of the constructed channel (Section 2.3), a shoulder area for clearance from the channel and from the wall, and an added minimum maintenance corridor width. The shoulder area and maintenance corridor width are the same as identified for the tunnel criteria (Section 2.4).

Further information is provided in Section 3.4 about the preliminary design of the water bridge and how it meets the selected criteria.

2.6 Conduit Criteria

Conduits may be used as a functional element for some of the alternatives, particularly for downstream passage and/or to accommodate a wide range of water surface elevations at the upstream end of an upstream passage alternative. Conduits can be U-shaped (i.e. an open flume) or a round pipe (i.e. a closed conduit). These conduits would be used to convey fish either up- or downstream of the barrier. Selected design criteria for conduits are provided in Table 7. Further information about the preliminary design of this functional element and how it meets the selected criteria is provided in Section 3.5.

Table 7
Selected Design Criteria for Conduits

Element	Criteria	Source
Minimum flow depth	40 percent pipe diameter	NMFS 2023
Velocity	2 feet per second minimum; 6 – 12 feet per second for operational range of bypass flow	NMFS 2023
Minimum diameter	10 inches	NMFS 2023
Width/shape	U-shaped flume or round pipe	NMFS 2023
Minimum design bypass flow[1]	5% total flow	NMFS 2023
Maximum velocity at outfall	25 feet per second	NMFS 2023

Note:
1. Only applicable to downstream passage applications

2.7 Fish Ladder Criteria

Fish ladders may be used as functional elements for upstream fish passage for some of the alternatives. There are many different types of fishways that can provide upstream fish passage. To ensure functionality during low flows and limit impact to power generation, a half Ice Harbor style fishway is proposed for most of the ladder length. Ice Harbor style fishways consist of weirs, pools, and orifices, which allow upstream migrating fish to choose their pathway; they can leap or swim over the weir or swim through the orifice (NMFS 2023). This provides passage options for a wider variety of swimming capabilities, which accommodates a larger population of upstream migrating salmonids.

Per NMFS 2023, a half Ice Harbor style fishway keeps the same advantages of a full Ice Harbor style fishway but requires lower flow to meet fish passage criteria. The criteria summarized in Table 8 is specific to a half Ice Harbor style fishway. Vertical slot style fishway components may be proposed at the fishway entrance or exit to accommodate a wider range of water surface elevations. Table 9 summarizes criteria for vertical slot fish ladders. Further information about the preliminary design of the technical fish ladder(s) and how it meets the selected criteria is provided in Section 3.6.

Table 8
Design Criteria for Half-Ice Harbor Fish Ladders

Element	Criteria	Source
Attraction flow	Between 5% and 10% of the high fish passage design flow	NMFS 2023
Minimum fishway entrance width	4 feet	NMFS 2023
Minimum fishway entrance depth	6 feet	NMFS 2023
Maximum hydraulic drop per pool	1 foot	NMFS 2023
Minimum pool dimensions	8 feet long, 6 feet wide, 5 feet deep	NMFS 2023
Minimum dimensions of orifices	18 inches high by 15 inches wide	NMFS 2023
Ladder flow	35-50 cubic feet per second	Engineering judgment

Table 9
Design Criteria for Vertical Slot Fish Ladders

Element	Criteria	Source
Attraction flow	Between 5% and 10% of the high fish passage design flow	NMFS 2023
Minimum fishway entrance width	4 feet	NMFS 2023
Minimum fishway entrance depth	6 feet	NMFS 2023
Maximum hydraulic drop per pool	1 foot	NMFS 2023
Minimum pool dimensions	10 feet long	NMFS 2023
Minimum slot width	1 foot	NMFS 2023
Minimum slot depth	2 feet	NMFS 2023
Ladder flow	35-50 cubic feet per second	Engineering judgment

2.8 Fish Passage Design Flows

This section characterizes riverine flows in the Nomtipom Waywaket at Shasta and Keswick dams during periods when fish are anticipated to migrate upstream. The magnitude and variability of discharges from Shasta Dam and Powerhouse and from Keswick Dam and Powerhouse will influence the design of upstream fish passage facilities. A summary of seasonal flow variability and specific flows used to inform design of fish passage facilities are provided in the subsections below.

2.8.1 Discharge Data

Daily average discharge data were used to calculate flow duration statistics and evaluate flow seasonality downstream of Shasta and Keswick dams. The data sources from which daily discharge data were obtained are described below.

2.8.1.1 Shasta Outflows

Daily average outflows from Shasta Dam and Powerhouse were approximated as the total inflow into Keswick Reservoir with outflows from Spring Creek Debris Dam and Spring Creek Powerhouse removed. Total daily average inflows into Keswick Reservoir were obtained from the U.S. Bureau of Reclamation (USBR)-operated California Data Exchange Center (CDEC) Keswick Reservoir gauge (CDEC Site ID = KES) located at Keswick Dam actively operated by USBR. Daily average outflows from the Spring Creek Debris Dam were obtained from the USBR-operated CDEC Spring Creek Debris Dam gauge CDEC Site ID = SPC. Daily average outflows from Spring Creek Powerhouse were obtained from the inactive USGS Spring C PH A Keswick CA gauge (USGS Station ID = 11371600). Daily discharge values from the CDEC SPC and USGS 11371600 gauges were summed and then subtracted from the CDEC KES gauge discharge values to obtain an estimate for daily average outflow from Shasta Dam and Powerhouse. The overlapping period of record for all three gauges extends from December 25, 2001 to September 30, 2024. A summary of the daily discharge data used is provided in Table 10.

2.8.1.2 Keswick Outflows

Daily average outflows from Keswick Dam and Powerhouse were obtained from the USBR-operated CDEC KES gauge. The period of record for this data extends from October 2, 1993 to May 15, 2025. A summary of the daily discharge data used is provided in Table 10.

Table 10
Daily Average Discharge Data Sources

Gauge Name	Gauge ID	Description	Operating Agency	Period of Record	Source
Keswick Reservoir	KES (sensor 76)	Daily average inflows into Keswick Reservoir	USBR	01/01/1994 to 05/15/2025	CDEC
Keswick Reservoir	KES (sensor 23)	Daily average outflows from Keswick Reservoir (including powerhouse flows)	USBR	10/02/1993 to 05/15/2025	CDEC
Spring Creek Debris Dam	SPC	Daily average outflows from Spring Creek Debris Dam	USBR	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	National Water Information System (NWIS)

2.8.2 Flow Seasonality

Daily average discharge values were used to calculate flow duration statistics and evaluate seasonality of flows downstream of Shasta and Keswick dams. Per NMFS (2023) guidelines, the most recent 25 water years (October through September) of data were used to characterize flows for fish passage purposes. A summary of seasonal discharges at each location, as well as a comparison of seasonal discharges to adult Chinook Salmon upstream migration periods are provided below.

2.8.2.1 Shasta Outflows

Water years 2003 through 2024 were used to characterize flows for fish passage purposes downstream of Shasta Dam. Because the overlapping period of record for the data used to estimate outflows from Shasta Dam and Powerhouse ranged from December 25, 2001 to September 30, 2024, this analysis only includes 22 water years rather than the 25-years recommended by NMFS (2023). Monthly and annual duration statistics were calculated for this period and are provided in Table 11. Results of this analysis indicate that combined daily average outflows from Shasta Dam and Powerhouse ranged from 2,516 cfs (95 percent exceedance value) to 13,403 cfs (5 percent exceedance value) 90 percent of the time, with an annual median daily discharge of 5,754 cfs.

Figure 2 shows the combined daily average outflows from Shasta Dam and Powerhouse by water year. Outflows are generally less than 10,000 cfs from September through April and gradually rise to between approximately 5,000 and 15,000 cfs throughout late spring and summer, peaking in July depending on irrigation demands. This trend is further illustrated in Figure 3, which shows 5 percent exceedance, 50 percent exceedance, and 95 percent exceedance flows throughout the water year.

Outflows are most variable throughout winter and early spring, remaining below 5,000 cfs approximately 50 percent of the time but experiencing periodic large magnitude releases on the order of 20,000 to 70,000 cfs to address flood control needs. As shown in Figure 3, 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 percent of the time.

Table 11
Percent Exceedance of Daily Average Outflows from Shasta Dam for Water Years 2003 through 2024

Percent of Time Exceeded	Jan (cfs)	Feb (cfs)	Mar (cfs)	Apr (cfs)	May (cfs)	Jun (cfs)	Jul (cfs)	Aug (cfs)	Sep (cfs)	Oct (cfs)	Nov (cfs)	Dec (cfs)	Annual (cfs)
99	865	703	629	1,266	3,084	3,744	4,413	4,284	3,786	2,544	2,824	1,263	1,267
95	1,921	1,263	1,596	2,334	4,153	5,525	5,356	4,918	4,289	3,786	3,214	2,440	2,516
90	2,490	2,136	1,920	2,782	5,835	6,475	6,310	5,542	4,773	4,033	3,424	2,833	3,009
80	2,884	2,589	2,563	3,295	6,764	7,739	8,020	6,666	5,308	4,502	3,841	3,195	3,598
50	3,702	3,422	3,322	5,179	8,562	9,735	10,954	8,900	6,620	5,534	4,502	3,973	5,754
25	4,906	4,435	5,322	7,883	10,021	11,030	12,464	10,087	7,655	6,292	5,089	4,824	9,039
15	7,702	9,118	13,034	10,073	10,996	11,799	12,974	10,872	8,048	6,737	5,478	5,199	10,734
10	12,259	14,925	20,303	15,726	11,684	12,208	13,218	11,452	8,323	7,017	5,643	5,951	11,719
5	19,602	34,195	28,546	26,879	13,053	12,956	13,581	12,013	8,844	7,291	5,995	9,729	13,403
2	31,793	53,517	38,349	35,708	18,409	13,659	13,973	12,489	9,280	7,742	6,293	12,961	24,692
1	46,208	64,535	43,071	37,193	23,217	14,825	14,627	12,626	9,456	7,985	6,894	13,813	34,413
0.1	49,801	72,363	53,781	39,969	37,430	18,462	15,303	13,733	9,827	8,297	7,578	34,229	63,191

Figure 2
Daily Average Outflows from Shasta Dam for Water Year 2003 through Water Year 2024

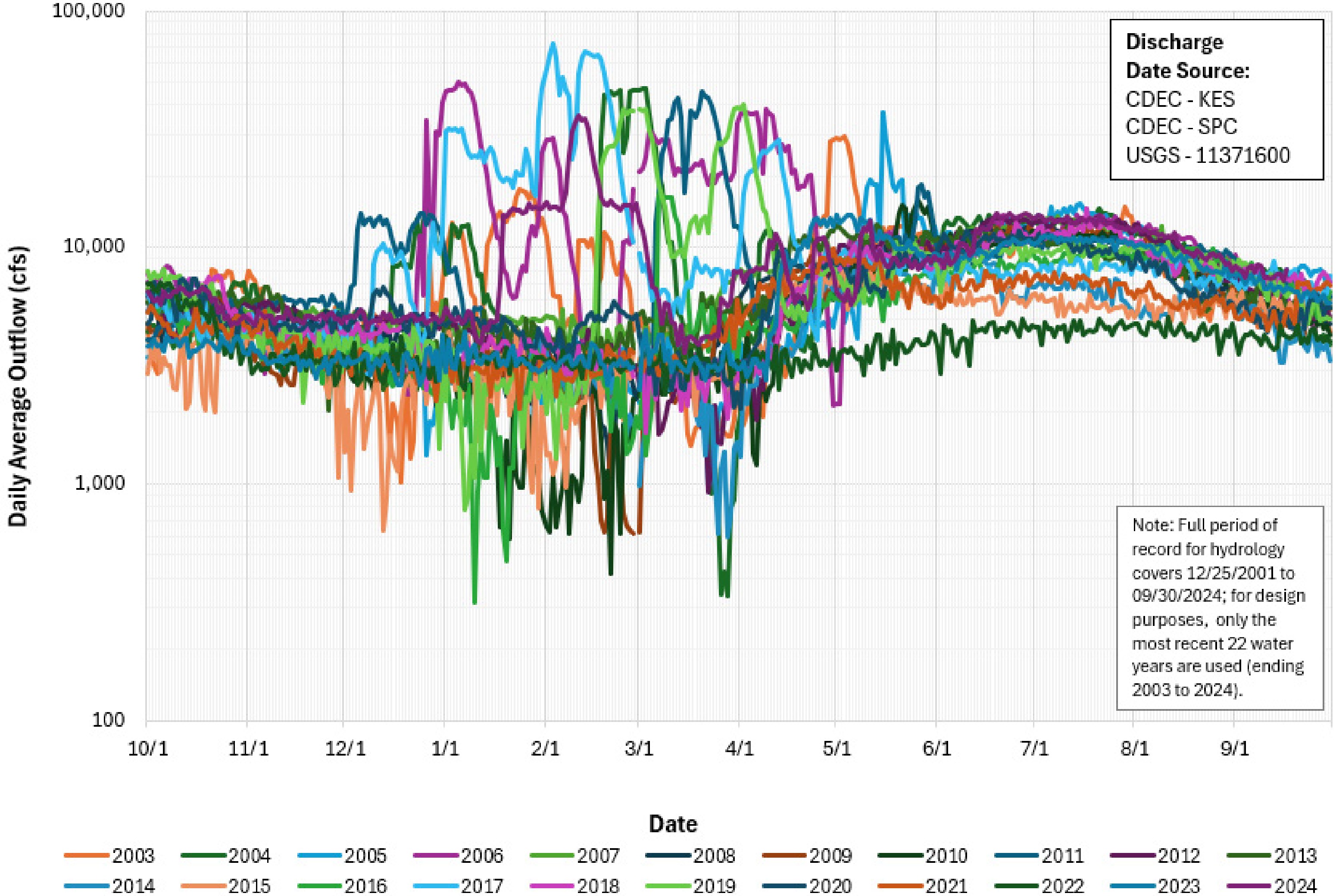
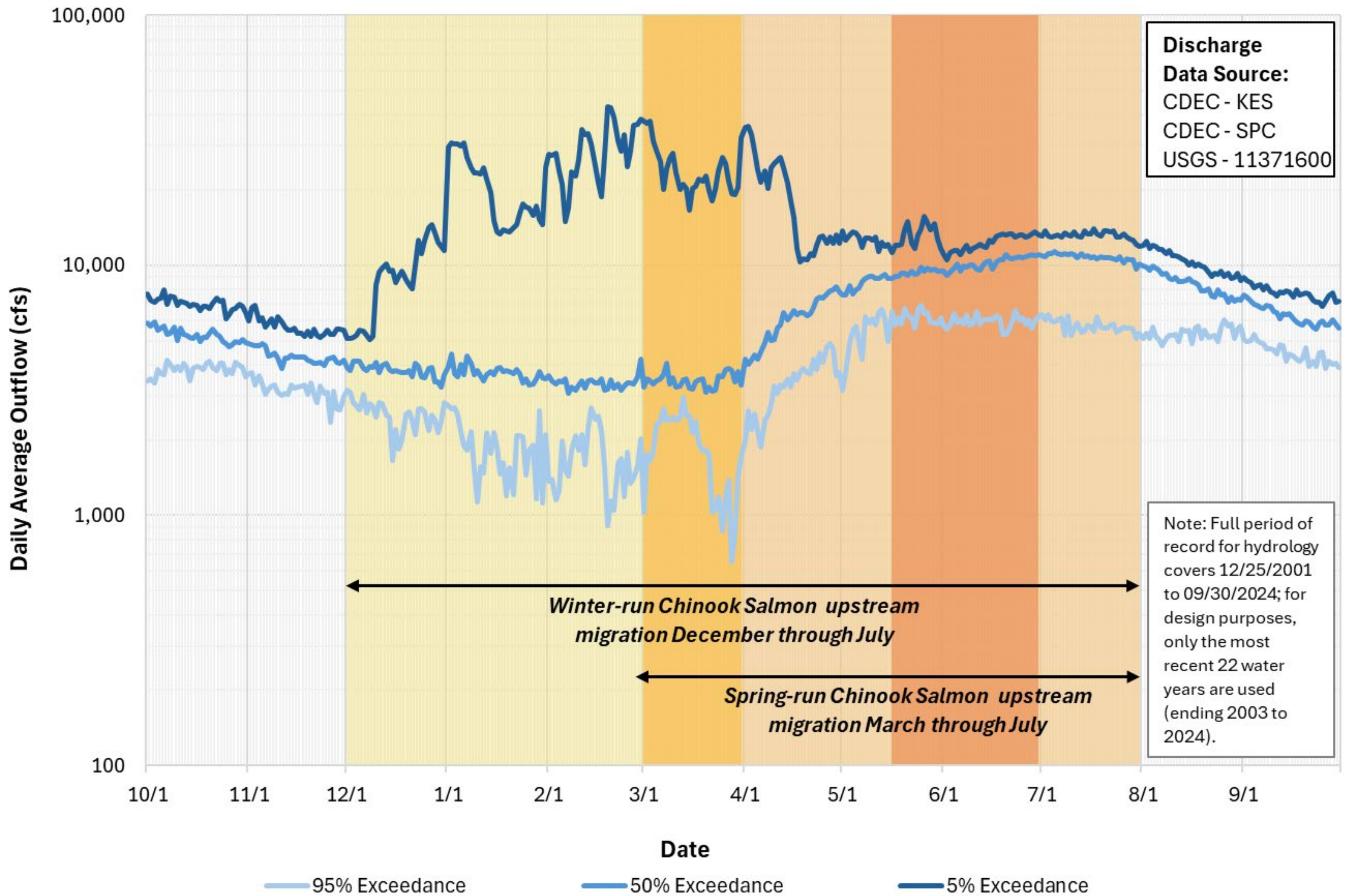


Figure 3
Seasonal Variation of Outflows from Shasta Dam Outflows versus Chinook Salmon Migration



Note: Darker shaded areas represent peak adult migration periods for winter-run and spring-run Chinook Salmon.

2.8.2.2 Keswick Outflows

Data for water years 2000 through 2024 were used to characterize flows for fish passage purposes downstream of Keswick Dam. Monthly and annual duration statistics were calculated for this period and are provided in Table 12. Results of this analysis indicate that combined daily average outflows from Keswick Dam and Powerhouse ranged from 3,254 cfs (95 percent exceedance value) to 14,952 cfs (5 percent exceedance value) 90 percent of the time, with an annual median daily discharge of 6,823 cfs.

Figure 4 shows the combined daily average outflows from Keswick Dam and Powerhouse by water year. Since the dams are operated in tandem to achieve the goals of the Central Valley Project, seasonal outflow patterns at Keswick Dam generally reflect those observed at Shasta Dam, with Keswick Dam generally exhibiting slightly larger releases. Outflows are generally less than 10,000 cfs from September through April and gradually rise to between 10,000 and 20,000 cfs throughout late spring and summer, peaking in mid to late July depending on irrigation demands. This trend is demonstrated in Figure 5, which shows the 95 percent exceedance, 50 percent exceedance, and 5 percent exceedance flows throughout the water year. 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 and 10,000 cfs approximately 50 percent of the time but experience periodic large magnitude releases on the order of 20,000 to 70,000 cfs to address flood control needs. As can be observed on Figure 5 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 percent of the time.

Table 12
Percent Exceedance of Daily Average Outflows from Keswick Dam for Water Years 2000 through 2024

Percent of Time Exceeded	Jan (cfs)	Feb (cfs)	Mar (cfs)	Apr (cfs)	May (cfs)	Jun (cfs)	Jul (cfs)	Aug (cfs)	Sep (cfs)	Oct (cfs)	Nov (cfs)	Dec (cfs)	Annual (cfs)
99	2,845	2,753	2,627	2,664	3,263	3,948	4,505	4,492	4,105	3,916	3,258	3,051	2,936
95	2,974	3,040	3,017	3,045	5,093	6,929	6,951	6,834	4,960	4,450	3,483	3,261	3,254
90	3,105	3,127	3,114	3,259	6,193	7,571	9,204	7,188	6,404	5,012	3,862	3,295	3,305
80	3,268	3,263	3,258	3,526	7,138	8,879	9,862	8,744	6,830	5,837	4,054	3,611	4,006
50	4,055	3,754	4,017	5,871	9,079	11,015	12,932	10,178	7,697	6,473	5,011	4,517	6,823
25	5,061	4,990	6,068	8,048	10,910	13,016	14,299	11,556	8,495	7,009	5,647	5,087	10,088
15	8,870	12,768	15,103	9,756	12,481	13,918	14,823	12,282	8,946	7,459	6,014	5,555	12,399
10	13,423	20,560	22,685	14,052	13,080	14,149	14,976	12,981	9,149	7,565	6,182	6,992	13,659
5	19,456	36,140	33,754	26,592	14,279	14,502	15,190	13,706	9,588	7,977	6,993	9,894	14,952
2	32,394	50,053	42,486	37,180	19,764	14,845	15,458	14,252	10,507	8,374	7,011	13,796	26,400
1	47,954	67,376	47,581	39,706	25,039	14,976	15,681	14,420	10,757	8,540	7,420	14,580	37,148
0.1	49,962	73,966	66,365	42,237	37,697	19,184	16,309	15,203	11,223	9,332	7,556	38,184	66,247

Figure 4
Daily Average Outflows from Keswick Dam for Water Year 2000 through Water Year 2024

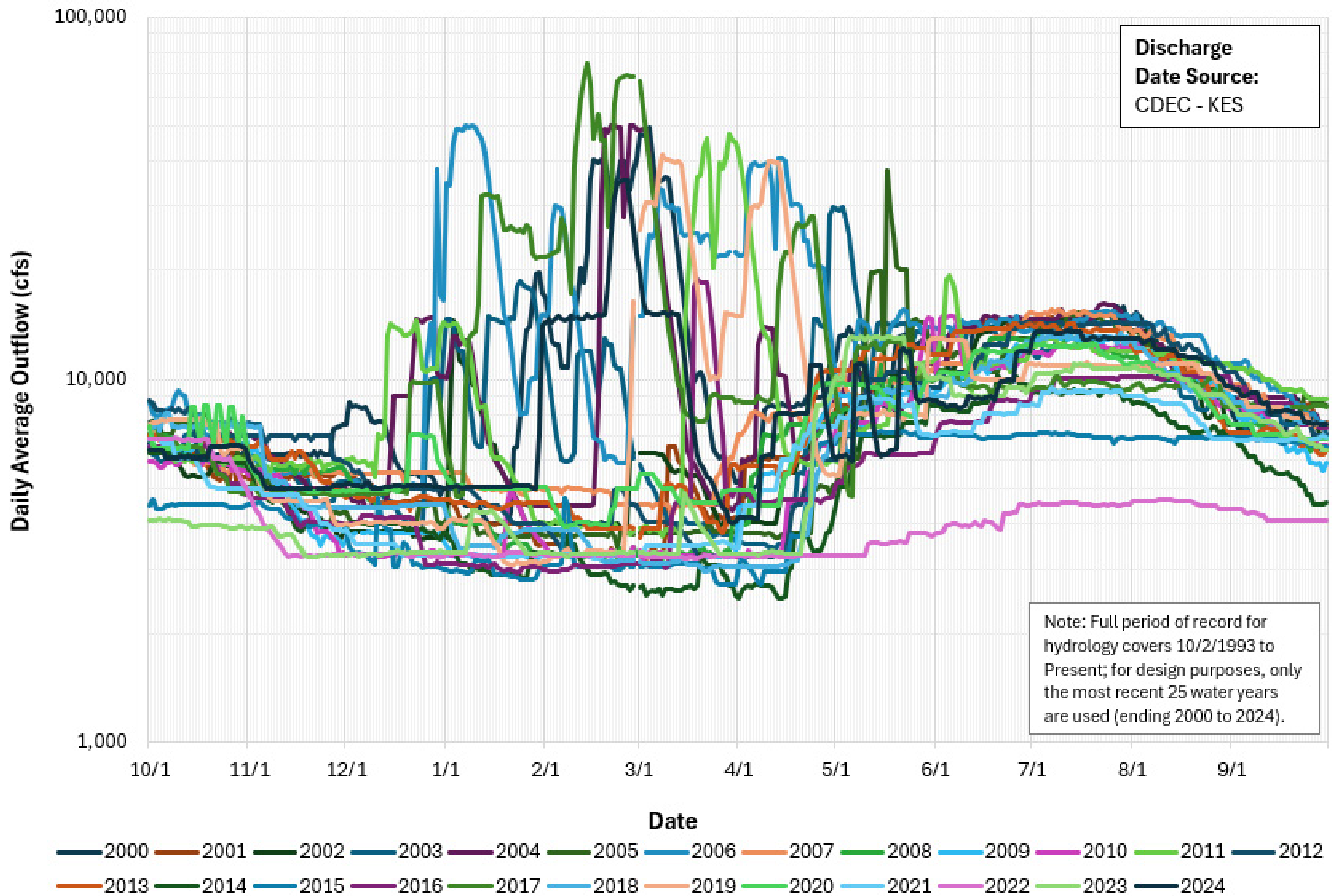
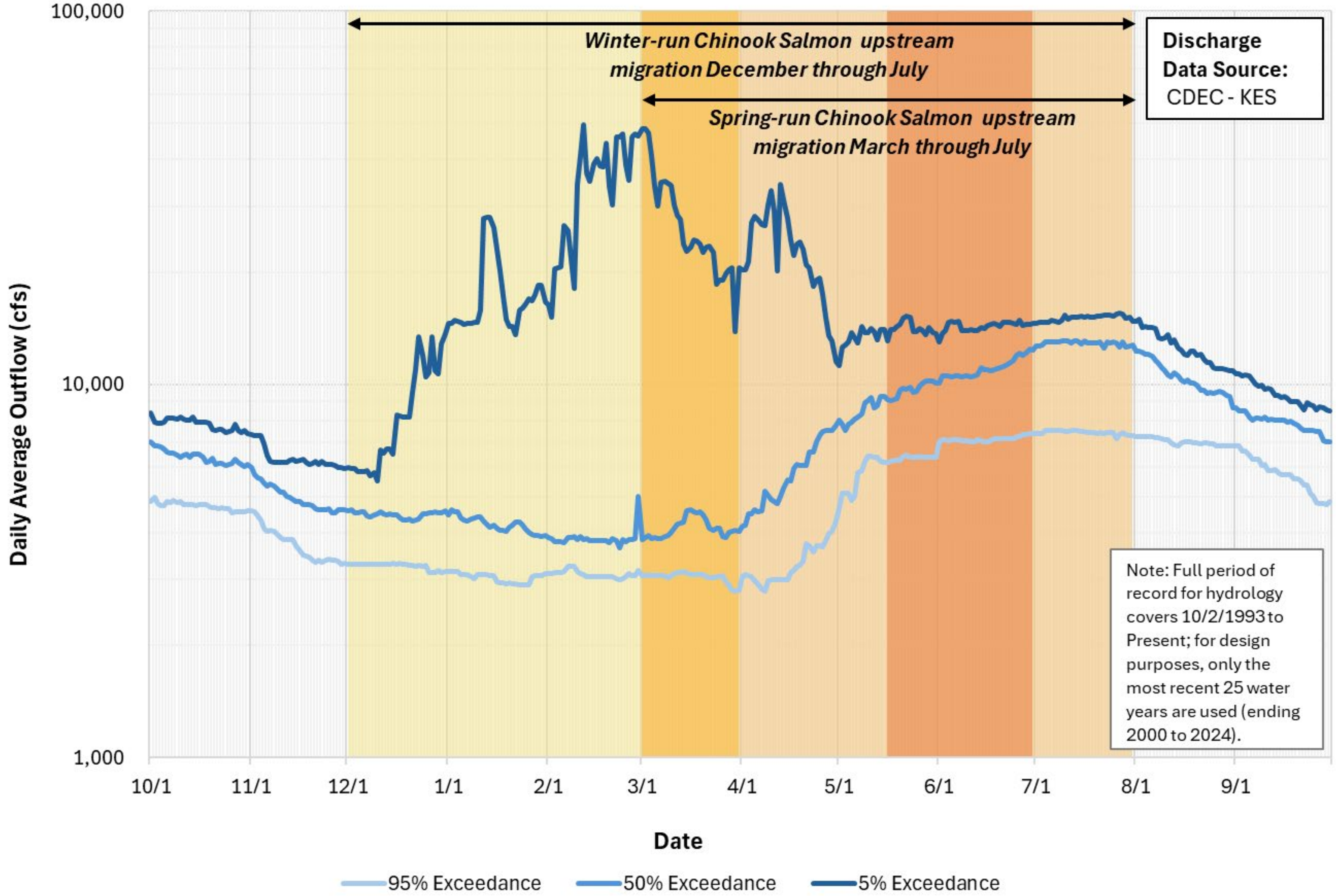


Figure 5
Seasonal Variation of Outflows from Keswick Dam Outflows versus Chinook Salmon Migration Timing



Note: Darker shaded areas represent peak adult migration periods for winter-run and spring-run Chinook Salmon.

2.8.3 Fish Passage Design Flows

Per NMFS (2023), 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 percent average daily flow exceedance value (low fish passage design flow) and the 5 percent average daily flow exceedance value (high fish passage design flow). This guidance is intended to ensure that the passage facilities are designed to maintain favorable hydraulics (e.g., depths, velocities, turbulence) while the facility is utilized by target species. Additionally, NMFS (2023) recommends that attraction flow used to encourage upstream migrating fish into passage facilities be 5 to 10 percent of the high fish passage design flow.

The 95 percent and 5 percent average daily flow exceedance values for outflows from Shasta Dam and Keswick Dam were calculated for each month as part of the duration analysis described in Section 2.8.2. Flow exceedance values (refer to Table 11 and Table 12) were cross-referenced with the adult winter-run and spring-run Chinook Salmon migration timing shown in Figure 3 and Figure 5, and the minimum 95 percent exceedance value and maximum 5 percent exceedance value observed across the months coinciding with adult Chinook Salmon migration timing were selected as the low and high fish passage design flows, respectively. Flows values of 1,921 cfs and 34,195 cfs were identified as the low and high fish passage flows, respectively, for downstream of Shasta Dam, corresponding to the 95 percent exceedance and 5 percent exceedance values for the month of February. Flow values of 2,974 cfs and 36,140 cfs were identified as the low and high fish passage flows, respectively, for downstream of Keswick Dam, corresponding to the 95 percent exceedance value for January and the 5 percent exceedance value for February. Fish passage design flows are summarized in Table 13.

Based on the NMFS (2023) criteria for attraction flows described above, 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 13). 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. 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 13
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 percent average daily flow exceedance value during months which the adult Chinook Salmon migration period, based on NMFS (2023) criteria.
2. Calculated as the maximum 5 percent average daily flow exceedance value during months which the adult Chinook Salmon migration period, based on NMFS (2023) criteria.
3. Calculated as 5 percent of the High Fish Passage Design Flow, based on NMFS (2023) criteria.
4. Calculated as 10 percent of the High Fish Passage Design Flow, based on NMFS (2023) criteria.
5. Modified based on anticipated capacity of fish ladder entrance.

3 Preliminary Design of Alternative Functional Elements

This section provides preliminary designs for alternative functional elements based on the design criteria in Section 2. The criteria and preliminary designs will be updated during future phases of design. The preliminary information will serve to inform the analysis of water requirements for the various functional elements.

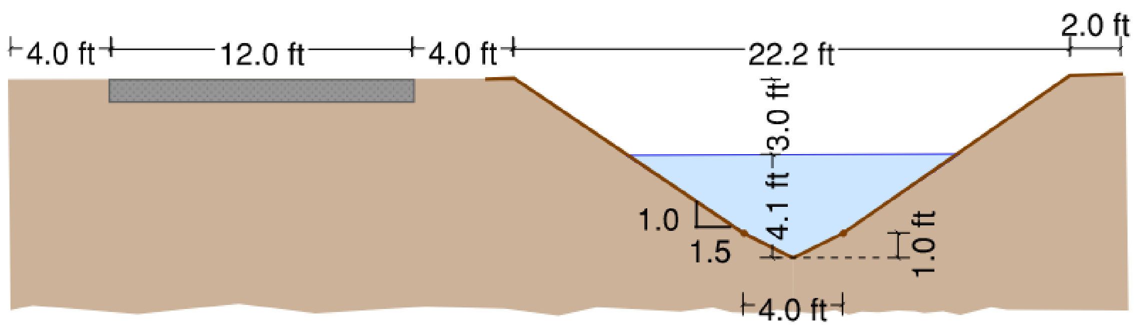
3.1 Modified Channel

As described in Section 2.2, natural channels utilized as part of the volitional swimway for Alternative 1 will be modified as necessary to meet design targets. The channel planform varies throughout each of the creeks (Dry Creek, Little Cow Creek, and Cow Creek) so the necessary modifications will vary throughout the different creeks. If the creeks meet design targets, no modifications would be necessary. A detailed analysis to determine if the design targets are achieved in each of the creeks is not provided as part of this document but will be developed in later steps of design.

3.2 Constructed Channel

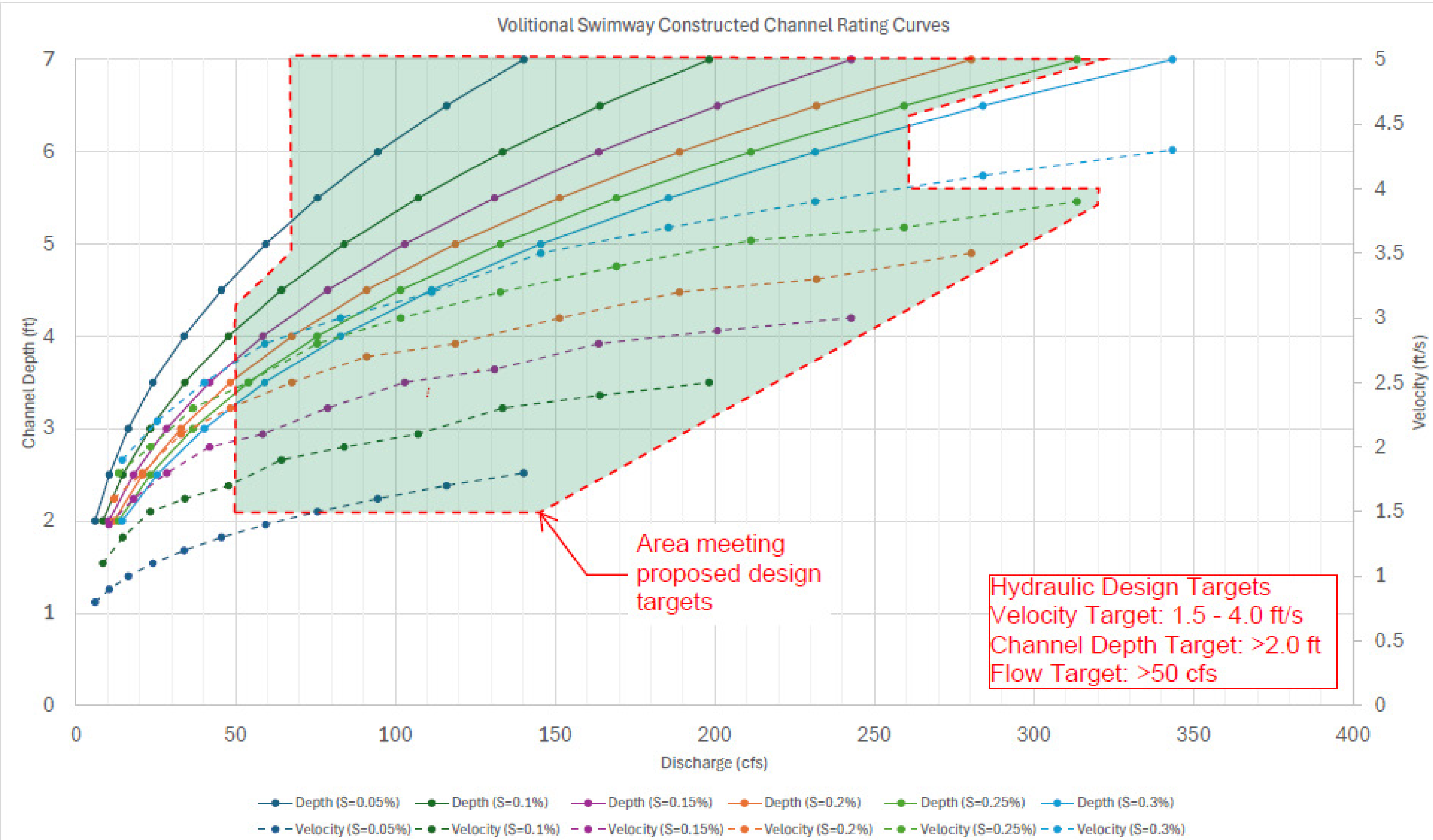
Based on the design criteria listed in Section 2.3, a constructed channel would likely have a cross section similar to that shown in Figure 6. The bottom width meets the minimum width criteria described in Table 5; and a low flow channel with a 1-foot depth is also incorporated with side slopes of 10 percent. The bank slopes are 66.7 percent, the maximum assumed constructible slope in order to minimize the top width of the channel. This channel shape may be altered at later steps of design; as noted previously, some areas may be wider to incorporate resting areas or additional habitat elements. The channel design will be based upon stream simulation criteria, by incorporating nature-based designs and habitat elements like those found in nearby natural streams. At this stage, the channel shape is provided only to inform the water requirements analysis and may be altered as design progresses. Four feet is provided as a buffer between the channel and the maintenance access road, and 12 feet is provided as the width of the access road to allow heavy machinery to access the channel for maintenance.

Figure 6
Constructed Channel Design Cross Section



Using the channel shape in Figure 6 and a proposed channel roughness of 0.04 assuming that the constructed channel is clean, winding, with some pools and shoals (Chow 1959), Manning's equation was used to generate a series of nomographs depicting a range of potential design options meeting design criteria. Inputs for the equation included the channel shape, Manning's n, slope, and depth. Outputs included the resulting hydraulic parameters such as flow quantity and corresponding velocity. Therefore, the nomographs in Figure 7 depict a range of possible constructed channel options meeting design criteria which can be considered when advancing the design.

Figure 7
Nomographs for Constructed Channel Design Cross Section



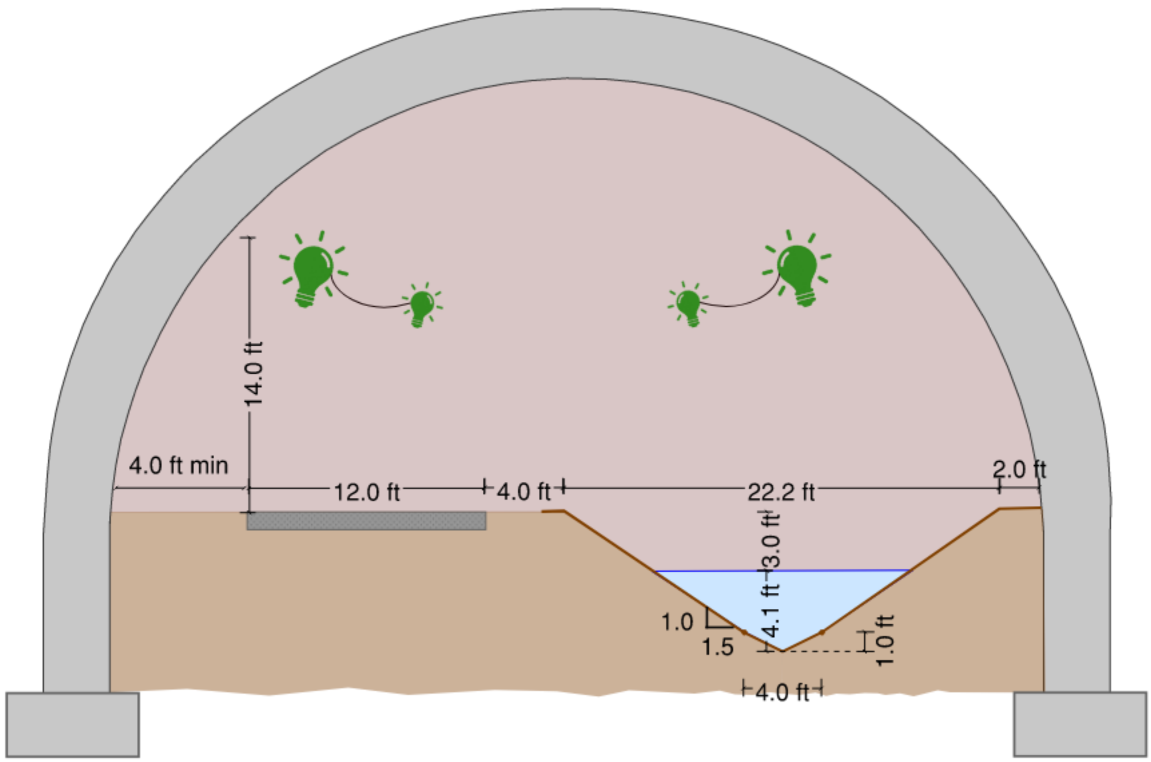
The area shaded green in Figure 7 can be used to select a constructed channel slope and flow rate that meets design criteria. For an option to meet all design criteria, the dashed line representing velocity criteria and the solid line representing depth criteria must both fall within the design target 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. It is important to note the interrelation between the different design targets. A design option with a higher depth will require more flow than one with a lower depth. Similarly, selecting an option with a higher channel slope will also require more flow than an option with a lower gradient.

Refer to the Alternative 1 design in Section 4.1 for the preliminary option design for this functional element and its corresponding water requirements.

3.3 Tunnel

Based on the design criteria listed in Section 2.4, a tunnel with a constructed channel would likely have a cross section similar to that shown in Figure 8. Incorporating the design section shown in Figure 6, three feet of freeboard is provided above the water surface elevation to the top of the channel. Similar to the constructed channel, four feet is provided as a buffer between the channel and the maintenance access road, and 12 feet is provided as the width of the access road to allow heavy machinery to access the channel for maintenance. At the edge of the road, a minimum height of 14 feet is provided for the heavy machinery. The overall maximum height of the tunnel may change depending on the radius of the arch used for the structure; lighting must be provided throughout the tunnel and will likely be blue or green. Tunnel shape may be refined at later stages of design as maintenance requirements are further developed.

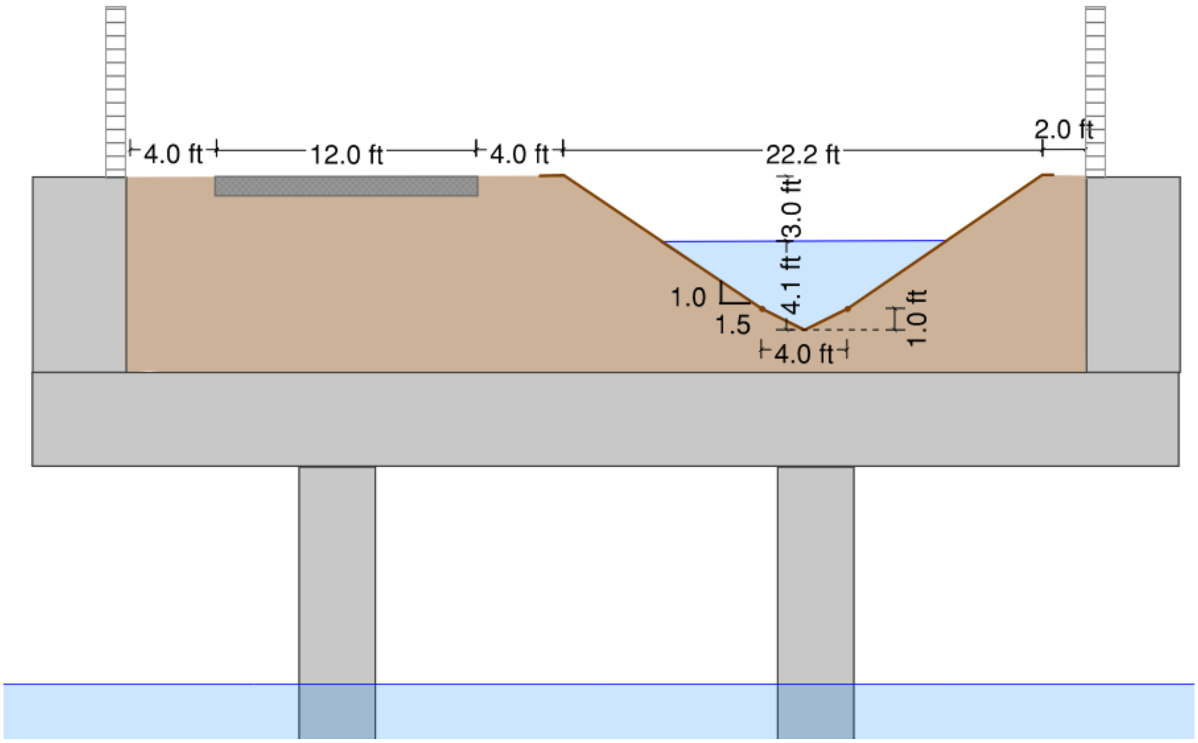
Figure 8
Tunnel Design Cross Section



3.4 Water Bridge

Based on the design criteria listed in Section 2.5, a water bridge with a constructed channel would likely have a cross section similar to that shown in Figure 9. Incorporating the design section shown in Figure 6, the maintenance road design and clearances are the same as described in Section 3.3. A fence is provided on either side of the water bridge. This water bridge shape may be altered at later stages of design as the channel shape is refined and as maintenance requirements are further developed.

Figure 9
Water Bridge Design Cross Section



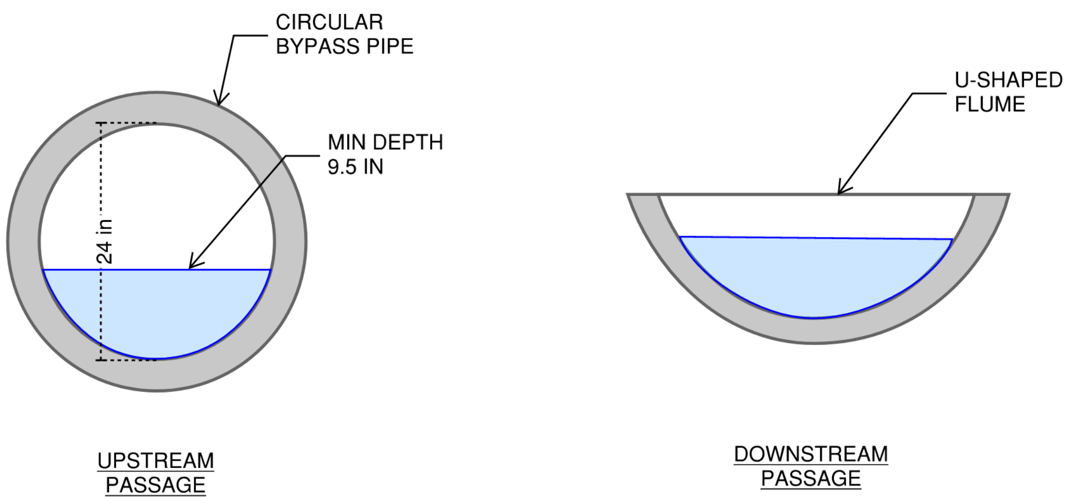
3.5 Conduits

A conduit may be used to convey fish in both upstream and downstream passage applications. The following paragraphs describe a potential design for each application; however, conduit geometry and configuration may be altered at later stages of design.

For upstream passage applications, a conduit would likely attach to the upstream end of a volitional passage structure to accommodate a wide range of water surface elevations at the fishway exit, called an adult return flume. This type of conduit would likely be a round pipe with a 12-inch diameter, at a slope low enough to provide safe passage that meets the minimum flow depth and velocity criteria outlined in Section 2.6. Figure 10 presents a potential cross section for an upstream passage conduit (left).

For downstream passage applications, a bypass conduit would likely be a U-shaped flume that would convey fish from the upstream side of a barrier to the downstream side. This type of conduit would need to be sized to meet criteria for providing 5 percent of the total powerhouse flow (planning level estimate of approximately 750 cfs), which should provide adequate attraction flow and approach velocity. Figure 10 presents a potential cross section for a conduit used for downstream passage (right).

Figure 10
Potential Conduit Geometry



Note: Not drawn to scale

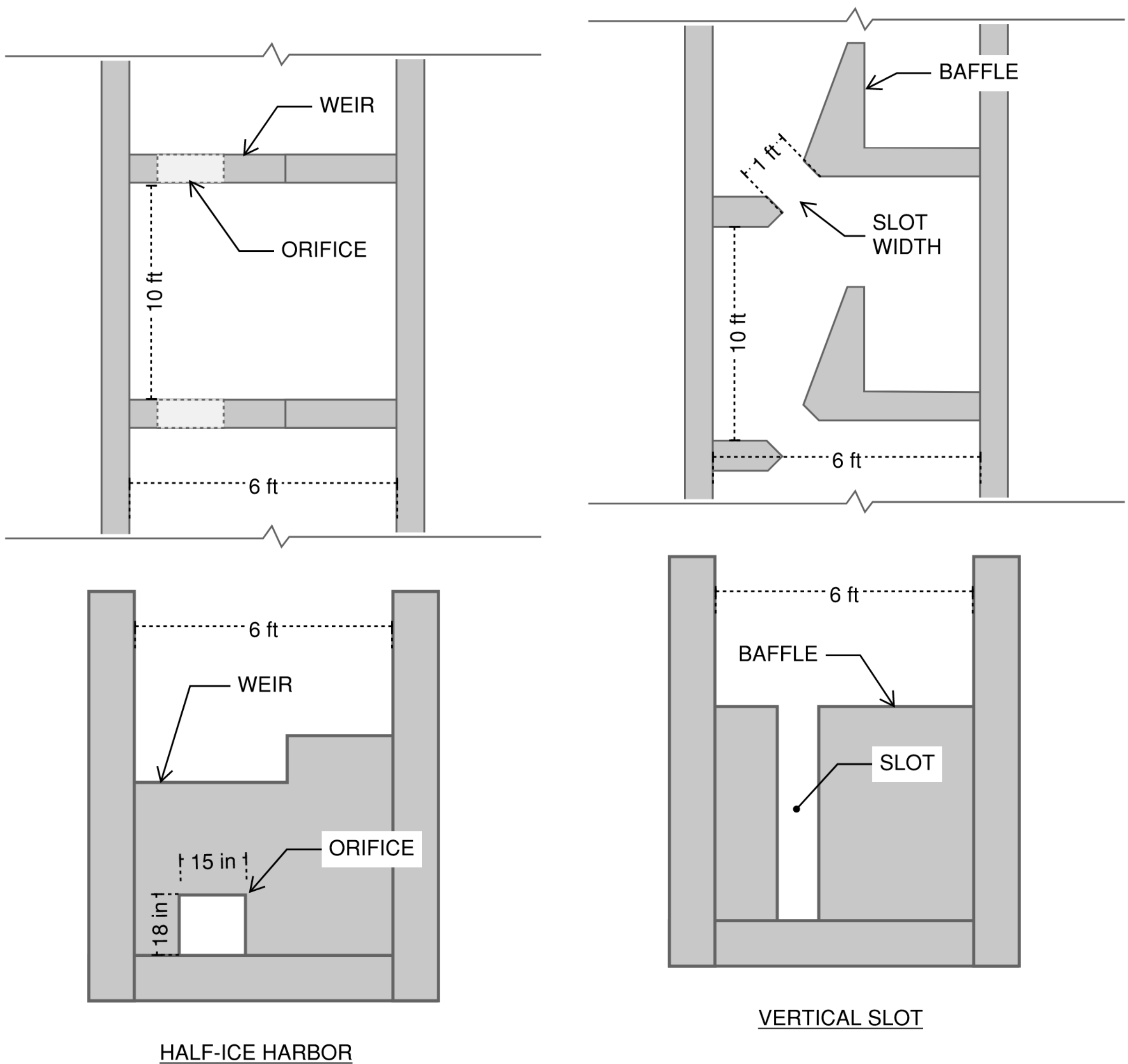
3.6 Fish Ladders

Fish ladders may be implemented at Keswick and/or Shasta dams to provide volitional or semi-volitional passage routes for upstream migrating fish.

A Half-Ice Harbor style fish ladder is anticipated to be proposed at both sites. Total length and entrance and exit configurations will vary for each site and each potential alternative, but the following paragraphs describe general design elements that are anticipated for each ladder. Vertical slot style fishway components may be proposed at the fishway entrance or exit to accommodate a wide range of water surface elevations.

Figure 11 provides a conceptual illustration of general ladder geometry that may be used in alternative development, showing geometry for both Half-Ice Harbor (left) and vertical slot style (right) fishways.

Figure 11
Potential Fish Ladder Geometry



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

4 Water Requirements for Potential Alternative Concepts

This section uses the preliminary designs developed in Section 3.0 to determine the water quantity requirements for each alternative based on the design criteria and the results of the thermal gain evaluation described in *Thermal Accumulation in Migratory Corridors and Channels* (Appendix J).

4.1 Alternative 1: Volitional Tributary Bypass from Cow Creek to the Winnemem Waywaket

This alternative includes a single channel to provide fully volitional passage of both adults and juvenile fish from the Nomtipom Waywaket to the Winnemem Waywaket. Adult fish would migrate up Cow, Little Cow, and Dry creeks and bypass Shasta Reservoir to the Winnemem Waywaket via a system of constructed channels, tunnels, and water bridges extending from Jones Valley, across Shasta Reservoir, and to the Winnemem Waywaket. Downstream migrating juvenile fish would be guided from the Winnemem Waywaket to the same route using a fixed, in-river juvenile fish guidance/barrier system that would operate effectively across a broad range of river flow conditions. The guidance system also acts as a flow bifurcation facility that modulates the required magnitude of flow down the bypass channel.

See Figure 12 through Figure 15 for plan and profile layouts of the alternative, and refer to Table 14 for a full description of each functional element, its length, elevation, and slope for design.

Figure 12
Alternative 1 Volitional Tributary Bypass Overall Key Map

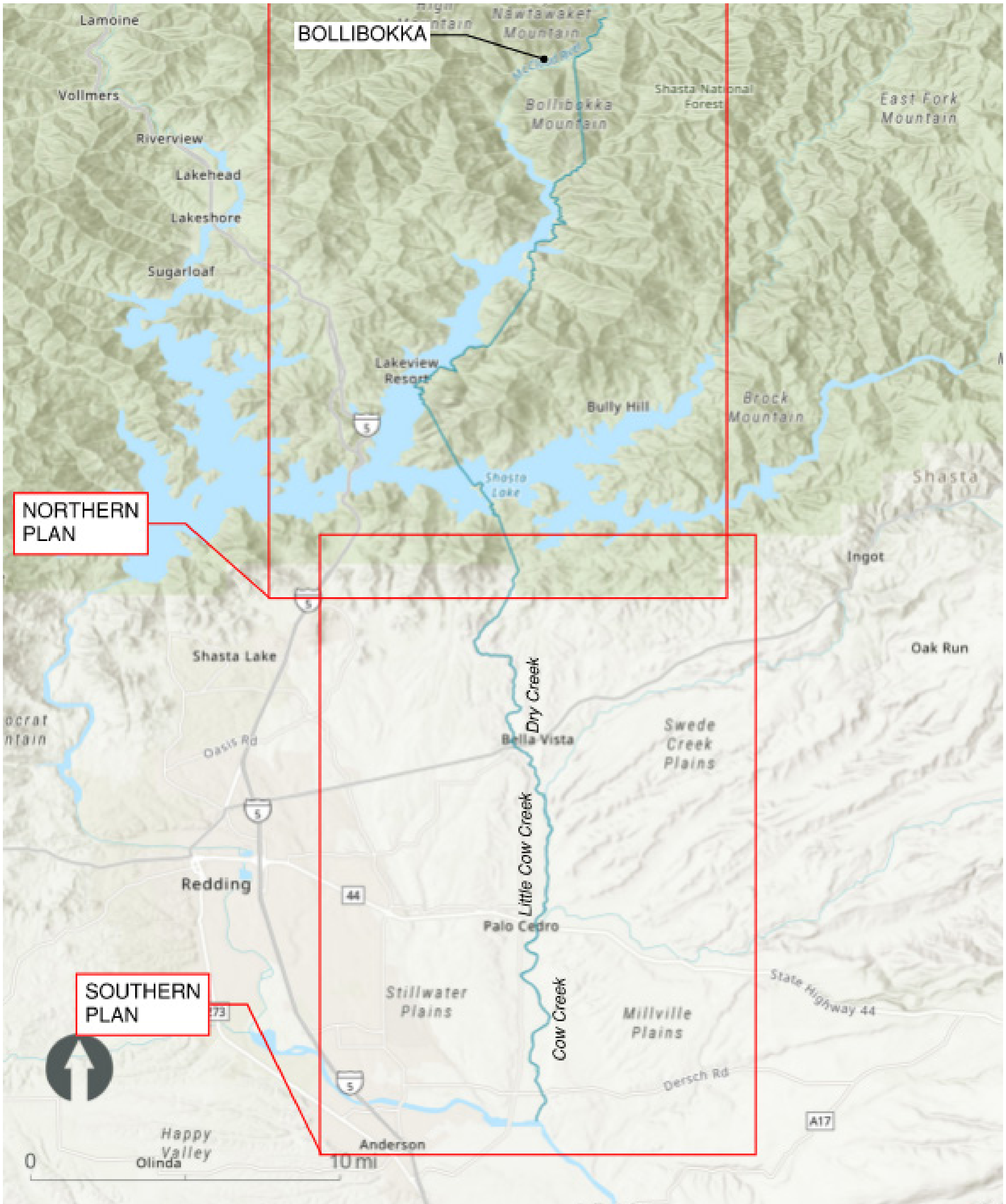


Figure 13
Alternative 1 Volitional Tributary Bypass Southern Plan (Cow Creek, Little Cow Creek, Dry Creek)

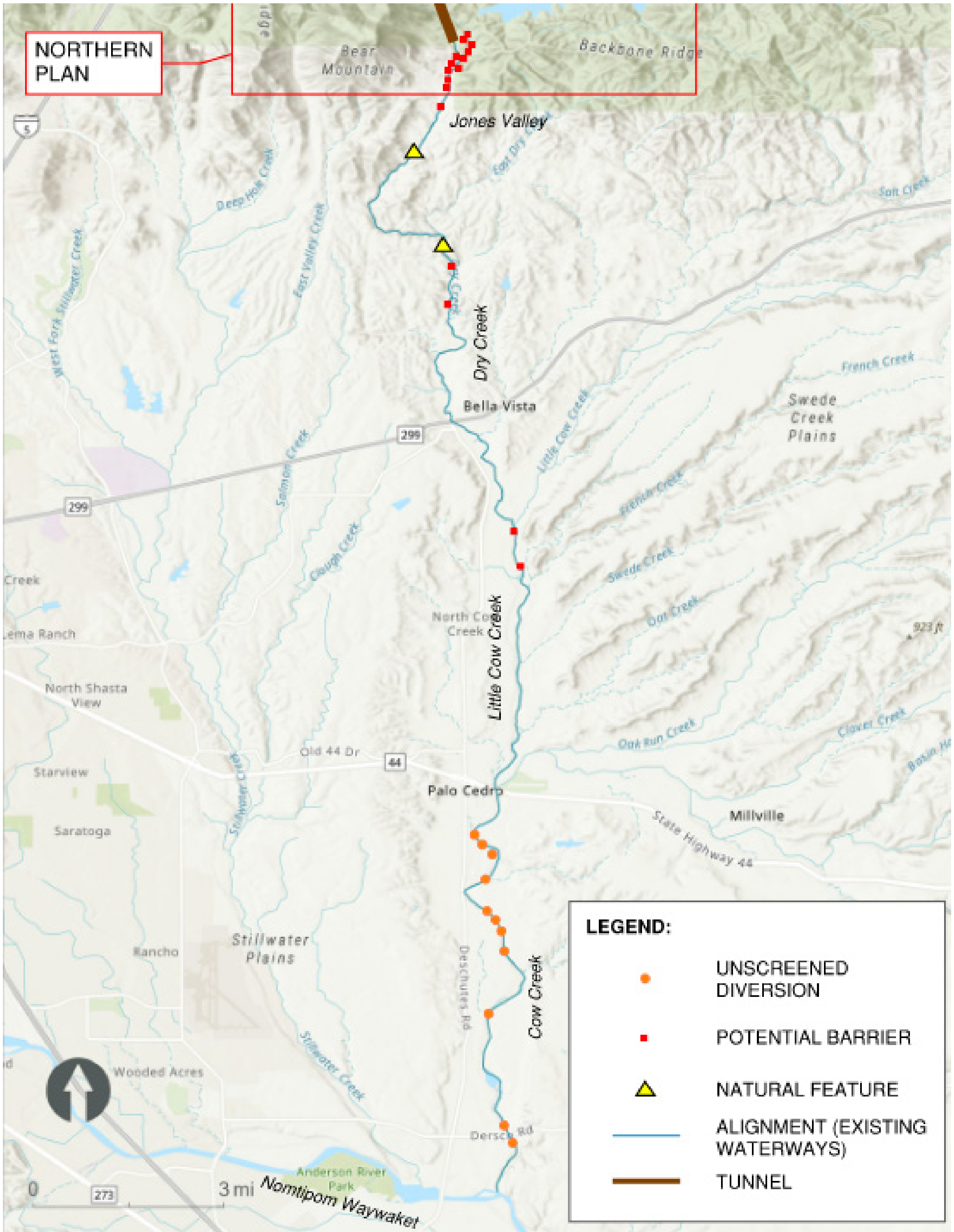


Figure 14
Alternative 1 Volitional Tributary Bypass Northern Plan (Dry Creek, Constructed Channel, Winnemem Waywaket)

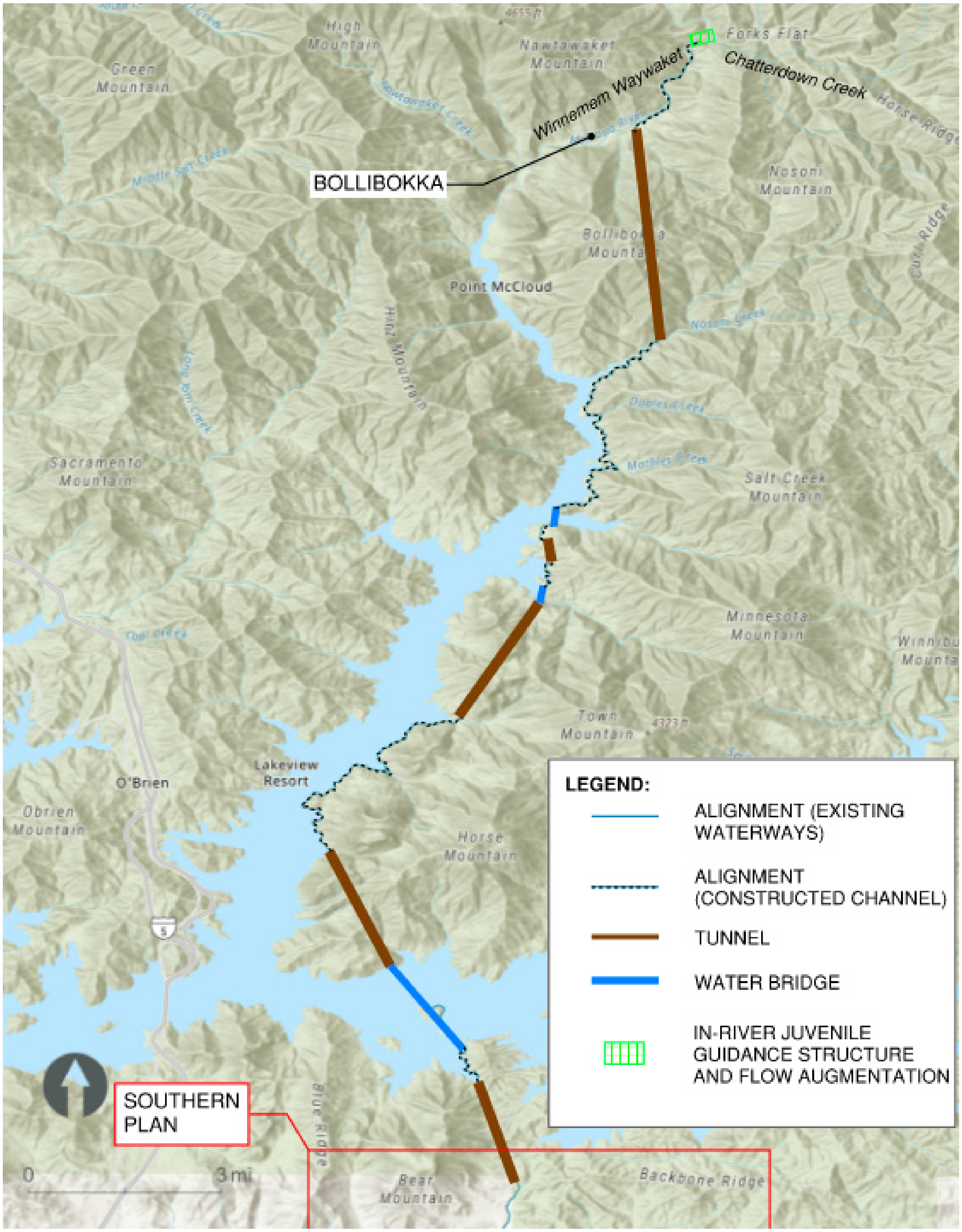


Figure 15
Alternative 1 Volitional Tributary Bypass Profile

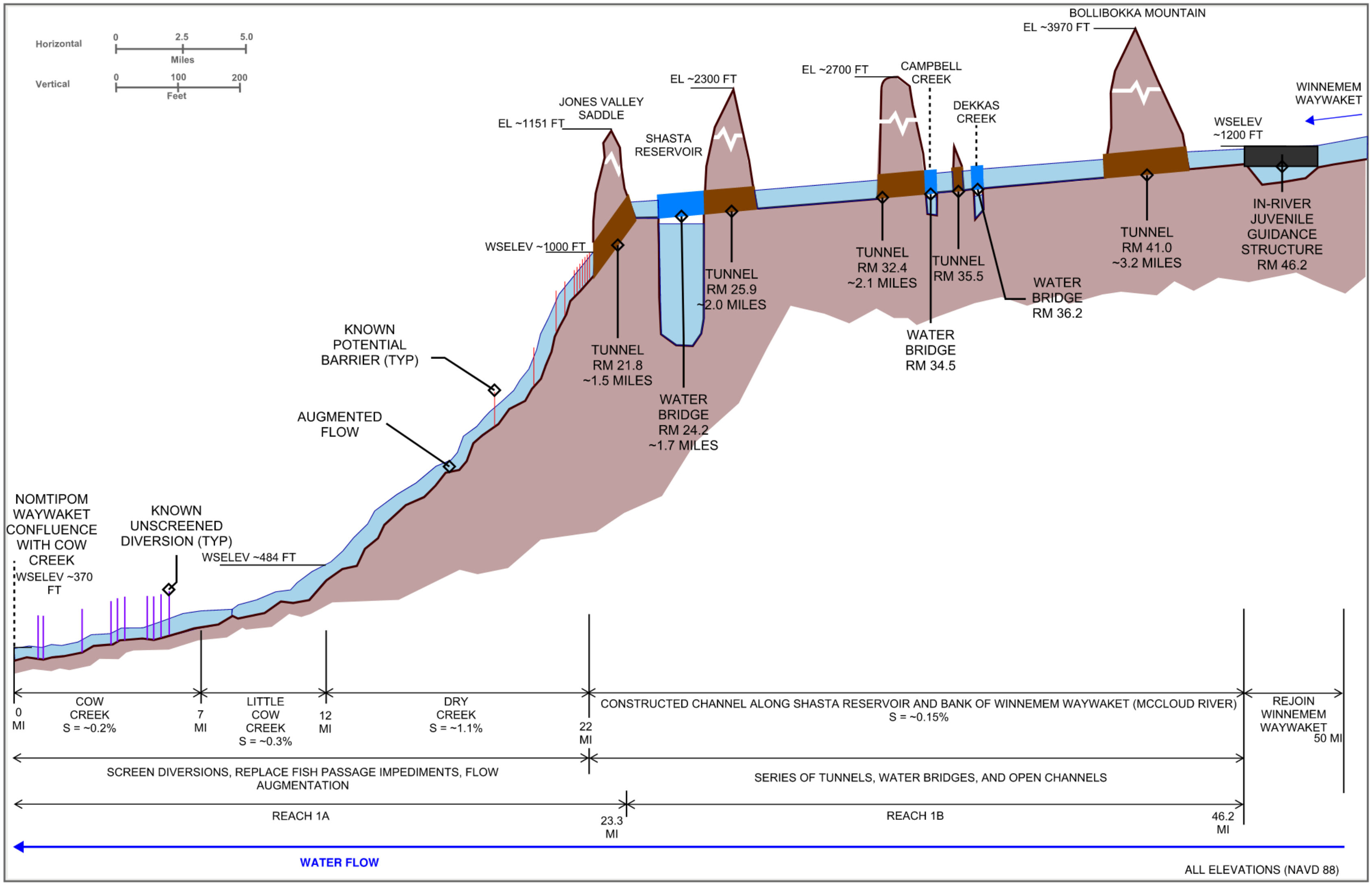


Table 14
Alternative 1 Design Information

Element	Starting Station (mile)	Starting Elevation (feet)	Length (mile)	Slope (Percent)
Modified channel: Confluence of Nomtipom Waywaket with Cow Creek	0	370.2	7.4	0.15
Modified channel: Little Cow Creek	7.4	428.3	4.3	0.24
Modified channel: Dry Creek	11.7	483.7	10.0	0.97
Tunnel	21.8	998.3	1.5	1.15
Constructed channel	23.3	1090	0.9	0.1
Water bridge	24.2	1095	1.7	0.1
Tunnel	25.9	1100	2.0	0.1
Constructed channel	27.9	1108	4.5	0.1
Tunnel	32.4	1130	2.1	0.1
Water bridge	34.5	1148	0.1	0.1
Constructed channel	34.6	1148.5	0.9	0.1
Tunnel	35.5	1150	0.1	0.1
Constructed channel	35.6	1151	0.6	0.1
Water bridge	36.2	1152	0.2	0.1
Constructed channel	36.3	1153	4.6	0.1
Tunnel	41.0	1166	3.2	0.1
Constructed channel	44.2	1195	2.0	0.1
In-river juvenile guidance structure	46.2	1202	N/A	N/A

As shown in Table 14, a design slope of 0.1 percent was selected for Alternative 1 from RM 23.3 to 46.2. A greater slope would extend the total length of the alignment meaning that the constructed channel would join the Winnemem Waywaket at a higher RM station and would bypass some spawning and rearing habitat in the lower Winnemem Waywaket.

Review of the nomographs generated in Section 3.2 supports that a 0.1 percent slope would result in an average 2.2 feet of depth and a velocity of 1.8 ft/s with a flow rate of 50 cubic ft/s within the constructed channel. This gradient is the lowest preferred that still promotes fish passage. This preliminary design meets depth and velocity requirements throughout the constructed channel reach while limiting water consumption, an important consideration in this water-limited environment, and reducing overall construction cost. Therefore, 50 cfs is the amount of water needed for the constructed channel functional element from RM Station 23.2 to 46.2. This will be analyzed further 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.

As previously described, from RM Station 0 to 21.8, the natural channels of Cow Creek, Little Cow Creek, and Dry Creek may need to be modified to fit the flow requirement of the constructed channel and to meet depth and velocity targets in the natural channel. At this time, it is assumed that there is no additional flow required from RM Station 0 to 21.8 beyond that needed for the constructed channel from RM Station 23.2 to 46.2. Additional water or channel modifications may be required to overcome depth barriers as discussed in *Physical Barriers to Fish Passage* (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.

The tunnel from RM Station 21.8 to 23.2 is the only constructed element that is not designed using a constant slope. The downstream endpoint of the tunnel is located at the upstream end of Dry Creek and its elevation is fixed at this point. The tunnel alignment travels north through the Jones Valley Saddle and its upstream endpoint elevation is set at a fixed point above the projected future Shasta Reservoir water surface elevation, providing 5 feet of freeboard over the reservoir. Considering these two fixed elevations, the slope is steeper through this tunnel than the rest of the constructed channel. The alignment may be revisited in the future to reduce the slope. At this time, it is assumed that the tunnel would utilize the straightest, shortest alignment and would use baffles, resting areas, and a variety of different slopes throughout to provide a more nature-like corridor and to meet depth, velocity, and flow targets. It is further assumed that there is no additional flow required from RM Station 21.8 to 23.2 beyond that needed for the constructed channel from RM Station 23.2 to 46.2.

The water for Alternative 1 is assumed to originate from the Winnemem Waywaket. As presented in *Thermal Accumulation in Migratory Corridors and Channels* (Appendix J), the 7-DADM temperature increases within Dry Creek, Little Cow Creek, and Cow Creek during the winter, and decreases during the summer with augmented flow because the water originating from the Winnemem Waywaket is heavily impacted by the temperature within the tunnels throughout the constructed channel alignment. Analysis of turbulent heat transfer in these tunnels found that the water would always exit the tunnel at the same temperature as the rock wall, approximately 58°F. Therefore, even if the amount of flow diverted from the Winnemem Waywaket to the Alternative 1 alignment were increased, thermal accumulation would remain unchanged. Refer to *Thermal Accumulation in Migratory Corridors and Channels* (Appendix J) for an in-depth explanation of the thermal accumulation model created based on historic temperature data and an individual analysis of each functional element used along the alignment.

The projected water requirements for Alternative 1 based on the preliminary design described in this Section are provided in Table 15.

Table 15
Alternative 1 Water Requirements

Element	Flow Requirement (cfs)	Water Source
Constructed channel	50	Winnemem Waywaket
Total	**50**	

In this analysis and the thermal accumulation evaluation in *Thermal Accumulation in Migratory Corridors and Channels* (Appendix J), a water quantity of 50 cfs was used. Additional flows (100 and 150 cfs) were evaluated, though they were found to provide relatively few additional benefits as well as numerous drawbacks. Using a higher design flow will also increase the size of the constructed channel (Section 2.3) and the minimum size of a tunnel and water bridge (Sections 2.4 and 2.5). Altogether, the design becomes more costly and complex with increased water quantity. If Alternative 1 is selected to move to the next phase of design, the water requirement for the alternative would need to be refined.

See Section 5.1 for a discussion of the data gaps for the water quantity analysis for Alternative 1.

4.2 Alternative 2: Semi-volitional Tributary Bypass from ACID Dam to the Winnemem Waywaket via Railroad Grade

This alternative includes a migration barrier system at the existing Anderson-Cottonwood Irrigation District (ACID) Dam to guide upstream migrating adult Chinook Salmon present within the Nomtipom Waywaket to a short section of technical fish ladder. Adult Chinook Salmon would ascend the fish ladder, pass through a segregation facility, and volitionally transition to a newly constructed bypass channel located within the existing railroad right-of-way. At the transition, fish would pass through a segregation facility to be sorted based on various fish management strategies required to reach biological goals and objectives. Fish selected for return to the Nomtipom Waywaket would be returned from holding pools via a return flume, while fish continuing their migration to the Winnemem Waywaket would continue upstream of the segregation facility to the bypass channel. From the segregation facility, the bypass channel would extend over Shasta Reservoir along the existing Interstate 5 crossing and would continue via a combination of constructed tunnels, water bridges, and channels to a point at or near Bollibokka. From here, a return flume would convey adult Chinook Salmon to the Winnemem Waywaket. Downstream migrating juvenile Chinook Salmon would be guided from the Winnemem Waywaket to a collection pool using a fixed, in-river juvenile fish guidance/barrier system that would operate effectively across a broad range of river flow conditions. Juvenile Chinook Salmon would be collected and then transferred into transport pods and lifted a short distance up to the volitional bypass channel or to a bypass pipe. The bypass channel or the bypass pipe would then provide passage downstream to a release point in the Nomtipom Waywaket downstream of ACID Dam.

Alternative 2 would involve long stretches of constructed channels, water bridges, and tunnels throughout its alignment with thermal accumulation and water requirements anticipated to be similar to those for Alternative 1. Further analysis was not performed on this alternative both due to the similarities to Alternative 1 and because of the improbability of construction feasibility along the railroad right-of-way and on the Pit River Bridge (carrying bot the railroad and Interstate 5).

4.3 Alternative 3: Semi-volitional Passage in the Nomtipom Waywaket over Keswick and Shasta Dams to the Winnemem Waywaket

Alternative 3 integrates both volitional and non-volitional technologies to enable adult fish to migrate upstream via the Nomtipom Waywaket, bypass Keswick Dam into Keswick Reservoir, continue to and pass over Shasta Dam, enter Shasta Reservoir, and proceed through the reservoir to reach the Winnemem Waywaket. At Keswick Dam, a fish ladder on either the right or left bank would provide routing to the top of the dam and access to the reservoir via a) an adult fish return flume or b) a fish ladder exit that accommodates reservoir fluctuations (both are shown in Figure 17). At the base of Shasta Dam, adult fish would enter a ladder on the left bank associated with a potential new Livingston Stone National Fish Hatchery (LSNFH). A broodstock collection facility would be incorporated into the ladder for hatchery broodstock collection and fish sorting, and fish destined for the Winnemem Waywaket would continue to transition up the ladder. At the top of Shasta Dam, fish would transition to a temperature-controlled reservoir release structure that would allow fish to acclimate to the reservoir environment. From the release structure, fish would transit the reservoir and migrate to the Winnemem Waywaket. This reservoir transit strategy would allow for the self-selection of the Nomtipom Waywaket above Shasta Reservoir, the Winnemem Waywaket, and/or other tributaries that flow into Shasta Reservoir.

Downstream migrating juvenile Chinook Salmon would be guided from the Winnemem Waywaket to a collection pool using a fixed, in-river juvenile fish guidance/barrier system that would operate effectively across a broad range of fish sizes and river flow conditions (Section 4.5). After collection, juvenile Chinook Salmon would be transferred into transport pods and transported to Shasta Dam via barge or truck. At Shasta Dam, fish present within the transport pods would be transferred to acclimation tanks or raceways for temperature acclimation at the new LSNFH before being released into the fish ladder leading downstream to Keswick Reservoir. Juvenile fish would then continue to migrate downstream to Keswick Dam and would be bypassed to the tailrace through a high-volume, surface flow outlet and return flume likely located in the space currently being used for adult broodstock collection.

A key map of potential facilities included in Alternative 3 is provided in Figure 16. A plan and profile of potential technologies and functional elements for upstream and downstream passage at both Keswick and Shasta dams are provided as Figure 17 through Figure 22.

Figure 16
Alternative 3 Key Map Plan

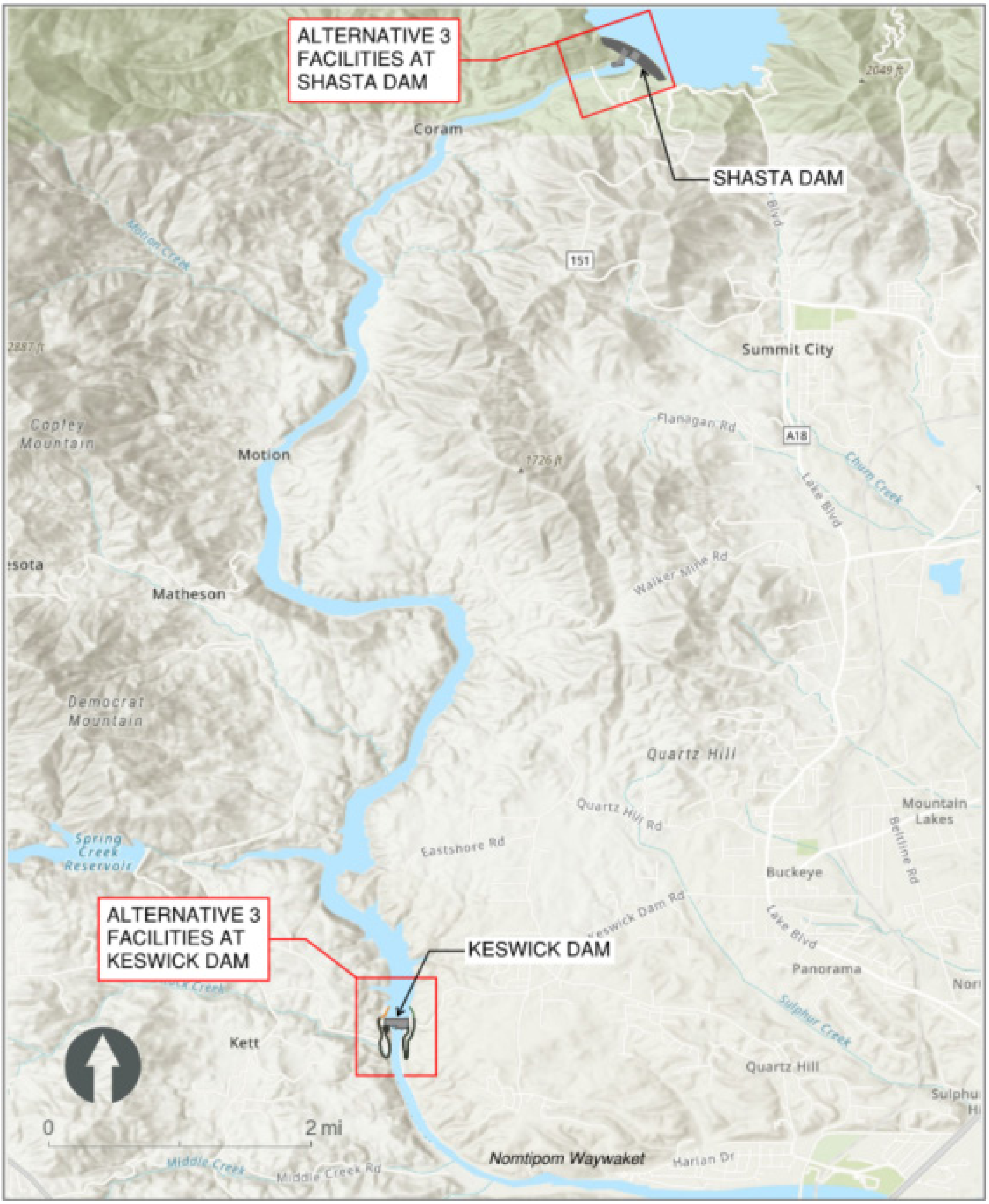


Figure 17
Alternative 3 Upstream Passage at Keswick Dam (Plan)

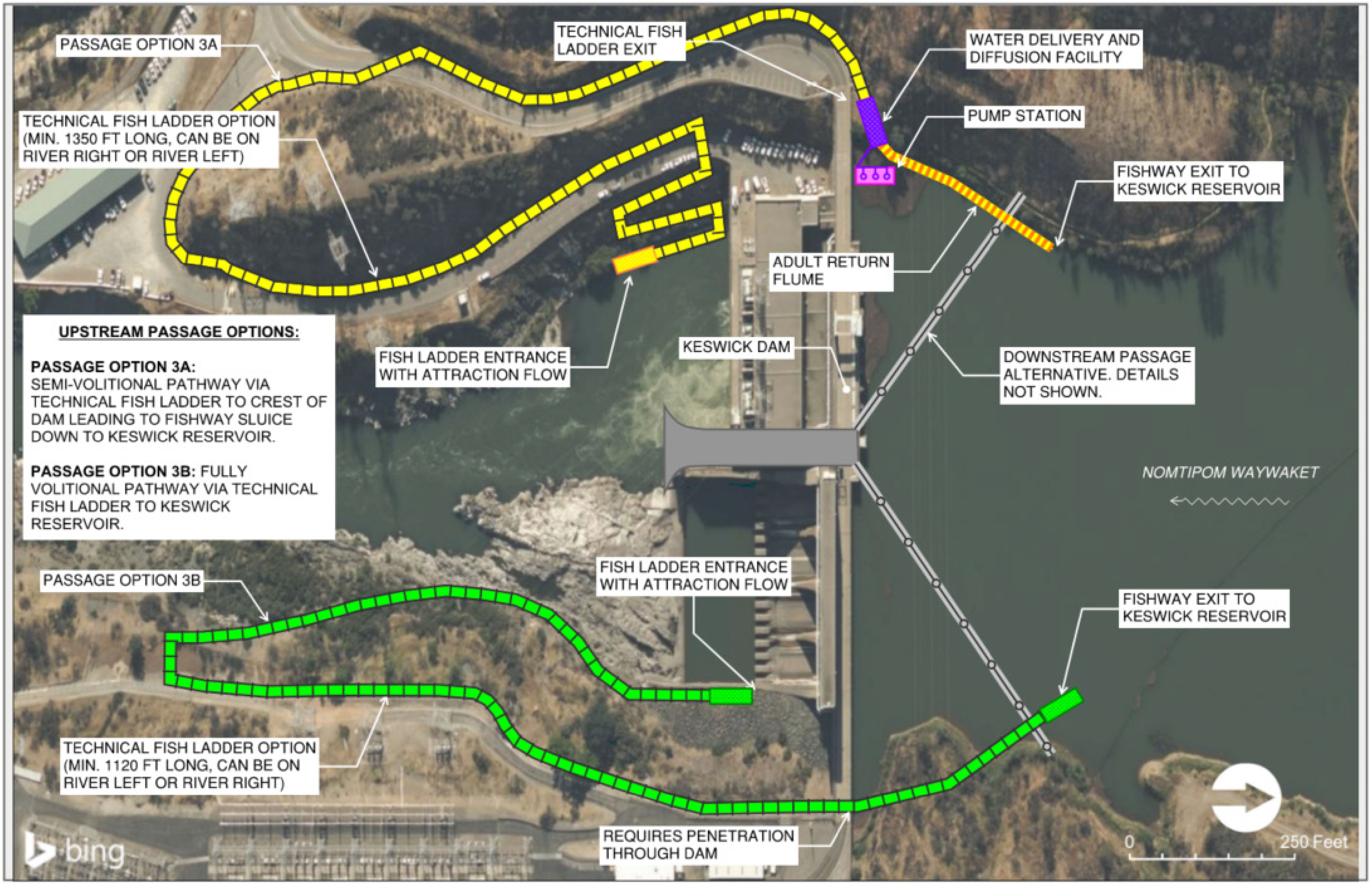


Figure 18
Alternative 3 Upstream Passage at Keswick Dam (Profile)

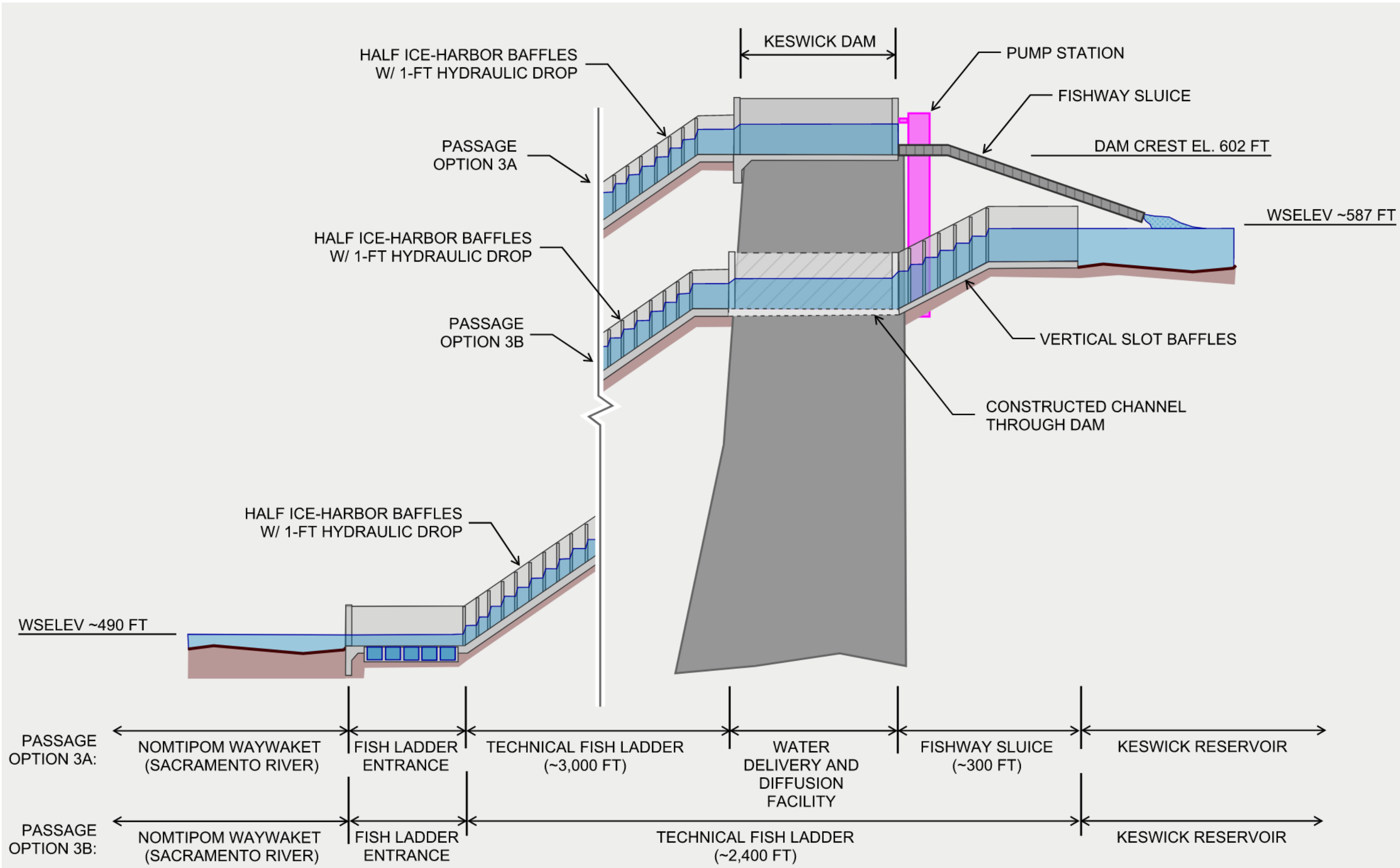


Figure 19
Alternative 3 Downstream Passage at Keswick Dam (Plan)

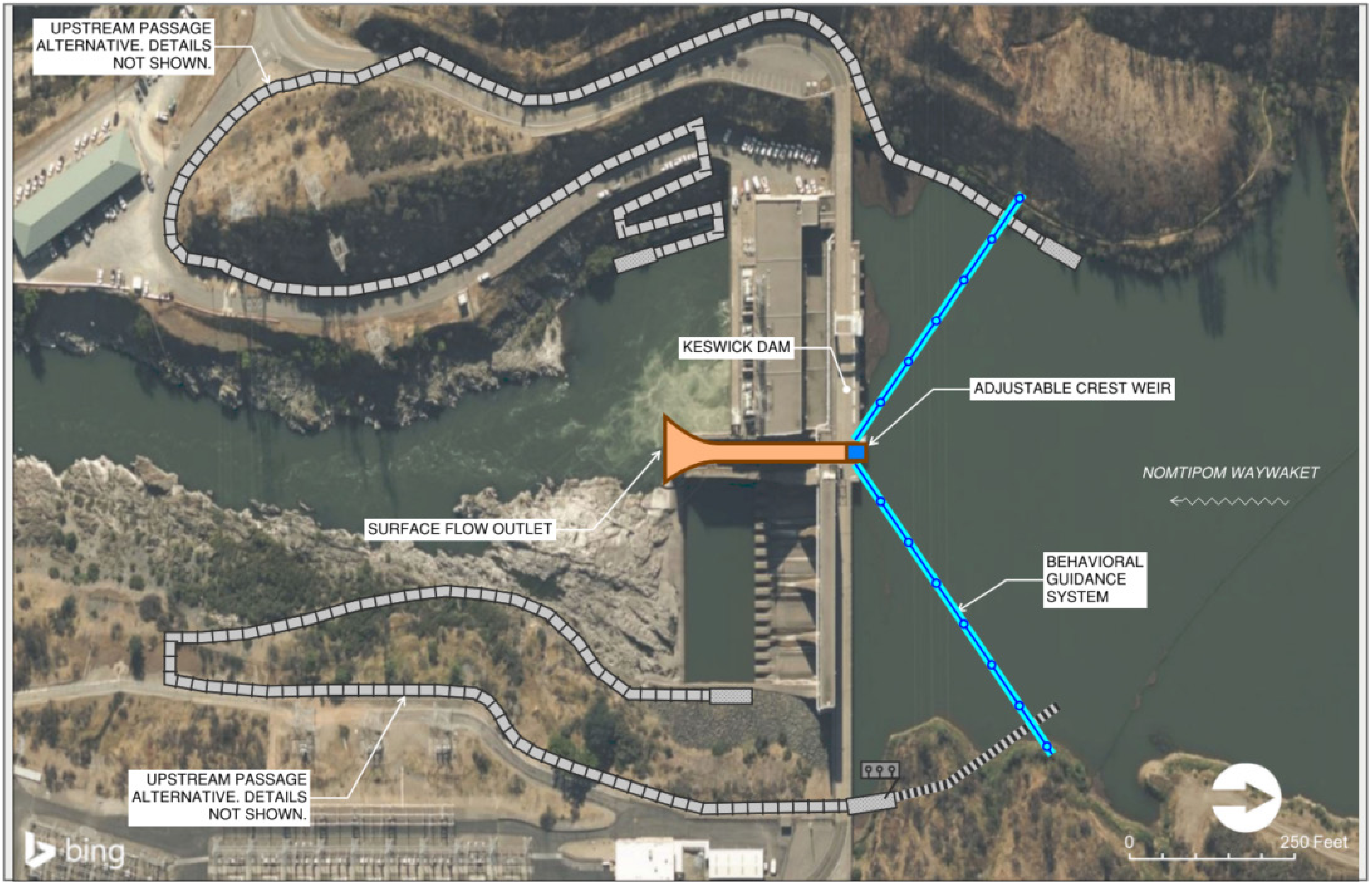


Figure 20
Alternative 3 Downstream Passage at Keswick Dam (Profile)

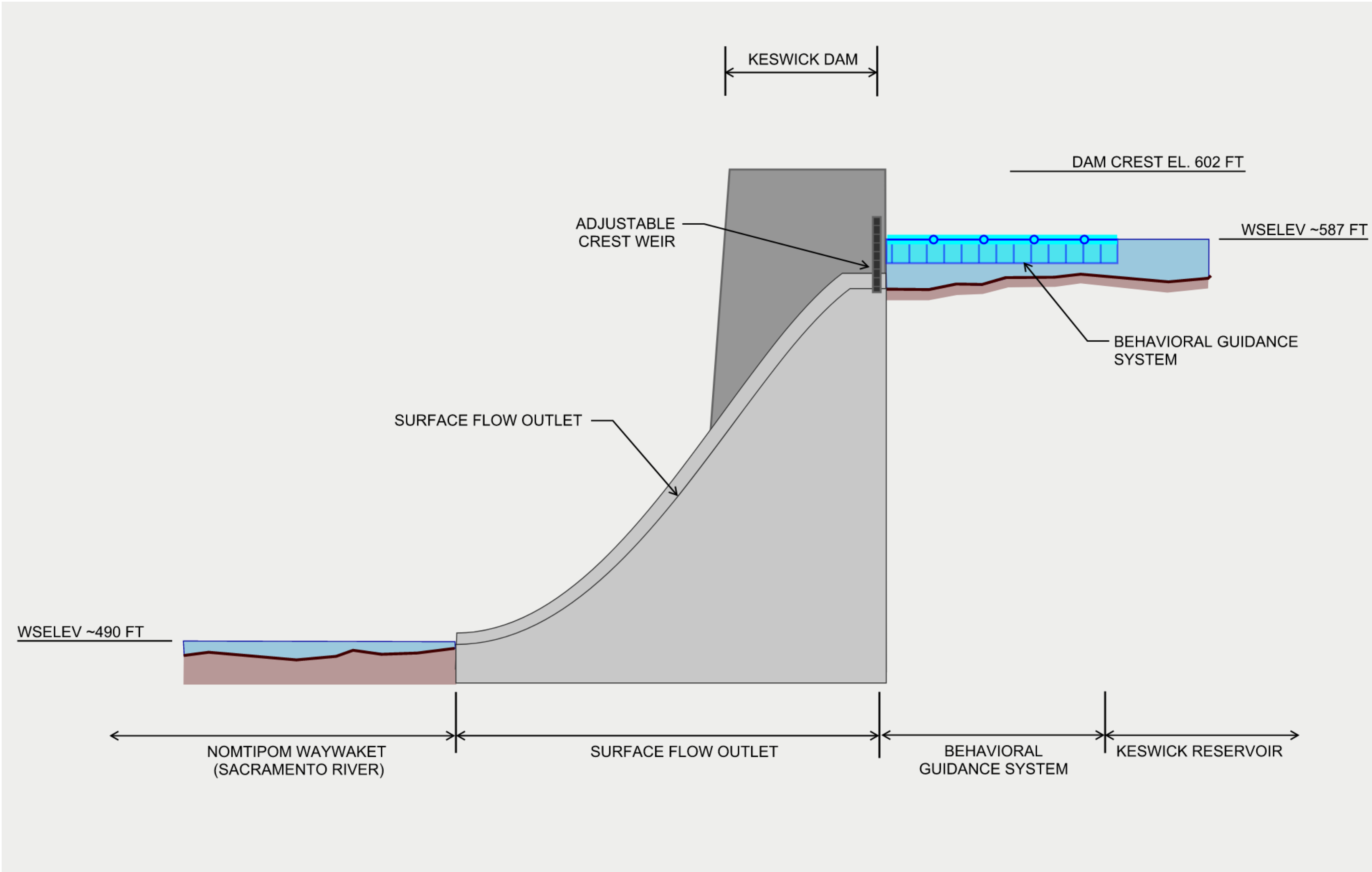


Figure 21
Alternative 3 Upstream Passage at Shasta Dam (Plan)

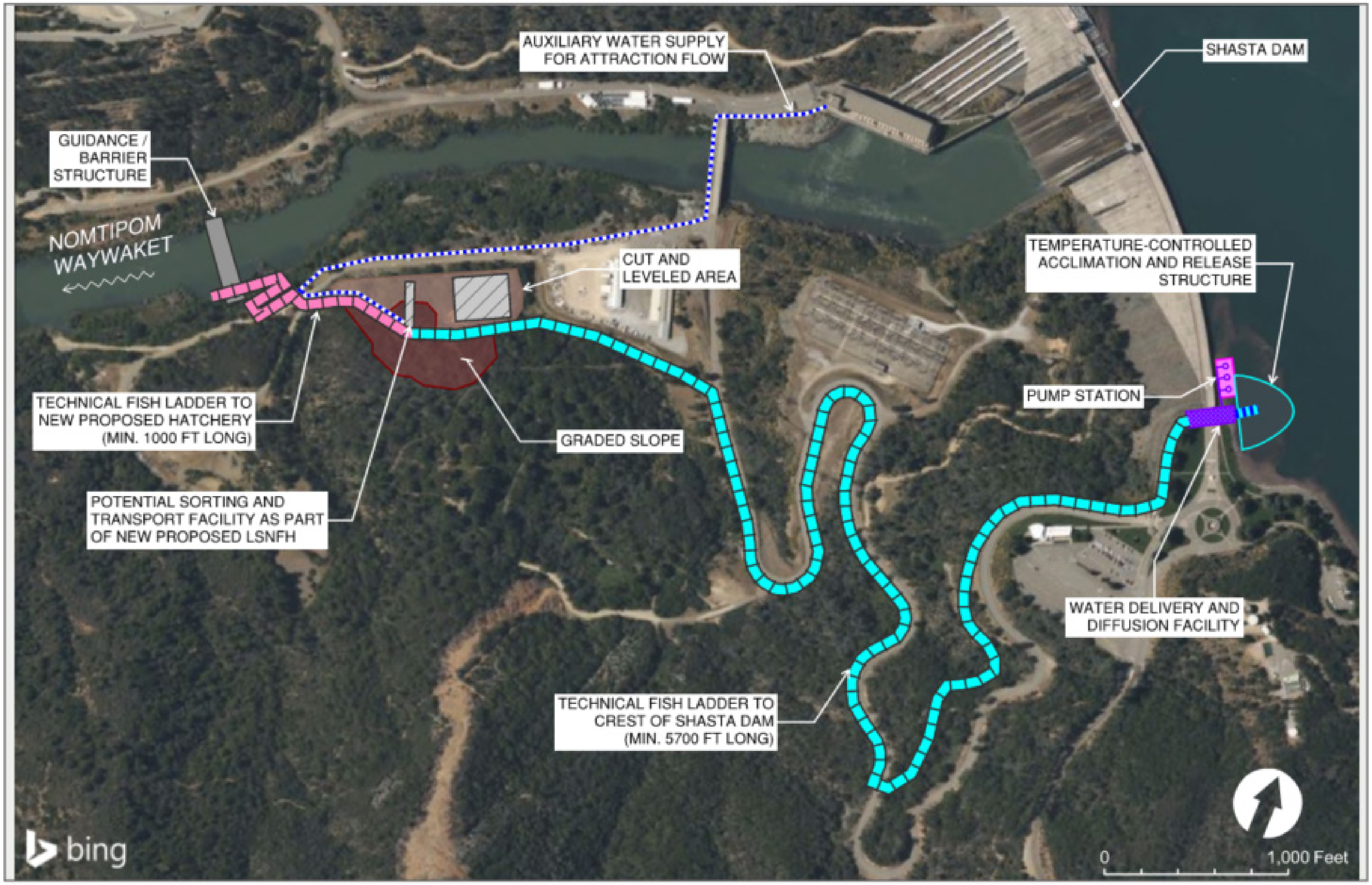


Figure 22
Alternative 3 Upstream Passage at Shasta Dam (Profile)

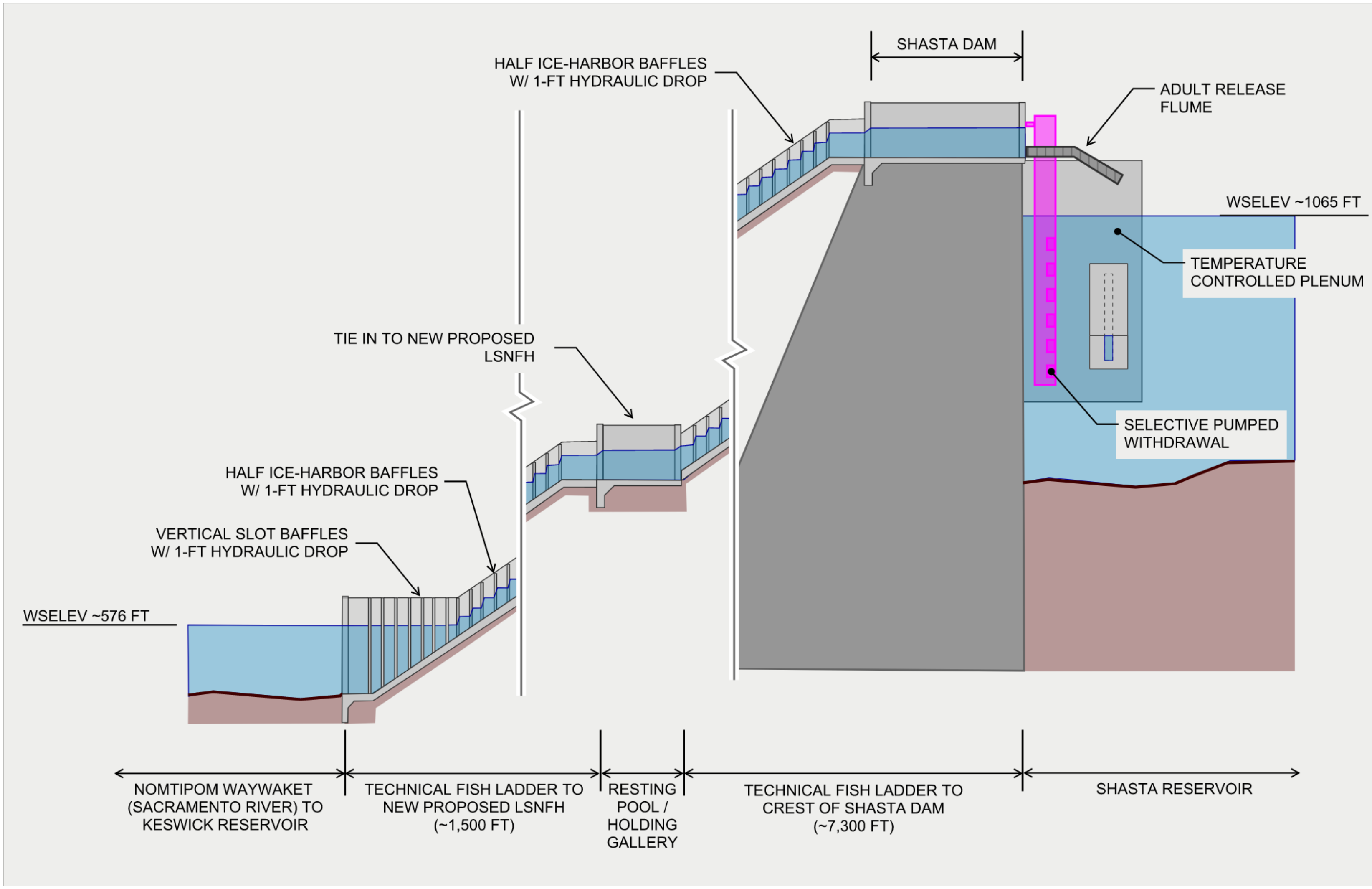


Table 16 summarizes anticipated water requirements for Alternative 3 based on elements in the preliminary design. The water requirements consider the most conservative assumptions (e.g., highest flow requirement) to include worst-case scenario water requirements. For *Thermal Accumulation in Migratory Corridors and Channels* (Appendix J), a water quantity of 35 cfs was used to show a more conservative assumption for thermal gain, which includes minimum flow in the fish ladders. Water quantity requirements may be refined as design progresses.

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 is always suitable for adult Chinook Salmon migration and smolt out-migration.

Table 16
Alternative 3 Water Requirements

Element	Maximum Anticipated Flow Requirement (cfs)	Water Source
Keswick Dam fish ladder	35 - 50	Keswick Reservoir
Keswick Dam fish ladder attraction flow[1]	400	Keswick Reservoir
Keswick Dam adult return flume	25	Keswick Reservoir
Keswick Dam surface flow outlet	750	Keswick Reservoir, Nomtipom Waywaket
Shasta Dam fish ladder	35 - 50	Shasta Reservoir
Shasta Dam adult return flume	25	Shasta Reservoir
Shasta Dam fish ladder attraction flow[1]	400	Shasta Powerhouse, Shasta Reservoir
Total	**1,670 - 1,700**	-

Notes:

1. Attraction flows modified from NMFS (2023) criteria as described in Section 2.8.3
2. All values may be adjusted in later stages of design, based on computational fluid dynamic (CFD) modeling

4.4 Trap and Haul Facility

The upstream passage strategy proposed for trap and haul consists of a non-volitional trap and haul facility at Shasta Dam to collect and transport adult upstream migrating fish to the Winnemem Waywaket. Downstream juvenile passage at Shasta Dam would consist primarily of a downstream fish migration guidance and collection facility from which fish could be transported downstream and released into the Nomtipom Waywaket (Section 4.5). It should be noted that the concept proposed for the trap and haul method assumes that means of passage upstream and downstream of Keswick Dam, such as use of existing adult collection facilities at Keswick Dam or via passage strategies presented as part of Alternative 3 (Section 4.3), would be operational at the time of implementation.

This fish passage method is included as required by the CDFW grant agreement for comparison to Alternatives 1, 2, and 3.

Conceptually, the adult collection and sorting facility would be located on the left bank (looking downstream) of the Nomtipom Waywaket, immediately downstream of Shasta Dam to facilitate integration into the proposed new LSNFH. The facility would accommodate collection and sorting of fish, detailed monitoring, and selective passage that could support a broad range of potential fish colonization and management strategies. From this facility, collected adult fish may be relocated upstream to the Winnemem Waywaket or selected as broodstock for LSNFH to fulfill specific fisheries management goals based upon species, life history, population dynamics, genetics, impacts to resident populations, and other inputs not yet known at this phase of the Project. Adult fish destined for the Winnemem Waywaket would be transferred into transport pods and transported by truck to the release point near Bollibokka on the Winnemem Waywaket.

A key map of potential facilities included in trap and haul is provided in Figure 23. A plan and profile of potential technologies and functional elements for upstream and downstream passage are provided as Figure 24 through Figure 25. Note that downstream guidance and collection is described in Section 4.5.

Figure 23
Trap and Haul Key Map Plan

Figure 24
Trap and Haul Facility (Plan)

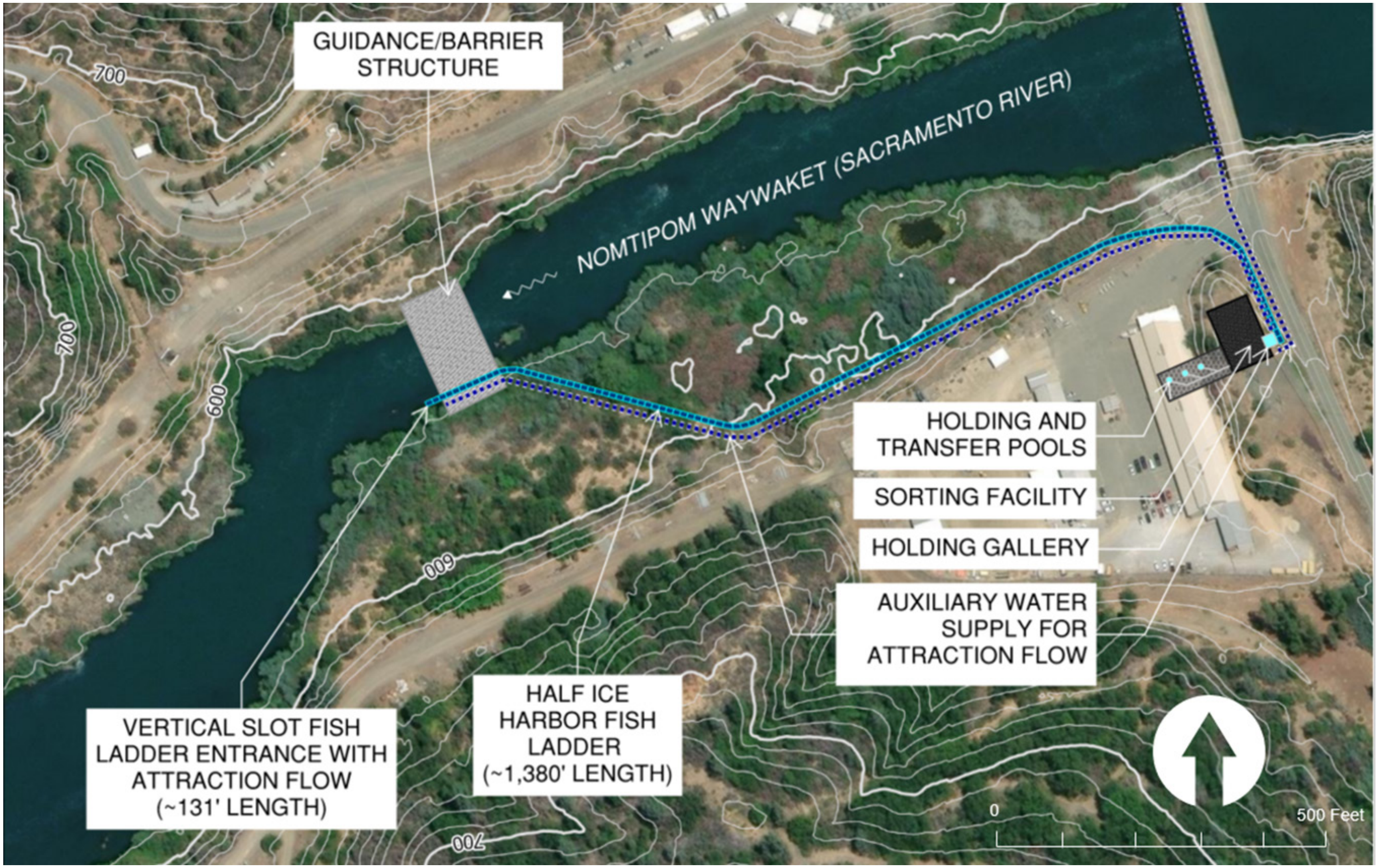
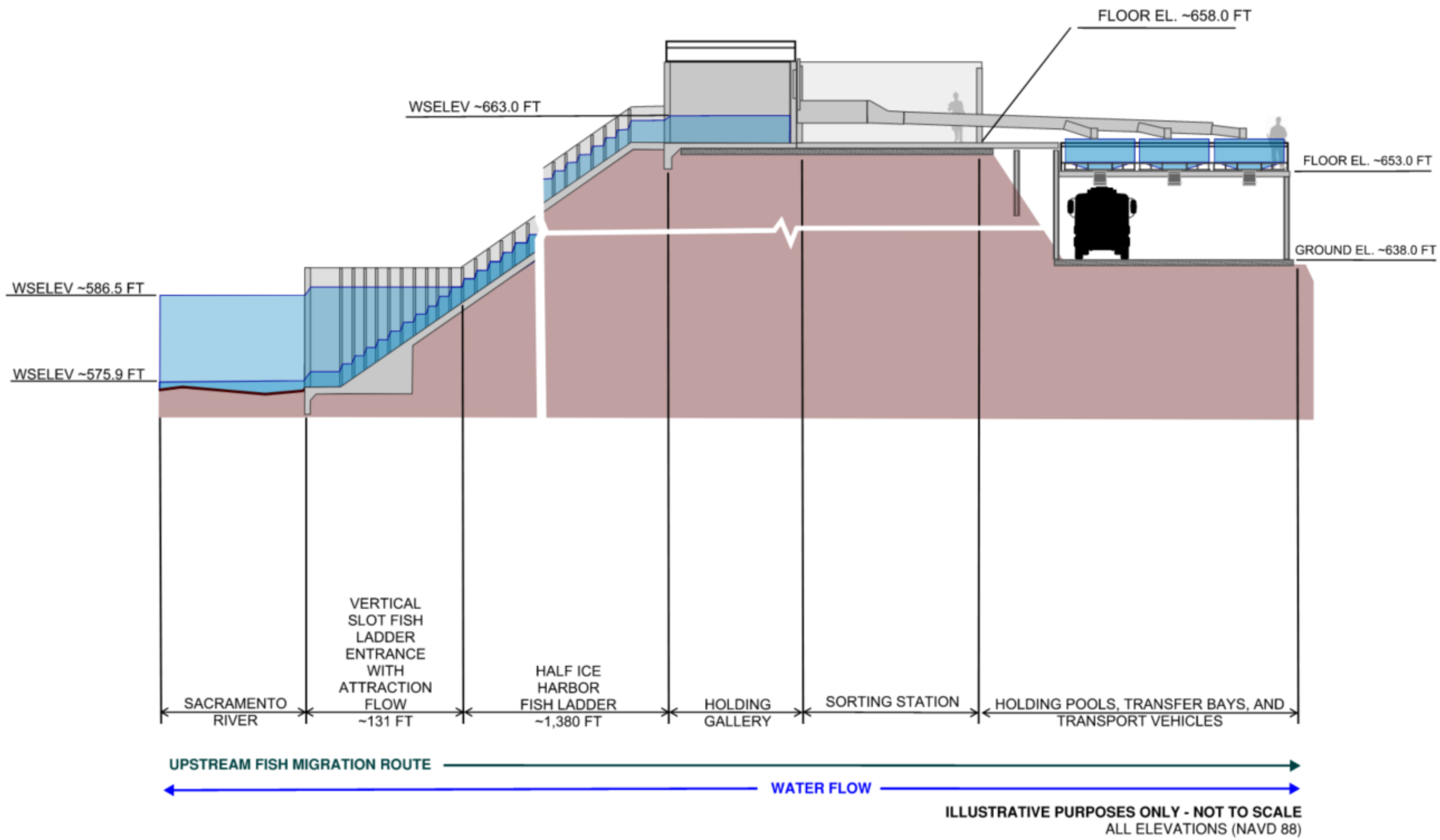


Figure 25
Trap and Haul Facility (Profile)



Trap and haul was not included in the thermal suitability analysis documented in *Thermal Accumulation in Migratory Corridors and Channels* (Appendix J), as Alternative 3 poses a higher thermal accumulation risk since it includes similar functional elements and a larger total ladder length. Table 17 summarizes anticipated water requirements for trap and haul based upon elements in the preliminary design presented within this section. The water requirements consider the most conservative assumptions (e.g., highest flow requirement) to include worst-case scenario water requirements.

Table 17
Trap and Haul Water Requirements

Element	Flow Requirement (cfs)	Water Source
Keswick Dam fish ladder	35 - 50	Keswick Reservoir
Keswick Dam fish ladder attraction flow[1]	400	Keswick Reservoir
Keswick Dam adult return flume	25	Keswick Reservoir
Keswick Dam surface flow outlet	750	Keswick Reservoir, Nomtipom Waywaket
Shasta Dam fish ladder	35 - 50	Shasta Reservoir
Shasta Dam adult return flume	25	Shasta Reservoir
Shasta Dam fish ladder attraction flow[1]	400	Shasta Powerhouse, Shasta Reservoir
Process at Shasta holding facility	20	Shasta Powerhouse, Shasta Reservoir
Total	**1,690 - 1,720**	-

Note:
1. Attraction flows modified from NMFS (2023) criteria as described in Section 2.8.3

4.5 Downstream Fish Migration Guidance and Collection

Downstream migrating juvenile Chinook Salmon would be guided from the Winnemem Waywaket to a collection pool using a fixed, in-river juvenile fish guidance/barrier system that would operate effectively across a broad range of river flow conditions. The guidance/barrier system for Alternative 1 would route fish back into the volitional channel, and for Alternatives 2 through 3 and trap and haul would route fish to a juvenile collection facility. After collection, juvenile Chinook Salmon would be transferred into transport pods and transported to either the fish lift via water-to-water transfer (Alternative 2), or Shasta Dam via barge or truck (Alternatives 3 and trap and haul). The location and design of the guidance and collection facility will be finalized through future design efforts.

Downstream passage was not included in the thermal suitability analysis documented in *Thermal Accumulation in Migratory Corridors and Channels* (Appendix J), as flows that would be used for the guidance/barrier system would be returned to the river. Table 18 summarizes anticipated water requirements for the downstream migration guidance and collection facility.

Table 18
Downstream Fish Migration Guidance and Collection Facility (Alternatives 2 – 3 and Trap and Haul) Water Requirements

Element	Flow Requirement (cfs)	Water Source
Juvenile collection and transport facility	20	Winnemem Waywaket
Total	**20**	-

5 Summary of Findings

This document summarizes the design criteria and outlines the preliminary hydraulic design of functional elements shared across multiple alternatives. It also incorporates findings from *Thermal Accumulation in Migratory Corridors and Channels* (Appendix J) to estimate the preliminary water quantity requirements for each alternative. Data gaps identified are discussed in Section 5.1.

5.1 Data Gaps

Data gaps were identified for each alternative as detailed below.

5.1.1 Alternative 1: Volitional Tributary Bypass from Cow Creek to the Winnemem Waywaket and Alternative 2: Semi-Volitional Tributary Bypass from ACID Dam to the Winnemem Waywaket via Railroad Grade

The source of water for both Alternative 1 and Alternative 2 is presumed to be the Winnemem Waywaket, originating from the constructed channel's confluence with the Winnemem Waywaket near Chatterdown Creek. As discussed previously and in *Thermal Accumulation in Migratory Corridors and Channels* (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. One possible considered solution was to provide a buried pipe system with water from the Winnemem Waywaket to inject cool water to the constructed channel during warmer months. Based on the results from the thermal accumulation analysis (*Thermal Accumulation in Migratory Corridors and Channels* [Appendix J]), cool water injection from a buried pipe carrying water originating from the Winnemem Waywaket would not provide benefits to the tributary bypass because the temperature of the water in the buried pipe would be the same as that in the constructed channel, due to the fact that passage of the water through the tunnels in the alternative will always return the water to the same temperature as the ambient tunnel temperature.

Other water sources could be investigated for Alternative 1 and 2 to help reduce the water temperature, which could result in an increased amount of water required for the tributary bypass. Other potential water sources may include:

- Pit River / Pit 7 Power House
- Groundwater and private wells within the Dry Creek, Little Cow Creek, and Cow Creek watersheds

- Existing water supply systems such as Jones Valley County Service Area No. 6

Additionally, there is no guidance facility proposed at the confluence of the Nomtipom Waywaket and Cow Creek for Alternative 1 at this time. As fish migrate upstream, fish would either continue swimming up the Nomtipom Waywaket or would enter the smaller Cow Creek tributary to begin migrating through the volitional tributary bypass. Homing cues, particularly since flow augmentation within Cow Creek would be sourced from the Winnemem Waywaket, may provide attraction and allow fish to enter Cow Creek of their own volition. There is a high level of uncertainty associated with this method because there are no examples of past projects using homing cues within the water source as the method of attraction flow. Further study and pilot testing may be needed at subsequent stages of design to inform the method of attraction to be used at the confluence of the Nomtipom Waywaket and Cow Creek, which could result in an increased amount of water required for the alternative. Additionally, the Winnemem Wintu Tribe has been conducting ceremonies and laying down prayers along the volitional tributary bypass, including the confluence. The Consultant Team's interpretation of the Tribe's Indigenous Traditional Ecological Knowledge suggests that the ceremonies and prayers, among other cues, will help the Chinook Salmon find their way back to the Winnemem Waywaket.

5.1.2 Alternative 3: Semi-Volitional Passage in the Nomtipom Waywaket over Keswick and Shasta Dams to the Winnemem Waywaket

Additional information regarding water temperature at varying locations and depths within Keswick and Shasta reservoirs would provide context for identifying the best location to implement pumps to provide adequate cold water to the fish ladders.

6 References

Allen, Mark. 2000. Seasonal Microhabitat Use by Juvenile Spring Chinook Salmon in the Yakima River Basin Washington.

Anchor QEA, 2026. *Nomtipom Waywaket Chinook Salmon Life Historical Summary*. Study of Physical Data Gaps to Inform the Implementation of Nur Rematriation Upstream of Shasta Dam. January 2026.

Anchor QEA and HDR, 2026. *Background Compendium and Design Criteria Report for the Feasibility of Volitional Fish Passage above Keswick and Shasta Dams*.

Anchor QEA and HDR Engineering, Inc., 2026. *Alternatives Formulation and Evaluation Report*. Feasibility Study of Salmon Passage at Shasta and Keswick Dams. January 2026.

Burner, Clifford J. 1951. Characteristics of Spawning Nests of Columbia River Salmon. United States Department of the Interior, Fish and Wildlife Service.

California Department of Fish and Wildlife (CDFW). 2017. Standard Operating Procedure for Critical Riffle Analysis for Fish Passage. CDFW-IFP-001. Accessed 20 Feb 2025.

California Department of Transportation (CalTrans). 2020. Highway Design Manual 7th Edition.

CalTrans. 2025. Transportation Permits (Oversize/Overweight Vehicles). Accessed July 3, 2025.

Carter, K. 2008. Effects of Temperature, Dissolved Oxygen/Total Dissolved Gas, Ammonia, and pH on Salmonids Implications for California's North Coast.

Chambers, J.S., G.H. Allen and R.T. Pressey. 1955. Research relating to study of spawning gravels in natural areas. Annual Report 1955. Wash. Dept. Fisheries. Olympia.

Chow, V.T. 1959. Open Channel Hydraulics. McGraw-Hill, New York.

Hamilton, R., and Buell, J.W. 1976. Effects of modified hydrology on Campbell River salmonids. Technical Report Series No. PAC/T-76-20. Department of the Environment, Fisheries and Marine Service, Habitat Protection Directorate, Vancouver, B.C.

Keeley, E.R. and Slaney, P.A. 1996. Quantitative Measures of Rearing and Spawning Habitat Characteristics for Stream-Dwelling Salmonids: Guidelines for Habitat Restoration. Province of British Columbia, Ministry of Environment, Lands and Parks, and Ministry of Forests. Watershed Restoration Project Report 4.

Myrick, C. A., and J. J. Cech. 2004. Temperature effects on juvenile anadromous salmonids in California's Central Valley: what don't we know? Reviews in Fish Biology and Fisheries 14:113–123.

National Marine Fisheries Service (NMFS). 2023. NOAA Fisheries West Coast Region Anadromous Salmonid Passage Design Manual, NMFS, WCR, Portland, Oregon. Addendum No. 1 Issue Date February 22, 2023.

USEPA. 2003. EPA Region 10 Guidance for Pacific Northwest State and Tribal Temperature Water Quality Standards.

Zillig, K.W., 2022. *Variation in Thermal Physiology Among Chinook Salmon Populations*. Dissertation. Davis, California. University of California, Davis.

Zillig, K.W., A.M. FitzGerald, R.A. Lusardi, D.E. Cocherell, N.A. Fangue, 2023. "Intraspecific variation among Chinook Salmon populations indicates physiological adaptation to local environmental conditions." *Conservation Physiology*, 11(1).

Zillig, K.W., H.N. Bell, A.M. FitzGerald, and N.A. Fangue, 2025. "Patterns of interpopulation variation and physiological trade-offs of the acute thermal tolerance of juvenile Chinook salmon (Oncorhynchus tshawytscha)." *Frontiers in Fish Science* 2:1508746.