FA-08 FISH ENTRAINMENT STUDY REPORT

SKAGIT RIVER HYDROELECTRIC PROJECT
FERC NO. 553

Seattle City Light

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Updated Study Report

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List of Acronyms and Abbreviations

ac-ft ....acre-feet
ADF&G......................Alaska Department of Fish and Game
ADW..........................Animal Diversity Web
BO.............................Biological Opinion
°C ....degrees Celsius
cfs..............................cubic feet per second
City Light...................Seattle City Light
CoSD..........................City of Seattle datum
EPRI...........................Electric Power Research institute
FERC..........................Federal Energy Regulatory Commission
fps..............................feet per second
ft................................feet
gpm ....gallons per minute
hr ....hour
ISR ....Initial Study Report
ITS.............................Incidental Take Statement
LP..............................licensing participant
m ....meter
mg/L..........................milligram per liter
mm ....millimeter
NAVD 88...................North American Vertical Datum of 1988
NMFS.........................National Marine Fisheries Service
NOAA........................National Oceanic and Atmospheric Administration
NPS ....National Park Service
PAD...........................Pre-Application Document
PRM ....Project River Mile
Project ....Skagit River Hydroelectric Project
RM ....river mile
RSP ....Revised Study Plan
SPD ....Study Plan Determination
sq. mi.........................square miles

TBSA ....Turbine Blade Strike Analysis

TL...............................total length

USFWS ......................U.S. Fish and Wildlife Service

USGS .........................U.S. Geological Survey

USR............................Updated Study Report

WDFW.......................Washington Department of Fish and Wildlife

WSE...........................water surface elevation

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1.0 INTRODUCTION

The FA-08 Fish Entrainment Study is being conducted in support of the relicensing of the Skagit River Hydroelectric Project (Project), Federal Energy Regulatory Commission (FERC) No. 553, as identified in the Revised Study Plan (RSP) submitted by Seattle City Light (City Light) on April 7, 2021 (City Light 2021a). On June 9, 2021, City Light filed a "Notice of Certain Agreements on Study Plans for the Skagit Relicensing" (June 9, 2021 Notice)[1] that detailed additional modifications to the RSP agreed to between City Light and supporting licensing participants (LP) (which include the Swinomish Indian Tribal Community, Upper Skagit Indian Tribe, National Marine Fisheries Service [NMFS], National Park Service [NPS], U.S. Fish and Wildlife Service [USFWS], Washington State Department of Ecology, and Washington Department of Fish and Wildlife [WDFW]). The June 9, 2021 Notice included agreed to modifications to the Fish Entrainment Study.

In its July 16, 2021 Study Plan Determination (SPD), FERC approved the Fish Entrainment Study with modifications. Specifically, FERC did not require City Light to conduct field-based entrainment studies during the second study season. Notwithstanding, City Light is implementing the Fish Entrainment Study as proposed in the RSP with the agreed to modifications described in the June 9, 2021 Notice.

Although FERC ultimately did not require a field-based entrainment study in the SPD, City Light agreed to evaluate the need for a field-based entrainment study following the completion of a desktop analysis in Year 1, as stated in the June 9, 2021 Notice. Therefore, this report details the methods, results, and conclusions of the desktop assessment portion of the Fish Entrainment Study and assesses the need for a field-based entrainment study.

On March 8, 2022, City Light filed its Initial Study Report (ISR). WDFW, NPS, and the Upper Skagit Indian Tribe filed requests for study modification. FERC's August 8, 2022 Determination on Requests for Study Modifications required no modifications to the Fish Entrainment Study.

This study is complete[2] and a report of the study efforts is being filed with FERC as part of City Light's Updated Study Report (USR).

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1 Referred to by FERC in its July 16, 2021 Study Plan Determination as the "updated RSP."

2 This study report was complete with the filing of the ISR. Except for updates to the title page, attachment cover pages, headers and footers, and this Section 1.0, no other changes were made to this study report.

2.0 STUDY GOALS AND OBJECTIVES

Fish that reside in the Project reservoirs may be susceptible to impingement on trashracks or entrainment through operating turbines or other non-turbine flow pathways (e.g., bypass channels, spillways, etc.). The goals of this study are to evaluate fish impingement and entrainment at the Ross, Diablo, and Gorge dams and the potential effect on the Skagit River fish community.

Specific objectives to meet these goals are to:

- Describe the physical characteristics of the Project powerhouses and intake structures, including locations, dimensions, turbine specifications, and trashrack spacing.
- Summarize water quality characteristics in the vicinity of the Project intake structures using existing data or data collected as part of the FA-01a Water Quality Monitoring Study.
- Estimate intake velocities at each of the intake structures at Ross, Diablo, and Gorge dams.
- Describe the fish community and compile a target species list for entrainment and impingement analyses.
- Characterize the risk of impingement to target species based on Project intake velocities, trashrack bar spacing, and target species life history information and estimated swim speeds.
- Characterize the risk of turbine and non-turbine (e.g., spillway or bypass) entrainment to target species based on body size, life stage, periodicity, habitat requirements, and Project operations (i.e., velocities, spill versus generation).
- Conduct a literature review and desktop analysis of historical turbine entrainment and entrainment survival studies to estimate turbine entrainment and entrainment survival at Project intakes.
- Characterize probability of passage and survival for target species at the Project facilities (turbine and spillway passage) using site-specific physical and operational parameters, estimated non-turbine (spillway) entrainment mortality rates, and the USFWS Turbine Blade Strike Analysis Model (USFWS 2020).
- Provide a qualitative summary of entrainment and impingement potential for target species at the Project facilities based on physical and operational information, turbine and non-turbine entrainment and mortality rates, comparison of burst swim speeds to intake velocity, body size exclusion, and species and life stage periodicity.

In addition to the above, the June 9, 2021 Notice identified two additional goals of this Fish Entrainment Study: (1) inform the need for further entrainment studies during the second year of study and potentially a longer-term study; and (2) inform future assessments of passage, abundance, migration, and survival through entrainment and entrainment of each potential downstream passage route: turbines, spillway, bypasses or gates, for all size classes of Bull Trout (*Salvelinus confluentus*), native fishes, and nonnative fishes at each of the unique Project structures.

2.1 Project Operations and Potential Effects on Resources

2.1.1 Background

This study evaluated the potential direct effects of Project operations on reservoir fish populations in the form of fish impingement and entrainment at Project facilities. Downstream fish passage through hydroelectric facilities via water intakes and turbine and non-turbine flow pathways (e.g., bypass channels, spillways, etc.) may result in injury or mortality. Injuries and mortalities can result from fish becoming impinged against trashracks, encountering the turbine blades or other mechanical components or natural structures during passage over the spillway ("spillway entrainment"), and/or pressure changes and cavitation through the Project facilities.

The potential for fish to become impinged or entrained at a hydroelectric facility depends on a variety of factors such as fish life history, size, and swimming ability; water quality; operating regimes (i.e., generation versus spill); inflow; magnitude of intake velocities; trashrack bar spacing; and intake/turbine configurations (Čada et al. 1997). Proximity to feeding and rearing habitats can also influence fish impingement and entrainment risk. Impingement occurs when a fish does not pass through the trashrack but is instead held against (impinged) the racks due to forces created by the intake velocities. Entrainment happens when a fish is passed through the Project structures and can occur through turbine and non-turbine pathways (e.g., spillway entrainment). These factors and several others are used to make general assessments of impingement and entrainment risk at hydroelectric projects using a desktop study approach.

A gradient of fish impingement and entrainment potential at hydroelectric facilities exist both temporally and spatially related to typical fluctuations in abundance (i.e., higher abundance after dispersal) or diurnal or seasonal movements. Physical and operational characteristics of a project, including trashrack bar spacing, intake velocities, intake depth, thermal stratification, intake proximity to feeding and rearing habitats, and frequency of generation versus spill can also affect the potential for a fish to become entrained. These and several other factors are used to make general assessments of entrainment and impingement potential at hydroelectric projects using a desktop study approach.

2.1.2 Existing Information

The Project's intake structures and spillways are unscreened and, as a result, fish residing in the Project reservoirs could be entrained into the Project's intakes and turbines or enter the Project's spillways during spill events (City Light 2020a). Fish that become entrained into these facilities may survive and add to the fish populations located downstream of the powerhouse or suffer mortality or injury. Fish entrainment was not studied as part of the previous Project relicensing.

Entrainment at Ross, Diablo, and Gorge dams may potentially occur whenever generation is underway, which is almost constant on a year-round basis except during short periods of planned or unplanned outages during which spillway entrainment could occur (City Light 2020a). On an annual basis, the Project facilities spill 1 to 2 percent of the time with spill flows and duration varying greatly, ranging from a few hundred to a few thousand cubic feet per second (cfs) and for as short as an hour to several days or weeks at a time depending on the circumstances. From 2015 to 2020, Ross Dam spilled an average of 6 days (Table 2.2-1). Gorge and Diablo dams were similar in that they spilled 37 and 39 days, respectively.

Table 2.2-1. Number of days of spill from 2015 to 2020.

Project Reservoir	2015	2016	2017	2018	2019	2020	Average Annual
Ross Lake	10	0	0	0	0	11	6
Diablo Lake	14	24	195[1]	203[1]	64	54	39[2]
Gorge Lake	11	37	29	35	2	17	37

Source: City Light 2016, 2017, 2018, 2019, 2020b, 2021b.

1 Extended maintenance outages at Diablo powerhouse in 2017 and 2018 (in comparison, average spill at Diablo Dam in 2015, 2016, 2019, and 2020 was 39 days).

2 Excluding 2017 and 2018 due to maintenance outages.

2.1.2.1 Recent and Ongoing Field-based Bull Trout Entrainment Studies

Biological Evaluation – Impacts of Entrainment on Bull Trout (City Light 2012)

2009-2012 Acoustic Tracking

City Light conducted a study of habitat use (including depths and temperatures), daily migration patterns, and seasonal migration timing of Bull Trout in Ross Lake using acoustic telemetry from 2009 to 2012 (City Light 2012). The internal acoustic tags transmitted an ultrasonic signal at approximately two-minute intervals for a period of about two years. These tags were digitally encoded with an identification number for each tagged fish. A subset of tags recorded pressure and/or temperature, transmitting the depth and temperature of the tag along with the identification number. Acoustic signals were recorded on a continuous basis with receivers deployed underwater on long-line cables from fixed objects on the shore or suspended on vertical cables from floating objects (e.g., boat dock, logbooms). Twelve receivers were deployed in Ross Lake with three receivers located in the dam forebay and a fourth located on the Ross Lake Resort dock. The locations for the remainder of the receivers spanned the length of Ross Lake and included the mouths of the major tributaries. Acoustic tags were implanted in 42 Bull Trout ranging from 365-600 millimeters (mm) during the fall of 2009.

All 42 Bull Trout were detected during fall 2009 through winter 2012 (City Light 2012). An analysis of tag detections over time indicates that Bull Trout were detected on nearly a continuous basis, with the only major gaps in detections observed when some fish likely moved into tributary streams in August and September prior to spawning. These fish were later detected after returning to the reservoir in October and November following spawning. The majority of the tagged fish (31 out of 42) were last detected at receivers located near the mouths of the tributaries. Two fish were last detected at the "Ross Dam" acoustic receiver located near the intake. One of the fish was determined to have died. The second fish made several vertical movements in the Ross Dam forebay before being detected at a depth of 55 feet (ft) in front of the intake and was then assumed to have been entrained.

An analysis of time spent in the vicinity of the intake forebay indicated the majority of the fish spent 1 percent or less of the tag battery lifespan (approximately three years, however two tags lasted five years) in the vicinity of the intake forebay. Five fish never migrated into the intake forebay area; conversely, another five fish frequented the intake forebay area. Only one of the five "frequent users" of the intake forebay was determined to have been entrained. Most (50 percent) of the detections in the intake forebay area occurred during May and October. The least number of detections near the intakes occurred during the winter months of January, March, and the summer months of July and August.

Results of this study suggest that most of the Bull Trout in Ross Lake spend relatively little time in the intake forebay. Acoustic tagging results for Bull Trout in comparable waterbodies with similar facilities also found that Bull Trout occupied the intake forebays at relatively low rates, instead preferring the upstream portions of the reservoirs (Martins et al. 2013; Harrison et al 2020). This conclusion is also supported by the genetic distinction between Bull Trout populations upstream and downstream of the Project reservoirs (Smith 2010). None of the several hundred Bull Trout sampled downstream exhibited genetic contributions from Bull Trout populations above the dams.

Intake Entrainment and Mortality Estimation

Incidental take from entrainment for the entire Skagit Project's existing operations was initially estimated to develop a baseline from which to evaluate a potential increase in take from the proposed—but not implemented—'Gorge Second Tunnel' project (City Light 2012). This project was formerly considered for conveyance of additional waters to the Gorge Powerhouse and was formally consulted on under Section 7 of the ESA for impacts to Bull Trout (USFWS 2013). While not implemented, the baseline analysis of turbine and spillway mortalities from entrainment are relevant to the analysis of future operations considered under relicensing because the method for estimating annual take continues to be employed under the current license. As such, the estimation that was performed for the study is summarized below.

<u>Ross Lake</u>

Entrainment and mortality of Ross Lake Bull Trout were estimated from a review of the acoustic monitoring data over the two years of the study (City Light 2012). Based on an analysis of over 2.4 million data points, one of the 42 Bull Trout tagged was entrained through the Ross intake (i.e., 1.19 percent). To estimate a population-level entrainment rate from the Project operations involving Ross Lake, a population estimate for Bull Trout was required. Using data derived from Canadian spawning ground index surveys that were assumed to represent 40 percent of the usable spawning habitat in the system, the (rounded) Ross Lake Bull Trout spawning population of Bull Trout was estimated at 4,800 fish. Although a portion of the Bull Trout population was recognized to be unaccounted for in spawning ground surveys (estimated at 30 percent), the spawning population was used as the basis for entrainment, as the acoustic data suggested that the spawning population was the component of the total population vulnerable to entrainment based on their high mobility and detection of spawning sized tagged fish frequently observed within the forebay. Acoustic telemetry data further showed that numerous tagged fish could disappear from detection amongst the array for well over a year at times and reappear in the detection array at a later time, indicating their movement back into tributary streams for long term fluvial residency—and inaccessibility to entrainment (Connor 2022). These assumptions were supported by the USFWS in their take authorization (USFWS 2013). Thus, from the entrainment data and population size estimation, 57 Bull Trout were estimated to be entrained annually in Ross turbines by multiplying the spawning population estimate by the percentage of tagged fish documented to be entrained in this study (1.19 percent/year). Assuming 22 percent turbine mortality, an annual turbine mortality estimate of 13 fish was calculated.

Diablo and Gorge

Acoustic tracking of Bull Trout in Diablo and Gorge lakes was not conducted during this study period and incidental take for the Diablo and Gorge operations was estimated based on the assumption that the percentage of Bull Trout entrained in Diablo and Gorge reservoirs would be proportionally greater than Ross Lake based on Diablo and Gorge having larger size intake structures relative to the surface area of Diablo and Gorge lakes, respectively. The intake surface area to reservoir surface area ratio for each facility was divided by the ratio for Ross Lake to obtain multipliers that were applied to the annual percentage of fish entrained in Ross Lake. This analysis provided estimates of the annual percentage of the Bull Trout population entrained at Diablo and Gorge lakes of 4.3 percent and 16.4 percent, respectively. Applying the annual turbine mortality rate, the incidental take of adult Bull Trout was estimated to be four Bull Trout each at Diablo and Gorge dams during this study period. Estimates of entrainment of Bull Trout using this methodology are provided to the USFWS annually from the tagging program, which is ongoing as a compliance condition of the current FERC license.

Spillway Entrainment and Mortality

Ross

Spill mortality at Ross Dam was calculated using the percentage of time that Bull Trout spent in the forebay area from the analysis of data from acoustically tagged fish. This analysis determined that Bull Trout spent an average 3.2 percent of their residency time within the forebay of Ross Lake per year in the zone where they could be entrained by spill. Based on the spill frequency analysis used from the data over the course of the study, spills occurred an average of 0.6 percent of the time annually. The percentage of time in which Bull Trout were considered vulnerable to spill was obtained by multiplying the average time that the tagged Bull Trout spent in the forebay by the amount of time that spill occurred (0.032 x 0.006 = 0.019 percent). An estimate of annual spill mortality was then calculated by multiplying the assumed population size by the percent of time Bull Trout were assumed to reside in the forebay; 100 percent mortality was assumed for fish spilled and take was estimated at 1 fish per year (i.e., 4,800 x 0.00019 x 1 = 0.912 fish ~ 1 Bull Trout).

Although a 100 percent mortality rate for fish entrained in Ross spill was assumed for this analysis, earlier empirical evidence indicates that some fish may survive entrainment over the Ross spillway. During an unusually long (60-day) spill event in 1972, 14 Rainbow Trout (*Oncorhynchus mykiss*) tagged in Ross Lake were recaptured in both Diablo and Gorge lakes (Johnston 1989). The 14 Rainbow Trout comprised 2 fish tagged in 1971 (of 514 Rainbow Trout tagged, or 0.4 percent) and 12 fish tagged in 1972 (of 837 Rainbow Trout tagged, or 1.4 percent).

Diablo and Gorge

The Ross Lake spill entrainment rate was adjusted by the percentage of time that the Diablo and Gorge facilities spilled annually and the volumes of each reservoir to obtain estimates of the annual spillway entrainment rates for each facility. The number of Bull Trout entrained into the spillways of Diablo Dam each year would be 12 fish, and the number entrained into the spillways of Gorge Dam would be 32 fish. Estimates of spillway mortality based on field and laboratory studies from similar facilities were 55 percent for Diablo and 10 percent for Gorge (City Light 2012) (see

Section 4.6.2 of this study report). Thus, the annual incidental take for the Diablo and Gorge spillways was estimated at 6 and 3 adult Bull Trout, respectively.

Incidental Take Statement and Continued Acoustic Monitoring

The Incidental Take Statement (ITS; USFWS 2013) requires that City Light implement an annual Bull Trout acoustic monitoring program and submit an annual Bull Trout take report. The monitoring program was initiated in early 2013 following the issuance of the ITS and is required to be continued through the duration of the existing license. Vemco VR2W acoustic receivers installed in all three reservoirs are used to monitor the movement of Bull Trout, to detect the entrainment of fish surgically implanted with acoustic transmitter tags into the power tunnel intakes, and to determine whether any entrained fish survive passing from the power tunnels through the turbines. The goal of the annual monitoring program for Bull Trout is to maintain 30 active tags in Ross Lake, 10 in Diablo Lake, and 10 in Gorge Lake. Intake forebay acoustic receiver arrays were designed specifically to track the movement of tagged Bull Trout in the areas of the reservoirs where entrainment of fish into the power intakes and spillways could potentially occur. In addition, receivers were located immediately downstream of each facility in the tailrace to detect tagged trout that were entrained through the turbines or over the spillways.

Similar to the findings of the 2009-2012 telemetry study summarized above (City Light 2012), results of the ongoing acoustic monitoring program from 2015 to 2020 indicated low instance and risk of entrainment of adult Bull Trout at the Project (City Light 2016, 2017, 2018, 2019, 2020b, 2021b) (Table 2.2-2). During the monitoring period, only two fish were entrained at the Diablo intake (one in 2016 and one in 2018), comprising 4.0 percent of all tracked fish in Diablo Lake (2 of 50 active tags). These fish survived passage through the turbines as evident by the detection of these tagged fish in Gorge Lake for many months. No tagged fish were observed to be entrained at Ross or Gorge dams during the monitoring period. Therefore, the estimated take due to turbine entrainment from 2015 to 2020 was zero fish.

Table 2.2-2. Acoustic monitoring program results 2015-2020.

Project Reservoir	Number of Fish	2015	2016	2017	2018	2019	2020	Total
Ross Lake	Number of Active Tags	50	31	37	20	20	31	189
	Number Fish Entrained	0	0	0	0	0	0	0
Diablo Lake	Number of Active Tags	11	4	4	11	11	9	50
	Number Fish Entrained	0	1 (25%)	0	1 (9%)	0	0	2
Gorge Lake	Number of Active Tags	14	11	10	10	10	8	63
	Number Fish Entrained	0	0	0	0	0	0	0

Source: City Light 2016, 2017, 2018, 2019, 2020b, 2021b.

Forebay usage varied greatly among the three Project reservoirs based on analysis of fish movements (i.e., number of acoustic receiver detections) from 2015 to 2018 (City Light 2016, 2017, 2018, 2019). Forebay presence in Ross Lake ranged from 18 percent in 2017 to 79 percent in 2018 (Table 2.2-2), with an average of 55 percent. The elevated frequency in 2018 was largely attributable to only two fish which may have established foraging territories near Ross Lake Resort and Ross Lake Boathouse. Excluding 2018 from this analysis reduces forebay frequency in Ross

Lake to 47 percent. While Bull Trout appear to frequent the Ross Lake forebay regularly based on these acoustic detections, the presence of tagged fish in the intake zone was much less and ranged from 1.6 percent in 2016 to 25 percent in 2018, with an average of 10.6 percent. Furthermore, although tagged Bull Trout spend time in the forebay, no tagged fish were entrained during the monitoring period, suggesting these fish have limited risk either due to proximity to the intake (limited use of the area near the intake) and/or due to the ability of the fish to swim away from the area (i.e., escape intake approach velocity).

Forebay usage was substantially lower for Diablo and Gorge lakes (Table 2.2-3); however, there were elevated detection rates in the Diablo forebay in 2018 for unknown reasons and may represent the fish that passed through the turbines that year (Table 2.2-2). Notably, in the past six years of monitoring, no tagged Bull Trout in Gorge have been detected by receivers long established in this reservoir from below the Stetattle Creek confluence to the forebay. Why Bull Trout tagged in the upper portion of Gorge Lake appear to avoid the lower portion of the impoundment remains a focus of ongoing research. Further effort to tag Bull Trout in the lower reservoir is being pursued.

Table 2.2-3. Acoustic monitoring study results 2015-2020.

	Ross		Diablo	Gorge
Year	**Forebay[1]**	**Intake Zone[2]**	**Forebay[3]**	**Forebay**
2015	55.0	13.5	5.1	0.1
2016	68.0	1.6	1.3	1.6
2017	18.0	2.1	1.8	0
2018	79.0	25.0	27.0 (intake area) 45.0 (spillway area)	0
Average	**55.0**	**10.6**	**2.7**	**0.4**

Source: City Light 2016, 2017, 2018, 2019.
1 Percent of all detections in the reservoir.
2 Percent of forebay detections.
3 Represents combined intake and spillway area detections unless otherwise noted.

The acoustic monitoring study also indicated no spillway passage of Bull Trout during the 2015-2020 monitoring period except for one fish assumed to pass over the Gorge Dam spillway in 2016. Tagged fish passing over the spillways would first be detected in the forebay areas of the three dams then detected later by receivers located downstream of these facilities.

In addition to estimating take from turbine and spillway entrainment from the acoustically tagged fish, the ITS for Bull Trout (USFWS 2013) requires the estimation of spillway mortality based on the number of days of spill that are recorded during the year at each facility. This method conservatively overestimates annual spillway take as a protective measure for this species. Using this method, estimated take of Bull Trout between 2015 and 2020 varied widely depending on the days of spill during the monitoring period (see Table 2.2-1), which included periods of extended facility outages due to maintenance (such as Diablo Dam in 2017 and 2018) (Table 2.2-4).

Table 2.2-4. Summary of spillway mortality take estimates based on days of spill, 2015-2020.

Project Reservoir	2015	2016	2017	2018	2019	2020	Total[1]
Ross Lake	5	0	0	0	0	3	8
Diablo Lake	4	6	52	54	17	14	147
Gorge Lake	2	6[2]	4	5	0	3	20

Source: City Light 2016, 2017, 2018, 2019, 2020b, 2021b.

1 Authorize take for the Project is 435 Bull Trout from 2013-2025 (USFWS 2013).

2 Extended maintenance outages at Diablo powerhouse in 2017 and 2018 (in comparison, average spill at Diablo Dam from 2013-2016 was only 37 days).

3 Monitoring results suggest that one fish passed over the spillway at Gorge Dam in 2016.

City Light is expanding the acoustic telemetry monitoring program to include other species (in addition to Bull Trout) such as Rainbow Trout, Dolly Varden (*Salvelinus malma*), and Eastern Brook Trout in Project reservoirs to further inform understanding of interspecies interactions, behavior, and entrainment risk. Ongoing tracking of these fish will provide additional information on entrainment and entrainment risk of these species.

3.0 STUDY AREA

The study area includes Ross, Diablo, and Gorge dams, and specifically those locations nearest the existing intake structures within the reservoirs upstream of the facilities, the respective powerhouses, spillways, and the immediate tailraces. The locations of the Project facilities are depicted on Figure 3.0-1.

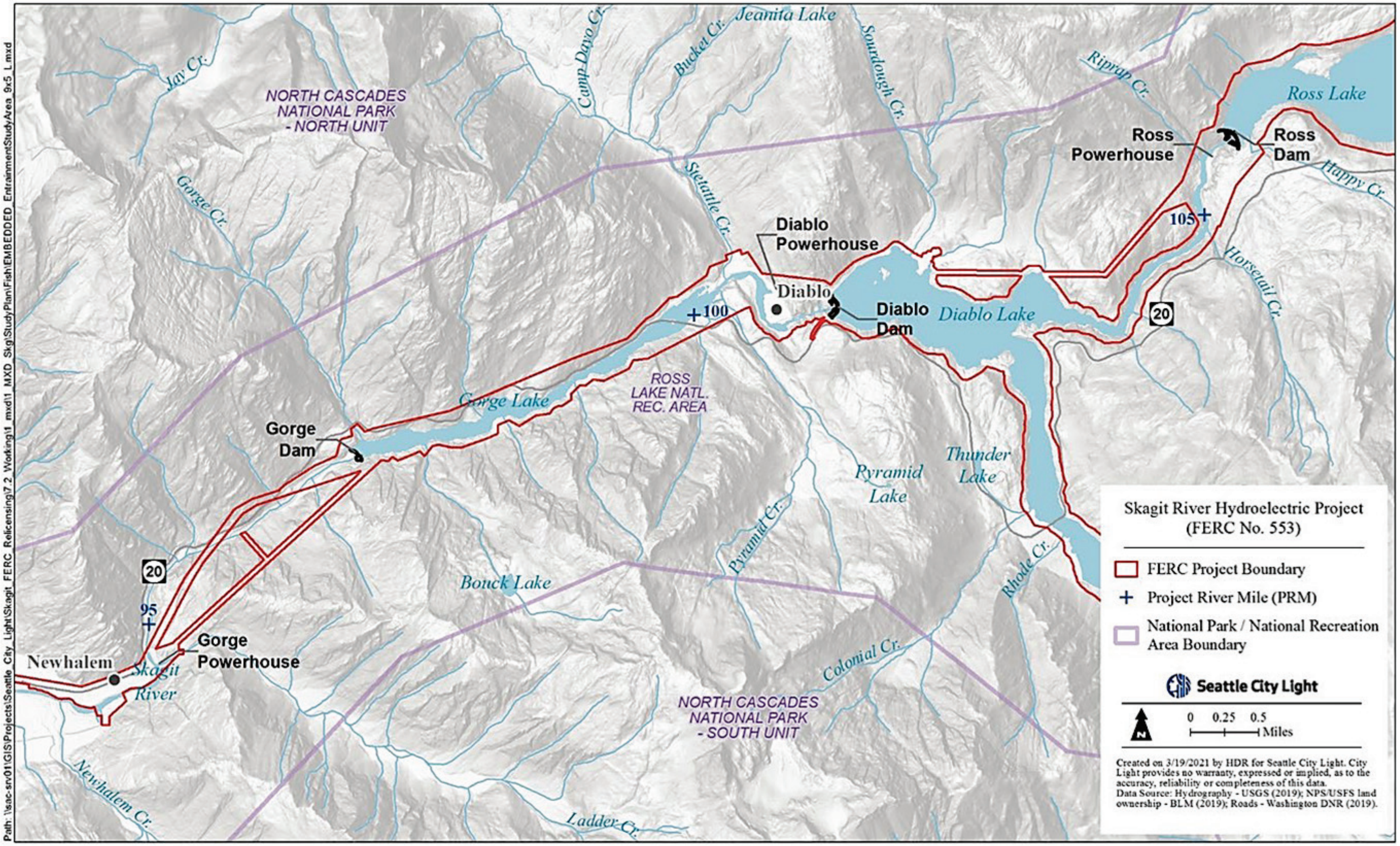

Figure 3.0-1. Study area for the Fish Entrainment Study for the Skagit River Hydroelectric Project.

3.1 Ross Dam

The Ross Dam is the furthest upstream of the three Project facilities. Ross Dam is located just upstream of Ross Powerhouse at Project River Mile (PRM) 105.5 (U.S. Geological Survey [USGS] River Mile [RM] 104.9); at 540 ft from bedrock to crest, it is the highest of the three Project dams (City Light 2020a). Ross Dam has a spillway on each side of the dam, each with six gates operated by an electric hoist. The Ross Powerhouse is about 1,100 ft downstream of Ross Dam, on the south side of Diablo Lake. Two concrete-lined power tunnels deliver water from the reservoir to four penstocks and into the powerhouse. Trashracks with 3.5-inch spacing are located at the entrance to the power tunnels intake structure. The Ross intake and dam with spillway are shown in Figure 3.1-1.

Ross Lake is nearly 24 miles long with a surface area of 11,680 acres and storage volume of 1,435,000 acre-feet (ac-ft) at the normal maximum water surface elevation (WSE) of 1,608.76 ft North American Vertical Datum of 1988 (NAVD 88) (1,602.5 ft City of Seattle Datum [CoSD]) (City Light 2020a). With a drainage basin of 381 square miles (sq. mi.) in British Columbia (USGS 2019), the Skagit River provides the greatest inflow into Ross Lake. There are, however, several tributaries that also make significant contributions. These include Ruby, Lightning, and Big Beaver creeks which drain 209, 133, and 64 sq. mi., respectively (USGS 2019). Several other smaller streams contribute as well, including Happy Creek which was diverted (circa 1962) via a tunnel into the reservoir from its original confluence with the Skagit River below the powerhouse.

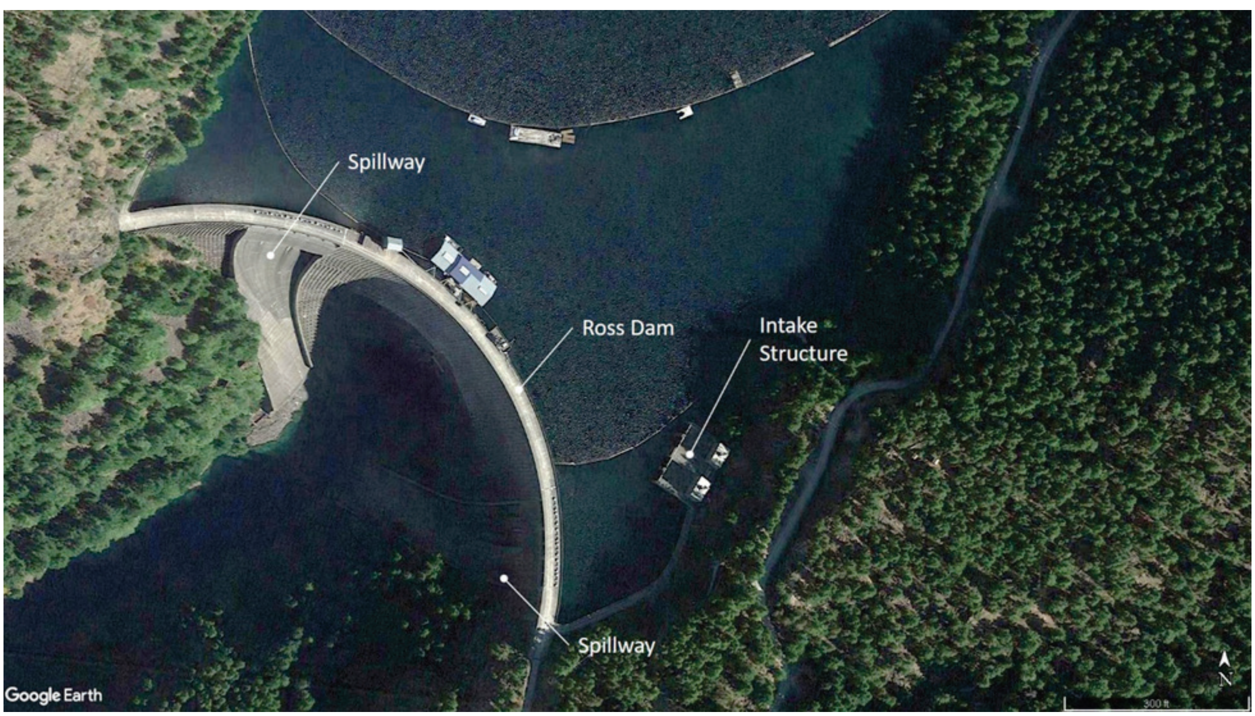

Figure 3.1-1. Aerial view of Ross Dam and appurtenant features at the Skagit River Hydroelectric Project.

3.2 Diablo Dam

The Diablo Dam is located about five miles upstream of Gorge Dam and four miles downstream of Ross Dam at PRM 101.6 (USGS RM 101.2) (City Light 2020a). In addition to generating power, it is used to reregulate flows between the other two facilities. The concrete arch dam is 389 ft from bedrock to crest. Diablo Dam has two spillways, one on each side, and a total of 19 spill gates: 7 on the south spillway and 12 on the north spillway. There are two bifurcated intakes at the dam but only one is in use. The second intake was originally planned for future expansion of the powerhouse, including a second tunnel, which was never constructed.

The Diablo Powerhouse is on the north bank of the Skagit River, about 4,000 ft downstream from Diablo Dam (City Light 2020a). Trashracks with 2.5-inch spacing are located at the entrance of a single power tunnel that conveys water to three penstocks and into the powerhouse. The Diablo intake and dam with spillway are shown in Figure 3.2-1.

Diablo Lake has a surface area of about 770 acres and gross storage of 50,000 ac-ft at a normal maximum WSE of 1,211.36 ft NAVD 88 (1,205 ft CoSD) (City Light 2020a). Tributaries to Diablo Lake include Thunder, Colonial, Rhode, Sourdough, and Deer creeks.

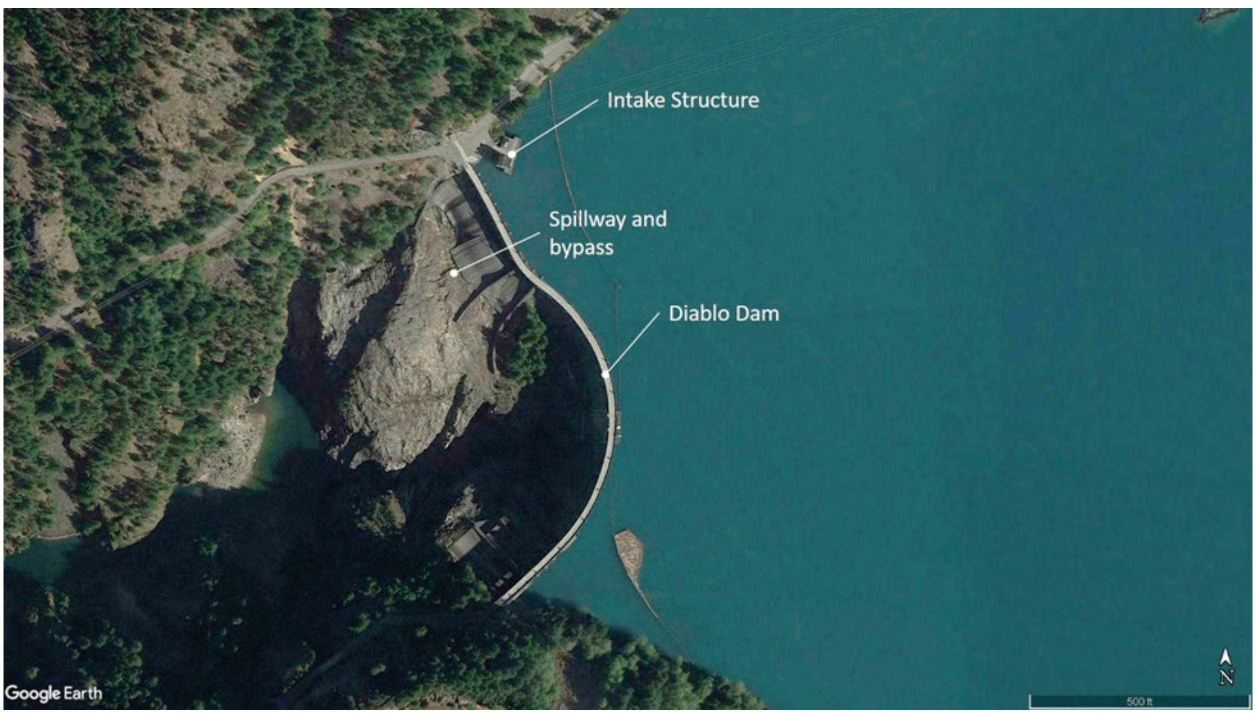

Figure 3.2-1. Aerial view of Diablo Dam and appurtenant features at the Skagit River Hydroelectric Project.

3.3 Gorge Dam

The Gorge Dam is the most downstream of the three Project facilities. In addition to power generation, it is responsible for regulating flows to the river downstream of the Project for fish protection, as stipulated by the current Project license (City Light 2020a). Water from Gorge Lake is conveyed via an intake structure in Gorge Dam into an 11,000-foot-long power tunnel to four penstocks that supply the powerhouse.

Gorge Dam is located at PRM 97.2 (USGS RM 96.6), about 2.5 miles upstream of the Gorge Powerhouse and 4.4 miles downstream of Diablo Dam (City Light 2020a). The concrete arch dam is 300 ft from bedrock to crest and has two spillways with electric hoist- operated gates. Trashracks with 3.5-inch spacing are located at the entrance of the power tunnel that conveys water to the penstocks and into the powerhouse. The Gorge intake and dam with spillway are depicted in Figure 3.3-1.

Gorge Lake is 4.5 miles long and extends to the base of Diablo Dam (City Light 2020a). At the normal maximum WSE of 881.51 ft NAVD 88 (875 ft CoSD), the reservoir has a surface area of 240 acres and gross storage of 8,500 ac-ft. Stetattle Creek, the only significant tributary to Gorge Lake, enters the Skagit River in a free-flowing section of river between the Diablo tailrace and the upper end of Gorge Lake.

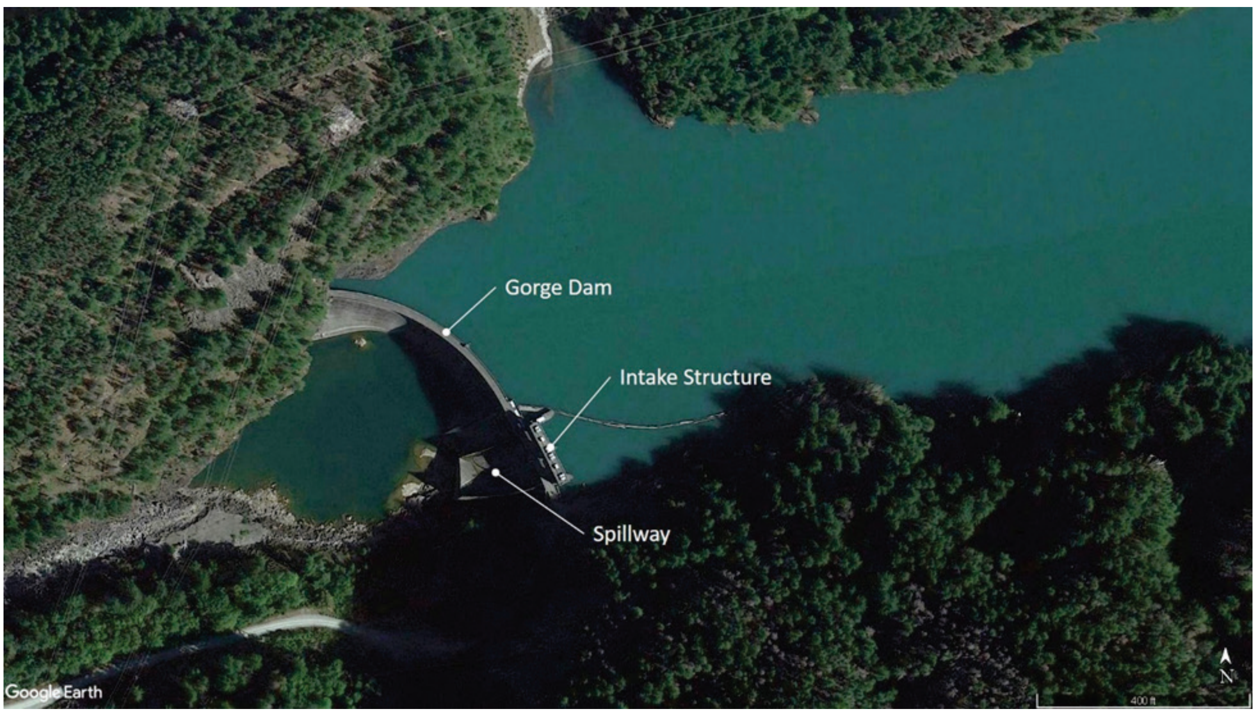

Figure 3.3-1. Aerial view of Gorge Dam and appurtenant features at the Skagit River Hydroelectric Project.

4.0 METHODS

City Light used a desktop assessment of fish entrainment and impingement as part of the RSP. Desktop analysis of entrainment and impingement at hydroelectric facilities is an approach that has been widely accepted by state and federal agencies and is considered a useful predictive tool in lieu of field studies (USFWS 2020). The desktop evaluation of the potential for fish entrainment, impingement, and associated mortality was performed based on the objectives described in Section 2.0 of this study report. This study included both qualitative and quantitative analyses such as evaluation of intake structural designs, intake velocities, water quality, fish life history characteristics and behavior, and estimate of entrainment rates.

Several entrainment studies of resident fish at hydroelectric projects have been performed over recent decades, with comprehensive reviews of those studies completed by FERC (1995), Electric Power Research Institute (EPRI; 1992 and 1997), and Winchell et al. (2000). Most of the studies included in these reviews were conducted on warm-water and cool-water fish species at low-head dams or run-of-river projects primarily located east of the Mississippi River, while reviews of other regionally relevant (i.e., west of the Mississippi) or structurally relevant (i.e., high head dams or deep-water intakes) studies are less common. Thus, entrainment studies such as Knutzen (1997), Devine Tarbell & Associates (2004), CH2MHILL (2007), Stable and Thomas (1992), and Meridian (2008) are more pertinent and applicable for evaluating entrainment risk at the Project reservoir intake structures. Results from these studies were considered in a traits-based approach to entrainment and impingement risk.

4.1 Intake Structural Characteristics and Velocities

As described in Sections 2.5.1 and 2.5.2 of the RSP, physical specifications and operational information were compiled and summarized for each of the Project reservoir intake structures. This information, such as intake structure depth and position, trashrack spacing, etc., were considered in various components of a traits-based risk assessment of entrainment and impingement.

Structural characteristics were used to calculate approach and through-bar velocities at each Project intake structure. Approach velocity is the average water velocity measured a few inches in front of the screen in the same direction as the flow; this velocity describes the velocity experienced by the fish as it swims freely near the front of the intake structure (i.e., trashracks) (EPRI 2000). Through-bar velocity is the velocity of the water as it passes between the structural components of the trashracks; by definition, through-bar velocity is always greater than approach velocity measured in front of the intake structure. Through-bar velocity would be experienced only when an organism is at the face of or passing through the trashracks. Velocities were calculated using normal, maximum and minimum (i.e., full draw-down) WSEs assuming maximum hydraulic capacities for the intake. The minimum WSE used in the calculation of approach and through-bar velocities was based on the minimum drawdown authorized by the current license, and therefore is likely greater than typical fluctuations.

4.2 Water Quality Characterization

As described in Section 2.5.1 of the RSP, existing water quality information was reviewed from the Project Pre-Application Document (PAD) (City Light 2020a) and the FA-01a Water Quality

Monitoring Study (City Light 2022a) to assess potential of water quality influence over fish distribution in the Project reservoirs; specifically, the depth at which fish may be found as affected by reservoir stratification. Therefore, an assessment of water temperature and dissolved oxygen concentrations by depth was performed as necessary part of this study.

4.3 Fish Community Characterization and Identification of Target Species

Existing information and data primarily reviewed from the PAD were used to characterize the fish community that may be susceptible to impingement and entrainment at Project facilities. Fish species included in this entrainment and impingement evaluation were also selected with input from LPs as provided in comments from the RSP and in accordance with commitments in the June 9, 2021 Notice.

4.4 Qualitative Risk of Entrainment and Impingement

Per Section 2.5.7 in the RSP, a qualitative, traits-based assessment (Čada and Schweizer 2012) was performed to evaluate entrainment and impingement risk for target species at each of the Project reservoirs intake structures. As stated by Čada and Schweizer (2012), "organism and/or species traits are valuable to risk assessors because they can include a wide variety of morphological, physiological, behavioral, and life history characteristics, some of which influence the animal's susceptibility to stressors." Therefore, a traits-based assessment was conducted using a matrix of identified risk factors and a stepwise assessment process (consistent with methods and factors described in Sections 2.5.1 through 2.5.4 of the RSP). The matrix summarizes the potential risk factors that increase susceptibility to entrainment, each of which must be met present before considering applicability of the next risk factor. For example, a life stage of a particular species must be present in the reservoir for it to be at risk of, and susceptible to, impingement or entrainment; if a life stage is restricted to environmental conditions not found in the reservoir (e.g., stream habitat), then it is assumed that the life stage is not present and not at risk of impingement or entrainment. Each of the risk factors are described in further detail in the following sections.

Although not currently present within the Project reservoirs, anadromous salmonids were included in the qualitative risk assessment at the request of LPs. Therefore, the results of the analysis specific to anadromous species are hypothetical and are intended to represent a high-level assessment of the potential risk these taxa may encounter should fish passage technologies be installed at Project dams at some future date.

4.4.1 Susceptibility by Species and Life Stage

As stated in Section 2.5.7 of the RSP, species life history characteristics were considered in the qualitative risk assessment. Impingement and entrainment susceptibility at intake and spillway structures can vary temporally depending on the life cycle and behavior of the fish community. Many fish species exhibit extensive or localized migrations related to spawning, overwintering, or foraging during certain times of year (e.g., cooler waters during summer), or for other reasons (e.g., shoreline areas associated with structural complexity for cover). These intra-reservoir migratory behaviors may result in fish encountering conditions near Project intakes or spillways where they are at an increased risk of impingement. Fish impingement and entrainment susceptibility increases with increasing proximity to Project intakes (specifically, within the zone of influence) or spillways due to increasing velocities (EPRI 2000). Certain habitat types near the Project dams, intakes, and spillways, if available, which may attract some species and life stages can result in greater susceptibility, depending on habitat preferences or requirements—including thermal habitat conditions. Therefore, the type of habitat near the Project intakes and spillways was compared to the seasonal habitat requirements of the target species to evaluate the influence of habitat availability on the variability of entrainment and impingement risk at the Project facilities.

4.4.2 Depth and Location of Intake Structure

The location and depth of water withdrawal of an intake structure have been shown to be important determining factors of entrainment risk (FERC 1995). Intake structures of dams can be located at the surface, along shorelines or at the center of a dam, or may be placed at depth. As a working hypothesis, fish must be present near the intakes to be at risk of entrainment or impingement. Position and depth of intakes relative to the shoreline are also important in relation to the type(s) of habitat available, which in turn influences the species and life stages of fish likely to occur near the intake where entrainment risks increase. Thus, the risk of impingement or entrainment at an intake structure is dependent on the intake location and the ability of the resident fish to encounter the intake structure, which can vary by species and life stage. Since the Project intakes are located at a variety of depths, a literature review of the target species' behavior, specifically related to depth positioning, was performed to assess the potential for the target species to come within proximity of the intakes.

4.4.3 Intake Structure Avoidance

Intake avoidance—the ability to avoid impingement or entrainment—was evaluated based on fish species' swim speed compared to calculated approach velocities at each of the Project's intake structures. There are three types of swimming capability: sustained continuous, prolonged continuous, and burst swimming (EPRI 2000). Sustained continuous swimming can be maintained indefinitely and is also called "cruising speed." Prolonged continuous swimming is maintainable for only a certain length of time before the fish becomes fatigued. Burst swimming are short and rapid starts or spring swimming typically used for catching prey, avoiding predators, or responding to disturbances. Swimming speed can vary depending on a number of factors, including fish species, length, body shape, growth rate, health condition, dissolved oxygen concentrations, temperature, lighting, schooling, and turbulence (EPRI 2000). For purposes of this analysis and under the presumption that fish would actively avoid the intake structures (as opposed to actively moving downstream), it was assumed that fish with swim burst speeds greater than intake approach velocities are able to avoid impingement or entrainment. Approach velocity was calculated for normal pool and minimum WSE.

4.4.4 Impingement Assessment

As described in Section 2.5.4 of the RSP, an assessment of fish exclusion was conducted to determine whether fish could become impinged on the intake trashracks. Only fish large enough to become impinged on the trashracks and unable to swim off and away from the trashracks are at risk of impingement mortality. The minimum size fish that could be impinged at each facility was determined by the trashrack bar spacing at each Project intake compared to their estimated fish body widths (i.e., body thickness from side to side for fusiform fish). Body widths were calculated using a scaling factor relating fish body length to body width (Smith 1985). Fish with body widths greater than the trashrack clear spacing have the potential to become impinged if unable to escape the intake through-bar velocity. Through-bar velocity was calculated for normal pool and minimum WSE.

4.4.5 Overall Risk of Impingement or Entrainment

A qualitative risk matrix for each Project facility was developed for all target species and life stages evaluated in this study. A separate evaluation for anadromous salmonids was also conducted under the assumption that fish passage technology was installed. An overall risk of low, medium, or high was applied based on the findings of each risk factor. The qualitative risk assessment exercise was used to refine the target species that would be carried forward to the entrainment rate analysis. Species with elevated (moderate or high) risks were evaluated for entrainment rates according to the EPRI (1997) database. The overall risk categories were defined as:

- Low:[3] species-life stage is generally not present in the reservoir; not found occupying habitat near the intake structures; and/or not susceptible to approach intake velocities.
- Moderate: species-life stage present in the reservoir; routinely or seasonally found occupying the habitat near the intake structures; and is susceptible to intake velocities.
- High: species-life stage is likely to be found occupying the habitat near the intake structures on a regular basis and is susceptible to intake velocities.

4.5 Estimate of Fish Entrainment Rates

While the risk assessment is useful as a qualitative approach to gaging entrainment and impingement risk, an effort to provide a quantitative entrainment rate estimate of target species at the Project intake structures was also completed, consistent with Section 2.5.5 of the RSP and described below.

4.5.1 EPRI (1997) Database Site Selection

A database developed by the EPRI provides detailed results of fish entrainment studies from 43 hydroelectric projects (EPRI 1997). This database was designed specifically to facilitate the desktop analyses based on empirically derived data to assess entrainment impacts at a hydroelectric facility.

Site characteristics (i.e., reservoir size, usable storage, plant capacity, operating mode, trashrack spacing and approach velocity, if available) and study data (i.e., species composition/entrainment data, collection efficiency) provided in the EPRI (1997) database were reviewed for applicability to the Project. Based on Project-specific characteristics, database facility details and locations, and with consideration of target species identified, Colton (NY), Crowley (WI), and Grand Rapids

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[3] Many of the target species are fluvial or adfluvial and spawn and rear their young in tributary streams from one to four years before moving into the riverine or reservoir portions of the Skagit River, and would not be at risk of entrainment (see Attachment C of this study report). However, a risk category of "low" versus "none" is applied to account for the potential for early life stage organisms to be flushed downstream into the Skagit River or Project reservoirs during infrequent extreme weather-induced high flows, where they may at risk of entrainment at Project intakes and spillways.

(MI/WI) facilities were selected for the entrainment rate analysis. The facilities used in this evaluation are detailed in Attachment A of this study report.

4.5.2 Entrainment Rate Calculation

The EPRI (1997) entrainment database provides results from field trials conducted at hydroelectric facilities using full-flow tailrace netting, which involves the placement of a conical net in the tailrace downstream to collect the entire discharge passing through the facility. These studies recorded the number of hours sampled and hydraulic capacity of the sampled units. Using the fish collection information from the facilities selected above, data was standardized to the number of fish per hour (fish/hr) of average sampled unit capacity (cfs), and then used to calculate fish entrainment rates (fish/hr) at the maximum hydraulic capacity for each Project intake. Entrainment rates were compiled by length class, month, season (winter = December, January, and February; spring = March, April, and May; summer = June, July, and August; and fall = September, October, and November), and annually.

4.6 Turbine Blade Strike and Spillway Mortality

Numerous fish turbine passage survival evaluations have been conducted over the past few decades, which were used to develop the EPRI (1997) turbine entrainment survival database. The EPRI (1997) database provides results of fish turbine entrainment passage survival studies from 51 hydroelectric projects and includes results from paired releases of treatment and control fish to estimate immediate and delayed turbine passage survival. The purpose of the survival database is to use facilities with comparable site characteristics and empirical survival data to estimate the survival of entrained fish through a hydroelectric project in a desktop analysis.

The data from the EPRI database can be used to qualitatively assess turbine passage survival at hydroelectric projects. Winchell et al. (2000) summarized turbine passage survival data provided in the EPRI database by fish size and turbine type and operational characteristics. Based on the consistency in results from numerous studies, it is apparent that fish size rather than species is the primary variable in determining the probability of survival of turbine passage (Franke et al. 1997; Winchell et al. 2000), with smaller fish being more likely to survive turbine passage. In addition, species-specific estimates of fish mortality through Francis type turbines (EPRI 1992) indicate that survival rates across species are generally uniform.

The EPRI (1997) survival database was “designed with the primary goal of facilitating examination of survival trends for specific size classes and/or species of fish at turbines with similar physical characteristics.” Site characteristics (i.e., turbine type, rated head, power, and flow, turbine speed, runner diameter, number of runner blades, etc.) of the 51 hydroelectric projects in the database were reviewed for applicability to the Project. Thirty facilities were found to have the same turbine type (Francis) as the Project facilities and have turbines with similar speeds. However, none of the database facilities have a rated head or a rated flow similar to the Project intakes. To better represent the Project, a more recently developed and site-specific methodology for estimating turbine blade strike and spillway mortality was used (Section 4.6.1 of this study report).

4.6.1 Turbine Blade Strike Mortality and Survival

Per Section 2.5.6 of the RSP, turbine blade strike and spillway mortalities were estimated using the most recent version of the Turbine Blade Strike Analysis (TBSA) Model (USFWS 2020). This Excel-based model was developed by the USFWS for the purpose of desktop turbine blade strike analyses outlined by Franke et al. (1997) for evaluating fish mortalities due to turbine entrainment and non-turbine entrainment (i.e., spillway). This tool allows for the estimation of turbine passage and mortality (blade strikes) based on site-specific physical information (i.e., turbine type, number of units, turbine specifications, turbine speed, among other parameters) and length distribution for target species used in this impingement and entrainment assessment. Using the model, fish can be subjected to up to 20 hazards, or routes, including three turbine types and bypasses or spillways, incorporating the Franke et al. (1997) equations into a Monte Carlo simulation that produces a probabilistic model result for turbine and non-turbine mortality.

Two blade strike analyses were performed for this evaluation. The first analysis focused solely on probability of turbine blade strike by size class. The upper limit of each size class identified in the entrainment analysis (i.e., 2-inch used for 0-2-inch size class) was input to the model with a population of 5,000 fish and a strike mortality coefficient value (λ) of 0.2, as recommended by the USFWS (2020). Therefore, blade strike probabilities were developed for each size class based on the site-specific parameters of each intake (Gorge, Diablo, and Ross).

A second analysis evaluated the passage survival of fish depending on units, spillways, and bypasses. Route selection probability for pathways used in this analysis were dependent upon the proportion of flow as indicated by reservoir outflows (i.e., the proportion of outflow greater than maximum facility capacity is assumed to be routed through spillways) presented in the PAD (City Light 2020a). For this analysis, fish lengths were based on the average length of Bull Trout reported in the Biological Opinion (23.6 inches; USFWS 2013), a smaller, hypothetical trout (12 inches), and three sizes of smaller fish (3, 4, and 5 inches). Estimated spillway mortality rates used to estimate passage survival were selected from the literature for each Project facility based on frequency of spill and individual spillway characteristics, as detailed in Section 4.6 of this study report.

4.6.2 Combined Turbine and Spillway Passage Survival

Spill typically occurs infrequently at the Project facilities (City Light 2020a) (see Section 2.1.2 of this study report); therefore, the risk of spillway entrainment is generally low. Notwithstanding, a strong relationship exists between the spillway height (i.e., hydraulic head) above the WSE of the downstream plunge pool, and the mortality rates of salmonid fish (Bull Trout, Dolly Varden, Rainbow Trout, Cutthroat Trout [*Oncorhynchus clarkii*], and Eastern Brook Trout [*Salvelinus fontinalis*]), as derived from regression equations on spillway mortality for a wide range of facilities in the Pacific Northwest with the primary driver of this relationship being the freefall velocity achieved by fish discharged from different heights (R2 Resource Consultants 1998; City Light 2012). In general, spillway passage mortality rates are less than 5 percent for dams with spillways less than 100 ft in height, and then increase to approximately 10 percent for spillways up to 180 ft in height (R2 Resource Consultants 1998). Mortality rates increase with dam elevation when spillways are more than 180 ft in height. Mortality rates over 50 percent are predicted for facilities which are 240 ft, and over 90 percent for facilities over 300 ft in height. Spillway types and stilling basins also affect mortality rates as related to shear effects, turbulence, strikes, scrapes, and abrasions (Ruggles and Murray 1983; R2 Resource Consultants 1998).

Water passing through the Ross Dam spill gates is 377 ft above the plunge pool and would attain a maximum velocity of approximately 160 feet per second (fps) when it enters the stilling basin (City Light 2012). Based on studies of facilities in the Pacific Northwest, these velocities would result in 100 percent mortality (R2 Resource Consultants 1998; City Light 2012). Therefore, a spillway mortality rate of 100 percent was used in the spillway analysis for Ross Dam (Table 4.6-1).

The Diablo Dam spillways are approximately 130 ft above the bedrock outcroppings over which they discharge, which would result in spillway velocities of about 100 fps (City Light 2012). The fish passing over the Diablo bedrock outcroppings proceed to a vertical freefall of about 200 ft to the plunge pool below. Spillway mortality estimates for juvenile salmonids obtained at dams in the Pacific Northwest with a hydraulic head of 240 ft range from 50.0 to 63.5 percent with a mean of 55 percent (R2 Resource Consultants 1998; City Light 2012) (Table 4.6-1). Therefore, a spillway mortality rate of 55 percent was used in the model for Diablo Dam.

The spillway drop from the crest of Gorge Dam is 125 ft, which would result in velocities of approximately 90 fps (City Light 2012). The channel downstream of the spillway is a shallow pool when Gorge is not spilling. However, a substantial plunge pool exists while spilling and there is no bedrock outcropping above the plunge pool that could cause additional sources of mortality such as strikes, scrapes, or abrasions. Based on mortality rates of less than 5 percent for facilities of 100 ft or less, a mortality rate of 10 percent would be a conservative estimate for Gorge (Table 4.6-1). Therefore, a spillway mortality rate of 10 percent was used in the model for Gorge Dam.

Table 4.6-1. Spillway mortality rates used in the model for fish taxa at the Skagit River Hydroelectric Project.

Taxa	Ross	Diablo	Gorge
Salmonids[1]	100	55	10
Redside Shiner	100	40	5

Source: R2 Resource Consultants 1998; City Light 2012.
1 Represents Bull Trout, Dolly Varden, Rainbow Trout, Cutthroat Trout, and Eastern Brook Trout.

The mortality estimates for Bull Trout are applicable to the other salmonids in the Project reservoirs since these estimates were derived from studies that included several salmonid species. In addition, the estimates for the remaining salmonids are conservative as Bull Trout can grow to larger sizes than other char present in the Project reservoirs (City Light 2020b) and mortality rates are generally lower for smaller fish (R2 Resource Consultants 1998).

No site-specific spillway mortality data is available for shiner species. Mortality estimates for Redside Shiner [*Richardsonius balteatus*] are based on best professional judgment related to smaller body size and potentially more robust scalation compared to salmonids. Spillway mortality rates for Redside Shiner were assigned as 100 percent for Ross based on the fall velocity of fish through the spillways (Table 4.6-1). A value of 40 percent spillway mortality was applied for Diablo based on mortality rates presented by R2 Resource Consultants (1998) for facilities with an estimated velocity of 100 fps, shallow stilling basins, and exposed rocks. For Gorge, a value of 5 percent spillway mortality was assigned based upon the discussion above of spillway height and mortality.

5.0 RESULTS

5.1 Intake Structural Characteristics and Velocities

Design and operational characteristics of each Project facility were used to inform the desktop entrainment and impingement risk assessment. For example, trashrack bar spacing contributed to both the intake avoidance and impingement assessments, and intake depths were evaluated as related to fish vertical positioning and behavior.

Approach and through-bar velocity for each of the Project intakes were calculated based on Project-specific parameters and WSEs. Design and operational parameters were obtained from numerous resources, compiled, and reviewed to confirm that the most current and accurate information available was used in the calculations. Table 5.1-1 summarizes the information used in the calculations, and details including formulas, parameter references, notes, assumptions, and quality control review documentation are provided in Attachment B of this study report.

Table 5.1-1. Specifications for intake structures at the Skagit River Hydroelectric Project.

Parameters and Variables	Ross	Diablo	Gorge
Waterbody Information			
Normal Maximum Water Elevation (ft)	1,608.76 NAVD 88 (1,602.5 CoSD)	1,211.36 NAVD 88 (1,205 CoSD)	881.51 NAVD 88 (875 CoSD)
Minimum Water Elevation (ft)[1]	1,480.76 NAVD 88 (1,474.5 CoSD)	1,204.36 NAVD 88 (1,198 CoSD)	831.51 NAVD 88 (825 CoSD)
Intake Details			
Dimensions (HxW) (ft)	27.5 x 20	15 x 17.75	23.7 x 20
Details	1 bifurcated intake with 2 openings	1 bifurcated intake with 2 openings	2 bifurcated intakes with 4 openings
Bar Rack Information			
Bar Rack Bar Spacing (inches)	3.5	2.5	3.5
Width of Bar Rack (ft)	20	17.75	20
Number of Spaces per Bar Rack	60	71	60
Support Backing/Bracing	Various	Various	Various
Elevation at Bar Rack Invert (ft)	1,429.2 NAVD 88 (1,423 CoSD)	1,086.65 NAVD 88 (1,080 CoSD)	801.3 NAVD 88 (795 CoSD)
Number of Intake Openings	4	2[2]	2
Width of Power Tunnel Immediately before Bar Rack (ft)	20	20	20
Bar Rack Percent Clogged	0%	0%	0%
Closed Frame Area (Normal Water Elevation) (ft^2)[3]	308.33	367.94	97.92
Closed Frame Area (Minimum Water Elevation) (ft^2) [3]	143.65	362.4	69.58
Cooling Water Intake Structure Design Hydraulic Capacity Information			
Design Hydraulic Capacity at Maximum Plant Output (gpm[4])	7,181,299	3,200,166	3,339,304

1 Minimum WSE authorized by the current license.
2 There are two cooling water intake structures at Diablo with four openings and four bar racks, but only one cooling water intake structure (two openings and two bar racks) are used. Intakes are not connected, therefore all water flows through a single intake. The area of the horizontal bars on the bar racks and panels between bar racks was calculated and subtracted from the total bar rack open area to achieve an accurate effective open area for water flow value.
3 The area of the horizontal bars on the bar racks and panels between bar racks was calculated and subtracted from the total bar rack open area to achieve an accurate effective open area for water flow value.
4 gpm = gallons per minute.

5.1.1 Ross Dam

The Ross Dam intake structure is located on the southern shore of Ross Lake at the entrance to a small inlet. It consists of two bifurcated intakes with four openings, each approximately 20 ft wide with 3.5-inch spaced trashracks (Figure 5.1-1). The intake invert is located at an elevation of 1,429.2 ft NAVD 88 (1,423 ft CoSD), or approximately 179.5 ft deep at normal maximum WSE and 51.5 ft from minimum WSE. Ross Dam has two spillways, one on each side and each with six gates operated by an electric hoist (Figure 5.1-2).

Figure 5.1-1. Ross power tunnel intake.

Figure 5.1-2. Ross Dam spillways.

Estimated approach and through-bar velocities are summarized in Table 5.1-2. Ross Lake begins drawdown shortly after Labor Day every year in anticipation of spring runoff and to provide for downstream flood control (City Light 2020a). Maximum drawdown is achieved around April or May, and in accordance with License Article 401, the reservoir will be filled as soon as possible after April 15 and achieve normal maximum WSE by July 31. Ross Lake has been drawn down to the minimum licensed WSE only once during the current license period (April 1999) in anticipation of a large snowpack runoff. Between 2009 and 2018, the average minimum WSE was 1,541.26 ft NAVD88 (1,535 ft CoSD). Velocities calculated at minimum WSEs combined with maximum hydraulic capacity result in a maximum potential intake velocity value. Based on the normal seasonal drawdown, Ross Lake elevation will be between normal maximum and minimum WSE for approximately half of the year, with intake velocities generally ranging from 1.11 to 3.88 fps for approach velocity and 1.41 to 5.28 for through-bar velocity.

Table 5.1-2. Estimated approach and through-bar velocities at the Ross intake structure.

Velocity Type	Water Surface Elevation	Velocity (fps)
Approach Velocity	Normal	1.11
	Minimum	3.88
Through-bar Velocity	Normal	1.41
	Minimum	5.28

5.1.2 Diablo Dam

The Diablo Dam intake structure is located on the right downstream-facing shoreline of Diablo Lake. It consists of two bifurcated intakes with four openings, each approximately 16.75 to 18.75 ft wide with 2.5-inch spaced trashracks (Figure 5.1-3). Although there are two intakes, only one is in operation. The second intake is inoperable and is not connected to the first intake (all water flows through a single intake). The intake invert is located at an elevation of 1,086.65 ft NAVD 88 (1,080 ft CoSD) and at a depth of approximately 125.0 ft from normal maximum WSE and 118 ft from minimum WSE. Diablo Dam has two spillways, one on each side of the dam.

Figure 5.1-3. Diablo intake and dam with spillway.

Table 5.1-3 summarizes the intake specifications used in the velocity calculations. The primary function of Diablo Lake is to regulate flows between the Ross and Gorge dams (City Light 2020a). Diablo Lake water elevation fluctuates approximately 4-5 ft daily, though drawdowns of 10-12 ft occur occasionally as needed for construction projects or maintenance activities. As stated above, drawdowns are infrequent at Diablo Lake, thus the minimum WSE occurs infrequently at Diablo Lake. As such, the estimated velocities at the minimum WSE are conservative values and are likely greater than those typically observed at the intakes.

Table 5.1-3. Estimated approach and through-bar velocities at the Diablo intake structure.

Velocity Type	Water Surface Elevation	Velocity (fps)
Approach Velocity	Normal	1.43
	Minimum	1.51
Through-bar Velocity	Normal	2.41
	Minimum	2.58

5.1.3 Gorge Dam

The Gorge Dam intake structure is located on the left side of Gorge Dam, facing downstream. It consists of one bifurcated intake with two 20-ft-wide openings with 3.5-inch spaced trashracks (Figure 5.1-4). The intake invert elevation is 801.3 ft NAVD 88 (795 ft CoSD) at a depth of approximately 80.0 ft from normal maximum WSE and 30 ft from minimum WSE. The Gorge Dam spillway is located on the left side of Gorge Dam.

Figure 5.1-4. Gorge intake and dam with spillway.

Table 5.1-4 summarizes the intake velocity estimates. The primary function of Gorge Lake is to regulate downstream flows for fish protection. Gorge Lake typically fluctuates 3-5 ft, but drawdowns of 50 ft are occasionally needed for spill gate maintenance or inspection. The lowest WSE recorded within the current license period was 788.51 NAVD88 (782 ft CoSD) in August 1997; there were also drawdowns (823.51-826.51 ft NAVD88 [817-820 ft CoSD]) for spill gate maintenance or testing in 2013 and 2019. Since the minimum WSE is significantly lower than typical operations, the approach and through-bar velocities calculated with this WSE are substantially higher than regularly observed at the intake.

Table 5.1-4. Estimated approach and through-bar velocities at the Gorge intake structure.

Velocity Type	Water Surface Elevation	Velocity (fps)
Approach Velocity	Normal	2.33
	Minimum	6.20
Through-bar Velocity	Normal	2.86
	Minimum	8.17

5.2 Water Quality Characterization

Water quality information was reviewed from the PAD (Section 4.4.5.2) and the FA-01a Water Quality Monitoring Study (City Light 2022a). If water quality parameters are outside the range of tolerance for the species of interest, these fish may avoid these areas. In reservoirs where thermal stratification occurs during summer, the lower portion of the water column has cooler water and may also have depleted dissolved oxygen concentrations, whereas the portion of the water column above the thermocline would have elevated dissolved oxygen, but higher water temperatures. Fish may avoid the water column below the thermocline if dissolved oxygen is not sufficient. Similarly, fish may avoid the upper water column if temperatures are higher than their preferred range. Therefore, water quality has the potential to influence what depth fish may be found depending on their temperature and dissolved oxygen requirements.

Temperature profiles in the Ross, Diablo, and Gorge Lake forebays collected from 2013 to 2017 indicate that some thermal stratification may occur in the Project reservoirs, and that Ross Lake experiences the strongest stratification and Gorge Lake the least (City Light 2022). During the monitoring period, profile measurements of water temperature did not exceed 20°C, the threshold temperature at which avoidance, and mortality may be observed in salmonids (Carter 2008). Furthermore, dissolved oxygen measurements collected from several areas in the reservoir did not decline below 7.0 milligrams per liter (mg/L) (City Light 2022). Studies summarized by the California North Coast Regional Water Quality Control Board (Carter 2008) suggest that salmonid avoidance behavior is not observed until dissolved oxygen reaches 6.0 mg/L or lower. Based on these data, the Project reservoirs provide suitable habitat for salmonids throughout the water column, year-round. Therefore, seasonal changes in temperature and dissolved oxygen may not influence fish behavior or distribution in the water column in the vicinity of the Project intakes.

5.3 Fish Community and Target Species

5.3.1 Skagit Project Fish Community

Information on the species composition, abundance, and life history characteristics of the fish community present in the Skagit River and Project reservoirs were compiled to support this desktop assessment of fish entrainment and impingement. The life history characteristics of the six resident species are summarized in Attachment C of this study report. At the Project, all three reservoirs are inhabited by Bull Trout, Dolly Varden, Rainbow Trout, Brook Trout and Redside Shiner (Table 5.3-1). Cutthroat Trout, the least abundant salmonid species upstream of Gorge Dam, were historically stocked in Ross Lake and are considered non-native (City Light 2020a). Cutthroat Trout have not been recorded in Diablo or Gorge Lakes in past or present studies and are thought to be either likely absent or very rare in these reservoirs (City Light 2012).

Table 5.3-1. Annual number and length (TL[1]) range for species collected with gill net sampling, 2005-2012[2], at Skagit River Hydroelectric Project.

Species	Ross	Diablo	Gorge
Native Char (Bull Trout and Dolly Varden)	24-92 (109-813 mm)	14-55 (115-730 mm)	22-29 (122-751mm)
Rainbow Trout	73-311 (106-538 mm)	161-170 (99-388 mm)	53-85 (103-322 mm)
Brook Trout	1-40 (120-351 mm)	67-94 (116-326 mm)	17-20 (124-290 mm)
Cutthroat Trout	6	0	0
Redside Shiner	4-224 (90-127 mm)	0-137 (85-123 mm)	0

Source: Anthony and Glesne 2014 as presented in City Light 2020a.
1 TL = Total Length
2 Sample years are: Ross 2006-2008, 2012; Diablo 2005, 2010; Gorge 2006, 2011.

Bull Trout are most prevalent in Ross Lake and least prevalent in Gorge Lake while Dolly Varden appear to be more prevalent than Bull Trout in Gorge and Diablo Lakes (Anthony and Glesne 2014). However, the low sample size based on gill net sampling creates uncertainty when comparing abundance of the two species across Project reservoirs, particularly due to species identification of individuals smaller than 300 mm which may be Bull Trout, Dolly Varden, or hybrids (City Light 2012). Genetic analysis indicates that most native char over 300 mm are likely

Bull Trout (Smith 2010; City Light 2011; Small et al. 2016). The annual number on native char collected by the NPS from gill net sampling ranged from 14 up to 92 fish (109-813 mm) depending on the reservoir sampled (Table 5.3-1). A snorkel count of native char and Redside Shiner was conducted along the Ross Lake shoreline in 2006 (Downen 2014). Using 300 mm as a conservative identification threshold, approximately 96 percent of the native char surveyed were adult Bull Trout (City Light 2012). With consideration of the biennial spawning strategy and areal coverage of Ross Lake, the estimated number of adult Bull Trout in Ross Lake was 4,800 fish (City Light 2012). The Ross Lake estimate was scaled down to the areal coverage of Diablo and Gorge lakes to obtain estimates of 370 and 100 Bull Trout, respectively.

Rainbow Trout are more abundant in Ross Lake, followed by Diablo and Gorge Lakes (Table 5.3-1). The annual number collected with gill net sampling ranged from 73-311 in Ross Lake with 53-85 collected in Gorge Lake. The size of fish collected across all reservoirs ranged from 99-538 mm. Brook Trout are more abundant in Diablo Lake and least abundant in Ross Lake. The size range collected across all reservoirs with gill net sampling ranged from 116-351 mm.

Redside Shiner was initially introduced into Ross Lake around 2000 and has since appeared in Diablo and Gorge lakes (City Light 2020a). In 2010, Redside Shiners were documented in Diablo Lake, and were observed in Gorge Lake in 2019, indicating that they are spreading to the downstream reservoirs through spill or entrainment through the turbines. Annual numbers collected with gill net sampling ranged from 4-224 in Ross Lake and 0-137 in Diablo Lake (Table 5.3-1). No Redside Shiner were collected with gill net sampling in Gorge Lake during the 2006 and 2011 study period. The size of fish collected ranged from 85-127 mm across all sampling for Ross and Diablo lakes. The Redside Shiner population in Ross Lake was estimated to exceed 1.2 million fish based on snorkel counts conducted in 2006 (Downen 2014).

Detailed summaries of the life history characteristics of the resident target species are provided in an attachment to this study report and also summarized below in Section 5.4.1 of this study report.

5.3.2 Target Species

The target species selections for this study were based on species presence and distribution across Project reservoirs, state or federal protection status, and management interest. The final list of target species evaluated in this study was formed with input from the LPs and is provided in the table below and included species with federal protection, recreational or commercially important species and associated forage fish species, and migratory (i.e., anadromous) species (Table 5.3-2).

Table 5.3-2. Target fish species included in the desktop fish entrainment study for the Skagit River Hydroelectric Project.

Common Name	Scientific Name	Project Distribution		
		Ross Lake	Diablo Lake	Gorge Lake
Bull Trout	*Salvelinus confluentus*	X	X	X
Cutthroat Trout	*Oncorhynchus clarkii*	X	NP	NP
Dolly Varden	*Salvelinus malma*	X	X	X
Eastern Brook Trout	*Salvelinus fontinalis*	X	X	X
Rainbow Trout	*Oncorhynchus mykiss*	X	X	X
Redside Shiner	*Richardsonius balteatus*	X	X	X
Anadromous Salmonids				
Chinook Salmon	*Oncorhynchus tshawytscha*	NP	NP	NP
Chum Salmon	*Oncorhynchus keta*	NP	NP	NP
Coho Salmon	*Oncorhynchus kisutch*	NP	NP	NP
Pink Salmon	*Oncorhynchus gorbuscha*	NP	NP	NP
Sockeye Salmon	*Oncorhynchus nerka*	NP	NP	NP
Steelhead Trout	*Oncorhynchus mykiss irideus*	NP	NP	NP

X: present; NP: not present.

5.4 Qualitative Risk of Entrainment and Impingement

There are a number of factors that may increase a species' risk of impingement or entrainment at an intake, including life history characteristics, behavior, and physical conditions at the intake. The following sections present supporting information for an overall risk of entrainment and impingement for each target species and life stage.

5.4.1 Susceptibility by Species and Life Stage

Risk of impingement or entrainment at the Project intakes was evaluated on a life stage and monthly basis for all target species. The species-specific life stage periods are identified in Table 5.4-1. Location (macrohabitat) for each life stage is included to provide context for proximity to Project intakes; for migratory life stages (i.e., adult migration and juvenile outmigration), the starting and ending habitats are provided. Detailed life history information is summarized in Attachment C of this study report.

Only the adult Bull Trout, Dolly Varden, Cutthroat Trout, Rainbow Trout, and Eastern Brook Trout utilize habitats in the Project reservoirs on a year-round basis; while the spawning habitat and early life stage rearing conditions required by these taxa occur primarily in the Project's tributary streams (City Light 2012, 2020a; Fish 2004). The eggs, alevins, fry, and parr of these species remain in the tributary streams between one to three years and are therefore generally not at risk of entrainment at Project facilities. Juvenile trout generally occupy stream habitats, however Dolly Varden, Rainbow Trout, and Cutthroat Trout may enter reservoirs early for increased food availability, or if flushed downstream by high flow events (Stable and Thomas 1992). Those fish that do enter the reservoir are likely to remain nearshore and around structurally complex habitats to avoid predation and for foraging and therefore are unlikely to occur near the intake structures.

Redside Shiner may be susceptible to entrainment as they inhabit both stream and lake environments for all life stages, including spawning. Redside Shiners broadcast demersal, adhesive eggs over gravel stream bottoms or vegetated shorelines in lakes (Welch 2012), which are habitats not found near the Project intakes. The adhesive fertilized eggs adhere to the substrate or vegetation; any free-floating eggs swept into or remaining in the current are vulnerable to predation by adult Redside Shiner or other piscivores.

Anadromous salmonids are not currently able to pass upstream of Gorge Dam, as fish passage facilities do not exist. Therefore, no life stages of these species are found in the study area. However, generally, anadromous salmonids spend their adult life in the ocean before migrating to streams to spawn. After spawning, most adults die with the exception of steelhead (*Oncorhynchus mykiss irideus*), which may spawn twice. Some salmonids remain in their natal streams until they begin juvenile outmigration, while others move downstream at fry emergence (such as Chum [*O. keta*] and Pink salmon [*O. gorbuscha*]). While Sockeye Salmon [*O. nerka*] may spawn in river or lake habitats, they are the only anadromous salmonid species (of the target species) that are known to utilize lake environments for spawning (September to December) and/or rearing. Once fry emerge (January to June), they remain in their natal habitat until juveniles outmigrate to the ocean, typically after one to three years (National Oceanic and Atmospheric Administration [NOAA] 2021).

Based on the life history characteristics of these species, and if fish passage technology were installed at the Project dams, it is unlikely that these adult anadromous salmonids would be at risk of impingement or entrainment. While some potential exists for entrainment during outmigration of early life stages (smolts, parr, and fry), any downstream fish passage facilities would be designed with the purpose of collecting outmigrants and most smolts, parr, and fry would be collected and safely passed downstream.

Table 5.4-1. Preliminary life stage periodicity for target fish species.

Common Name	Life Stage	Location[1]	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Bull Trout (Adfluvial)	Adult	Lakes												
	Spawning	Streams												
	Fry Emergence	Streams												
	Juvenile Rearing	Streams/Lakes[2]												
Dolly Varden	Adult	Lakes/Streams												
	Spawning	Streams												
	Fry Emergence	Streams												
	Juvenile Rearing	Streams/Lakes[2]												
Cutthroat Trout	Adult	Lakes/Streams												
	Spawning	Streams												
	Fry Emergence	Streams												
	Juvenile Rearing	Streams/Lakes[2]												
Rainbow Trout	Adult	Lakes												
	Spawning	Streams												
	Fry Emergence	Streams												
	Juvenile Rearing	Streams/Lakes[2]												
Brook Trout	Adult	Lakes/Streams												
	Spawning	Streams												
	Fry Emergence	Streams												
	Juvenile Rearing	Streams												
Redside Shiner	Adult	Lakes/Streams												
	Spawning	Lakes/Streams												
	Fry Emergence	Lakes/Streams												
	Juvenile Rearing	Lakes/Streams												
Anadromous Salmonids														
Upper Skagit Summer Chinook Salmon	Adult Migration	Ocean/Rivers/Streams												
	Spawning	Rivers/Streams												
	Fry Emergence	Rivers/Streams/Estuary												
	Juvenile Rearing	Rivers/Streams/Estuary												

Common Name	Life Stage	Location[1]	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
	Juvenile Outmigration	Rivers/Streams/Estuary												
Mainstem Skagit Fall Chum Salmon	Adult Migration	Ocean/Rivers												
	Spawning	Rivers												
	Fry Emergence + Juvenile Rearing[3]	Rivers/Estuary												
	Juvenile Outmigration	Estuary/Ocean												
Skagit Coho Salmon	Adult Migration	Ocean/Rivers/Streams												
	Spawning	Streams												
	Fry Emergence	Streams												
	Juvenile Rearing	Rivers/Streams												
	Juvenile Outmigration	Rivers/Streams/Ocean												
Skagit Pink Salmon	Adult Migration	Ocean/Rivers/Streams												
	Spawning	Rivers/Streams												
	Fry Emergence + Juvenile Rearing[3]	Rivers/Streams/Estuary												
	Juvenile Outmigration	Estuary/Ocean												
Skagit River Sockeye	Adult Migration	Ocean/Lakes												
	Spawning	Streams to Lakes/Lakes												
	Fry Emergence	Lakes												
	Juvenile Rearing	Lakes												
	Juvenile Outmigration	Lakes/Ocean												
Skagit Winter Steelhead	Adult Migration	Ocean/Rivers/Streams												
	Spawning	Rivers/Streams												
	Fry Emergence	Rivers/Streams												
	Juvenile Rearing	Rivers/Streams												
	Juvenile Outmigration	Rivers/Streams/Ocean												

Source: Animal Diversity Web (ADW) 2020a, 2020b, 2020c; City Light 2011, 2012, 2020a; Connor and Pflug 2004; Fish 2004; Johnson et al. 1999; Lowery et al. 2013; Trotter 1991; WDFW 2019; Weitkamp et al. 1995; Welch 2012; Zimmerman et al. 2015. Periods were also adjusted with consultation with LPs.

1 Locations are listed as primary/secondary. Anadromous salmonid locations are listed in order (e.g., Adults migrate from Ocean to Rivers/Streams).

2 Juvenile fish generally occupy stream habitats and may also enter reservoirs early for increased food availability, or if washed down by a high flow event. Those that enter the reservoir generally remain nearshore and around structurally complex habitats to avoid predation and for foraging.

3 Fry emerge and immediately outmigrate to the estuary.

5.4.2 Depth and Location of Intake Structure

The depth preference of adult native char (Knutzen 1997; Martins et al. 2013; Harrison et al. 2020) and *Oncorhynchus* spp. (Stable and Thomas 1992; CH2MHILL 2007; Meridian Environmental, Inc 2008) minimizes risk of entrainment or impingement to these species at the Project intakes. Devine Tarbell & Associates (2004) summarized entrainment risk for Rainbow and Brown Trout at seven facilities with deep-water intakes located in California. Adult trout were more common in the upper water column where food availability was greatest and juvenile trout were more abundant in near-shore habitat.

Similar patterns regarding depth distribution have been documented for Rainbow Trout and Cutthroat Trout in Spada Lake, Washington (Stable and Thomas 1992). A qualitative risk assessment with respect to fish size and distribution, and intake location and water withdrawal depth was based on a literature review of facilities with similar species and relatively deep-water intakes. Studies of the diel patterns in spatial distribution indicate that adult Cutthroat and Rainbow Trout were almost exclusively offshore and densities during the day were highest at intermediate depths of the water column (4-16 meters [m]). At night, trout were in intermediate and shallow depths (0-4 m) of the offshore and nearshore strata. Both species primarily inhabited the epilimnion and metalimnion.

Acoustic tracking studies conducted in 2006 and 2007 indicated that only 2 percent of the trout occurred in the west end of the lake nearest the dam and most of the trout (98 percent) occurred in the upper 15 m of the water column in all areas of Spada Lake (Meridian Environmental 2008). These results indicated that the risk of trout becoming entrained into the powerhouse intake at Spada Lake are low. Food availability was a major influencing factor regarding habitat and depth preference for all life stages. Predation avoidance was also important with respect to juvenile life stage associations with shoreline, littoral habitat.

Adult Bull Trout perform daily vertical migration that may bring them in closer proximity to the Project intakes. Daily vertical migrations of Bull Trout were documented with acoustic tagging in Ross Lake (Eckman et. al 2016). Adult Bull Trout were recorded at depths ranging from 2.1-59.8 m during, but most often at depths less than 25 m in July and August 2013. Vertical migrations to depths greater than 25 m (usually less than 40 m) may consist of fish seeking thermal refuge from the elevated summer peak surface water temperatures. However, water quality monitoring data from 2013 to 2017 (Section 5.2 of this study report) showed water temperature not to exceed 20°C. As such, Bull Trout are not expected to need to perform regular or frequent vertical migrations seeking thermal refuge in the Project reservoirs.

As summarized in Section 2.1.2 of this study report, the acoustic monitoring program has shown limited use of the forebay areas of Gorge and Diablo lakes by Bull Trout. Bull Trout frequent the forebay of Ross, but rarely enter the intake zone. Furthermore, only two fish of a possible 302 fish tagged from 2015-2020 are known to have been entrained at the Diablo intake, subsequently surviving and residing in Gorge Lake. These results suggest that Bull Trout behavior and habitat preferences minimize the likelihood that they will encounter the intakes, and their swim speeds and body size allow them to physically avoid entrainment during those periods when in the vicinity of the intakes.

Studies of Eastern Brook Trout movements, in a large lake by Mucha and Mackereth (2008) and a small lake by Lackey (1970), show that they typically reside in inshore areas in waters less than 7.6 m deep. Depths at which Eastern Brook Trout are found may be influenced by water temperature for at least part of the year, however this species may also exhibit daily diel vertical migrations (Mucha and Macerketh 2008).

Redside Shiner exhibit regular migration patterns that may increase entrainment risk, such as occupying shorelines during the day and pelagic waters at night (Welch 2012). During the spring and summer months, Redside Shiner can be found in high densities in the shallow areas of the reservoir (Welch 2012). Sampling of Redside Shiner in Ross Lake during July and August 2013 indicated that Redside Shiner was most abundant between 5 and 15 m during the summer months and no individuals were collected deeper than 25 m (Eckman et. al 2016). The Ross Lake population appears to migrate to deep water in the winter seeking warm water refuge, returning to the nearshore habitat around May as temperatures increase (Wydoski and Whitney 2003). However, the depth of the winter seasonal retreat is unknown.

5.4.3 Intake Structure Avoidance

Burst swim speeds for target or representative species were compared to the estimated intake velocities (Section 5.1 of this study report) to evaluate whether fish may be susceptible to intake flows at the Project. It is assumed that fish within the zone of influence of the intake are within the approach velocity, and if overcome by that velocity (i.e., swim burst speed is less than approach velocity), then either taken into the intake (entrained) or impinged, depending on body size. The velocity entrapping fish against trashracks (impinging) is the through-bar velocity. In order for a fish to overcome impingement, they would have to have a swim burst speed great enough to swim-off the trashracks at the through-bar velocity rate.

Burst (or darting) swim speed is used to escape predation, maneuver through high flows, or in this case, escape intake velocities and avoid entrainment or impingement. Burst swim speed data were compiled from the Katopodis and Gervais (2016) and Bell (1991) studies (Table 5.4-2). As stated in Bell (1991), if burst speed was not available, it was calculated as double critical (cruising) speed identified in literature. Swim burst speed increases with fish length and age (Table 5.4-2). Therefore, younger and smaller fish are more susceptible to intake velocities and are at greater risk of entrainment than larger size fish. However, if intake velocities are high, larger fish can also be entrained or impinged. Swim burst speed is not available for all fish species and size ranges, however assumptions can be made based on the data compiled. For example, many Bull Trout grow to sizes larger than 8.1 inches and based on the typical length-to-swim speed relationship, Bull Trout larger than this length likely have burst swim speed greater than 6.41 fps.

All of the species and life stages compiled in Table 5.4-2 have higher estimated swim burst speed than approach velocities at normal maximum WSE at the Ross intake (i.e., swim burst speed less than 1.11 fps). However, some species-life stages may be susceptible to entrainment due to approach velocity at minimum WSE. Depending on the body width of certain fish, some may also be susceptible to impingement due to through-bar velocity at minimum WSE (swim burst speed less than 5.28 fps).

The intake velocities at Diablo are relatively low, with approach velocities not exceeding 1.51 fps and through-bar velocities less than 2.58 fps. Therefore, Chum Salmon fry were the only life stage of the species identified in Table 5.4-2 that would be susceptible to entrainment or impingement at the Diablo intake.

At the Gorge intake, the resident target species have swim burst speeds that are sufficiently higher than the approach velocity at normal maximum WSE and are able to avoid impingement or entrainment (Table 5.4-2). Fry of two of the anadromous salmonids (Chum and Coho salmon) have documented swim burst speeds insufficient to overcome the approach velocity at normal maximum WSE and would be at risk of entrainment or impingement mortality at the Gorge intake structure or spillway.

Table 5.4-2. Average burst swim speeds and fish body sizes for target fish species.

Common Name	Fish Length or Life Stage	Burst (Darting) Speed (fps)[1]	Reference
Bull Trout	8.1 inches	6.41	Katopodis and Gervais 2016
Cutthroat Trout	3.9 inches	3.83	Katopodis and Gervais 2016
	Adult	13.0	Bell 1991
Dolly Varden	6.5 inches[2]	5.54	Katopodis and Gervais 2016
Eastern Brook Trout	5.2 inches	5.00	Katopodis and Gervais 2016
Rainbow Trout	4.6 inches	2.68	Katopodis and Gervais 2016
Redside Shiner	2.9 inches	4.95	Katopodis and Gervais 2016
	1.9 inches[3]	1.44	Katopodis and Gervais 2016
Anadromous Salmonids			
Chinook Salmon	12.8 inches	13.43	Katopodis and Gervais 2016
	Adult	21.5	Bell 1991
Chum Salmon	1.5 inches	1.16	Katopodis and Gervais 2016
Coho Salmon	8.6 inches	6.72	Katopodis and Gervais 2016
	Adult	21.0	Bell 1991
	2 inches	2.20	Bell 1991
	3.5 inches	3.50	Bell 1991
	4.75 inches	4.20	Bell 1991
Pink Salmon	7.4 inches	3.40	Katopodis and Gervais 2016
Sockeye Salmon	12.1 inches	8.54	Katopodis and Gervais 2016
	Adult	21.0	Bell 1991
	5.0 inches	4.50	Bell 1991
Steelhead Trout	17.7 inches	18.1	Katopodis and Gervais 2016
	Adult	27.0	Bell 1991

1 Burst swim speeds were calculated as 2x critical speed (Bell 1991), unless burst speed was provided in the literature.
2 Based on *Salvelinus* values (Katopodis and Gervais 2016).
3 Based on Spottail Shiner.

At minimum WSE at the Gorge intake, with approach velocities of 6.2 fps, additional species and life stages become susceptible to entrainment and impingement at the intake structures. An estimated 13 different species-life stages (i.e., Bull Trout, Dolly Varden, Eastern Brook Trout, Redside Shiners, Coho Salmon, and Pink Salmon adults) may be at risk of entrainment or impingement mortality due to inability to swim-off of trashracks at the much higher through-bar velocities (8.17 fps) that occur at minimum WSE. However, minimum WSE and associated elevated approach velocities occurs infrequently at the Project, on the order of every couple of years.

As noted previously, anadromous salmonids are not currently present in the Project reservoirs (in absence of fish passage facilities) and are not at risk of entrainment or impingement mortality.

5.4.4 Impingement Assessment

Fish species maximum body width was compared to the trashrack spacing at each intake to assess impingement risk. Maximum body width was calculated using proportional scaling factors developed from literature and applied to site-specific species morphometric (total length [TL]) data. If species morphometric data was not available from Project fish community data, maximum recorded length from literature was used. When the maximum reported size of a species was found to be potentially excluded by trashracks at any of the Project intakes, the minimum size that may be excluded was also calculated. Calculated body widths and potential for trashrack impingement is summarized in Table 5.4-3.

Table 5.4-3. Estimated minimum lengths (inches) of target species excluded by trashracks at the Skagit River Hydroelectric Project.

Common Name	Scaling Factor[1]	Maximum Reported Total Length (in)	Calculated Body Width (in)	Minimum Size (TL) Excluded by Project Trashracks			Scaling Factor References
				Ross	Diablo	Gorge	
Bull Trout*	0.12	32.0	3.8	29.1	20.4	29.1	Eastern Brook Trout
Cutthroat Trout	0.11	9.0	1.0	--	N/A	N/A	Rainbow Trout
Dolly Varden*[2]	0.12	11.8	1.4	--	--	--	Eastern Brook Trout
Eastern Brook Trout*	0.12	13.8	1.7	--	--	--	Smith 1985
Rainbow Trout*	0.11	21.2	2.3	--	--	--	Smith 1985
Redside Shiner*	0.14	5.0	0.7	--	--	--	Smith 1985; Speckled Dace surrogate
Anadromous Salmonids							
Chinook Salmon	0.1	62.6	6.3	34.9	24.9	34.9	Smith 1985; Atlantic Salmon surrogate
Chum Salmon	0.1	43.2	4.3	34.9	24.9	34.9	Average *Oncorhynchus*
Coho Salmon	0.1	30.0	3.0	34.9	24.9	34.9	Smith 1985; Atlantic Salmon surrogate
Pink Salmon	0.1	30.0	3.0	--	24.9	--	Average *Oncorhynchus*
Sockeye Salmon	0.09	30.0	2.7	--	27.7	--	Smith 1985; Atlantic Salmon surrogate
Steelhead Trout	0.11	21.2	2.3	--	--	--	Rainbow Trout

(*) – Maximum reported length values from Skagit community fish data; (N/A) – Cutthroat Trout are not present in Diablo or Gorge lakes; (--) – Not excluded based on maximum reported total length.

1 Scaling factor expresses body width as a proportion of length based on proportional measurements.

2 Native char greater than 11.8 inches (300 mm) are assumed to be Bull Trout (Smith 2010; Small et al. 2016; McPhail and Taylor 1995; City Light 2011).

Based on the trashrack spacing at the Project, Bull Trout is the only species currently present that may grow large enough to be excluded from the intake due to trashrack spacing. Several species of anadromous salmonids (adults) could also be excluded by trashrack spacing, however given their life history characteristics (senescence after spawning), there is no occasion for adult salmon to outmigrate and therefore would not be in the vicinity of intakes.

5.4.5 Overall Risk of Impingement or Entrainment

An assessment of the overall risk of entrainment and impingement at Project intake structures was performed based on the information compiled in Sections 5.4.1 through 5.4.4 of this study report. The assessment was conducted on a conditional basis, i.e., each condition must be met before the subsequent condition would be applicable. An overall risk of low, medium, or high was applied based on the findings of each condition. A separate evaluation for anadromous salmonids was also conducted under the assumption that fish passage technology was installed.

5.4.5.1 Ross Dam

Redside Shiner was the only species found to have an elevated risk of entrainment in Ross Lake (Table 5.4-4). Adult Redside Shiner have a greater swim burst speed than the estimated approach velocity at the Ross intake (4.95 fps swim burst speed versus 1.11 or 3.88 fps approach velocities), therefore they may not be entrained unless actively moving downstream. Early life stages are considered low risk of entrainment due to the location of Redside Shiner spawning habitat (littoral zone), which is not within the vicinity of the intake deep in the reservoir. Juvenile Redside Shiner, for the purposes of these analyses, are assumed to also occupy deeper areas of the reservoir during winter (like adults). Juvenile Redside Shiner may not have a swim burst speed great enough to avoid intake velocities at minimum WSE (1.44 fps swim burst speed versus 3.88 fps approach velocity), making this life stage at an elevated risk of entrainment at the Ross intake during periods of lower reservoir levels. Ross drawdown begins in September and continues to April 15, refilling to full pond by late July; therefore, maximum intake velocities at minimum WSE occurs around April 15 every year, but generally velocities are between normal maximum and minimum WSE estimates (see Section 5.1.1 of this study report). However, since this species uses the deeper water habitat for only a portion of year and the depth at which they occupy is not currently known (i.e., may be much shallower and outside the proximity of the intake), an overall risk assessment of "moderate" was applied for this species-life stage.

Some adult species including Rainbow Trout, Cutthroat Trout, and Eastern Brook Trout are present in the reservoir but commonly remain in the upper water column well above the intake (less than 52 ft deep compared to the intake at approximately 152 ft deep), and therefore are not susceptible to entrainment (Table 5.4-4). Adult Bull Trout and Dolly Varden can be found in deeper areas (up to 196 ft deep), however based on the swim speed analysis, both species are able to navigate and escape approach velocities near the intake (swim speeds greater than 3.88 fps; furthermore, many adult Bull Trout are larger than that estimated for the swim burst speed provided in Katopodis and Gervais [2016]). Additionally, multi-year acoustic telemetry studies of Bull Trout in Ross Lake indicate limited use of the intake zone (see Section 2.1.2 of this study report). Therefore, risk of entrainment for adult trout in Ross Lake is low.

Since spawning and early life stage rearing occur in tributary streams, trout eggs, alevins, and fry remain in natal streams until juveniles and are not at risk of entrainment (Table 5.4-4). While juveniles typically remain in natal streams, some Dolly Varden, Rainbow Trout and Cutthroat Trout may migrate early to the reservoir for greater foraging opportunities or if flushed downstream by high flow events. Juveniles in the reservoir environment typically remain in the littoral zone near structures to avoid predation, and therefore are not in the vicinity of the intake and are at low risk of entrainment (Stable and Thomas 1992).

5.4.5.2 Diablo Dam

Based on the characteristics evaluated above, the overall risk of impingement or entrainment to resident target species in Diablo Lake is the same as that in Ross Lake. For those species present in the reservoir and in proximity to the intake, only juvenile Redside Shiner were found to be susceptible to the minimum WSE approach velocity (1.44 fps swim burst speed versus 3.88 fps approach velocity) and therefore applied a “moderate” risk assessment rating (Table 5.4-5).

Table 5.4-4. Summary of the overall risk to target resident species in Ross Lake to impingement and entrainment at the Ross Dam intake structure.

Species	Life Stage	Present in Lake Habitat	Water Column Depth Preference[1]	Within proximity of intake	Susceptible to Approach Velocity	Susceptible to Through-bar Velocity[2]	Overall Risk of Entrainment or Impingement
Bull Trout	Adult (resident)	No	--	--	--	--	Low
	Adult (adfluvial)	Yes	7-196 ft; commonly <82 ft	Yes	No	--	Low[3]
	Juvenile	No	--	--	--	--	Low
	Eggs, alevins, and/or fry	No	--	--	--	--	Low
Dolly Varden	Adult	Yes	7-196 ft; commonly <82 ft	Yes	No	--	Low
	Juvenile	Possible	Nearshore/littoral	No	--	--	Low
	Eggs, alevins, and/or fry	No	--	--	--	--	Low
Eastern Brook Trout	Adult	Yes	0-25 ft	No	--	--	Low
	Juvenile	No	--	--	--	--	Low
	Eggs, alevins, and/or fry	No	--	--	--	--	Low
Rainbow Trout	Adult	Yes	0-52 ft	No	--	--	Low
	Juvenile	Possible	0-52 ft	No	--	--	Low
	Eggs, alevins, and/or fry	No	--	--	--	--	Low
Cutthroat Trout	Adult	Yes	0-52 ft	No	--	--	Low
	Juvenile	Possible	0-52 ft	No	--	--	Low
	Eggs, alevins, and/or fry	No	--	--	--	--	Low
Redside Shiner	Adult	Yes	Deep water during winter[4]	Yes	No	--	Low
	Juvenile	Yes	Deep water during winter[4]	Yes	Minimum WSE	Yes	Moderate (ENT)
	Eggs, alevins, and/or fry	Yes	Shoreline	No	--	--	Low

(--) – Prior condition not met.

1 Depth to intake opening height is 152.0 ft based on normal maximum WSE.
2 Entrainable organisms that meet susceptibility to approach velocity are assumed automatically susceptible to through-bar velocity.
3 Recent and ongoing telemetry studies also suggest that risk of entrainment to adult adfluvial Bull Trout is low (see Section 2.1 of this study report).
4 It is undetermined at what depth Redside Shiner resides during winter months.

Table 5.4-5. Summary of the overall risk to target species in Diablo Lake to impingement and entrainment at the Diablo Dam intake structure.

Species	Life Stage	Present in Lake Habitat	Water Column Depth Preference[1]	Within proximity of intake	Susceptible to Approach Velocity	Susceptible to Through-bar Velocity[2]	Overall Risk of Entrainment or Impingement
Bull Trout	Adult (resident)	No	--	--	--	--	Low
	Adult (adfluvial)	Yes	7-196 ft; commonly <82 ft	Yes	No	--	Low[3]
	Juvenile	No	--	--	--	--	Low
	Early Life Stage (eggs, alevins, fry)	No	--	--	--	--	Low
Dolly Varden	Adult	Yes	7-196 ft; commonly <82 ft	Yes	No	--	Low
	Juvenile	Possible	Nearshore/littoral	No	--	--	Low
	Early Life Stage (eggs, alevins, fry)	No	--	--	--	--	Low
Eastern Brook Trout	Adult	Yes	<25 ft	No	--	--	Low
	Juvenile	No	--	--	--	--	Low
	Early Life Stage (eggs, alevins, fry)	No	--	--	--	--	Low
Rainbow Trout	Adult	Yes	0-52 ft	No	--	--	Low
	Juvenile	No	--	--	--	--	Low
	Early Life Stage (eggs, alevins, fry)	No	--	--	--	--	Low
Redside Shiner	Adult	Yes	Deep water during winter[4]	Yes	No	--	Low
	Juvenile	Yes	Deep water during winter[4]	Yes	Minimum WSE	N/A	Moderate (ENT)
	Early Life Stage (eggs, larvae)	Yes	Shoreline	No	--	--	Low

(--) – Prior condition not met.

1 Depth to intake opening height is 110.0 ft based on normal WSE.

2 Entrainable organisms that are susceptible to approach velocity would be drawn into the intake and therefore, through-bar velocity susceptibility is not applicable (i.e., through-bar velocity is only applicable to impingeable-size fish).

3 Recent and ongoing telemetry studies also suggest that risk of entrainment to adult adfluvial Bull Trout is low (see Section 2.1 of this study report).

4 It is undetermined at what depth Redside Shiner resides during winter months.

5.4.5.3 Gorge Dam

The Gorge Dam intake is at a shallower elevation than either Diablo or Ross intakes (approximately 56.3 ft), and also has greater intake velocities (see Section 5.1.3 of this study report). According to the intake avoidance evaluation (Section 5.4.3 of this study report), adult Bull Trout and Rainbow Trout are likely able to escape approach velocities in the vicinity of Gorge Dam. Furthermore, acoustic telemetry study results indicate the majority of Bull Trout in Gorge Lake are congregated in the Diablo Dam tailrace for foraging opportunities, rather than the forebay or intake area (City Light 2018).

Adult Dolly Varden may be susceptible to entrainment at minimum WSE (5.54 fps burst swim speed versus 6.2 fps approach velocity) (Table 5.4-6). Dolly Varden, based on the impingement analysis, does not grow large enough to be at risk of impingement at the Gorge intake (see Section 5.4.4 of this study report). Since Dolly Varden would only be susceptible to the approach velocity at minimum WSE, an elevated risk category of “moderate” was applied to this species-life stage.

Unlike the Ross and Diablo intakes, adult Redside Shiner would be at risk of entrainment at the Gorge intake during periods of minimum WSE (4.95 fps swim burst speed versus 6.2 fps approach velocity) (Table 5.4-6). Since this species would only be susceptible at minimum WSE and only during certain portions of the year (i.e., winter), it is considered at moderate risk of entrainment.

Juvenile Redside Shiner would be susceptible to approach velocities at normal or minimum WSE (Table 5.4-6). However, this life stage would only be at risk of entrainment during the winter season when they may be at a depth close to the intake, therefore it is also considered at moderate risk of entrainment.

Table 5.4-6. Summary of the overall risk to target species in Gorge Lake to impingement and entrainment at the Gorge Dam intake structure.

Species	Life Stage	Present in Lake Habitat	Water Column Depth Preference[1]	Within proximity of intake	Susceptible to Approach Velocity	Susceptible to Through-bar Velocity[2]	Overall Risk of Entrainment or Impingement
Bull Trout	Adult (resident)	No	--	--	--	--	Low
	Adult (adfluvial)	Yes	7-196 ft; commonly <82 ft	Yes	No	--	Low[3]
	Juvenile	No	--	--	--	--	Low
	Early Life Stage (eggs, alevins, fry)	No	--	--	--	--	Low
Dolly Varden	Adult	Yes	7-196 ft; commonly <82 ft	Yes	Minimum WSE	N/A	Moderate
	Juvenile	Possible	Nearshore/littoral	No	--	--	Low
	Early Life Stage (eggs, alevins, fry)	No	--	--	--	--	Low
Eastern Brook Trout	Adult	Yes	<25 ft	No	--	--	Low
	Juvenile	No	--	--	--	--	Low
	Early Life Stage (eggs, alevins, fry)	No	--	--	--	--	Low
Rainbow Trout	Adult	Yes	0-52 ft	Yes	No	--	Low
	Juvenile	No	--	--	--	--	Low
	Early Life Stage (eggs, alevins, fry)	No	--	--	--	--	Low
Redside Shiner	Adult	Yes	Deep water during winter[4]	Yes	Minimum WSE	N/A	Moderate (ENT)
	Juvenile	Yes	Deep water during winter[4]	Yes	Normal and minimum WSE	N/A	Moderate (ENT)
	Early Life Stage (eggs, larvae)	Yes	Shoreline	No	--	--	Low

(--) – Prior condition not met.

1 Depth to intake opening height is 110.0 ft based on normal WSE.

2 Entrainable organisms that are susceptible to approach velocity would be drawn into the intake and therefore, through-bar velocity susceptibility is not applicable (i.e., through-bar velocity is only applicable to impingeable-size fish).

3 Recent and ongoing telemetry studies also suggest that risk of entrainment to adult adfluvial Bull Trout is low (see Section 2.1 of this study report).

4 It is undetermined at what depth Redside Shiner resides during winter months.

5.4.5.4 Anadromous Salmonids

Adult anadromous salmonids are not likely to be susceptible to impingement at Project intakes given their life history characteristics (senescence after spawning) (Table 5.4-7), and the impingement of adult anadromous salmonids on trashrack bars, if it occurs, would likely represent dead or moribund fish impingement. The primary life stages of anadromous salmonids at risk of entrainment are outmigrating smolts (Chinook Salmon, Coho Salmon, Sockeye Salmon, and steelhead trout) and fry (Chum Salmon and Pink Salmon).

The period of smoltification of anadromous species in the Skagit River may pose an increased risk of entrainment and/or turbine blade strike as fish may move through the Project facilities during their downstream migration. However, the installation of downstream fish passage technology would greatly reduce the risk of entrainment through the intakes. The species-specific size and time of year of outmigration is provided in Table 5.4-8.

The life cycle of many anadromous salmonids includes significant structural and functional transformations prior to their downstream outmigration from freshwater to marine environments (Stefansson et al. 2008). During smoltification, juvenile salmonids typically become pelagic and exhibit schooling behavior to minimize predation in open water environments. Smolts also increase buoyancy and develop a preference for downstream movement. Additional developmental changes in physiology, morphology, biochemistry, and behavior also coincide with smoltification to allow different species to adapt to the transition from limnic to marine ecosystems. Smoltification for most species in the Skagit River occurs in the late winter and spring, with some species having an extended outmigration period throughout the summer. Some species, such as Chum and Pink salmon, outmigrate as fry instead of the smolt life stage.

Based on these data, outmigrating salmon smolts or fry are likely to experience higher susceptibility to approach velocities near intake structures due to their limited swim burst speed at these life stages. However, as stated previously, the presence of these species in the Project reservoirs are assumed to only occur concurrent with the installation of effective fish passage technologies at Project facilities, to provide safe passage to outmigrating organisms and keep their entrainment risk at a low level. Since fish passage facilities do not exist, there is no entrainment risk for anadromous salmonids at the Project at the current time.

Table 5.4-7. Entrainment and impingement risk assessment for anadromous salmonids assuming fish passage technology is installed at the Skagit River Hydroelectric Project.

Species	Life Stage[1]	Present in Lake Habitat	Water Column Depth Preference[2]	Within proximity of intake	Susceptible to Approach Velocity	Susceptible to Through-bar Velocity[3]	Overall Risk of Entrainment or Impingement[4]
Chinook Salmon	Adult	No	--	--	--	--	N/A
	Smolt	Yes	Variable	Yes	Yes	N/A	Low
	Early Life Stage (eggs, alevins, fry)	No	--	--	--	--	Low
Chum Salmon	Adult	No	--	--	--	--	N/A
	Smolt	No	--	--	--	--	N/A
	Early Life Stage (eggs, alevins, fry)	Yes (fry)	Variable	Yes	Yes	N/A	Low
Coho Salmon	Adult	No	--	--	--	--	N/A
	Smolt	Yes	Variable	Yes	Yes	N/A	Low
	Early Life Stage (eggs, alevins, fry)	No	--	--	--	--	Low
Pink Salmon	Adult	No	--	--	--	--	N/A
	Smolt	No	--	--	--	--	N/A
	Early Life Stage (eggs, alevins, fry)	Yes (fry)	Variable	Yes	Yes	N/A	Low
Sockeye Salmon	Adult	No	--	--	--	--	N/A
	Smolt	Yes	Variable	Yes	Yes	N/A	Low
	Early Life Stage (eggs, alevins, fry)	No	--	--	--	--	Low
Steelhead Trout	Adult	No	--	--	--	--	N/A
	Smolt	Yes	Variable	Yes	Yes	N/A	Low
	Early Life Stage (eggs, larvae)	No	--	--	--	--	Low

(--) – Prior condition not met.

1 Life stages actively moving downstream are assumed susceptible to approach and through-bar velocities.
2 Depth to intake opening height is 152.0 ft based on normal WSE.
3 Entrainable organisms that are susceptible to approach velocity would be drawn into the intake and therefore, through-bar velocity susceptibility is not applicable (i.e., through-bar velocity is only applicable to impingeable-size fish).
4 N/A was applied to adult salmon which would die following spawning and life stages that would develop outside of the study area (i.e., Chum and Pink salmon outmigrate at an earlier life stage and therefore the smolts would not be present upstream of Gorge Dam).

Table 5.4-8. Anadromous salmonid outmigration details.

Species	Life Stage	Size		Migration Period	Reference
		mm	inches		
Chinook	Smolt	90-130	3.5-5.1	January-August	Pearsons et al. 1998
Coho	Smolt	70-142	2.8-5.6	March-July	Bramblett et al. 2002
Sockeye	Smolt	149-200	5.9-7.9	March-August	Gustafson et al. 1997
Steelhead	Smolt	90-185	3.5-7.3	May	Bramblett et al. 2002
Chum	Fry	30-70	1.2-2.8	February-May	Fuller et al. 2021
Pink	Fry/Parr	20-30	0.8-1.2	February-April	Gallagher et al. 1997; ADF&G[1] 2003

1 ADF&G = Alaska Department of Fish and Game.

5.4.6 Summary of Qualitative Risk Assessment

The traits-based assessment of entrainment and impingement risk for the three Project intakes indicated low risk for most of the target species. Smaller size classes of salmonids that would be most susceptible to intake approach and through-bar velocities are not found in the vicinity of the intakes; they are commonly found in stream habitats or in the littoral zone of lakes where cover is available. Adult salmonids such as Bull Trout (infrequently) and Dolly Varden may exhibit diel migrations to deeper areas in the forebay where they may encounter the Project intakes. However, Dolly Varden was the only target species identified as potentially susceptible to intake velocities, which is expected to occur at most under specific but infrequent conditions (i.e., such as at minimum WSE in Gorge Lake). As indicated by the acoustic monitoring program, Bull Trout are infrequently found in the forebay areas of the Project intakes, with the lowest frequency of occurrence at the Diablo and Gorge lakes compared to Ross Lake, where Bull Trout have been documented near the intake structure for short durations (see Section 2.1.2 of this study report). Acoustic monitoring data indicate that Bull Trout spend more time in tributaries or at the confluence of tributaries; therefore, Bull Trout entrainment risk is still relatively low at the Project developments.

Redside Shiner is the only species aside from Dolly Varden in Gorge Lake determined to have a moderate risk of entrainment at the Project intakes. Redside Shiner is a pelagic species and may migrate to deeper waters regularly (daily or seasonally); therefore, this species has an elevated risk of entrainment during those periods for fish that are utilizing the forebay where they may encounter the Project intakes. Based on velocity and swim speed information, juvenile Redside Shiner is expected to be at the greatest risk of entrainment at minimum WSE except in Gorge Lake, where both, juvenile and adult Redside Shiner may be susceptible. Similarly, Dolly Varden is expected to be at the greatest risk when intake approach velocities are increased due to water levels at minimum WSE in Diablo Lake. Minimum WSE are considered a worst-case scenario as drawdowns to the minimum licensed elevation occur rarely. Therefore, although these species may be susceptible during these periods, these occurrences are infrequent and unlikely to have a substantial influence on the fish community.

Based on the results of the trait-based risk assessment, Dolly Varden and Redside Shiner are the target species identified with elevated potential (i.e., moderate or high) for entrainment at Project facilities; therefore, Dolly Varden and Redside Shiner were carried forward to the entrainment rate analysis summarized in the next section.

5.5 Estimate of Fish Entrainment Rates

Fish species identified as having elevated risk of entrainment by the traits-based qualitative assessment were carried forward to the entrainment rate analysis; rates were then estimated using the EPRI (1997) entrainment database based on results of studies completed at comparable facilities. Although the database contains entrainment data for a broad range of fish species, the target species identified from the qualitative risk assessment were not represented in the database. As such, surrogate species from the database were used to represent the target species and were selected based on taxonomy, and similarities in body morphology and life history characteristics such as seasonal timing and habitat preferences for spawning (Table 5.5-1).

Table 5.5-1. Fish species from the EPRI (1997) entrainment database used to estimate entrainment rates for the Skagit River Hydroelectric Project.

Study Target Species Common Name	Database Species Common Name	Database Species Justification[1]
Dolly Varden	Lake Whitefish, Cisco, Unidentified *Coregonus* spp.	Surrogate in same family (Salmonidae); similar behavioral characteristics
Redside Shiner	Spottail Shiner	Surrogate in same subfamily; similar in body size and life history characteristics

Under the current relicensing effort, a separate study (FA-04 Fish Passage Technical Studies Program) is evaluating the potential for providing fish passage at the Project facilities, which could eventually facilitate upstream and downstream passage of several species of anadromous salmonids, including Chinook Salmon, steelhead, Coho Salmon, Sockeye Salmon, and Pink and Chum salmon (City Light 2022b). The current upstream range and distribution of these species in the Skagit River terminates just downstream of the Gorge Dam. Since there is the future potential for anadromous salmon to be present upstream of Project dams if fish passage is provided as a condition of the next license, consideration was given to these salmonid species in this desktop entrainment evaluation.

However, a review of the EPRI (1997) database failed to identify facilities with fish passage facilities that were part of the historical entrainment studies. Furthermore, it is not possible to understand the potential population size or distributions that could occur in Project reservoirs for each of the salmonid species if they were able to pass upstream of the Project dams. Without this information, it is not feasible to fully estimate entrainment risk or quantitatively determine entrainment rates of anadromous salmonids at the Project intakes or spillways. Entrainment rates of these species (as well as the other target species included in this analysis) should be revisited if or when fish passage technology is implemented.

5.5.1 Entrainment Length Frequency

Based on the study results from comparable facilities presented in the EPRI (1997) database and surrogate species selected to represent this Project, entrainment at the Project intake structures is likely dominated (97.6 percent) by fish measuring less than 4 inches in length. As illustrated in

Figure 5.5-1, the Redside Shiner (surrogate Spottail Shiner) represents the majority of small fishes potentially entrained at the Project, comprising over 77 percent of entrainment for fish under 4 inches, while Dolly Varden (surrogate *Coregonus* spp.) comprise just over 20 percent. Entrainment of Dolly Varden greater than 4 inches in length was estimated at less than 2 percent between the two species.

The facilities selected from the EPRI (1997) database and used in this analysis have trashrack bar spacing smaller than those at the Project intakes. While this prevents the misrepresentation or overestimation of large fish in the entrainment analysis (i.e., those that would be impinged at the Project intakes but would be entrained according to the database facilities), the fish that may be excluded by trashracks with spacing of 2.375 inches (the widest trashrack spacing of the database facilities) and entrained through trashracks with 2.5-inch spacing (the narrowest trashrack spacing at the Project intakes) are not observed. Based on the scaling factors and maximum reported total lengths of Redside Shiner and Dolly Varden in the impingement assessment (Section 5.4.4 of this study report), neither species would grow large enough to be impinged on trashracks with spacing of 2.375 inches. Therefore, the facilities and fish species included from the EPRI (1997) database sufficiently represent the Project intakes with respect to trashrack spacing.

Results of the intake avoidance assessment (Section 5.4.3 of this study report) suggests that the increased swimming performance of larger fish allows them to overcome intake approach velocities and avoid impingement or entrainment at the intake structures. Thus, the entrainment of trout larger than 4 to 6 inches in length would likely be restricted to small-bodied adults or larger juveniles lacking sufficient burst swim speeds to overcome the approach velocities.

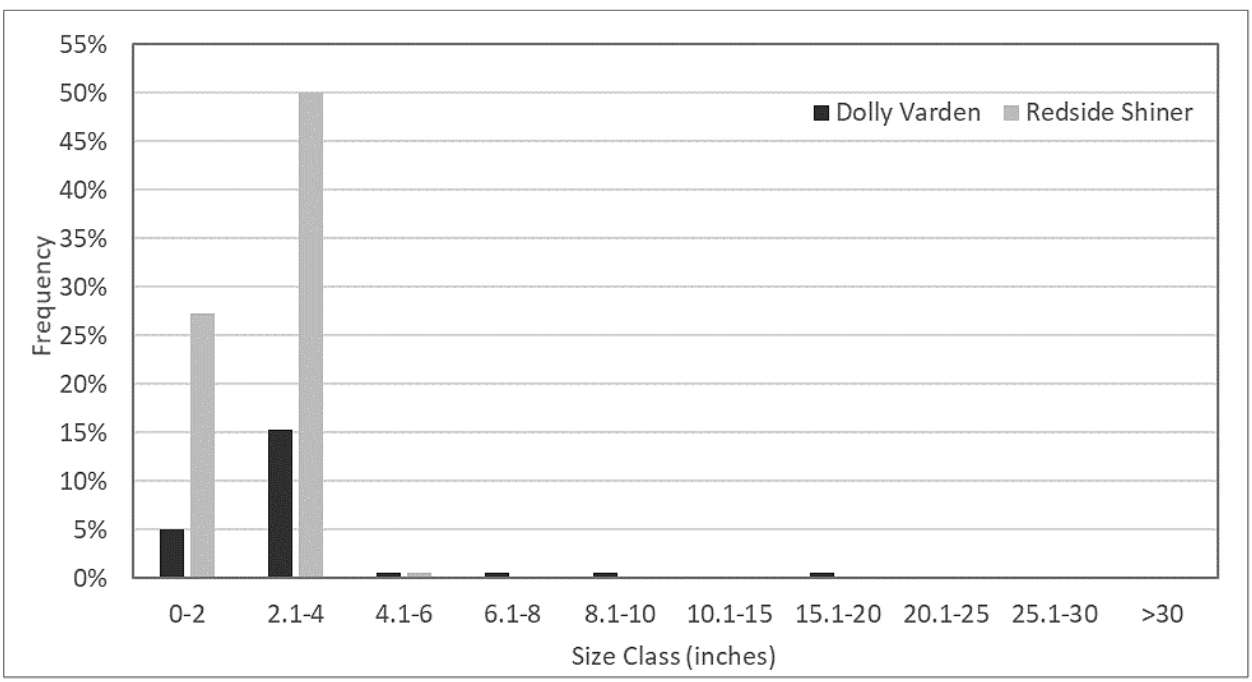

Figure 5.5-1. Length-frequency of entrained fish from database selections for the Fish Entrainment Study.

With consideration of Table 5.4-1 in Section 5.4.1 of this study report, habitat utilization and fish distribution of trout species is life stage-dependent, with early life stages residing in tributary streams and older life stages moving out into the Project reservoirs. Only life stages utilizing lake habitats—especially those near the Project intake structures or spillways—would be susceptible to entrainment. For the target species in this analysis and based on the qualitative, traits-based risk assessment, that includes adult Dolly Varden (juveniles that move into the reservoir are likely associated with the littoral zone near cover, and away from the deep intakes at the Project).

Redside Shiner use lake habitats throughout its life cycle; however, only older life stages are likely to occur near the intake where they would be susceptible to entrainment, while younger life stages reside along the shoreline and in the littoral zone. Based on fish community data, Redside Shiner collected from Project reservoirs range from 3 to 7 inches in length (City Light 2020a), sizes that would be susceptible to entrainment at the intake structures should they migrate to depths near the intake structures.

5.5.2 Entrainment Rates

Dolly Varden and Redside Shiner exhibited elevated estimated entrainment rates at different times of year, corresponding to life stage habitat selection, changes in distribution based on seasonal spawning behaviors, and/or other potential drivers that may encourage certain species to move closer to or further away from Project intakes and spillways (Figure 5.5-2). Results of the desktop entrainment analysis indicate that Dolly Varden may be entrained at higher rates during the summer months, which may correspond to their seeking thermal refuge from elevated summer surface water temperatures. Redside Shiner entrainment rates would be expected to increase during winter months, which is consistent with Skagit-specific monitoring results indicating seasonal migration to deeper water during the winter (see Section 5.4.2 of this study report). A smaller, seasonal increase during summer may also be indicative of avoidance of elevated surface water temperatures during summer.

As stated in Section 5.5 of this study report, fish species identified as having elevated risk of entrainment by the traits-based qualitative assessment were carried forward to the entrainment rate analysis. Adult Dolly Varden was the only salmonid showing potential susceptibility to entrainment based on the qualitative risk assessment and would only be susceptible at the Gorge intake during periods of minimum WSE. The swim burst speed estimated for Dolly Varden is based on the *Salvelinus* genus as a surrogate, with a mean length of 6.5 inches; the differential between intake velocity at minimum WSE and Dolly Varden swim burst speed is only 0.66 fps. Dolly Varden maximum size at the Project is 11.8 inches. Bull Trout, which is similar phenotypically, is estimated to have a swim burst speed greater than the Gorge approach intake velocity at minimum WSE (for a fish 8.1 inches in length). Based on this, adult Dolly Varden individuals greater than 6.5 inches likely have a swim burst speed greater than the Gorge approach intake velocity at minimum WSE. Furthermore, as stated in Section 5.1.3 of this study report, Gorge Dam is a regulating facility with operations purposed for downstream fish protection. Drawdowns to authorized minimum WSE at Gorge Lake occur infrequently (three times over the last 15 years) for maintenance activities. Therefore, the seasonal estimated entrainment rates presented for Dolly Varden are only applicable during periods of drawdown and likely overestimate the number of fish entrained based on swim speed versus approach intake velocity.

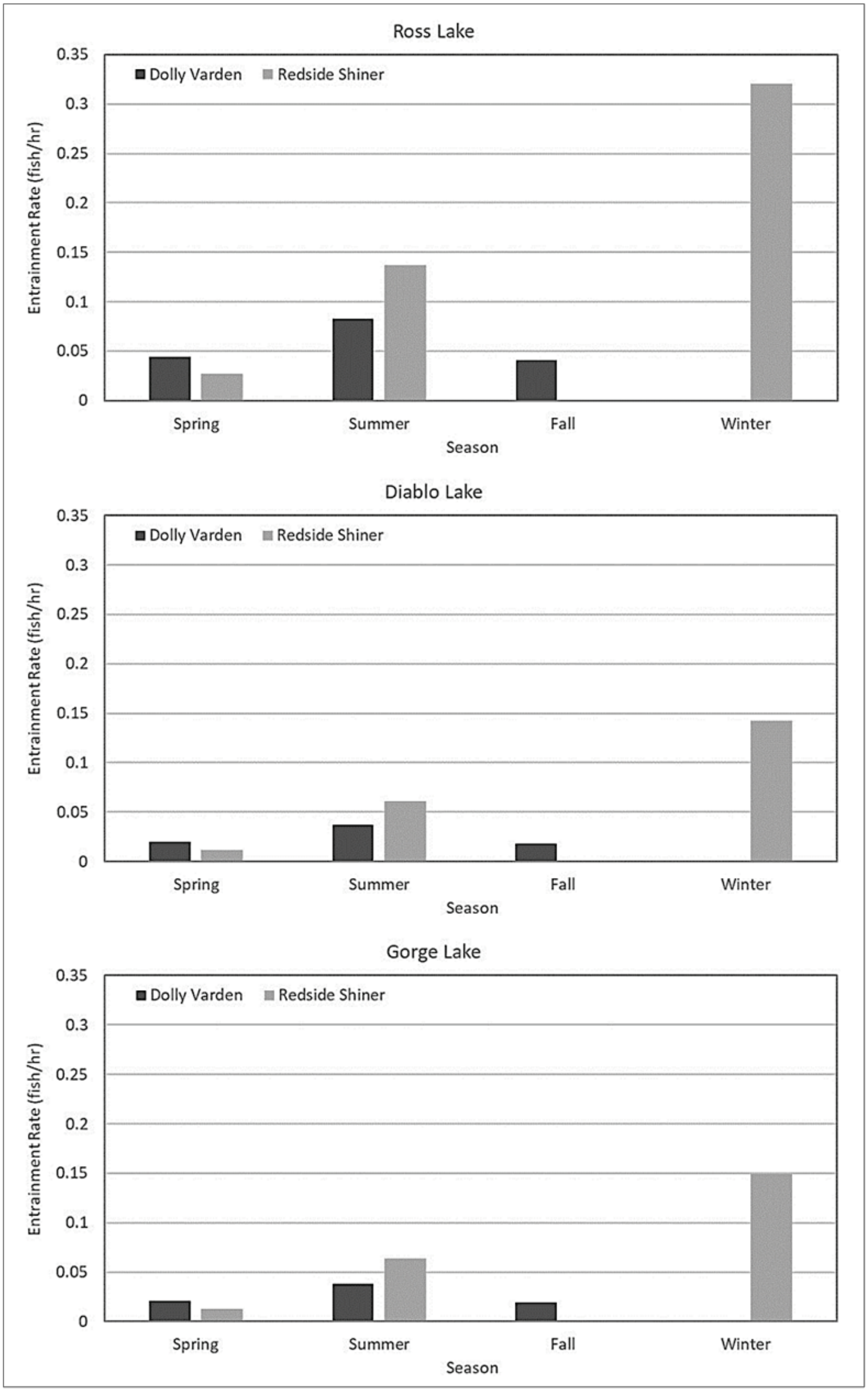

Figure 5.5-2. Average entrainment rate (fish/hr) by target species and season.

Ross Lake has the highest estimated entrainment rates of the three Project facilities, followed by Gorge and Diablo lakes, and is in part determined by the differences in total plant capacity at each of the facilities. However, site-specific characteristics, such as those discussed in the qualitative risk assessment (intake depth, trashrack spacing, intake velocities), suggest entrainment at the Ross intake may potentially be lower than that at the Gorge or Diablo intakes.

Inherent uncertainty exists with the use of the EPRI (1997). Based on the information reviewed for the qualitative risk assessment, the existing and ongoing acoustic tagging study, and naturally limited fish populations in the Project reservoirs, the approximated entrainment rates likely overestimate actual entrainment at the Project intakes. Detailed results from the entrainment analysis by month, target species, and size class for each Project facility are included in Attachment D of this study report.

5.6 Turbine Blade Strike and Spillway Mortality

Based on the qualitative risk assessment and the estimated entrainment rates, most life stages of the target species evaluated are at low risk of entrainment or impingement, with only two species exhibiting life-stage specific elevated (i.e., moderate or high) entrainment or impingement risk at the Project facilities. Two analyses were performed for this evaluation and included an evaluation focused solely on probability of turbine blade strike by size class and an analysis of passage survival of fish depending on units, spillways, and bypasses. Route selection probability for pathways used in this analysis were dependent upon the proportion of flow (i.e., the volume of outflow greater than maximum facility capacity is assumed to be routed through spillways) as indicated by reservoir outflows presented in the PAD (City Light 2020a). Estimated spillway mortality rates (Table 4.6-1) used to estimate passage survival were selected from the literature for each Project facility based on volume of spill and individual spillway characteristics, as detailed in Section 4.6 of this study report. Although most target species are not likely to be entrained at the Project, all target species were included in this analysis and presented as (a) salmonids or (b) Redside Shiner. It is important to note that the results of these analyses would only impact those fish that are actually entrained at the spillways or intake structures.

Blade strike probabilities and associated survival rates of an individual of a given size were calculated for the size classes used in the entrainment analysis (2, 4, 6, 8, 10, 15, 20, 25, and 30^+ inch classes). The inputs and results from the TBSA Model (USFWS 2020) for each of the Project intakes are provided in Attachment E of this study report. Results of the turbine blade strike mortality and survival evaluation are summarized below for Ross, Diablo, and Gorge dams.

5.6.1 Turbine Blade Strike Mortality and Survival

5.6.1.1 Ross Dam

Calculated blade strike probabilities ranged from 2.5 to 44.6 percent for the size classes evaluated and with the chance of blade strike increasing with fish size (Table 5.6-1) as more body surface area would be exposed to turbine blades. However, approximately 97.6 percent of the fish that would be expected to be entrained at the Project were less than 4 inches in length (see Section 5.5.1 of this study report); the probability of blade strike for fish in these size classes is low, ranging from 2.7 to 5.9 percent at Ross Dam. Generally, fish larger than 6 inches in length exhibited a higher probability of blade strike but are estimated to be entrained less frequently (less than 3 percent of entrained fish). Fish greater than 30 inches had the lowest survival probability due to blade strike yet represented zero percent of entrainment estimated for Ross Dam.

Table 5.6-1. Estimated blade strike and survival probabilities by size class at Ross Dam.

Fish Length Class (inches)	Turbine Blade Strike Probability (%)				Turbine Passage Survival Probability
	Unit 41	Unit 42	Unit 43	Unit 44	
2	3.0	2.7	3.0	2.5	97.1
4	5.9	5.2	5.8	4.9	94.4
6	8.9	7.9	8.8	7.5	91.1
8	12.0	10.6	11.7	10.0	88.8
10	14.8	13.1	14.6	12.4	86.9
15	22.3	19.8	21.9	18.7	79.0
20	29.8	26.4	29.3	25.0	71.3
25	37.1	32.9	36.5	31.1	65.7
30	44.6	39.6	43.8	37.4	59.0

5.6.1.2 Diablo Dam

Calculated blade strike probabilities varied from 2.7 to 40.3 percent at Diablo Dam for the size classes evaluated, with the chance of blade strike increasing with fish size (Table 5.6-2). Fish less than 4 inches in length exhibited the highest likelihood of entrainment with a probability of blade strike from 2.7 to 5.3 percent. Fish 6 inches in length or larger exhibited a higher probability of blade strike mortality but are entrained less frequently. Fish greater than 30 inches had the lowest blade strike survival probability yet represented zero percent of entrainment.

Table 5.6-2. Estimated blade strike and survival probabilities by size class at Diablo Dam.

Fish Length Class (inches)	Turbine Blade Strike Probability (%)		Turbine Passage Survival Probability
	Unit 35	Unit 36	
2	2.7	2.7	97.2
4	5.3	5.3	94.8
6	8.1	8.1	91.8
8	10.8	10.8	89.3
10	13.4	13.4	87.0
15	20.1	20.1	79.5
20	26.9	26.9	73.3
25	33.5	33.5	67.5
30	40.3	40.3	61.8

5.6.1.3 Gorge Dam

Model-estimated blade strike probabilities for Gorge Dam ranged from 2.9 to 51.1 percent for the size classes evaluated and with the chance of blade strike increasing with fish size (Table 5.6-3). Fish less than 4 inches would experience a blade strike probability of 2.9 to 6.7 percent. Fish 6 inches in length or larger exhibited a higher probability of blade strike mortality but are estimated to be entrained less frequently. Fish greater than 30 inches had the lowest survival probability due to blade strike yet represented zero percent of entrainment estimated for Gorge Dam.

Table 5.6-3. Estimated blade strike and survival probabilities by size class at Gorge Dam.

Fish Length Class (inches)	Turbine Blade Strike Probability (%)				Turbine Passage Survival Probability
	Unit 21	Unit 22	Unit 23	Unit 24	
2	3.5	3.5	3.5	2.9	96.9
4	6.7	6.7	6.4	5.6	93.6
6	10.2	10.2	9.7	8.5	90.6
8	13.7	13.7	13.0	11.4	87.1
10	17.0	17.0	16.1	14.2	84.4
15	25.5	25.5	24.3	21.3	77.3
20	34.1	34.1	32.5	28.5	69.2
25	42.5	42.5	40.4	35.5	61.5
30	51.1	51.1	48.6	42.7	52.6

5.6.2 Combined Turbine and Spillway Passage Survival

5.6.2.1 Ross Dam

Estimated overall downstream passage survival, which is inclusive of turbine entrainment and spillway passage, as well as the likelihood of route selection was estimated for multiple sizes of salmonids and Redside Shiner (Table 5.6-4). These values represent the estimated survival of fish that exit the reservoir and pass downstream and do not reflect those fish that remain in the reservoir. Spill occurs infrequently at Ross Dam due to the large reservoir storage capacity (see Section 2.1 of this study report; City Light 2020a), with an average of 2.5 days per year or 0.68 percent of the time. The average spill volume from days there was spill from 2013-2020 was used to determine the route selection probability.

Spillway mortality ranged 10.5 to 11.2 percent for the species-life stages evaluated (Table 5.6-4). Combined turbine and spillway passage survival correlated with fish length—smaller fish experience greater passage survival than larger fish. Combined downstream passage survival rates for 23.4-inch and 12-inch salmonids were 59.7 percent and 75.8 percent, respectively. Downstream passage survival rates for 3 to 5-inch Redside Shiner ranged from 83.3 to 85.3 percent.

Table 5.6-4. Model estimated turbine blade strike and passage survival summary for salmonids and Redside Shiner at Ross Dam.

Species	Size[1] (in)	Turbine Blade Strike[2] (%)	Spillway Mortality[3] (%)	Combined Turbine and Spillway Passage Survival (%)
Salmonids	12	13.1	11.1	75.8
	23.6	29.8	10.5	59.7
Redside Shiner	3	3.9	10.8	85.3
	4	4.8	11.2	84.0
	5	5.9	10.8	83.3
Model Input Parameters	Average Spill Volume (cfs) during 2013-2020 spill events			1,779
	Assumed Spillway Passage Mortality Rate for Salmonids and Redside Shiner			100%
	Spill Route Selection Probability[4]			0.1099
	Combined Turbine Route Selection Probability			0.8901

1 A length of 23.6 inches for salmonids represents the average size of an adult Bull Trout, a value used in previous analyses. A length of 12 inches was used to represent smaller length salmonids.
2 Percent probability of an entrained fish experiencing a blade strike; and does not address likelihood of entering dam forebay or encountering spillway or intakes.
3 Scenario assumes all units at maximum capacity with excess flows passed over the spillway.
4 Assumes route selection is directly proportional to the annual volume (cfs) of flow to each route and does not address likelihood of encountering spillway or intakes.

5.6.2.2 Diablo Dam

Estimated overall downstream passage survival, which is inclusive of turbine entrainment and spillway passage, as well as the likelihood of route selection was estimated for multiple sizes of salmonids and Redside Shiner (Table 5.6-5). These estimates represent the estimated survival of fish that exit the reservoir and pass downstream and do not reflect the fish that remain in the reservoir. Diablo serves as a reregulation facility between Ross and Gorge dams, and therefore spill occurs more frequently at Diablo Dam than at either of the other Project facilities (City Light 2020a). Diablo Dam can spill anytime inflow to the reservoir exceeds plant capacity (typically during periods of high runoff), and/or when additional water is needed to meet downstream flow requirements at Gorge Dam. For Diablo Lake, spill may occur an average of 37 days per year or 10.1 percent of the time.

Spillway mortality ranged 7.2 to 10.0 percent for the species-life stages evaluated (Table 5.6-5). Combined downstream passage survival rates for 23.4-inch and 12-inch salmonids were 64.2 percent and 76.9 percent, respectively. Downstream passage survival rates for 3 to 5-inch Redside Shiner ranged from 86.5 to 89.3 percent.

Table 5.6-5. Model estimated turbine blade strike and passage survival summary for salmonids and Redside Shiner at Diablo Dam.

Species	Size[1] (in)	Turbine Blade Strike[2] (%)	Spillway Mortality[3] (%)	Combined Turbine and Spillway Passage Survival (%)
Salmonids	12	13.4	9.7	76.9
	23.6	25.8	10.0	64.2
Redside Shiner	3	3.5	7.2	89.3
	4	4.1	8.0	87.9
	5	6.2	7.3	86.5
Model Input Parameters	Average Spill Volume (cfs) during 2013-2020 spill events			2,473
	Assumed Spillway Passage Mortality Rate for Salmonids			55%
	Assumed Spillway Passage Mortality Rate for Redside Shiner			40%
	Spill Route Selection Probability[4]			0.178
	Combined Turbine Route Selection Probability			0.822

1 A length of 23.6 inches for salmonids represents the average size of an adult Bull Trout, a value used in previous analyses. A length of 12 inches was used to represent smaller length salmonids.
2 Percent probability of an entrained fish experiencing a blade strike; and does not address likelihood of entering dam forebay or encountering spillway or intakes.
3 Scenario assumes all units at maximum capacity with excess flows passed over the spillway.
4 Assumes route selection is directly proportional to the annual volume (cfs) of flow to each route and does not address likelihood of encountering spillway or intakes.

5.6.2.3 Gorge Dam

Estimated overall downstream passage survival, which is inclusive of turbine entrainment and spillway passage, as well as the likelihood of route selection was estimated for multiple sizes of salmonids and Redside Shiner (Table 5.6-6). These estimates represent the estimated survival of fish that exit the reservoir and pass downstream and do not reflect the fish that remain in the reservoir. These estimates also include spillway mortality; spill occurs at Diablo Dam if the Gorge powerhouse is not generating enough to maintain downstream minimum flow requirements for fish protection (City Light 2020a). Gorge Dam may also spill in preparation for a predicted flood event. Gorge Dam typically spills an average of 27.5 days per year or 7.5 percent of the time for these purposes.

Estimated spillway mortality for Gorge Dam was low, ranging from 0.8 to 2.3 percent for the species-life stages evaluated (Table 5.6-6). Combined downstream passage survival rates for 23.6-inch and 12-inch salmonids were 68.7 percent and 84.8 percent, respectively. Downstream passage survival rates for 3 to 5-inch Redside Shiner ranged from 92.3 to 95.1 percent.

Table 5.6-6. Model estimated turbine blade strike and passage survival summary for salmonids and Redside Shiner at Gorge Dam.

Species	Size[1] (in)	Turbine Blade Strike[2] (%)	Spillway Mortality[3] (%)	Combined Turbine and Spillway Passage Survival (%)
Salmonids	12	13.5	1.7	84.8
	23.6	29	2.3	68.7
Redside Shiner	3	4.1	0.8	95.1
	4	4.7	1.3	94.0
	5	6.7	1	92.3
Model Input Parameters	Average Spill Volume (cfs) during 2013-2020 spill events			2,131
	Assumed Spillway Passage Mortality Rate for Salmonids			10%
	Assumed Spillway Passage Mortality Rate for Redside Shiner			5%
	Spill Route Selection Probability[4]			0.199
	Combined Turbine Route Selection Probability			0.801

1 A length of 23.6 inches for salmonids represents the average size of an adult Bull Trout, a value used in previous analyses. A length of 12 inches was used to represent smaller length salmonids.
2 Percent probability of an entrained fish experiencing a blade strike; and does not address likelihood of entering dam forebay or encountering spillway or intakes.
3 Scenario assumes all units at maximum capacity with excess flows passed over the spillway.
4 Assumes route selection is directly proportional to the annual volume (cfs) of flow to each route and does not address likelihood of encountering spillway or intakes.

6.0 DISCUSSION AND FINDINGS

Entrainment and impingement potential at the Project varies with time of year, fish species, life stage, swim speed, body size, and hydropower operations. Water quality characteristics do not appear to preclude the presence of fish near the intakes based on temperature and dissolved oxygen data showing that adequate conditions for trout habitat are present throughout the water column year-round. Based on the qualitative risk assessment, few species or life stages have elevated (i.e., moderate or high) risk of entrainment or impingement. This is primarily due to trout species' spawning and rearing habitat requirements (i.e., tributary streams) combined with the depth of intake structures (versus depth preference of each fish species considered), infrequent drawdown of the Project reservoirs, and swimming ability of the size classes of fish that may be in the vicinity of the Project intakes. Adult native char (Bull Trout and Dolly Varden) are the life stages of trout species that may occur in the dam forebays or near the intakes in the Project reservoirs, however, their swim burst speeds are sufficient to overcome approach velocities and avoid entrainment or impingement at the intakes (with the exception of Dolly Varden at the Gorge intake at minimum WSE, as the shallow depth of the intake combined with low water level during drawdown increases intake velocities). Furthermore, acoustic telemetry studies have documented Bull Trout in the forebays of Diablo and Gorge on a limited basis, and while they may frequent the Ross forebay, frequency of occurrence within the intake zone was low (City Light 2016, 2017, 2018, 2019).

In addition to Bull Trout and Dolly Varden, adult Rainbow Trout may also occur in the forebay as indicated by the 1972 telemetry study which saw 14 Rainbow Trout pass through the spillway and remain in Diablo and Gorge lakes (Johnston 1989). However, the intake avoidance analysis showed that Bull Trout and Rainbow Trout adults are likely to escape approach velocities based on swim burst speeds. Adult Dolly Varden may be susceptible to the elevated approach velocities at Gorge Lake that occur with minimum WSE, however drawdowns of this magnitude are infrequent and have only happened three times over the current license period (City Light 2020a).

The non-adult (egg to juvenile) life stage of the trout species evaluated in this study are generally not at risk of impingement or entrainment at the Project intakes based on spawning and rearing preference for tributary streams which are located miles from each of the dams. Since these trout spawn and rear their young for one to four years in tributary streams, by the time they migrate to the reservoir they have grown to adult size with sufficient burst swim speeds to avoid impingement or entrainment at the Project intakes. Redside Shiner, an introduced species, is expected to experience the greatest risk of entrainment, with seasonal peaks occurring at each of the Project intakes. Like Dolly Varden, Redside Shiner may also have the highest risk of entrainment at Gorge Lake since in addition to juveniles, adults may also be susceptible to approach velocities at the minimum WSE (which occurs rarely, as previously stated).

Entrainment rates estimated using the EPRI (1997) database indicate that the majority of fish entrainment at Project intakes likely consists of fish less than 4 inches in length and is expected to be dominated by Redside Shiner, followed by Dolly Varden. Adult Redside Shiner likely exhibit elevated entrainment rates during the winter periods when these populations migrate to deeper water (Wydoski and Whitney 2003), which would bring them into the forebay in proximity to the intakes. Conversely, Dolly Varden may perform diel vertical migrations to deeper water seeking thermal refuge from occasional, elevated surface water temperatures. Although the water quality characterization presented in Section 5.2 concluded that adequate trout habitat is present throughout the water column of Project reservoirs throughout the year; rare, cyclical climatic extremes (i.e., summer heat waves) may occur near the Project.

The EPRI (1997) database is a popular tool and widely accepted resource for performing desktop assessments of potential entrainment rates at Projects based on results of studies performed at comparable hydroelectric facilities. However, the database is unable to capture all of the site- or species-specific factors that could influence entrainment risk at a project. Differences between the position (on the dam) and depth (e.g., lower depths) of the intake structures at the Project, compared to the position and depth of intakes at the facilities included in the database (e.g., mix of depths and locations), could result in entrainment risk being overestimated. Differences in waterbody productivity and related fish population relative abundance, intake velocities, and many other factors could also influence entrainment rates. The traits-based risk assessment used in this study allows for a qualitative assessment of these other Project-specific design and operational factors that influence the overall entrainment risk at the Project intakes. This approach provides a targeted framework for determining the overall likelihood that a species will utilize the Project reservoirs in a way that would bring them near the Project intakes where they would be susceptible to entrainment. This approach allows for greater confidence in the rates of entrainment estimated for the Project based on the EPRI (1997) database.

The entrainment rates estimated from the database suggest that Dolly Varden are entrained at lower rates than Redside Shiner. While the total number of Dolly Varden in Ross Lake and its tributaries is unknown, available data suggests there are at least several thousand adults present, with less in Gorge and Diablo lakes due to limited habitat (City Light 2020a). The qualitative risk assessment suggested that Dolly Varden are not susceptible to entrainment under most conditions. Dolly Varden may have elevated susceptibility of entrainment at the Gorge intake but only at approach velocities under minimum WSE, which happens rarely. Furthermore, Dolly Varden swim burst speed may be greater than the approach velocity for fish larger than 6.5 inches in length, therefore the entrainment rate estimate for Dolly Varden should be considered judiciously as it likely overestimates the number of fish entrained for this species. Redside Shiner, on the other hand, is an introduced species with a population estimate of greater than 1.2 million fish in Ross Lake alone. The entrainment database appears to adequately estimate the relative entrainment rates of Redside Shiner as compared to Dolly Varden given the results of the risk assessment and current understanding of these populations' relative abundance in the Project reservoirs.

The likelihood of turbine blade strike mortality based on facility-specific turbine specifications and operational information is comparable for the three Project intakes. For the size lengths evaluated, turbine blade strike probability ranged from 2.5 to 44.6 percent at Ross Dam, 2.7 to 40.3 percent at Diablo Dam, and 2.9 to 51.1 percent for Gorge Dam. The majority (97.6 percent) of estimated entrainment consisted of small fish (less than 4 inches in length) with the lowest risk of turbine blade strike, ranging from 2.7 to 5.9 percent at Ross Dam, 2.7 to 5.3 percent at Diablo Dam, and 2.9 to 6.7 percent at Gorge Dam. However, the risk analysis indicates that larger fish (i.e., adult trout and some larger juveniles) are unlikely to be entrained based on life history characteristics, position of the intakes, habitat preferences and utilization, spawning and migratory behavior, and swimming ability.

The likelihood of fish mortality was higher for fish passing over Project spillways; however, the frequency and total volume of spill for the Projects is low, thus reducing the risk of spill-related mortality. Based on data presented in the PAD (City Light 2020a), spill volume and spill frequency were lowest at Ross (2.5 days per year), followed by Gorge (27.5 days per year), and highest at Diablo (37 days per year). The combined survival of fish most frequently entrained (fish less than 4 inches in length) was estimated at 84 percent or greater at Ross, greater than 87 percent at Diablo, and 94 percent or greater at Gorge. While results of the turbine blade strike and spillway mortality analyses are presented for the target species, the results of these analyses would only impact those fish that are actually entrained at the spillways or intake structures.

The greatest opportunity for fish mortality at the Project occurs during potential contact with the turbine runner blades; however, injuries and mortalities can also occur from extreme pressure changes and shear stress that may occur as fish are passed through the penstocks to the tailraces, or from shear stress, water turbulence, cavitation, and grinding which can result from passage over spillways. Additionally, fish passed below dams may be more vulnerable to predation resulting from disorientation due to passage associated with injury, pressure effects, cavitation, shear, and turbulence (R2 Resource Consultants 1998; USFWS 2013; City Light 2012). Increased exposure to predation may result from recovery time associated with non-life-threatening injuries.

The Project facilities are considered high-head dams, and therefore, pressure-related injuries and mortalities are more likely to occur than at other, smaller dams. However, the effects from the rapid changes in pressure may be alleviated at the Project, somewhat, due to the depth of the intakes which reduces the overall vertical distance fish are traveling through the development. Salmonids and shiners are also physostomous, meaning part of their swim bladder morphology includes a pneumatic duct which may help limit effects of rapid decompression during passage (Čada and Schweizer 2012). Furthermore, based on this analysis, entrainment of fish through the Project facilities is likely to be low, with mortality of passing fish not expected to significantly affect fish populations or the fish community of the Project reservoirs.

Out-migrating anadromous salmonids would be at low risk of entrainment or mortality from turbine blade strike due to the presumed installation of fish passage technology to facilitate downstream migration. In the absence of fish passage technologies, the anadromous salmonids reviewed in this study (Chinook Salmon, Chum Salmon, Coho Salmon, Pink Salmon, Sockeye Salmon, and steelhead trout) are not present in the Project reservoirs, and are therefore, not susceptible to impingement or entrainment at the Project facilities.

6.1 Recommendations and Next Steps

This desktop analysis provides sufficient information to evaluate the potential risk of impingement and entrainment at the Project. As such, City Light does not currently recommend a field-based study based on the following factors:

- Entrainment is likely low based on the design and operations of each Project facility, fish species' habitat preferences and behavior within the reservoirs, and fish population abundance of the Skagit system. The existing layout of the Project intakes minimize entrainment and impingement risk.
- This study sufficiently describes potential entrainment at the Project, which consists primarily of smaller fish that are inherently at greater risk of entrainment due to poor swimming ability. However, due to site configurations, and species-specific habitat requirements and behavior, it

is unlikely that small fish come within proximity to the intake on a regular basis. Furthermore, smaller fish that are entrained have low probability of mortality due to turbine blade strike. Overall risk to small or young fish is low at the Project.

- There are existing and ongoing telemetry studies evaluating the potential for Bull Trout entrainment, which is also being expanded to include additional trout species (Dolly Varden and Rainbow Trout).
- A field-based study (i.e., fish tagging and tailrace netting) would be logistically difficult and cost prohibitive given the size and capacity of the Project facilities, and the extent and type of fish tagging requested by agencies and LPs. This desktop entrainment assessment provides sufficient information to characterize entrainment and impingement risk to fish within the study area, including federally protected species. Given the existing information available for the Project and from comparable studies, this desktop entrainment study demonstrates that the current design and operation of the Project facilities minimize entrainment, and for those species that are entrained, overall passage survival at the Project facilities is high.

7.0 VARIANCES FROM FERC-APPROVED STUDY PLAN AND PROPOSED MODIFICATIONS

In the RSP (City Light 2021a), City Light proposed to evaluate turbine mortality using both the EPRI (1997) survival database and the USFWS TBSA model (USFWS 2020). After review of the available information included in the EPRI (1997) survival database for applicability to the Project, City Light determined that the physical and operational characteristics of the facilities included in the survival database were sufficiently different from the Project facilities that the results of a desktop assessment of survival would not be representative of potential survival at the Project. Therefore, turbine and spillway survival at the Project facilities were estimated using the USFWS TBSA model (USFWS 2020) and site-specific turbine and intake structure specifications. These results were supplemented with relevant, literature-based data on turbine and spillway survival from assessments performed at comparable facilities. Therefore, the study objective to characterize the probability of passage and survival for target species at the Project facilities was completed.

City Light is not proposing any additional modifications to this study.

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FISH ENTRAINMENT STUDY REPORT

ATTACHMENT A

SITE CHARACTERISTICS OF SELECTED HYDROPOWER FACILITIES FROM THE ELECTRIC POWER RESEARCH INSTITUTE (1997) ENTRAINMENT DATABASE

Table A-1. Facilities selected from the Electric Power Research Institute (EPRI) 1997 database for analysis in the Fish Entrainment Study.

Site Name	State	River	River Mile	Reservoir Area (acres)	Reservoir Volume (ac-ft)	Usable Storage (ac-ft)	Fluctuation Limits (ft)	Total Plant Capacity (cfs)	Number of Units	Operating Mode[1]	Average Velocity at Trashracks (ft/sec)	Trashrack Clear Spacing (in)
Colton	NY	Raquette		195	620	103	0.5	1,503	3	PK		2
Crowley	WI	N.F. Flambeau	82	422	3,539		1	2,400	2	ROR	1.4	2.375
Grand Rapids	MI/WI	Menominee	26	250			1	3,870	5	ROR		1.75

1 PK: peaking; ROR: run-of-river.

FISH ENTRAINMENT STUDY REPORT

ATTACHMENT B

ENGINEERING ESTIMATES OF APPROACH AND THROUGH-BAR VELOCITY FOR THE SKAGIT RIVER HYDROELECTRIC PROJECT

Engineering Estimates of Approach Velocity and Through-bar Velocity for Existing Bar Racks at the Gorge Powerhouse Cooling Water Intake Structure, the Diablo Powerhouse Cooling Water Intake Structures, and the Ross Powerhouse Cooling Water Intake Structures

Originator: **Spencer Nush, EIT** 9/17/2021

Reviewer: **Shane Galloway, EIT** 10/1/2021

Approver: **Scott Loughery, PE** 10/1/2021

Revision No.	Revised by:	Approved by:	Description
0	-	-	-

Calculation Summary:

Estimated Approach Velocity and Through-bar Velocity	Units	Gorge Powerhouse	Diablo Powerhouse	Ross Powerhouse
Normal Water Elevation Bar-rack Approach Velocity	fps	2.33	1.43	1.11
Minimum Water Elevation Bar-rack Approach Velocity	fps	6.20	1.51	3.88
Normal Water Elevation Through-bar Velocity	fps	2.86	2.41	1.41
Minimum Water Elevation Through-bar Velocity	fps	8.17	2.58	5.28

System Description:

The Skagit River Hydroelectric Project supplies power to Seattle City Light's customer base. The project consists of three developments: Gorge Powerhouse, Diablo Powerhouse, and Ross Powerhouse. Each of these developments has a dam, a powerhouse, and a reservoir, operations of which are hydraulically coordinated. Gorge Powerhouse, Diablo Powerhouse, and Ross Powerhouse are each four-unit hydroelectric-powered plants and all three powerhouses are located on the Skagit River in Whatcom County, WA.

Calculation Purpose:

Calculate the approach velocity and the through-bar velocity at the normal and minimum water elevations at the Gorge Powerhouse cooling water intake structure, the Diablo Powerhouse cooling water intake structures, and the Ross Powerhouse cooling water intake structures.

Calculation Objectives:

1. Identify the bar rack physical parameters and design hydraulic capacity.
2. Calculate the open width at each bar rack open for water flow.
3. Calculate the approach and through-bar velocities for the normal and minimum water elevations.

Calculation Methodology:

Formula 1 $V_{app} = Q / (C1 * CS * WD)$

Units: fps

where:

V_{app} = Approach velocity (fps)
Q = Flow rate (gpm)
C1 = 449 (1 cfs = 449 gpm)
CS = Width of power tunnel immediately before bar rack (ft)
WD = Bar rack area available to flow (ft)

Formula 2 $V_{bar} = Q / (((WD * OW_{bar}) - FA) * C1)$

Units: fps

where:

V_{bar} = Through-bar velocity (fps)
OW_{bar} = Open width at each bar rack (ft)
FA = Bar rack horizontal bar and panel closed area (ft^2)

Formula 3 $OW_{bar} = (n * BS) / C2$

Units: ft

where:

n = Number of spaces per bar rack
BS = Bar rack bar spacing (inch)
C2 = Conversion factor from inch to ft (1 foot = 12 inches)

Design Inputs:

Parameters and Variables	Gorge Powerhouse	Diablo Powerhouse	Ross Powerhouse	Units	References / Notes
Waterbody Information					
Datum	NAVD 88	NAVD 88	NAVD 88		Note 1
Normal Water Elevation	881.51	1211.36	1608.76	ft	[3], Note 1
Minimum Water Elevation	831.51	1204.36	1480.76	ft	[4], Note 1
Bar Rack Information					
Bar Rack Bar Spacing	3.5	2.5	3.5	inch	[1], [5], [7]
Width of Bar Rack	20.0	17.75	20.0	ft	[1], [5], [7]
Number of Spaces per Bar Rack	60	71	60		[1], [5], [7]
Elevation at Bar Rack Invert	801.51	1,086.36	1,429.26	ft	[4], Note 1
Number of Intake Openings	2	2	4		[2], Note 2
Width of Power Tunnel Immediately before Bar Rack	20.0	20.0	20.0	ft	[2], [6], [8]
Bar Rack Percent Clogged	0%	0%	0%		Assumption 2
Closed Frame Area (Normal Water Elevation)	97.92	367.94	308.33	ft^2	Note 3
Closed Frame Area (Minimum Water Elevation)	69.58	362.40	143.65	ft^2	Note 3
Cooling Water Intake Structure Design Hydraulic Capacity Information					
Design Hydraulic Capacity at Maximum Plant Output	3,339,304	3,200,166	7,181,299	gpm	[4]

Assumptions:

1. The cooling water intake structures have not been modified since dates of references used.
2. For the purposes of these calculations, the bar racks are assumed to be free of debris and 100% clean. The through-bar velocity would increase with the presence of debris.

Notes:

1. NAVD 88 was used as the datum for normal water elevation, minimum water elevation, and elevation at bar rack invert at all three powerhouses.
2. There are two cooling water intake structures at Diablo with four openings and four bar racks, but only one cooling water intake structure (two openings and two bar racks) are used.
3. The area of the horizontal bars on the bar racks and panels between bar racks was calculated and subtracted from the total bar rack open area to achieve an accurate effective open area for water flow value.

References:

[1] City of Seattle. 1997. Skagit Project - Gorge Development: Gorge High Dam Details of Trashrack Panels for Intake Structure. Drawing No. D-18692. 16 Apr 1997.
[2] City of Seattle. 1996. Skagit Project - Gorge Development: Gorge High Dam Reinforcement of Intake Structure for 20X25-foot Fixed Wheel Gate. Drawing No. D-18523. December 1996.
[3] USACE. 2002. Water Control Manual. Skagit River Project - Skagit River, Washington.
[4] City of Seattle. 2020. Seattle City Light Response to Additional Information Request for Skagit River Project (No. 553) Revised Exhibits M and K (Docket Numbers 553-223 & -236). 19 Aug 2020.
[5] City of Seattle. Undated. Skagit General - Power Tunnel Proposed Trash Rack Modifications, Trash Rack Details. Drawing No. D-25131.
[6] Seattle City Light. 2013. Diablo Dam & Reservoir - Diablo Dam Trash Rack Cleaning Plan, Sections & Location Map. Drawing No. D-45844. 10 Sep 2013.
[7] City of Seattle. 1997. Skagit Project - Ross Development: Ross Dam 3rd Step Power Tunnel Intake Structure Trashrack, Guide, Bearing Plates, and Sill - Details. Drawing No. D-13320-6. 28 Jan 1997.
[8] City of Seattle. 1996. Skagit Project - Ross Development: Ross Dam 3rd Step Power Tunnel Intake Structure General Details. Drawing No. D-13320. December 1996.

Calculations:

1. Bar Rack Physical Parameters and Design Hydraulic Capacity

Given:

Variables	Gorge Powerhouse	Diablo Powerhouse	Ross Powerhouse	Units
Q_{Total} =	3,339,304	3,200,166	7,181,299	gpm
Q =	1,669,652	1,600,083	1,795,325	gpm
$WD_{Normal\ Water}$ =	80.0	125.0	179.5	ft
$WD_{Minimum\ Water}$ =	30.0	118.0	51.5	ft
C1 =	449	449	449	1 cfs = 449 gpm
C2 =	12	12	12	1 ft = 12 inch
BS =	3.5	2.5	3.5	inch
PC =	100%	100%	100%	
CS =	20.0	20.0	20.0	ft
n =	60	71	60	
FA_{NW} =	97.9	367.9	308.3	ft^2
FA_{MW} =	69.6	362.4	143.6	ft^2

2. Design Approach Velocity

Formula Used:
Formula 1

Given:
Intake structure dimensions and stated assumptions

Calculate:

V_{app} = Q / (C1 * CS * WD) =

Estimated Bar-rack Approach Velocity	Gorge Powerhouse	Diablo Powerhouse	Ross Powerhouse	Units
Normal Water Elevation	2.33	1.43	1.11	fps
Minimum Water Elevation	6.20	1.51	3.88	fps

3. Design Through-bar Velocity at Bar Rack

Formulas Used:
Formulas 2 and 3

Given:
Bar rack parameters as shown in design inputs

Calculate:

OW_{bar} = (n * BS) / C2 =

Gorge Powerhouse	Diablo Powerhouse	Ross Powerhouse	Units
17.50	14.79	17.50	ft

V_{bar} = Q / (((WD * OW_{bar}) - FA) * C1) =

Estimated Through-bar Velocity	Gorge Powerhouse	Diablo Powerhouse	Ross Powerhouse	Units
Normal Water Elevation	2.86	2.41	1.41	fps
Minimum Water Elevation	8.17	2.58	5.28	fps

FISH ENTRAINMENT STUDY REPORT

ATTACHMENT C

RESIDENT TARGET SPECIES LIFE HISTORY SUMMARIES

Bull Trout (Resident, Migratory, and Anadromous)

Bull Trout populations in the Skagit River and tributaries downstream of the Gorge Dam exhibit complex gradients within four life history types (resident, adfluvial, fluvial, and anadromous). Genetic analyses of Bull Trout upstream and downstream of Gorge Dam indicate that Bull Trout populations downstream of Gorge Dam are significantly genetically different from the upstream populations which are more closely related to populations in the Frazier River system (Smith 2010; Small et al. 2016). This suggests that entrainment of Bull Trout at Gorge is minimal and that upstream migration of anadromous Bull Trout into the Gorge was limited historically by migratory barriers documented in the Gorge bypass reach. Fish populations in the Project reservoirs are "freshwater resident," though instream migratory behavior between tributaries and the reservoirs has been observed (City Light 2020). Native char found upstream of Gorge Dam exhibit resident, adfluvial, and fluvial life history types (R2 Resource Consultants 2009; McPhail and Taylor 1995).

Resident Bull Trout spawn, rear, and live as adults generally in one headwater stream where they live out their entire life cycle. Spawning occurs from August through September with optimal spawning temperatures between 14-16°C. Redds are dug in gravel substrates found in pool tailouts. Migratory Bull Trout (adfluvial and fluvial) spawn and rear in headwater streams and then after 4-5 years migrate downstream to larger rivers (fluvial) or lakes and reservoirs (adfluvial) where they grow to maturity. Almost 70 percent of the Bull Trout in Ross Reservoir are adfluvial (City Light 2012). Spawning occurs in mid-September through mid- to late November as water temperatures decrease to below 9°C. Spawning occurs in low gradient stream reaches with loose, clean gravel, near springs or other sources of cold groundwater. Juveniles are reared in stream bottoms with cool water temperatures, abundant riparian vegetation, pools, boulders, and low water velocities. Anadromous Bull Trout remain in freshwater for one to three years before migrating to the marine environment as an adult or subadult (City Light 2020; Lowery et al 2015).

Bull Trout eggs range in size from 5-6 mm in diameter and have an incubation period of approximately 220 days in water that is ideally between 2-4°C (Fish 2004). After hatching, fry take approximately 65-90 days to absorb their yolk sacs, after which they spend three weeks developing parr marks and actively feeding on benthic and drifting aquatic insects. Fry emerge from stream beds between 25-28 mm total length. Growth is influenced by water temperature with increased temperatures decreasing juvenile growth rates. Average female fecundity is 5,000 eggs while larger individuals have been documented as having approximately 12,000 eggs (ADW 2020a).

Bull Trout smolt typically spend 1-4 years in their natal streams before migratory populations travel downstream to the coast, a larger river, or lake to recruit to the adult stage (Fish 2004). Sexual maturity is reached in 4-7 years. Spawning is typically biennial, occurring every other year or every third year, when mature adults return to the specific headwater in which they were produced to spawn. Total lifespan may be greater than 12 years with variable duration of occupancy in freshwater and marine environments (City Light 2020).

Native char in Ross Lake and the upper Skagit River system average 556 mm TL (range: 345-720 mm) and genetic studies indicate that native char over 300 mm TL are likely Bull Trout rather than Dolly Varden (City Light 2012). Most of the native char captured in Diablo Lake were <350 mm TL. Based on genetic analysis and gill net sampling, only 6-21 percent of native char in Diablo

Lake are Bull Trout with the remainder being Dolly Varden and Dolly Varden-Bull Trout hybrids. Native char captured in Gorge Lake were 130-255 mm TL with only 4 individuals being >600 mm TL. Most of the native char captured in Stetattle Creek, the only suitable Bull Trout spawning area in Gorge Lake, were Bull Trout (75 percent) based on genetic analysis. Based on snorkel counts conducted during 2006 the number of adult Bull Trout in Ross Lake was estimated to be around 4,800 fish (City Light 2012). No snorkel surveys were conducted in Diablo or Gorge Lakes during the 2006 survey. However, abundance was estimated to be 370 for Diablo Lake and 100 for Gorge Lake based upon the estimate in Ross Lake scaled down by the surface area at full pool for each reservoir.

Results of multi-year acoustic tracking indicate that adult Bull Trout are widely ranging within the Project reservoirs and move freely in and out of the vicinity of the intake forebays (City Light 2012). Results for Bull Trout in similar waterbodies with similar facilities indicate that Bull Trout occupied the vicinity of the intake forebays at relatively low rates preferring the upper portions of the reservoirs instead (Knutzen 1997; Martins et al. 2013; Harrison et al 2020).

Cutthroat Trout (Freshwater Resident and Anadromous)

Cutthroat Trout life history is complex with migratory and non-migratory forms within the same population. Anadromous individuals rarely over-winter and typically do not make extensive ocean migrations (Johnson et al. 1999, from City Light 2020). Anadromous populations are found in the mainstem Skagit River and tributaries throughout the anadromous reaches of the system; resident populations are found in the Skagit River and major tributaries but distribution and abundance above the Gorge Dam is not well documented. Cutthroat Trout are considered non-native upstream of Gorge Dam and were historically stocked in Ross Lake (City Light 2020). Cutthroat Trout have not been recorded in Diablo or Gorge Lakes in past or present studies and are thought to be either likely absent or very rare in these reservoirs.

Both migratory and non-migratory types are spring spawners (January through mid-June) with spawning time driven by latitude, altitude, water temperature and flow conditions (Trotter 1991 from City Light 2020). Spawning takes place over low gradient riffles and in shallow pool tail-outs with preference for clean pea-sized to walnut-sized gravel located near deep pools, which are presumably used by adults for cover. Flow in spawning streams seldom exceeds 10 cfs during the low flow period (City Light 2020). A single spawning event produces between 1,000-2,000 eggs and egg duration is typically two months (ADW 2020b).

Juvenile rearing habitat for anadromous populations includes low velocity stream margins, backwater, and side channel habitat with abundant instream cover (fry; City Light 2020). Yearlings disperse throughout the mainstem. The optimal rearing temperature is 10°C with a maximum rearing temperature threshold of 22.8°C. Sexual maturity is reached between the ages of 4 and 5, following their first year in the marine environment.

Resident Cutthroat Trout spawn from March to July. Redds are dug in gravel substrates found in pool tailouts and juveniles inhabit stream pools with gravel, rubble, or boulder substrate and overhead cover (City Light 2020). The optimal rearing temperature is 15.5°C with a maximum rearing temperature threshold of 21°C. The typical lifespan of resident Cutthroat Trout is 4 to 5 years.

Based on creel surveys and reservoir gillnet surveys, Cutthroat Trout appear to be the least abundant salmonid species upstream of Gorge Dam (City Light 2020). Cutthroat Trout were only captured in 2008 (six individuals in Ross Lake), which represented 1.0 percent of the total catch during the 2008 survey. Although available data are sparse, Cutthroat Trout populations upstream of Gorge Dam appear to be self-sustaining and primarily restricted to the upper Skagit watershed and feeder streams.

Rainbow Trout (Freshwater Resident)

Resident Rainbow Trout populations are found in small, fast flowing streams, small to large rivers, and cool lakes. In riverine settings, they prefer relative complex habitat with an array of riffles and pools, submerged wood, boulders, undercut banks, and aquatic vegetation. Rainbow Trout are native to all three Skagit Project reservoirs and exhibit fluvial, adfluvial, and resident life histories upstream of Gorge Dam. Resident fluvial populations are also present in the lower mainstem and some tributaries below the dams. Populations in British Columbia and Ross Lake are highly migratory. Genetic separation was identified among the three upper Skagit River natural resident Rainbow Trout groups. However, they were all significantly different from natural-origin and hatchery-origin steelhead collections but not from the resident Rainbow Trout from Baker River. Freshwater resident Rainbow Trout were also significantly different from adult and juvenile steelhead collections from the same sub-watershed.

Spawning typically occurs during spring and early summer. Rainbow Trout spawning habitat includes cool, clear, and well-oxygenated streams. Redd sites are located at pool tailouts often associated with deep pools and abundant instream cover. In the Skagit River Basin, the spawning period occurs between March and June.

Juveniles prefer relatively small, fast flowing streams with a high proportion of riffles and pools. The optimal rearing temperatures are between 10-13°C with a maximum rearing temperature of 23.9°C. Rearing for resident Rainbow Trout typically occurs for 1-2 years in larger streams or they migrate from smaller streams to the lake in large numbers during their first summer. Migration into the upper mainstem Skagit River from Ross Lake is typically initiated in late March and April to spawn, after which 85 percent of individuals return to Ross Lake and the remaining 15 percent remain in the river. Stetattle Creek is the only tributary to Gorge Lake, and Thunder and Colonial creeks are the only tributaries to Diablo Lake that are known to support regular spawning of Rainbow Trout. Typical lifespan is between 4-5 years.

Size ranges documented for Rainbow Trout in Project reservoirs based on gill net surveys are Ross (106-538 mm TL), Diablo (99-388 mm TL), and Gorge (103-322 mm TL) (City Light 2020).

Devine Tarbell & Associates (2004) summarized entrainment risk for Rainbow and Brown Trout at seven facilities with deep-water intakes located in California. Adult trout generally prefer the headwater portions of reservoirs, and young-of-the-year and juvenile trout prefer near-shore habitat. Adult trout were more common in the upper water column where food availability was the greatest. The preferred habitats (away from the intakes) for each life stage serve to minimize entrainment risk. The surface-oriented distribution of adult Cutthroat and Rainbow Trout along with preference for the head waters was also considered to be an important factor in minimization of entrainment risk at Spada Lake, Washington (Stable and Thomas 1992; CH2MHILL 2007, Meridian Environmental, Inc 2008). Food availability was a major influencing factor regarding habitat preference for all life stages. Predation avoidance was also important with respect to juvenile life stage associations with shoreline, littoral habitat.

Dolly Varden (Resident)

Dolly Varden found upstream of Gorge Dam exhibit resident, adfluvial, and fluvial life history types. Migration towards spawning areas occurs in mid- to late-September. Pre-spawning adults have been observed to stage at the mouth of spawning tributaries and to move into holding pools while they ripen (City Light 2020). Spawning occurs in late September through late November, peaking in October.

Sexual maturity is reached at age 3 and an individual will not spawn more than three times in their lifespan, male or female (ADW 2020c). Spawning often occurs every 2-3 years and spawning is determined by food availability throughout that year. Females can lay up to 10,000 eggs in the redd depending on size. Redds are dug in gravel substrates found in pool tailouts typically located in upper reaches of accessible tributary habitats.

Egg incubation can last 3-6 months depending on water temperature (ADW 2020c). Alevins hatch in early spring and emerge from the sediment as fry when they are 2 mm in length and the yolk-sac is depleted. Fry spend 2-4 years in their natal stream before venturing into larger rivers or the ocean.

Resident juvenile rearing habitat includes both lakes and streams, and juveniles often travel upstream into spring-fed areas or smaller tributaries (City Light 2020). Optimal juvenile rearing temperature ranges from 2-16°C with a maximum rearing temperature threshold of above 18°C. Dolly Varden move into larger streams or rivers further downstream where larger prey is available after 2-4 years (ADW 2020c). Resident Dolly Varden typically live up to 10 years while anadromous individuals can live up to 19 years.

Brook Trout (Resident)

Brook Trout are found in rivers, lakes and marine environments and were introduced to the upper Skagit River drainage in the early 1900s and have since become well established in the Project Reservoirs (City Light 2020). Brook Trout are most common in Diablo Lake and least common in Ross Lake. Freshwater populations occur in clear, cool, well-oxygenated streams and lakes and thrive where temperatures remain below 18.8°C and there is little to no siltation (ADW 2020d). Stream-dwelling Brook Trout require resting areas in pools, feeding sites near riffles or swiftly flowing water, and cover typically provided by undercut banks, wood debris, trees, or large rock ledges.

They have similar life histories to Bull Trout and Dolly Varden and may hybridize with both, however, Brook Trout tend to mature earlier and at smaller sizes than Bull Trout (City Light 2020). Spawning occurs in later summer or fall depending on latitude and temperature (ADW 2020d). Spawning occurs over loose, clean gravel in shallow riffles, or along shorelines with oxygen-rich water due to upwelling. Mature individuals may travel many miles upstream to reach sufficient spawning habitat.

Brook Trout typically reach maturity at age 2 and spawn annually (ADW 2020d). Females create redds that typically only one male is able to fertilize. In the Skagit River they inhabit stream environments and spawn and rear in numerous tributaries to the Project reservoirs (City Light 2020).

Size ranges documented for Brook Trout in Project reservoirs based on gill net surveys are Ross (120-351 mm TL), Diablo (116-326 mm TL), and Gorge (124 – 290 mm TL).

Redside Shiner (Resident)

Redside Shiner are native to the lower Skagit River and historically were not upstream of the Gorge but were introduced into Ross Lake in 2000 and became established by 2004 (City Light 2020). They were documented in Diablo Lake in 2010 and Gorge Lake in 2019, indicating they are spreading into the downstream reservoirs through spill or entrainment through the turbines.

They use both littoral and pelagic areas and slow to moderately fast-moving water, including runs and pools of small headwater streams, larger creeks, and small to medium rivers as well as lakes and ponds, and are typically found over mud or sand near vegetation (Welch 2012; City Light 2020). They exhibit daily and seasonal migration patterns such as occupying shorelines during the day and pelagic waters at night. Additionally, during late spring, summer and early fall they occupy shoreline habitat and shallow waters but remain in deep water from October through May. However, the depth of nightly and seasonal retreat is unknown.

Spawning in the Skagit River Basin occurs from April to July and begins when temperatures reach 10°C (City Light 2020). Spawning often extends into late fall in Ross Lake where water temperatures are warmer. Spawning habitat consists of gravel stream bottoms or vegetation along lake shorelines and occurs at night (Welch 2012). Fertilized eggs adhere to the substrates and non-adhered eggs are typically consumed. Hatching estimates are between 7 and 15 days depending on temperature, with faster hatching occurring in warmer water.

Juvenile rearing habitat includes runs and standing pools of headwaters, creeks, and small to medium rivers as well as lakes and ponds. Usually found over mud or sand, often near vegetation. Optimal rearing temperature ranges between 14-18°C while the maximum rearing temperature threshold is 24°C.

Adults range from 3-7 inches in length and are generally considered a bait or forage fish (City Light 2020). Redside Shiner can live up to 7 years and spawning can occur in the second year. Based upon snorkel surveys conducted along the shoreline of Ross Lake in 2006, Downen (2014) estimated the Redside Shiner population in Ross Lake exceeded 1.2 million fish.

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FISH ENTRAINMENT STUDY REPORT

ATTACHMENT D

FISH ENTRAINMENT RATES CALCULATED USING THE ELECTRIC POWER RESEARCH INSTITUTE (1997) ENTRAINMENT DATABASE

TableD-1. Entrainment rates (fish/hr) calculated from the EPRI (1997) database for the Skagit River Hydroelectric Project.

Month	Target Species	Size Class (inches)	Entrainment Rate (fish/hr) by Project Intake		
			Gorge	Diablo	Ross
1	Redside Shiner	0-2	1.49	1.43	3.20
1	Redside Shiner	2.1-4	0.00	0.00	0.00
1	Redside Shiner	4.1-6	0.00	0.00	0.00
1	Redside Shiner	6.1-8	0.00	0.00	0.00
1	Redside Shiner	8.1-10	0.00	0.00	0.00
1	Redside Shiner	10.1-15	0.00	0.00	0.00
1	Redside Shiner	15.1-20	0.00	0.00	0.00
1	Redside Shiner	20.1-25	0.00	0.00	0.00
1	Redside Shiner	25.1-30	0.00	0.00	0.00
1	Redside Shiner	>30	0.00	0.00	0.00
3	Redside Shiner	0-2	0.00	0.00	0.00
3	Redside Shiner	2.1-4	0.11	0.11	0.24
3	Redside Shiner	4.1-6	0.00	0.00	0.00
3	Redside Shiner	6.1-8	0.00	0.00	0.00
3	Redside Shiner	8.1-10	0.00	0.00	0.00
3	Redside Shiner	10.1-15	0.00	0.00	0.00
3	Redside Shiner	15.1-20	0.00	0.00	0.00
3	Redside Shiner	20.1-25	0.00	0.00	0.00
3	Redside Shiner	25.1-30	0.00	0.00	0.00
3	Redside Shiner	>30	0.00	0.00	0.00
4	Redside Shiner	0-2	0.05	0.05	0.12
4	Redside Shiner	2.1-4	0.03	0.03	0.06
4	Redside Shiner	4.1-6	0.00	0.00	0.00
4	Redside Shiner	6.1-8	0.00	0.00	0.00
4	Redside Shiner	8.1-10	0.00	0.00	0.00
4	Redside Shiner	10.1-15	0.00	0.00	0.00
4	Redside Shiner	15.1-20	0.00	0.00	0.00
4	Redside Shiner	20.1-25	0.00	0.00	0.00
4	Redside Shiner	25.1-30	0.00	0.00	0.00
4	Redside Shiner	>30	0.00	0.00	0.00
5	Dolly Varden	0-2	0.00	0.00	0.00
5	Dolly Varden	2.1-4	0.00	0.00	0.00
5	Dolly Varden	4.1-6	0.07	0.07	0.15
5	Dolly Varden	6.1-8	0.07	0.07	0.15
5	Dolly Varden	8.1-10	0.07	0.07	0.15
5	Dolly Varden	10.1-15	0.00	0.00	0.00
5	Dolly Varden	15.1-20	0.00	0.00	0.00
5	Dolly Varden	20.1-25	0.00	0.00	0.00

Month	Target Species	Size Class (inches)	Entrainment Rate (fish/hr) by Project Intake		
			Gorge	Diablo	Ross
5	Dolly Varden	25.1-30	0.00	0.00	0.00
5	Dolly Varden	>30	0.00	0.00	0.00
5	Redside Shiner	0-2	0.06	0.06	0.13
5	Redside Shiner	2.1-4	0.10	0.09	0.21
5	Redside Shiner	4.1-6	0.02	0.02	0.04
5	Redside Shiner	6.1-8	0.00	0.00	0.00
5	Redside Shiner	8.1-10	0.00	0.00	0.00
5	Redside Shiner	10.1-15	0.00	0.00	0.00
5	Redside Shiner	15.1-20	0.00	0.00	0.00
5	Redside Shiner	20.1-25	0.00	0.00	0.00
5	Redside Shiner	25.1-30	0.00	0.00	0.00
5	Redside Shiner	>30	0.00	0.00	0.00
6	Dolly Varden	0-2	0.12	0.12	0.26
6	Dolly Varden	2.1-4	0.21	0.20	0.44
6	Dolly Varden	4.1-6	0.00	0.00	0.00
6	Dolly Varden	6.1-8	0.00	0.00	0.00
6	Dolly Varden	8.1-10	0.00	0.00	0.00
6	Dolly Varden	10.1-15	0.00	0.00	0.00
6	Dolly Varden	15.1-20	0.00	0.00	0.00
6	Dolly Varden	20.1-25	0.00	0.00	0.00
6	Dolly Varden	25.1-30	0.00	0.00	0.00
6	Dolly Varden	>30	0.00	0.00	0.00
6	Redside Shiner	0-2	0.43	0.41	0.91
6	Redside Shiner	2.1-4	0.73	0.70	1.57
6	Redside Shiner	4.1-6	0.00	0.00	0.00
6	Redside Shiner	6.1-8	0.00	0.00	0.00
6	Redside Shiner	8.1-10	0.00	0.00	0.00
6	Redside Shiner	10.1-15	0.00	0.00	0.00
6	Redside Shiner	15.1-20	0.00	0.00	0.00
6	Redside Shiner	20.1-25	0.00	0.00	0.00
6	Redside Shiner	25.1-30	0.00	0.00	0.00
6	Redside Shiner	>30	0.00	0.00	0.00
7	Dolly Varden	0-2	0.00	0.00	0.00
7	Dolly Varden	2.1-4	0.44	0.42	0.95
7	Dolly Varden	4.1-6	0.00	0.00	0.00
7	Dolly Varden	6.1-8	0.00	0.00	0.00
7	Dolly Varden	8.1-10	0.00	0.00	0.00
7	Dolly Varden	10.1-15	0.00	0.00	0.00
7	Dolly Varden	15.1-20	0.00	0.00	0.00
7	Dolly Varden	20.1-25	0.00	0.00	0.00
7	Dolly Varden	25.1-30	0.00	0.00	0.00

Month	Target Species	Size Class (inches)	Entrainment Rate (fish/hr) by Project Intake		
			Gorge	Diablo	Ross
7	Dolly Varden	>30	0.00	0.00	0.00
7	Redside Shiner	0-2	0.10	0.10	0.22
7	Redside Shiner	2.1-4	0.52	0.49	1.11
7	Redside Shiner	4.1-6	0.00	0.00	0.00
7	Redside Shiner	6.1-8	0.00	0.00	0.00
7	Redside Shiner	8.1-10	0.00	0.00	0.00
7	Redside Shiner	10.1-15	0.00	0.00	0.00
7	Redside Shiner	15.1-20	0.00	0.00	0.00
7	Redside Shiner	20.1-25	0.00	0.00	0.00
7	Redside Shiner	25.1-30	0.00	0.00	0.00
7	Redside Shiner	>30	0.00	0.00	0.00
8	Redside Shiner	0-2	0.00	0.00	0.00
8	Redside Shiner	2.1-4	0.13	0.13	0.29
8	Redside Shiner	4.1-6	0.00	0.00	0.00
8	Redside Shiner	6.1-8	0.00	0.00	0.00
8	Redside Shiner	8.1-10	0.00	0.00	0.00
8	Redside Shiner	10.1-15	0.00	0.00	0.00
8	Redside Shiner	15.1-20	0.00	0.00	0.00
8	Redside Shiner	20.1-25	0.00	0.00	0.00
8	Redside Shiner	25.1-30	0.00	0.00	0.00
8	Redside Shiner	>30	0.00	0.00	0.00
10	Dolly Varden	0-2	0.00	0.00	0.00
10	Dolly Varden	2.1-4	0.00	0.00	0.00
10	Dolly Varden	4.1-6	0.00	0.00	0.00
10	Dolly Varden	6.1-8	0.00	0.00	0.00
10	Dolly Varden	8.1-10	0.00	0.00	0.00
10	Dolly Varden	10.1-15	0.00	0.00	0.00
10	Dolly Varden	15.1-20	0.19	0.18	0.41
10	Dolly Varden	20.1-25	0.00	0.00	0.00
10	Dolly Varden	25.1-30	0.00	0.00	0.00
10	Dolly Varden	>30	0.00	0.00	0.00

FISH ENTRAINMENT STUDY REPORT

ATTACHMENT E

U.S. FISH AND WILDLIFE SERVICE TURBINE BLADE STRIKE ANALYSIS MODEL OUTPUTS BY SIZE CLASS

Table E-1. Ross Dam turbine blade strike model parameter inputs, Skagit River Hydroelectric Project.

Term	Units	Description	Ross Units			
			41	42	43	44
Blades	*(#)*	Number of blades on the turbine runner	19	17	17	15
Type	*(-)*	Francis, Kaplan, propeller, or bypass	Francis	Francis	Francis	Francis
Net Head	*(ft)*	Net head on the turbine; HW to TW, less head loss through system	330	330	330	330
Runner Dia. at Discharge	*(ft)*	Diameter at the outlet of the runner (typ. before the draft tube; see Figure 4.3.2-3 in Franke et al., 1997)	12	12.7	12.7	12.7
Runner Dia. at Inlet	*(ft)*	Diameter at the intake of the runner (typ. beyond the guide vanes; see Figure 4.3.2-3 in Franke et al., 1997)	14.4	14	7.5	13.1
Runner Diameter	*(ft)*	Nominal diameter of runner; maximum radius is assumed to be 1/2 of diameter	12.81	13.17	12.81	13.17
Runner Height	*(ft)*	Runner height at inlet (see Figure 4.3.2-3 in Franke et al., 1997 for clarification)	2.15	2.38	2.39	2.41
Speed	*(rpm)*	Runner revolutions per minute (model automatically converts to radians per second)	150	150	150	150
Swirl Coefficient	*(-)*	Ratio between Q with no exit swirl and Q_{OPT} (recommended x=1.1 for Francis turbines)	1.1	1.1	1.1	1.1
Turbine Discharge	*(cfs)*	Turbine discharge	3,500	3,700	3,700	3,500
Turbine Efficiency	*(-)*	Ratio of output shaft power to input fluid power; typ. from vendor curves or index testing	0.93	0.96	0.96	0.93
Discharge at Opt. Efficiency	*%*	Ratio of turbine discharge at best efficiency to hydraulic capacity	73.6	83.2	83.2	73.6
Model Routes		Unit 41, 42, 43, 44, and spillway				

Table E-2. Diablo Dam turbine blade strike model parameter inputs, Skagit River Hydroelectric Project.

Term	Units	Description	Diablo Units	
			35	36
Blades	*(#)*	Number of blades on the turbine runner	15	15
Type	*(-)*	Francis, Kaplan, propeller, or bypass	Francis	Francis
Net Head	*(ft)*	Net head on the turbine; HW to TW, less head loss through system	320	330
Runner Dia. at Discharge	*(ft)*	Diameter at the outlet of the runner (typ. before the draft tube; see Figure 4.3.2-3 in Franke et al., 1997)	11.3	11.3
Runner Dia. at Inlet	*(ft)*	Diameter at the intake of the runner (typ. beyond the guide vanes; see Figure 4.3.2-3 in Franke et al., 1997)	12.4	12.4
Runner Diameter	*(ft)*	Nominal diameter of runner; maximum radius is assumed to be 1/2 of diameter	12.81	12.81
Runner Height	*(ft)*	Runner height at inlet (see Figure 4.3.2-3 in Franke et al., 1997 for clarification)	2.4	2.4
Speed	*(rpm)*	Runner revolutions per minute (model automatically converts to radians per second)	171	171
Swirl Coefficient	*(-)*	Ratio between Q with no exit swirl and Q_{OPT} (recommended x=1.1 for Francis turbines)	1.1	1.1
Turbine Discharge	*(cfs)*	Turbine discharge	3,500	3,500
Turbine Efficiency	*(-)*	Ratio of output shaft power to input fluid power; typ. from vendor curves or index testing	0.96	0.96
Discharge at Opt. Efficiency	%	Ratio of turbine discharge at best efficiency to hydraulic capacity	85.7	85.7
Model Routes		Unit 31, Unit 32, spillway		

Table E-3. Gorge Dam turbine blade strike model parameter inputs, Skagit River Hydroelectric Project.

Term	Units	Description	Gorge Units			
			21	**22**	**23**	**24**
Blades	*(#)*	Number of blades on the turbine runner	13	13	13	17
Type	*(-)*	Francis, Kaplan, propeller, or bypass	Francis	Francis	Francis	Francis
Net Head	*(ft)*	Net head on the turbine; HW to TW, less head loss through system	380	380	380	380
Runner Dia. at Discharge	*(ft)*	Diameter at the outlet of the runner (typ. before the draft tube; see Figure 4.3.2-3 in Franke et al., 1997)	7.4	7.4	7.1	11.3
Runner Dia. at Inlet	*(ft)*	Diameter at the intake of the runner (typ. beyond the guide vanes; see Figure 4.3.2-3 in Franke et al., 1997)	8.7	8.7	7.5	13.1
Runner Diameter	*(ft)*	Nominal diameter of runner; maximum radius is assumed to be 1/2 of diameter	8.36	8.36	8.14	14.03
Runner Height	*(ft)*	Runner height at inlet (see Figure 4.3.2-3 in Franke et al., 1997 for clarification)	1.58	1.58	1.58	2.56
Speed	*(rpm)*	Runner revolutions per minute (model automatically converts to radians per second)	257	257	257	164
Swirl Coefficient	*(-)*	Ratio between Q with no exit swirl and Q_{OPT} (recommended x=1.1 for Francis turbines)	1.1	1.1	1.1	1.1
Turbine Discharge	*(cfs)*	Turbine discharge	1,500	1,500	1,380	4,200
Turbine Efficiency	*(-)*	Ratio of output shaft power to input fluid power; typ. from vendor curves or index testing	0.94	0.94	0.93	0.94
Discharge at Opt. Efficiency	*%*	Ratio of turbine discharge at best efficiency to hydraulic capacity	72.1	72.1	88.9	76.8
Model Routes		Unit 21, 22, 23, 24, and spillway				

Ross Dam Turbine Blade Strike Model Runs

Skagit River Hydroelectric Project, FERC Project No. 553 ARCHIVED RUN .N5000-L2-S97 10/6/2021

Ross Development: Entrained Fish JCASSONE

Release 200316

	ROUTE SELECTION			TURBINE DATA													BYPASS
					D	N	B	Q	Q_{OPT}/Q	H	ω	ζ	λ	D_1	D_2	η	P_B
Route Name	Route Selection Prob.	Prob. Lower Bound	Calc. Type	Route Type	Runner Dia. (ft)	Blades (#)	Runner Height (ft)	Turbine Discharge (cfs)	Discharge at Opt. Eff. (%)	Net. Head (ft)	Speed (rpm)	Swirl Coeff. (-)	Correlation Coeff. (-)	Runner Dia. at Inlet (ft)	Runner Dia. at Disch. (ft)	Turbine Eff. (-)	Estimated Mortality (-)
41	0.243	0.000	1	Francis	12.81	19	2.15	3,500	73.6%	330.0	150.0	1.10	0.20	14.4	12.0	0.93	
42	0.256	0.243	1	Francis	13.17	17	2.38	3,700	83.2%	330.0	150.0	1.10	0.20	14.0	12.7	0.96	
43	0.256	0.499	1	Francis	12.81	17	2.39	3,700	83.2%	330.0	150.0	1.10	0.20	7.5	12.7	0.96	
44	0.243	0.755	1	Francis	13.17	15	2.41	3,500	73.6%	330.0	150.0	1.10	0.20	13.1	12.7	0.93	

	MODEL SIMULATION INPUT PARAMETERS	
n_f	5,000	Number of fish
μ	2.0	Mean length (inches)
σ	0.0	SD in length (inches)

BLADE STRIKE SIMULATION RESULTS		
Turbine Strike	144 of 5000 fish	2.9%
Bypass Failure	0 of 5000 fish	0.0%
Passed:	4856 of 5000 fish	97.1%

Skagit River Hydroelectric Project, FERC Project No. 553 ARCHIVED RUN .N5000-L4-S94 — 10/6/2021

Ross Development: Entrained Fish — JCASSONE

Release 200316

	ROUTE SELECTION			TURBINE DATA													BYPASS
					D	N	B	Q	Q_{OPT}/Q	H	ω	ζ	λ	D_1	D_2	η	P_B
Route Name	Route Selection Prob.	Prob. Lower Bound	Calc. Type	Route Type	Runner Dia. (ft)	Blades (#)	Runner Height (ft)	Turbine Discharge (cfs)	Discharge at Opt. Eff. (%)	Net. Head (ft)	Speed (rpm)	Swirl Coeff. (-)	Correlation Coeff. (-)	Runner Dia. at Inlet (ft)	Runner Dia. at Disch. (ft)	Turbine Eff. (-)	Estimated Mortality (-)
41	0.243	0.000	1	Francis	12.81	19	2.15	3,500	73.6%	330.0	150.0	1.10	0.20	14.4	12.0	0.93	
42	0.256	0.243	1	Francis	13.17	17	2.38	3,700	83.2%	330.0	150.0	1.10	0.20	14.0	12.7	0.96	
43	0.256	0.499	1	Francis	12.81	17	2.39	3,700	83.2%	330.0	150.0	1.10	0.20	7.5	12.7	0.96	
44	0.243	0.755	1	Francis	13.17	15	2.41	3,500	73.6%	330.0	150.0	1.10	0.20	13.1	12.7	0.93	

MODEL SIMULATION INPUT PARAMETERS		
n_f	5,000	Number of fish
μ	4.0	Mean length (inches)
σ	0.0	SD in length (inches)

BLADE STRIKE SIMULATION RESULTS		
Turbine Strikes	279 of 5000 fish	5.6%
Bypass Failures	0 of 5000 fish	0.0%
Passed:	4721 of 5000 fish	94.4%

Skagit River Hydroelectric Project, FERC Project No. 553 ARCHIVED RUN .N5000-L6-S91 — 10/6/2021

Ross Development: Entrained Fish — JCASSONE

Release 200316

	ROUTE SELECTION			TURBINE DATA													BYPASS
					D	N	B	Q	Q_{OPT}/Q	H	ω	ζ	λ	D_1	D_2	η	P_B
Route Name	Route Selection Prob.	Prob. Lower Bound	Calc. Type	Route Type	Runner Dia. (ft)	Blades (#)	Runner Height (ft)	Turbine Discharge (cfs)	Discharge at Opt. Eff. (%)	Net. Head (ft)	Speed (rpm)	Swirl Coeff. (-)	Correlation Coeff. (-)	Runner Dia. at Inlet (ft)	Runner Dia. at Disch. (ft)	Turbine Eff. (-)	Estimated Mortality (-)
41	0.243	0.000	1	Francis	12.81	19	2.15	3,500	73.6%	330.0	150.0	1.10	0.20	14.4	12.0	0.93	
42	0.256	0.243	1	Francis	13.17	17	2.38	3,700	83.2%	330.0	150.0	1.10	0.20	14.0	12.7	0.96	
43	0.256	0.499	1	Francis	12.81	17	2.39	3,700	83.2%	330.0	150.0	1.10	0.20	7.5	12.7	0.96	
44	0.243	0.755	1	Francis	13.17	15	2.41	3,500	73.6%	330.0	150.0	1.10	0.20	13.1	12.7	0.93	

MODEL SIMULATION INPUT PARAMETERS		
n_f	5,000	Number of fish
μ	6.0	Mean length (inches)
σ	0.0	SD in length (inches)

BLADE STRIKE SIMULATION RESULTS		
Turbine Strikes	447 of 5000 fish	8.9%
Bypass Failures	0 of 5000 fish	0.0%
Passed:	4553 of 5000 fish	91.1%

Skagit River Hydroelectric Project, FERC Project No. 553 ARCHIVED RUN .N5000-L10-S87 10/6/2021

Ross Development: Entrained Fish JCASSONE

Release 200316

	ROUTE SELECTION			TURBINE DATA													BYPASS
					D	N	B	Q	Q_{OPT}/Q	H	ω	ζ	λ	D_1	D_2	η	P_B
Route Name	Route Selection Prob.	Prob. Lower Bound	Calc. Type	Route Type	Runner Dia. (ft)	Blades (#)	Runner Height (ft)	Turbine Discharge (cfs)	Discharge at Opt. Eff. (%)	Net. Head (ft)	Speed (rpm)	Swirl Coeff. (-)	Correlati on Coeff. (-)	Runner Dia. at Inlet (ft)	Runner Dia. at Disch. (ft)	Turbine Eff. (-)	Estimated Mortality (-)
41	0.243	0.000	1	Francis	12.81	19	2.15	3,500	73.6%	330.0	150.0	1.10	0.20	14.4	12.0	0.93	
42	0.256	0.243	1	Francis	13.17	17	2.38	3,700	83.2%	330.0	150.0	1.10	0.20	14.0	12.7	0.96	
43	0.256	0.499	1	Francis	12.81	17	2.39	3,700	83.2%	330.0	150.0	1.10	0.20	7.5	12.7	0.96	
44	0.243	0.755	1	Francis	13.17	15	2.41	3,500	73.6%	330.0	150.0	1.10	0.20	13.1	12.7	0.93	

MODEL SIMULATION INPUT PARAMETERS		
n_f	5,000	Number of fish
μ	10.0	Mean length (inches)
σ	0.0	SD in length (inches)

BLADE STRIKE SIMULATION RESULTS		
Turbine Strikes	657 of 5000 fish	13.1%
Bypass Failures	0 of 5000 fish	0.0%
Passed:	4343 of 5000 fish	86.9%

ARCHIVED RUN .N5000-L15-S79 10/6/2021

Ross Development: Entrained Fish JCASSONE

Release 200316

	ROUTE SELECTION			TURBINE DATA													BYPASS
					D	N	B	Q	Q_{OPT}/Q	H	ω	ζ	λ	D_1	D_2	η	P_B
Route Name	Route Selection Prob.	Prob. Lower Bound	Calc. Type	Route Type	Runner Dia. (ft)	Blades (#)	Runner Height (ft)	Turbine Discharge (cfs)	Discharge at Opt. Eff. (%)	Net. Head (ft)	Speed (rpm)	Swirl Coeff. (-)	Correlati on Coeff. (-)	Runner Dia. at Inlet (ft)	Runner Dia. at Disch. (ft)	Turbine Eff. (-)	Estimated Mortality (-)
41	0.243	0.000	1	Francis	12.81	19	2.15	3,500	73.6%	330.0	150.0	1.10	0.20	14.4	12.0	0.93	
42	0.256	0.243	1	Francis	13.17	17	2.38	3,700	83.2%	330.0	150.0	1.10	0.20	14.0	12.7	0.96	
43	0.256	0.499	1	Francis	12.81	17	2.39	3,700	83.2%	330.0	150.0	1.10	0.20	7.5	12.7	0.96	
44	0.243	0.755	1	Francis	13.17	15	2.41	3,500	73.6%	330.0	150.0	1.10	0.20	13.1	12.7	0.93	

MODEL SIMULATION INPUT PARAMETERS		
n_f	5,000	Number of fish
μ	15.0	Mean length (inches)
σ	0.0	SD in length (inches)

BLADE STRIKE SIMULATION RESULTS		
Turbine Strikes	1052 of 5000 fish	21.0%
Bypass Failures	0 of 5000 fish	0.0%
Passed:	3948 of 5000 fish	79.0%

Skagit River Hydroelectric Project, FERC Project No. 553 ARCHIVED RUN .N5000-L20-S71 — 10/6/2021

Ross Development: Entrained Fish — JCASSONE

Release 200316

	ROUTE SELECTION			TURBINE DATA													BYPASS
					D	N	B	Q	Q_{OPT}/Q	H	ω	ζ	λ	D_1	D_2	η	P_B
Route Name	Route Selection Prob.	Prob. Lower Bound	Calc. Type	Route Type	Runner Dia. (ft)	Blades (#)	Runner Height (ft)	Turbine Discharge (cfs)	Discharge at Opt. Eff. (%)	Net. Head (ft)	Speed (rpm)	Swirl Coeff. (-)	Correlation Coeff. (-)	Runner Dia. at Inlet (ft)	Runner Dia. at Disch. (ft)	Turbine Eff. (-)	Estimated Mortality (-)
41	0.243	0.000	1	Francis	12.81	19	2.15	3,500	73.6%	330.0	150.0	1.10	0.20	14.4	12.0	0.93	
42	0.256	0.243	1	Francis	13.17	17	2.38	3,700	83.2%	330.0	150.0	1.10	0.20	14.0	12.7	0.96	
43	0.256	0.499	1	Francis	12.81	17	2.39	3,700	83.2%	330.0	150.0	1.10	0.20	7.5	12.7	0.96	
44	0.243	0.755	1	Francis	13.17	15	2.41	3,500	73.6%	330.0	150.0	1.10	0.20	13.1	12.7	0.93	

MODEL SIMULATION INPUT PARAMETERS		
n_f	5,000	Number of fish
μ	20.0	Mean length (inches)
σ	0.0	SD in length (inches)

BLADE STRIKE SIMULATION RESULTS		
Turbine Strikes	1436 of 5000 fish	28.7%
Bypass Failures	0 of 5000 fish	0.0%
Passed:	3564 of 5000 fish	71.3%

Skagit River Hydroelectric Project, FERC Project No. 553 ARCHIVED RUN .N5000-L25-S66 — 10/6/2021

Ross Development: Entrained Fish — JCASSONE

Release 200316

	ROUTE SELECTION			TURBINE DATA													BYPASS
					D	N	B	Q	Q_{OPT}/Q	H	ω	ζ	λ	D_1	D_2	η	P_B
Route Name	Route Selection Prob.	Prob. Lower Bound	Calc. Type	Route Type	Runner Dia. (ft)	Blades (#)	Runner Height (ft)	Turbine Discharge (cfs)	Discharge at Opt. Eff. (%)	Net. Head (ft)	Speed (rpm)	Swirl Coeff. (-)	Correlation Coeff. (-)	Runner Dia. at Inlet (ft)	Runner Dia. at Disch. (ft)	Turbine Eff. (-)	Estimated Mortality (-)
41	0.243	0.000	1	Francis	12.81	19	2.15	3,500	73.6%	330.0	150.0	1.10	0.20	14.4	12.0	0.93	
42	0.256	0.243	1	Francis	13.17	17	2.38	3,700	83.2%	330.0	150.0	1.10	0.20	14.0	12.7	0.96	
43	0.256	0.499	1	Francis	12.81	17	2.39	3,700	83.2%	330.0	150.0	1.10	0.20	7.5	12.7	0.96	
44	0.243	0.755	1	Francis	13.17	15	2.41	3,500	73.6%	330.0	150.0	1.10	0.20	13.1	12.7	0.93	

MODEL SIMULATION INPUT PARAMETERS		
n_f	5,000	Number of fish
μ	25.0	Mean length (inches)
σ	0.0	SD in length (inches)

BLADE STRIKE SIMULATION RESULTS		
Turbine Strikes	1716 of 5000 fish	34.3%
Bypass Failures	0 of 5000 fish	0.0%
Passed:	3284 of 5000 fish	65.7%

Skagit River Hydroelectric Project, FERC Project No. 553 ARCHIVED RUN .N5000-L30-S59 10/6/2021

Ross Development: Entrained Fish JCASSONE

Release 200316

	ROUTE SELECTION			TURBINE DATA													BYPASS
					D	N	B	Q	Q_{OPT}/Q	H	ω	ζ	λ	D_1	D_2	η	P_B
Route Name	Route Selection Prob.	Prob. Lower Bound	Calc. Type	Route Type	Runner Dia. (ft)	Blades (#)	Runner Height (ft)	Turbine Discharge (cfs)	Discharge at Opt. Eff. (%)	Net. Head (ft)	Speed (rpm)	Swirl Coeff. (-)	Correlation Coeff. (-)	Runner Dia. at Inlet (ft)	Runner Dia. at Disch. (ft)	Turbine Eff. (-)	Estimated Mortality (-)
41	0.243	0.000	1	Francis	12.81	19	2.15	3,500	73.6%	330.0	150.0	1.10	0.20	14.4	12.0	0.93	
42	0.256	0.243	1	Francis	13.17	17	2.38	3,700	83.2%	330.0	150.0	1.10	0.20	14.0	12.7	0.96	
43	0.256	0.499	1	Francis	12.81	17	2.39	3,700	83.2%	330.0	150.0	1.10	0.20	7.5	12.7	0.96	
44	0.243	0.755	1	Francis	13.17	15	2.41	3,500	73.6%	330.0	150.0	1.10	0.20	13.1	12.7	0.93	

MODEL SIMULATION INPUT PARAMETERS		
n_f	5,000	Number of fish
μ	30.0	Mean length (inches)
σ	0.0	SD in length (inches)

BLADE STRIKE SIMULATION RESULTS		
Turbine Strikes	2048 of 5000 fish	41.0%
Bypass Failures	0 of 5000 fish	0.0%
Passed:	2952 of 5000 fish	59.0%

Skagit River Hydroelectric Project, FERC Project No. 553 ARCHIVED RUN .N5000-L8-S89 10/6/2021

Ross Development: Entrained Fish JCASSONE

Release 200316

	ROUTE SELECTION			TURBINE DATA													BYPASS
					D	N	B	Q	Q_{OPT}/Q	H	ω	ζ	λ	D_1	D_2	η	P_B
Route Name	Route Selection Prob.	Prob. Lower Bound	Calc. Type	Route Type	Runner Dia. (ft)	Blades (#)	Runner Height (ft)	Turbine Discharge (cfs)	Discharge at Opt. Eff. (%)	Net. Head (ft)	Speed (rpm)	Swirl Coeff. (-)	Correlation Coeff. (-)	Runner Dia. at Inlet (ft)	Runner Dia. at Disch. (ft)	Turbine Eff. (-)	Estimated Mortality (-)
41	0.243	0.000	1	Francis	12.81	19	2.15	3,500	73.6%	330.0	150.0	1.10	0.20	14.4	12.0	0.93	
42	0.256	0.243	1	Francis	13.17	17	2.38	3,700	83.2%	330.0	150.0	1.10	0.20	14.0	12.7	0.96	
43	0.256	0.499	1	Francis	12.81	17	2.39	3,700	83.2%	330.0	150.0	1.10	0.20	7.5	12.7	0.96	
44	0.243	0.755	1	Francis	13.17	15	2.41	3,500	73.6%	330.0	150.0	1.10	0.20	13.1	12.7	0.93	

MODEL SIMULATION INPUT PARAMETERS		
n_f	5,000	Number of fish
μ	8.0	Mean length (inches)
σ	0.0	SD in length (inches)

BLADE STRIKE SIMULATION RESULTS		
Turbine Strikes	557 of 5000 fish	11.1%
Bypass Failures	0 of 5000 fish	0.0%
Passed:	4443 of 5000 fish	88.9%

Diablo Dam Turbine Blade Strike Model Runs

Skagit River Hydroelectric Project, FERC Project No. 553

Diablo Development: Entrained Fish

Release 200316

ARCHIVED RUN .N5000-L2-S97

	ROUTE SELECTION			TURBINE DATA													BYPASS
					D	N	B	Q	Q_{OPT}/Q	H	ω	ζ	λ	D_1	D_2	η	P_B
Route Name	Route Selection Prob.	Prob. Lower Bound	Calc. Type	Route Type	Runner Dia. (ft)	Blades (#)	Runner Height (ft)	Turbine Discharge (cfs)	Discharge at Opt. Eff. (%)	Net. Head (ft)	Speed (rpm)	Swirl Coeff. (-)	Correlation Coeff. (-)	Runner Dia. at Inlet (ft)	Runner Dia. at Disch. (ft)	Turbine Eff. (-)	Estimated Mortality (-)
31	0.500	0.000	1	Francis	12.81	15	2.40	3,500	85.7%	320.0	171.0	1.10	0.20	12.4	11.3	0.96	
32	0.500	0.500	1	Francis	12.81	15	2.40	3,500	85.7%	330.0	171.0	1.10	0.20	12.4	11.3	0.96	

MODEL SIMULATION INPUT PARAMETERS		
n_f	5,000	Number of fish
μ	2.0	Mean length (inches)
σ	0.0	SD in length (inches)

BLADE STRIKE SIMULATION RESULTS		
Turbine Strikes:	140 of 5000 fish	2.8%
Bypass Failures:	0 of 5000 fish	0.0%
Passed:	860 of 5000 fish	97.2%

Skagit River Hydroelectric Project, FERC Project No. 553 ARCHIVED RUN .N5000-L4-S95

Diablo Development: Entrained Fish

Release 200316

	ROUTE SELECTION			TURBINE DATA													BYPASS
					D	N	B	Q	Q_{OPT}/Q	H	ω	ζ	λ	D_1	D_2	η	P_B
Route Name	Route Selection Prob.	Prob. Lower Bound	Calc. Type	Route Type	Runner Dia. (ft)	Blades (#)	Runner Height (ft)	Turbine Discharge (cfs)	Discharge at Opt. Eff. (%)	Net. Head (ft)	Speed (rpm)	Swirl Coeff. (-)	Correlation Coeff. (-)	Runner Dia. at Inlet (ft)	Runner Dia. at Disch. (ft)	Turbine Eff. (-)	Estimated Mortality (-)
31	0.500	0.000	1	Francis	12.81	15	2.40	3,500	85.7%	320.0	171.0	1.10	0.20	12.4	11.3	0.96	
32	0.500	0.500	1	Francis	12.81	15	2.40	3,500	85.7%	330.0	171.0	1.10	0.20	12.4	11.3	0.96	

MODEL SIMULATION INPUT PARAMETERS		
n_f	5,000	Number of fish
μ	4.0	Mean length (inches)
σ	0.0	SD in length (inches)

BLADE STRIKE SIMULATION RESULTS		
Turbine Strik	262 of 5000 fish	5.2%
Bypass Failur	0 of 5000 fish	0.0%
Passed:	4738 of 5000 fish	94.8%

Skagit River Hydroelectric Project, FERC Project No. 553 ARCHIVED RUN .N5000-L6-S92

Diablo Development: Entrained Fish

Release 200316

	ROUTE SELECTION			TURBINE DATA													BYPASS
					D	N	B	Q	Q_{OPT}/Q	H	ω	ζ	λ	D_1	D_2	η	P_B
Route Name	Route Selection Prob.	Prob. Lower Bound	Calc. Type	Route Type	Runner Dia. (ft)	Blades (#)	Runner Height (ft)	Turbine Discharge (cfs)	Discharge at Opt. Eff. (%)	Net. Head (ft)	Speed (rpm)	Swirl Coeff. (-)	Correlation Coeff. (-)	Runner Dia. at Inlet (ft)	Runner Dia. at Disch. (ft)	Turbine Eff. (-)	Estimated Mortality (-)
31	0.500	0.000	1	Francis	12.81	15	2.40	3,500	85.7%	320.0	171.0	1.10	0.20	12.4	11.3	0.96	
32	0.500	0.500	1	Francis	12.81	15	2.40	3,500	85.7%	330.0	171.0	1.10	0.20	12.4	11.3	0.96	

MODEL SIMULATION INPUT PARAMETERS		
n_f	5,000	Number of fish
μ	6.0	Mean length (inches)
σ	0.0	SD in length (inches)

BLADE STRIKE SIMULATION RESULTS		
Turbine Strik	409 of 5000 fish	8.2%
Bypass Failur	0 of 5000 fish	0.0%
Passed:	4591 of 5000 fish	91.8%

Skagit River Hydroelectric Project, FERC Project No. 553 ARCHIVED RUN .N5000-L8-S89

Diablo Development: Entrained Fish

Release 200316

	ROUTE SELECTION			TURBINE DATA													BYPASS
					D	N	B	Q	Q_{OPT}/Q	H	ω	ζ	λ	D_1	D_2	η	P_B
Route Name	Route Selection Prob.	Prob. Lower Bound	Calc. Type	Route Type	Runner Dia. (ft)	Blades (#)	Runner Height (ft)	Turbine Discharge (cfs)	Discharge at Opt. Eff. (%)	Net. Head (ft)	Speed (rpm)	Swirl Coeff. (-)	Correlation Coeff. (-)	Runner Dia. at Inlet (ft)	Runner Dia. at Disch. (ft)	Turbine Eff. (-)	Estimated Mortality (-)
31	0.500	0.000	1	Francis	12.81	15	2.40	3,500	85.7%	320.0	171.0	1.10	0.20	12.4	11.3	0.96	
32	0.500	0.500	1	Francis	12.81	15	2.40	3,500	85.7%	330.0	171.0	1.10	0.20	12.4	11.3	0.96	

MODEL SIMULATION INPUT PARAMETERS		
n_f	5,000	Number of fish
μ	8.0	Mean length (inches)
σ	0.0	SD in length (inches)

BLADE STRIKE SIMULATION RESULTS		
Turbine Strik	535 of 5000 fish	10.7%
Bypass Failur	0 of 5000 fish	0.0%
Passed:	4465 of 5000 fish	89.3%

Skagit River Hydroelectric Project, FERC Project No. 553 ARCHIVED RUN .N5000-L10-S87 10/6/2021

Diablo Development: Entrained Fish JCASSONE

Release 200316

	ROUTE SELECTION			TURBINE DATA													BYPASS
					D	N	B	Q	Q_{OPT}/Q	H	ω	ζ	λ	D_1	D_2	η	P_B
Route Name	Route Selection Prob.	Prob. Lower Bound	Calc. Type	Route Type	Runner Dia. (ft)	Blades (#)	Runner Height (ft)	Turbine Discharge (cfs)	Discharge at Opt. Eff. (%)	Net. Head (ft)	Speed (rpm)	Swirl Coeff. (-)	Correlation Coeff. (-)	Runner Dia. at Inlet (ft)	Runner Dia. at Disch. (ft)	Turbine Eff. (-)	Estimated Mortality (-)
31	0.500	0.000	1	Francis	12.81	15	2.40	3,500	85.7%	320.0	171.0	1.10	0.20	12.4	11.3	0.96	
32	0.500	0.500	1	Francis	12.81	15	2.40	3,500	85.7%	330.0	171.0	1.10	0.20	12.4	11.3	0.96	

MODEL SIMULATION INPUT PARAMETERS		
n_f	5,000	Number of fish
μ	10.0	Mean length (inches)
σ	0.0	SD in length (inches)

BLADE STRIKE SIMULATION RESULTS		
Turbine Strik	651 of 5000 fish	13.0%
Bypass Failur	0 of 5000 fish	0.0%
Passed:	4349 of 5000 fish	87.0%

Skagit River Hydroelectric Project, FERC Project No. 553 ARCHIVED RUN .N5000-L15-S80

Diablo Development: Entrained Fish

Release 200316

	ROUTE SELECTION			TURBINE DATA													BYPASS
					D	N	B	Q	Q_{OPT}/Q	H	ω	ζ	λ	D_1	D_2	η	P_B
Route Name	Route Selection Prob.	Prob. Lower Bound	Calc. Type	Route Type	Runner Dia. (ft)	Blades (#)	Runner Height (ft)	Turbine Discharge (cfs)	Discharge at Opt. Eff. (%)	Net. Head (ft)	Speed (rpm)	Swirl Coeff. (-)	Correlation Coeff. (-)	Runner Dia. at Inlet (ft)	Runner Dia. at Disch. (ft)	Turbine Eff. (-)	Estimated Mortality (-)
31	0.500	0.000	1	Francis	12.81	15	2.40	3,500	85.7%	320.0	171.0	1.10	0.20	12.4	11.3	0.96	
32	0.500	0.500	1	Francis	12.81	15	2.40	3,500	85.7%	330.0	171.0	1.10	0.20	12.4	11.3	0.96	

MODEL SIMULATION INPUT PARAMETERS		
n_f	5,000	Number of fish
μ	15.0	Mean length (inches)
σ	0.0	SD in length (inches)

BLADE STRIKE SIMULATION RESULTS		
Turbine Strik	1024 of 5000 fish	20.5%
Bypass Failur	0 of 5000 fish	0.0%
Passed:	3976 of 5000 fish	79.5%

Skagit River Hydroelectric Project, FERC Project No. 553 ARCHIVED RUN .N5000-L20-S73

Diablo Development: Entrained Fish

Release 200316

	ROUTE SELECTION			TURBINE DATA													BYPASS
					D	N	B	Q	Q_{OPT}/Q	H	ω	ζ	λ	D_1	D_2	η	P_B
Route Name	Route Selection Prob.	Prob. Lower Bound	Calc. Type	Route Type	Runner Dia. (ft)	Blades (#)	Runner Height (ft)	Turbine Discharge (cfs)	Discharge at Opt. Eff. (%)	Net. Head (ft)	Speed (rpm)	Swirl Coeff. (-)	Correlation Coeff. (-)	Runner Dia. at Inlet (ft)	Runner Dia. at Disch. (ft)	Turbine Eff. (-)	Estimated Mortality (-)
31	0.500	0.000	1	Francis	12.81	15	2.40	3,500	85.7%	320.0	171.0	1.10	0.20	12.4	11.3	0.96	
32	0.500	0.500	1	Francis	12.81	15	2.40	3,500	85.7%	330.0	171.0	1.10	0.20	12.4	11.3	0.96	

MODEL SIMULATION INPUT PARAMETERS		
n_f	5,000	Number of fish
μ	20.0	Mean length (inches)
σ	0.0	SD in length (inches)

BLADE STRIKE SIMULATION RESULTS		
Turbine Strik	1336 of 5000 fish	26.7%
Bypass Failur	0 of 5000 fish	0.0%
Passed:	3664 of 5000 fish	73.3%

Skagit River Hydroelectric Project, FERC Project No. 553 ARCHIVED RUN .N5000-L25-S67

Diablo Development: Entrained Fish

Release 200316

	ROUTE SELECTION			TURBINE DATA													BYPASS
					D	N	B	Q	Q_{OPT}/Q	H	ω	ζ	λ	D_1	D_2	η	P_B
Route Name	Route Selection Prob.	Prob. Lower Bound	Calc. Type	Route Type	Runner Dia. (ft)	Blades (#)	Runner Height (ft)	Turbine Discharge (cfs)	Discharge at Opt. Eff. (%)	Net. Head (ft)	Speed (rpm)	Swirl Coeff. (-)	Correlation Coeff. (-)	Runner Dia. at Inlet (ft)	Runner Dia. at Disch. (ft)	Turbine Eff. (-)	Estimated Mortality (-)
31	0.500	0.000	1	Francis	12.81	15	2.40	3,500	85.7%	320.0	171.0	1.10	0.20	12.4	11.3	0.96	
32	0.500	0.500	1	Francis	12.81	15	2.40	3,500	85.7%	330.0	171.0	1.10	0.20	12.4	11.3	0.96	

MODEL SIMULATION INPUT PARAMETERS		
n_f	5,000	Number of fish
μ	25.0	Mean length (inches)
σ	0.0	SD in length (inches)

BLADE STRIKE SIMULATION RESULTS		
Turbine Strik	1627 of 5000 fish	32.5%
Bypass Failur	0 of 5000 fish	0.0%
Passed:	3373 of 5000 fish	67.5%

Skagit River Hydroelectric Project, FERC Project No. 553 ARCHIVED RUN .N5000-L30-S62

Diablo Development: Entrained Fish

Release 200316

	ROUTE SELECTION			TURBINE DATA													BYPASS
					D	N	B	Q	Q_{OPT}/Q	H	ω	ζ	λ	D_1	D_2	η	P_B
Route Name	Route Selection Prob.	Prob. Lower Bound	Calc. Type	Route Type	Runner Dia. (ft)	Blades (#)	Runner Height (ft)	Turbine Discharge (cfs)	Discharge at Opt. Eff. (%)	Net. Head (ft)	Speed (rpm)	Swirl Coeff. (-)	Correlation Coeff. (-)	Runner Dia. at Inlet (ft)	Runner Dia. at Disch. (ft)	Turbine Eff. (-)	Estimated Mortality (-)
31	0.500	0.000	1	Francis	12.81	15	2.40	3,500	85.7%	320.0	171.0	1.10	0.20	12.4	11.3	0.96	
32	0.500	0.500	1	Francis	12.81	15	2.40	3,500	85.7%	330.0	171.0	1.10	0.20	12.4	11.3	0.96	

MODEL SIMULATION INPUT PARAMETERS		
n_f	5,000	Number of fish
μ	30.0	Mean length (inches)
σ	0.0	SD in length (inches)

BLADE STRIKE SIMULATION RESULTS		
Turbine Strik	1911 of 5000 fish	38.2%
Bypass Failur	0 of 5000 fish	0.0%
Passed:	3089 of 5000 fish	61.8%

Gorge Dam Turbine Blade Strike Model Runs

Skagit River Hydroelectric Project, FERC Project No. 553 ARCHIVED RUN .N5000-L2-S97 10/6/2021

Gorge Development, Strike Probability By Length: Entrained Fish JCASSONE

Release 200316

	ROUTE SELECTION			TURBINE DATA													BYPASS
Route Name	Route Selection Prob.	Prob. Lower Bound	Calc. Type	Route Type	D Runner Dia. (ft)	N Blades (#)	B Runner Height (ft)	Q Turbine Discharge	Q_{OPT}/Q Discharge at Opt. Eff. (%)	H Net. Head (ft)	ω Speed (rpm)	ζ Swirl Coeff. (-)	λ Correlation Coeff. (-)	D_1 Runner Dia. at Inlet (ft)	D_2 Runner Dia. at Disch. (ft)	η Turbine Eff. (-)	P_B Estimated Mortality (-)
21	0.175	0.000	1	Francis	8.36	13	1.58	1,500	72.1%	380.0	257.0	1.10	0.20	8.7	7.4	0.94	
22	0.175	0.175	1	Francis	8.36	13	1.58	1,500	72.1%	380.0	257.0	1.10	0.20	8.7	7.4	0.94	
23	0.160	0.350	1	Francis	8.14	13	1.18	1,380	88.9%	380.0	257.0	1.10	0.20	7.5	7.1	0.93	
24	0.490	0.510	1	Francis	14.03	17	2.56	4,200	76.8%	380.0	164.0	1.10	0.20	13.1	11.3	0.94	

MODEL SIMULATION INPUT PARAMETERS		
n_f	5,000	Number of fish
μ	2.0	Mean length (inches)
σ	0.0	SD in length (inches)

BLADE STRIKE SIMULATION RESULTS		
Turbine Strike	153 of 5000 fish	3.1%
Bypass Failure	0 of 5000 fish	0.0%
Passed:	4847 of 5000 fish	96.9%

Skagit River Hydroelectric Project, FERC Project No. 553 ARCHIVED RUN .N5000-L4-S94

Gorge Development, Strike Probability By Length: Entrained Fish JCASSONE

Release 200316

ROUTE SELECTION				TURBINE DATA													BYPASS
					D	N	B	Q	Q_{OPT}/Q	H	ω	ζ	λ	D_1	D_2	η	P_B
Route Name	Route Selection Prob.	Prob. Lower Bound	Calc. Type	Route Type	Runner Dia. (ft)	Blades (#)	Runner Height (ft)	Turbine Discharge (cfs)	Discharge at Opt. Eff. (%)	Net. Head (ft)	Speed (rpm)	Swirl Coeff. (-)	Correlation Coeff. (-)	Runner Dia. at Inlet (ft)	Runner Dia. at Disch. (ft)	Turbine Eff. (-)	Estimated Mortality (-)
21	0.175	0.000	1	Francis	8.36	13	1.58	1,500	72.1%	380.0	257.0	1.10	0.20	8.7	7.4	0.94	
22	0.175	0.175	1	Francis	8.36	13	1.58	1,500	72.1%	380.0	257.0	1.10	0.20	8.7	7.4	0.94	
23	0.160	0.350	1	Francis	8.14	13	1.18	1,380	88.9%	380.0	257.0	1.10	0.20	7.5	7.1	0.93	
24	0.490	0.510	1	Francis	14.03	17	2.56	4,200	76.8%	380.0	164.0	1.10	0.20	13.1	11.3	0.94	

MODEL SIMULATION INPUT PARAMETERS		
n_f	5,000	Number of fish
μ	4.0	Mean length (inches)
σ	0.0	SD in length (inches)

BLADE STRIKE SIMULATION RESULTS		
Turbine Strike	321 of 5000 fish	6.4%
Bypass Failure	0 of 5000 fish	0.0%
Passed:	4679 of 5000 fish	93.6%

Skagit River Hydroelectric Project, FERC Project No. 553 ARCHIVED RUN .N5000-L6-S91

Gorge Development, Strike Probability By Length: Entrained Fish JCASSONE

Release 200316

ROUTE SELECTION				TURBINE DATA													BYPASS
					D	N	B	Q	Q_{OPT}/Q	H	ω	ζ	λ	D_1	D_2	η	P_B
Route Name	Route Selection Prob.	Prob. Lower Bound	Calc. Type	Route Type	Runner Dia. (ft)	Blades (#)	Runner Height (ft)	Turbine Discharge (cfs)	Discharge at Opt. Eff. (%)	Net. Head (ft)	Speed (rpm)	Swirl Coeff. (-)	Correlation Coeff. (-)	Runner Dia. at Inlet (ft)	Runner Dia. at Disch. (ft)	Turbine Eff. (-)	Estimated Mortality (-)
21	0.175	0.000	1	Francis	8.36	13	1.58	1,500	72.1%	380.0	257.0	1.10	0.20	8.7	7.4	0.94	
22	0.175	0.175	1	Francis	8.36	13	1.58	1,500	72.1%	380.0	257.0	1.10	0.20	8.7	7.4	0.94	
23	0.160	0.350	1	Francis	8.14	13	1.18	1,380	88.9%	380.0	257.0	1.10	0.20	7.5	7.1	0.93	
24	0.490	0.510	1	Francis	14.03	17	2.56	4,200	76.8%	380.0	164.0	1.10	0.20	13.1	11.3	0.94	

MODEL SIMULATION INPUT PARAMETERS		
n_f	5,000	Number of fish
μ	6.0	Mean length (inches)
σ	0.0	SD in length (inches)

BLADE STRIKE SIMULATION RESULTS		
Turbine Strike	470 of 5000 fish	9.4%
Bypass Failure	0 of 5000 fish	0.0%
Passed:	4530 of 5000 fish	90.6%

Skagit River Hydroelectric Project, FERC Project No. 553 ARCHIVED RUN .N5000-L8-S87

Gorge Development, Strike Probability By Length: Entrained Fish JCASSONE

Release 200316

ROUTE SELECTION				TURBINE DATA													BYPASS
					D	N	B	Q	Q_{OPT}/Q	H	ω	ζ	λ	D_1	D_2	η	P_B
Route Name	Route Selection Prob.	Prob. Lower Bound	Calc. Type	Route Type	Runner Dia. (ft)	Blades (#)	Runner Height (ft)	Turbine Discharge (cfs)	Discharge at Opt. Eff. (%)	Net. Head (ft)	Speed (rpm)	Swirl Coeff. (-)	Correlation Coeff. (-)	Runner Dia. at Inlet (ft)	Runner Dia. at Disch. (ft)	Turbine Eff. (-)	Estimated Mortality (-)
21	0.175	0.000	1	Franci:	8.36	13	1.58	1,500	72.1%	380.0	257.0	1.10	0.20	8.7	7.4	0.94	
22	0.175	0.175	1	Franci:	8.36	13	1.58	1,500	72.1%	380.0	257.0	1.10	0.20	8.7	7.4	0.94	
23	0.160	0.350	1	Franci:	8.14	13	1.18	1,380	88.9%	380.0	257.0	1.10	0.20	7.5	7.1	0.93	
24	0.490	0.510	1	Franci:	14.03	17	2.56	4,200	76.8%	380.0	164.0	1.10	0.20	13.1	11.3	0.94	

MODEL SIMULATION INPUT PARAMETERS		
n_f	5,000	Number of fish
μ	8.0	Mean length (inches)
σ	0.0	SD in length (inches)

BLADE STRIKE SIMULATION RESULTS		
Turbine Strik	644 of 5000 fish	12.9%
Bypass Failu	0 of 5000 fish	0.0%
Passed:	4356 of 5000 fish	87.1%

Skagit River Hydroelectric Project, FERC Project No. 553 ARCHIVED RUN .N5000-L10-S84

Gorge Development, Strike Probability By Length: Entrained Fish JCASSONE

Release 200316

ROUTE SELECTION				TURBINE DATA													BYPASS
					D	N	B	Q	Q_{OPT}/Q	H	ω	ζ	λ	D_1	D_2	η	P_B
Route Name	Route Selection Prob.	Prob. Lower Bound	Calc. Type	Route Type	Runner Dia. (ft)	Blades (#)	Runner Height (ft)	Turbine Discharge (cfs)	Discharge at Opt. Eff. (%)	Net. Head (ft)	Speed (rpm)	Swirl Coeff. (-)	Correlation Coeff. (-)	Runner Dia. at Inlet (ft)	Runner Dia. at Disch. (ft)	Turbine Eff. (-)	Estimated Mortality (-)
21	0.175	0.000	1	Franci:	8.36	13	1.58	1,500	72.1%	380.0	257.0	1.10	0.20	8.7	7.4	0.94	
22	0.175	0.175	1	Franci:	8.36	13	1.58	1,500	72.1%	380.0	257.0	1.10	0.20	8.7	7.4	0.94	
23	0.160	0.350	1	Franci:	8.14	13	1.18	1,380	88.9%	380.0	257.0	1.10	0.20	7.5	7.1	0.93	
24	0.490	0.510	1	Franci:	14.03	17	2.56	4,200	76.8%	380.0	164.0	1.10	0.20	13.1	11.3	0.94	

MODEL SIMULATION INPUT PARAMETERS		
n_f	5,000	Number of fish
μ	10.0	Mean length (inches)
σ	0.0	SD in length (inches)

BLADE STRIKE SIMULATION RESULTS		
Turbine Strik	781 of 5000 fish	15.6%
Bypass Failu	0 of 5000 fish	0.0%
Passed:	4219 of 5000 fish	84.4%

Skagit River Hydroelectric Project, FERC Project No. 553 ARCHIVED RUN .N5000-L15-S77

Gorge Development, Strike Probability By Length: Entrained Fish JCASSONE

Release 200316

Route Name	ROUTE SELECTION: Route Selection Prob.	Prob. Lower Bound	Calc. Type	TURBINE DATA: Route Type	D Runner Dia. (ft)	N Blades (#)	B Runner Height (ft)	Q Turbine Discharge (cfs)	Q_{OPT}/Q Discharge at Opt. Eff. (%)	H Net. Head (ft)	ω Speed (rpm)	ζ Swirl Coeff. (-)	λ Correlation Coeff. (-)	D_1 Runner Dia. at Inlet (ft)	D_2 Runner Dia. at Disch. (ft)	η Turbine Eff. (-)	BYPASS: P_B Estimated Mortality (-)
21	0.175	0.000	1	Franci:	8.36	13	1.58	1,500	72.1%	380.0	257.0	1.10	0.20	8.7	7.4	0.94	
22	0.175	0.175	1	Franci:	8.36	13	1.58	1,500	72.1%	380.0	257.0	1.10	0.20	8.7	7.4	0.94	
23	0.160	0.350	1	Franci:	8.14	13	1.18	1,380	88.9%	380.0	257.0	1.10	0.20	7.5	7.1	0.93	
24	0.490	0.510	1	Franci:	14.03	17	2.56	4,200	76.8%	380.0	164.0	1.10	0.20	13.1	11.3	0.94	

MODEL SIMULATION INPUT PARAMETERS		
n_f	5,000	Number of fish
μ	15.0	Mean length (inches)
σ	0.0	SD in length (inches)

BLADE STRIKE SIMULATION RESULTS		
Turbine Strik	1136 of 5000 fish	22.7%
Bypass Failu	0 of 5000 fish	0.0%
Passed:	3864 of 5000 fish	77.3%

Skagit River Hydroelectric Project, FERC Project No. 553 ARCHIVED RUN .N5000-L20-S69

Gorge Development, Strike Probability By Length: Entrained Fish JCASSONE

Release 200316

Route Name	ROUTE SELECTION: Route Selection Prob.	Prob. Lower Bound	Calc. Type	TURBINE DATA: Route Type	D Runner Dia. (ft)	N Blades (#)	B Runner Height (ft)	Q Turbine Discharge (cfs)	Q_{OPT}/Q Discharge at Opt. Eff. (%)	H Net. Head (ft)	ω Speed (rpm)	ζ Swirl Coeff. (-)	λ Correlation Coeff. (-)	D_1 Runner Dia. at Inlet (ft)	D_2 Runner Dia. at Disch. (ft)	η Turbine Eff. (-)	BYPASS: P_B Estimated Mortality (-)
21	0.175	0.000	1	Franci:	8.36	13	1.58	1,500	72.1%	380.0	257.0	1.10	0.20	8.7	7.4	0.94	
22	0.175	0.175	1	Franci:	8.36	13	1.58	1,500	72.1%	380.0	257.0	1.10	0.20	8.7	7.4	0.94	
23	0.160	0.350	1	Franci:	8.14	13	1.18	1,380	88.9%	380.0	257.0	1.10	0.20	7.5	7.1	0.93	
24	0.490	0.510	1	Franci:	14.03	17	2.56	4,200	76.8%	380.0	164.0	1.10	0.20	13.1	11.3	0.94	

MODEL SIMULATION INPUT PARAMETERS		
n_f	5,000	Number of fish
μ	20.0	Mean length (inches)
σ	0.0	SD in length (inches)

BLADE STRIKE SIMULATION RESULTS		
Turbine Strik	1539 of 5000 fish	30.8%
Bypass Failu	0 of 5000 fish	0.0%
Passed:	3461 of 5000 fish	69.2%

Skagit River Hydroelectric Project, FERC Project No. 553 ARCHIVED RUN .N5000-L25-S61

Gorge Development, Strike Probability By Length: Entrained Fish JCASSONE

Release 200316

	ROUTE SELECTION			TURBINE DATA													BYPASS
					D	N	B	Q	Q_{OPT}/Q	H	ω	ζ	λ	D_1	D_2	η	P_B
Route Name	Route Selection Prob.	Prob. Lower Bound	Calc. Type	Route Type	Runner Dia. (ft)	Blades (#)	Runner Height (ft)	Turbine Discharge (cfs)	Discharge at Opt. Eff. (%)	Net. Head (ft)	Speed (rpm)	Swirl Coeff. (-)	Correlation Coeff. (-)	Runner Dia. at Inlet (ft)	Runner Dia. at Disch. (ft)	Turbine Eff. (-)	Estimated Mortality (-)
21	0.175	0.000	1	Franci:	8.36	13	1.58	1,500	72.1%	380.0	257.0	1.10	0.20	8.7	7.4	0.94	
22	0.175	0.175	1	Franci:	8.36	13	1.58	1,500	72.1%	380.0	257.0	1.10	0.20	8.7	7.4	0.94	
23	0.160	0.350	1	Franci:	8.14	13	1.18	1,380	88.9%	380.0	257.0	1.10	0.20	7.5	7.1	0.93	
24	0.490	0.510	1	Franci:	14.03	17	2.56	4,200	76.8%	380.0	164.0	1.10	0.20	13.1	11.3	0.94	

MODEL SIMULATION INPUT PARAMETERS		
n_f	5,000	Number of fish
μ	25.0	Mean length (inches)
σ	0.0	SD in length (inches)

BLADE STRIKE SIMULATION RESULTS		
Turbine Strik	1926 of 5000 fish	38.5%
Bypass Failu	0 of 5000 fish	0.0%
Passed:	3074 of 5000 fish	61.5%

Skagit River Hydroelectric Project, FERC Project No. 553 ARCHIVED RUN .N5000-L30-S53(2)

Gorge Development, Strike Probability By Length: Entrained Fish JCASSONE

Release 200316

	ROUTE SELECTION			TURBINE DATA													BYPASS
					D	N	B	Q	Q_{OPT}/Q	H	ω	ζ	λ	D_1	D_2	η	P_B
Route Name	Route Selection Prob.	Prob. Lower Bound	Calc. Type	Route Type	Runner Dia. (ft)	Blades (#)	Runner Height (ft)	Turbine Discharge (cfs)	Discharge at Opt. Eff. (%)	Net. Head (ft)	Speed (rpm)	Swirl Coeff. (-)	Correlation Coeff. (-)	Runner Dia. at Inlet (ft)	Runner Dia. at Disch. (ft)	Turbine Eff. (-)	Estimated Mortality (-)
21	0.175	0.000	1	Franci:	8.36	13	1.58	1,500	72.1%	380.0	257.0	1.10	0.20	8.7	7.4	0.94	
22	0.175	0.175	1	Franci:	8.36	13	1.58	1,500	72.1%	380.0	257.0	1.10	0.20	8.7	7.4	0.94	
23	0.160	0.350	1	Franci:	8.14	13	1.18	1,380	88.9%	380.0	257.0	1.10	0.20	7.5	7.1	0.93	
24	0.490	0.510	1	Franci:	14.03	17	2.56	4,200	76.8%	380.0	164.0	1.10	0.20	13.1	11.3	0.94	

MODEL SIMULATION INPUT PARAMETERS		
n_f	5,000	Number of fish
μ	30.0	Mean length (inches)
σ	0.0	SD in length (inches)

BLADE STRIKE SIMULATION RESULTS		
Turbine Strik	2370 of 5000 fish	47.4%
Bypass Failu	0 of 5000 fish	0.0%
Passed:	2630 of 5000 fish	52.6%

Ross Dam Model Runs for Salmonids Including Spillway Mortality

Skagit River Hydroelectric Project, FERC Project No. 553 ARCHIVED RUN .N5000-L24-S60 10/11/2021

Ross Development: Salmonids (23.6"): Average Spill JCASSONE

Release 200316

Route Name	Route Selection Prob.	Prob. Lower Bound	Calc. Type	Route Type	D Runner Dia. (ft)	N Blades (#)	B Runner Height (ft)	Q Turbine Discharge (cfs)	Q_{OPT}/Q Discharge at Opt. Eff. (%)	H Net. Head (ft)	ω Speed (rpm)	ζ Swirl Coeff. (-)	λ Correlation Coeff. (-)	D_1 Runner Dia. at Inlet (ft)	D_2 Runner Dia. at Disch. (ft)	η Turbine Eff. (-)	P_B Estimated Mortality (-)
	ROUTE SELECTION			TURBINE DATA													BYPASS
41	0.216	0.000	1	Francis	12.81	19	2.15	3,500	73.6%	330.0	150.0	1.10	0.20	14.4	12.0	0.93	
42	0.229	0.216	1	Francis	13.17	17	2.38	3,700	83.2%	330.0	150.0	1.10	0.20	14.0	12.7	0.96	
43	0.229	0.445	1	Francis	12.81	17	2.39	3,700	83.2%	330.0	150.0	1.10	0.20	7.5	12.7	0.96	
44	0.216	0.674	1	Francis	13.17	15	2.41	3,500	73.6%	330.0	150.0	1.10	0.20	13.1	12.7	0.93	
Spill	0.110	0.890	0	bypass													1.00

Skagit River Hydroelectric Project, FERC Project No. 553 ARCHIVED RUN .N5000-L12-S76 10/11/2021

Ross Development: Salmonids (12"): Average Spill JCASSONE

Release 200316

Route Name	Route Selection Prob.	Prob. Lower Bound	Calc. Type	Route Type	D Runner Dia. (ft)	N Blades (#)	B Runner Height (ft)	Q Turbine Discharge (cfs)	Q_{OPT}/Q Discharge at Opt. Eff. (%)	H Net. Head (ft)	ω Speed (rpm)	ζ Swirl Coeff. (-)	λ Correlation Coeff. (-)	D_1 Runner Dia. at Inlet (ft)	D_2 Runner Dia. at Disch. (ft)	η Turbine Eff. (-)	P_B Estimated Mortality (-)
	ROUTE SELECTION			TURBINE DATA													BYPASS
41	0.216	0.000	1	Francis	12.81	19	2.15	3,500	73.6%	330.0	150.0	1.10	0.20	14.4	12.0	0.93	
42	0.229	0.216	1	Francis	13.17	17	2.38	3,700	83.2%	330.0	150.0	1.10	0.20	14.0	12.7	0.96	
43	0.229	0.445	1	Francis	12.81	17	2.39	3,700	83.2%	330.0	150.0	1.10	0.20	7.5	12.7	0.96	
44	0.216	0.674	1	Francis	13.17	15	2.41	3,500	73.6%	330.0	150.0	1.10	0.20	13.1	12.7	0.93	
Spill	0.110	0.890	0	bypass													1.00

	MODEL SIMULATION INPUT PARAMETERS	
n_f	5,000	Number of fish
μ	12.0	Mean length (inches)
σ	0.0	SD in length (inches)

	BLADE STRIKE SIMULATION RESULTS	
Turbine Strikes:	655 of 5000 fish	13.1%
Bypass Failures:	554 of 5000 fish	11.1%
Passed:	3791 of 5000 fish	75.8%

Ross Dam Model Runs for Redside Shiner Including Spillway Mortality

Skagit River Hydroelectric Project, FERC Project No. 553 ARCHIVED RUN .N5000-L3-S85 10/11/2021
Ross Development: Redside Shiner (3"): Average Spill JCASSONE
Release 200316

ROUTE SELECTION				TURBINE DATA													BYPASS
					D	N	B	Q	Q_{OPT}/Q	H	ω	ζ	λ	D_1	D_2	η	P_B
Route Name	Route Selection Prob.	Prob. Lower Bound	Calc. Type	Route Type	Runner Dia. (ft)	Blades (#)	Runner Height (ft)	Turbine Discharge (cfs)	Discharge at Opt. Eff. (%)	Net. Head (ft)	Speed (rpm)	Swirl Coeff. (-)	Correlation Coeff. (-)	Runner Dia. at Inlet (ft)	Runner Dia. at Disch. (ft)	Turbine Eff. (-)	Estimated Mortality (-)
41	0.216	0.000	1	Francis	12.81	19	2.15	3,500	73.6%	330.0	150.0	1.10	0.20	14.4	12.0	0.93	
42	0.229	0.216	1	Francis	13.17	17	2.38	3,700	83.2%	330.0	150.0	1.10	0.20	14.0	12.7	0.96	
43	0.229	0.445	1	Francis	12.81	17	2.39	3,700	83.2%	330.0	150.0	1.10	0.20	7.5	12.7	0.96	
44	0.216	0.674	1	Francis	13.17	15	2.41	3,500	73.6%	330.0	150.0	1.10	0.20	13.1	12.7	0.93	
Spill	0.110	0.890	0	bypass													1.00

MODEL SIMULATION INPUT PARAMETERS		
n_f	5,000	Number of fish
μ	3.0	Mean length (inches)
σ	0.0	SD in length (inches)

BLADE STRIKE SIMULATION RESULTS		
Turbine Strikes:	195 of 5000 fish	3.9%
Bypass Failures:	541 of 5000 fish	10.8%
Passed:	4264 of 5000 fish	85.3%

Skagit River Hydroelectric Project, FERC Project No. 553 ARCHIVED RUN .N5000-L4-S84 10/11/2021
Ross Development: Redside Shiner (4"): Average Spill JCASSONE
Release 200316

ROUTE SELECTION				TURBINE DATA													BYPASS
					D	N	B	Q	Q_{OPT}/Q	H	ω	ζ	λ	D_1	D_2	η	P_B
Route Name	Route Selection Prob.	Prob. Lower Bound	Calc. Type	Route Type	Runner Dia. (ft)	Blades (#)	Runner Height (ft)	Turbine Discharge (cfs)	Discharge at Opt. Eff. (%)	Net. Head (ft)	Speed (rpm)	Swirl Coeff. (-)	Correlation Coeff. (-)	Runner Dia. at Inlet (ft)	Runner Dia. at Disch. (ft)	Turbine Eff. (-)	Estimated Mortality (-)
41	0.216	0.000	1	Francis	12.81	19	2.15	3,500	73.6%	330.0	150.0	1.10	0.20	14.4	12.0	0.93	
42	0.229	0.216	1	Francis	13.17	17	2.38	3,700	83.2%	330.0	150.0	1.10	0.20	14.0	12.7	0.96	
43	0.229	0.445	1	Francis	12.81	17	2.39	3,700	83.2%	330.0	150.0	1.10	0.20	7.5	12.7	0.96	
44	0.216	0.674	1	Francis	13.17	15	2.41	3,500	73.6%	330.0	150.0	1.10	0.20	13.1	12.7	0.93	
Spill	0.110	0.890	0	bypass													1.00

MODEL SIMULATION INPUT PARAMETERS		
n_f	5,000	Number of fish
μ	4.0	Mean length (inches)
σ	0.0	SD in length (inches)

BLADE STRIKE SIMULATION RESULTS		
Turbine Strikes:	238 of 5000 fish	4.8%
Bypass Failures:	560 of 5000 fish	11.2%
Passed:	4202 of 5000 fish	84.0%

Skagit River Hydroelectric Project, FERC Project No. 553 ARCHIVED RUN .N5000-L5-S83 10/11/2021

Ross Development: Redside Shiner (5"): Average Spill JCASSONE

Release 200316

Route Name	ROUTE SELECTION: Route Selection Prob.	Prob. Lower Bound	Calc. Type	TURBINE DATA: Route Type	D Runner Dia. (ft)	N Blades (#)	B Runner Height (ft)	Q Turbine Discharge (cfs)	Q_{OPT}/Q Discharge at Opt. Eff. (%)	H Net. Head (ft)	ω Speed (rpm)	ζ Swirl Coeff. (-)	λ Correlation Coeff. (-)	D_1 Runner Dia. at Inlet (ft)	D_2 Runner Dia. at Disch. (ft)	η Turbine Eff. (-)	BYPASS: P_B Estimated Mortality (-)
41	0.216	0.000	1	Francis	12.81	19	2.15	3,500	73.6%	330.0	150.0	1.10	0.20	14.4	12.0	0.93	
42	0.229	0.216	1	Francis	13.17	17	2.38	3,700	83.2%	330.0	150.0	1.10	0.20	14.0	12.7	0.96	
43	0.229	0.445	1	Francis	12.81	17	2.39	3,700	83.2%	330.0	150.0	1.10	0.20	7.5	12.7	0.96	
44	0.216	0.674	1	Francis	13.17	15	2.41	3,500	73.6%	330.0	150.0	1.10	0.20	13.1	12.7	0.93	
Spill	0.110	0.890	0	bypass													1.00

	MODEL SIMULATION INPUT PARAMETERS	
n_f	5,000	Number of fish
μ	5.0	Mean length (inches)
σ	0.0	SD in length (inches)

	BLADE STRIKE SIMULATION RESULTS	
Turbine Strikes:	297 of 5000 fish	5.9%
Bypass Failures:	540 of 5000 fish	10.8%
Passed:	4163 of 5000 fish	83.3%

Diablo Dam Model Runs for Salmonids Including Spillway Mortality

Skagit River Hydroelectric Project, FERC Project No. 553 ARCHIVED RUN .N5000-L24-S64 10/7/2021
Diablo Development: Salmonids (23.6") Average Spill JCASSONE
Release 200316

	ROUTE SELECTION			TURBINE DATA													BYPASS
					D	N	B	Q	Q_{OPT}/Q	H	ω	ζ	λ	D_1	D_2	η	P_B
Route Name	Route Selection Prob.	Prob. Lower Bound	Calc. Type	Route Type	Runner Dia. (ft)	Blades (#)	Runner Height (ft)	Turbine Discharge (cfs)	Discharge at Opt. Eff. (%)	Net. Head (ft)	Speed (rpm)	Swirl Coeff. (-)	Correlation Coeff. (-)	Runner Dia. at Inlet (ft)	Runner Dia. at Disch. (ft)	Turbine Eff. (-)	Estimated Mortality (-)
31	0.411	0.000	1	Francis	12.81	15	2.40	3,500	85.7%	330.0	171.0	1.10	0.20	12.4	11.3	0.96	
32	0.411	0.411	1	Francis	12.81	15	2.40	3,500	85.7%	330.0	171.0	1.10	0.20	12.4	11.3	0.96	
Spill	0.178	0.822	0	bypass													0.55

	MODEL SIMULATION INPUT PARAMETERS	
n_f	5,000	Number of fish
μ	23.6	Mean length (inches)
σ	0.0	SD in length (inches)

	BLADE STRIKE SIMULATION RESULTS	
Turbine Strikes:	1292 of 5000 fish	25.8%
Bypass Failures:	498 of 5000 fish	10.0%
Passed:	3210 of 5000 fish	64.2%

Skagit River Hydroelectric Project, FERC Project No. 553 ARCHIVED RUN .N5000-L12-S77 10/7/2021
Diablo Development: Salmonids (12") Average Spill JCASSONE
Release 200316

	ROUTE SELECTION			TURBINE DATA													BYPASS
					D	N	B	Q	Q_{OPT}/Q	H	ω	ζ	λ	D_1	D_2	η	P_B
Route Name	Route Selection Prob.	Prob. Lower Bound	Calc. Type	Route Type	Runner Dia. (ft)	Blades (#)	Runner Height (ft)	Turbine Discharge (cfs)	Discharge at Opt. Eff. (%)	Net. Head (ft)	Speed (rpm)	Swirl Coeff. (-)	Correlation Coeff. (-)	Runner Dia. at Inlet (ft)	Runner Dia. at Disch. (ft)	Turbine Eff. (-)	Estimated Mortality (-)
31	0.411	0.000	1	Francis	12.81	15	2.40	3,500	85.7%	330.0	171.0	1.10	0.20	12.4	11.3	0.96	
32	0.411	0.411	1	Francis	12.81	15	2.40	3,500	85.7%	330.0	171.0	1.10	0.20	12.4	11.3	0.96	
Spill	0.178	0.822	0	bypass													0.55

	MODEL SIMULATION INPUT PARAMETERS	
n_f	5,000	Number of fish
μ	12.0	Mean length (inches)
σ	0.0	SD in length (inches)

	BLADE STRIKE SIMULATION RESULTS	
Turbine Strikes:	670 of 5000 fish	13.4%
Bypass Failures:	484 of 5000 fish	9.7%
Passed:	3846 of 5000 fish	76.9%

Diablo Dam Model Runs for Redside Shiner Including Spillway Mortality

Skagit River Hydroelectric Project, FERC Project No. 553 ARCHIVED RUN .N5000-L5-S86 10/7/2021
Diablo Development: Redside Shiner (5"):Average Spill JCASSONE
Release 200316

	ROUTE SELECTION			TURBINE DATA													BYPASS
					D	N	B	Q	Q_{OPT}/Q	H	ω	ζ	λ	D_1	D_2	η	P_B
Route Name	Route Selection Prob.	Prob. Lower Bound	Calc. Type	Route Type	Runner Dia. (ft)	Blades (#)	Runner Height (ft)	Turbine Discharge (cfs)	Discharge at Opt. Eff. (%)	Net. Head (ft)	Speed (rpm)	Swirl Coeff. (-)	Correlation Coeff. (-)	Runner Dia. at Inlet (ft)	Runner Dia. at Disch. (ft)	Turbine Eff. (-)	Estimated Mortality (-)
31	0.411	0.000	1	Francis	12.81	15	2.40	3,500	85.7%	330.0	171.0	1.10	0.20	12.4	11.3	0.96	
32	0.411	0.411	1	Francis	12.81	15	2.40	3,500	85.7%	330.0	171.0	1.10	0.20	12.4	11.3	0.96	
Spill	0.178	0.822	0	bypass													0.40

	MODEL SIMULATION INPUT PARAMETERS	
n_f	5,000	Number of fish
μ	5.0	Mean length (inches)
σ	0.0	SD in length (inches)

BLADE STRIKE SIMULATION RESULTS		
Turbine Strikes:	309 of 5000 fish	6.2%
Bypass Failures:	367 of 5000 fish	7.3%
Passed:	4324 of 5000 fish	86.5%

Skagit River Hydroelectric Project, FERC Project No. 553 ARCHIVED RUN .N5000-L4-S88 10/7/2021
Diablo Development: Redside Shiner (4"): Average Spill JCASSONE
Release 200316

	ROUTE SELECTION			TURBINE DATA													BYPASS
					D	N	B	Q	Q_{OPT}/Q	H	ω	ζ	λ	D_1	D_2	η	P_B
Route Name	Route Selection Prob.	Prob. Lower Bound	Calc. Type	Route Type	Runner Dia. (ft)	Blades (#)	Runner Height (ft)	Turbine Discharge (cfs)	Discharge at Opt. Eff. (%)	Net. Head (ft)	Speed (rpm)	Swirl Coeff. (-)	Correlation Coeff. (-)	Runner Dia. at Inlet (ft)	Runner Dia. at Disch. (ft)	Turbine Eff. (-)	Estimated Mortality (-)
31	0.411	0.000	1	Francis	12.81	15	2.40	3,500	85.7%	330.0	171.0	1.10	0.20	12.4	11.3	0.96	
32	0.411	0.411	1	Francis	12.81	15	2.40	3,500	85.7%	330.0	171.0	1.10	0.20	12.4	11.3	0.96	
Spill	0.178	0.822	0	bypass													0.40

	MODEL SIMULATION INPUT PARAMETERS	
n_f	5,000	Number of fish
μ	4.0	Mean length (inches)
σ	0.0	SD in length (inches)

BLADE STRIKE SIMULATION RESULTS		
Turbine Strikes:	203 of 5000 fish	4.1%
Bypass Failures:	401 of 5000 fish	8.0%
Passed:	4396 of 5000 fish	87.9%

Skagit River Hydroelectric Project, FERC Project No. 553 ARCHIVED RUN .N5000-L3-S89 10/7/2021

Diablo Development: Redside Shiner (3"): Average Spill JCASSONE

Release 200316

	ROUTE SELECTION			TURBINE DATA													BYPASS
					D	N	B	Q	Q_{OPT}/Q	H	ω	ζ	λ	D_1	D_2	η	P_B
Route Name	Route Selection Prob.	Prob. Lower Bound	Calc. Type	Route Type	Runner Dia. (ft)	Blades (#)	Runner Height (ft)	Turbine Discharge (cfs)	Discharge at Opt. Eff. (%)	Net. Head (ft)	Speed (rpm)	Swirl Coeff. (-)	Correlation Coeff. (-)	Runner Dia. at Inlet (ft)	Runner Dia. at Disch. (ft)	Turbine Eff. (-)	Estimated Mortality (-)
31	0.411	0.000	1	Francis	12.81	15	2.40	3,500	85.7%	330.0	171.0	1.10	0.20	12.4	11.3	0.96	
32	0.411	0.411	1	Francis	12.81	15	2.40	3,500	85.7%	330.0	171.0	1.10	0.20	12.4	11.3	0.96	
Spill	0.178	0.822	0	bypass													0.40

MODEL SIMULATION INPUT PARAMETERS		
n_f	5,000	Number of fish
μ	3.0	Mean length (inches)
σ	0.0	SD in length (inches)

BLADE STRIKE SIMULATION RESULTS		
Turbine Strikes:	177 of 5000 fish	3.5%
Bypass Failures:	360 of 5000 fish	7.2%
Passed:	4463 of 5000 fish	89.3%

Gorge Dam Model Runs for Salmonids Including Spillway Mortality

Skagit River Hydroelectric Project, FERC Project No. 553 ARCHIVED RUN .N5000-L12-S85 10/7/2021

Gorge Development, Salmonids (12") Average Spill JCASSONE

Release 200316

ROUTE SELECTION				TURBINE DATA													BYPASS
					D	N	B	Q	Q_{OPT}/Q	H	ω	ζ	λ	D_1	D_2	η	P_B
Route Name	Route Selection Prob.	Prob. Lower Bound	Calc. Type	Route Type	Runner Dia. (ft)	Blades (#)	Runner Height (ft)	Turbine Discharge (cfs)	Discharge at Opt. Eff. (%)	Net. Head (ft)	Speed (rpm)	Swirl Coeff. (-)	Correlation Coeff. (-)	Runner Dia. at Inlet (ft)	Runner Dia. at Disch. (ft)	Turbine Eff. (-)	Estimated Mortality (-)
21	0.140	0.000	1	Francis	8.36	13	1.58	1,500	72.1%	380.0	257.0	1.10	0.20	8.7	7.4	0.94	
22	0.140	0.140	1	Francis	8.36	13	1.58	1,500	72.1%	380.0	257.0	1.10	0.20	8.7	7.4	0.94	
23	0.129	0.280	1	Francis	8.14	13	1.18	1,380	88.9%	380.0	257.0	1.10	0.20	7.5	7.1	0.93	
24	0.392	0.409	1	Francis	14.03	17	2.56	4,200	76.8%	380.0	164.0	1.10	0.20	13.1	11.3	0.94	
Spill	0.199	0.801	0	bypass													0.10

MODEL SIMULATION INPUT PARAMETERS		
n_f	5,000	Number of fish
μ	12.0	Mean length (inches)
σ	0.0	SD in length (inches)

BLADE STRIKE SIMULATION RESULTS		
Turbine Strikes:	673 of 5000 fish	13.5%
Bypass Failures	86 of 5000 fish	1.7%
Passed:	4241 of 5000 fish	84.8%

Skagit River Hydroelectric Project, FERC Project No. 553 ARCHIVED RUN .N5000-L24-S69 10/7/2021

Gorge Development, Salmonids (23.6") Average Spill JCASSONE

Release 200316

ROUTE SELECTION				TURBINE DATA													BYPASS
					D	N	B	Q	Q_{OPT}/Q	H	ω	ζ	λ	D_1	D_2	η	P_B
Route Name	Route Selection Prob.	Prob. Lower Bound	Calc. Type	Route Type	Runner Dia. (ft)	Blades (#)	Runner Height (ft)	Turbine Discharge (cfs)	Discharge at Opt. Eff. (%)	Net. Head (ft)	Speed (rpm)	Swirl Coeff. (-)	Correlation Coeff. (-)	Runner Dia. at Inlet (ft)	Runner Dia. at Disch. (ft)	Turbine Eff. (-)	Estimated Mortality (-)
21	0.140	0.000	1	Francis	8.36	13	1.58	1,500	72.1%	380.0	257.0	1.10	0.20	8.7	7.4	0.94	
22	0.140	0.140	1	Francis	8.36	13	1.58	1,500	72.1%	380.0	257.0	1.10	0.20	8.7	7.4	0.94	
23	0.129	0.280	1	Francis	8.14	13	1.18	1,380	88.9%	380.0	257.0	1.10	0.20	7.5	7.1	0.93	
24	0.392	0.409	1	Francis	14.03	17	2.56	4,200	76.8%	380.0	164.0	1.10	0.20	13.1	11.3	0.94	
Spill	0.199	0.801	0	bypass													0.10

MODEL SIMULATION INPUT PARAMETERS		
n_f	5,000	Number of fish
μ	23.6	Mean length (inches)
σ	0.0	SD in length (inches)

BLADE STRIKE SIMULATION RESULTS		
Turbine Strikes:	1452 of 5000 fish	29.0%
Bypass Failures	113 of 5000 fish	2.3%
Passed:	3435 of 5000 fish	68.7%

Gorge Dam Model Runs for Redside Shiner Including Spillway Mortality

Skagit River Hydroelectric Project, FERC Project No. 553 ARCHIVED RUN .N5000-L5-S92 10/7/2021

Gorge Development, Redside Shiner (5") Average Spill JCASSONE

Release 200316

ROUTE SELECTION				TURBINE DATA													BYPASS
Route Name	Route Selection Prob.	Prob. Lower Bound	Calc. Type	Route Type	D Runner Dia. (ft)	N Blades (#)	B Runner Height (ft)	Q Turbine Discharge (cfs)	Q_{OPT}/Q Discharge at Opt. Eff. (%)	H Net. Head (ft)	ω Speed (rpm)	ζ Swirl Coeff. (-)	λ Correlation Coeff. (-)	D_1 Runner Dia. at Inlet (ft)	D_2 Runner Dia. at Disch. (ft)	η Turbine Eff. (-)	P_B Estimated Mortality (-)
21	0.140	0.000	1	Francis	8.36	13	1.58	1,500	72.1%	380.0	257.0	1.10	0.20	8.7	7.4	0.94	
22	0.140	0.140	1	Francis	8.36	13	1.58	1,500	72.1%	380.0	257.0	1.10	0.20	8.7	7.4	0.94	
23	0.129	0.280	1	Francis	8.14	13	1.18	1,380	88.9%	380.0	257.0	1.10	0.20	7.5	7.1	0.93	
24	0.392	0.409	1	Francis	14.03	17	2.56	4,200	76.8%	380.0	164.0	1.10	0.20	13.1	11.3	0.94	
Spill	0.199	0.801	0	bypass													0.05

MODEL SIMULATION INPUT PARAMETERS		
n_f	5,000	Number of fish
μ	5.0	Mean length (inches)
σ	0.0	SD in length (inches)

BLADE STRIKE SIMULATION RESULTS		
Turbine Strikes	334 of 5000 fish	6.7%
Bypass Failures	49 of 5000 fish	1.0%
Passed:	4617 of 5000 fish	92.3%

Skagit River Hydroelectric Project, FERC Project No. 553 ARCHIVED RUN .N5000-L4-S94 10/7/2021

Gorge Development, Redside Shiner (4") Average Spill JCASSONE

Release 200316

ROUTE SELECTION				TURBINE DATA													BYPASS
Route Name	Route Selection Prob.	Prob. Lower Bound	Calc. Type	Route Type	D Runner Dia. (ft)	N Blades (#)	B Runner Height (ft)	Q Turbine Discharge (cfs)	Q_{OPT}/Q Discharge at Opt. Eff. (%)	H Net. Head (ft)	ω Speed (rpm)	ζ Swirl Coeff. (-)	λ Correlation Coeff. (-)	D_1 Runner Dia. at Inlet (ft)	D_2 Runner Dia. at Disch. (ft)	η Turbine Eff. (-)	P_B Estimated Mortality (-)
21	0.140	0.000	1	Francis	8.36	13	1.58	1,500	72.1%	380.0	257.0	1.10	0.20	8.7	7.4	0.94	
22	0.140	0.140	1	Francis	8.36	13	1.58	1,500	72.1%	380.0	257.0	1.10	0.20	8.7	7.4	0.94	
23	0.129	0.280	1	Francis	8.14	13	1.18	1,380	88.9%	380.0	257.0	1.10	0.20	7.5	7.1	0.93	
24	0.392	0.409	1	Francis	14.03	17	2.56	4,200	76.8%	380.0	164.0	1.10	0.20	13.1	11.3	0.94	
Spill	0.199	0.801	0	bypass													0.05

MODEL SIMULATION INPUT PARAMETERS		
n_f	5,000	Number of fish
μ	4.0	Mean length (inches)
σ	0.0	SD in length (inches)

BLADE STRIKE SIMULATION RESULTS		
Turbine Strikes	236 of 5000 fish	4.7%
Bypass Failures	63 of 5000 fish	1.3%
Passed:	4701 of 5000 fish	94.0%

Skagit River Hydroelectric Project, FERC Project No. 553 ARCHIVED RUN .N5000-L3-S95 10/7/2021

Gorge Development, Redside Shiner (3") Average Spill JCASSONE

Release 200316

Route Name	ROUTE SELECTION: Route Selection Prob.	Prob. Lower Bound	Calc. Type	TURBINE DATA: Route Type	D Runner Dia. (ft)	N Blades (#)	B Runner Height (ft)	Q Turbine Discharge (cfs)	Q_{OPT}/Q Discharge at Opt. Eff. (%)	H Net. Head (ft)	ω Speed (rpm)	ζ Swirl Coeff. (-)	λ Correlation Coeff. (-)	D_1 Runner Dia. at Inlet (ft)	D_2 Runner Dia. at Disch. (ft)	η Turbine Eff. (-)	BYPASS: P_B Estimated Mortality (-)
21	0.140	0.000	1	Francis	8.36	13	1.58	1,500	72.1%	380.0	257.0	1.10	0.20	8.7	7.4	0.94	
22	0.140	0.140	1	Francis	8.36	13	1.58	1,500	72.1%	380.0	257.0	1.10	0.20	8.7	7.4	0.94	
23	0.129	0.280	1	Francis	8.14	13	1.18	1,380	88.9%	380.0	257.0	1.10	0.20	7.5	7.1	0.93	
24	0.392	0.409	1	Francis	14.03	17	2.56	4,200	76.8%	380.0	164.0	1.10	0.20	13.1	11.3	0.94	
Spill	0.199	0.801	0	bypass													0.05

MODEL SIMULATION INPUT PARAMETERS		
n_f	5,000	Number of fish
μ	3.0	Mean length (inches)
σ	0.0	SD in length (inches)

BLADE STRIKE SIMULATION RESULTS		
Turbine Strikes	206 of 5000 fish	4.1%
Bypass Failures	40 of 5000 fish	0.8%
Passed:	4754 of 5000 fish	95.1%