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February 26, 2020
GO2-20-039
DIC 409.3

Ami Kidder
Siting and Compliance Manager
Energy Facility Site Evaluation Council
P.O. Box 47250
Olympia, WA 98504-7250

ELECTRONIC SUBMITTAL ONLY

Dear Ms. Kidder:

Subject: FISH ENTRAINMENT CHARACTERIZATION FINAL REPORT

Reference: 1. NPDES Permit No. WA002515-1 Condition S12.B

2. GO2-15-151, dated October 21, 2015, electronic submittal of "Columbia Generating Station Draft Fish Entrainment Characterization Study Plan" via State of Washington Department of Ecology's Online Reporting System.

3. Letter, GI2-16-060 dated June 22, 2016, from S. Posner (EFSEC) to RA Dutton (Energy Northwest) "NPDES Permit No. WA-002515-1 Condition S12.B.1: EFSEC Approval of Entrainment Characterization Study Plan."

4. Letter, GI2-17-061, dated March 23, 2017, from J. Rikhoff (Nuclear Regulatory Commission) to M. Reddermann (Energy Northwest) "Transmittal of the National Marine Fisheries Service's March 10, 2017, Final Biological Opinion for Columbia Generating Station", Condition 2.9.4.4.b.

5. GO2-18-013, dated January 17, 2018, from S. Khounnala (Energy Northwest) to J. LaSpina (EFSEC) "NPDES Permit Fish Entrainment Study Updated Schedule".

6. Letter, GI2-18-096, dated November 19, 2018, from S. Bumpus (EFSEC) to S. Khounnala (Energy Northwest) "Columbia Generating Station, Energy Northwest (EN) Fish Entrainment Study Updated Schedule National Pollutant Discharge Elimination System (NPDES) Permit No. WA002515-1".

7. GO2-19-035, dated February 7, 2019, from S. Khounnala (EN) to S. Bumpus (EFSEC) "Columbia Generating Station Fish Entrainment Study Interim Report".

Background

The Energy Facility Site Evaluation Council (EFSEC) reissued National Pollutant Discharge Elimination System (NPDES) Permit No. WA002515-1 to Energy Northwest (EN) for the Columbia Generating Station (CGS) on September 30, 2014. A second amendment was later made to the NPDES Permit on March 19, 2019 (see Reference 1). Permit Condition S12.B.1 required EN to prepare documentation of the proposed fish entrainment characterization study design and submit the study plan to EFSEC for approval by November 1, 2015. On October 15, 2015, EN submitted the draft entrainment characterization study plan to EFSEC and outlined a two-year monitoring study in which samples of entrained fish would be taken weekly mid-March through mid-June (the risk window for early juvenile Chinook salmon) and biweekly from July through September (see Reference 2). On June 22, 2016, EFSEC approved the entrainment characterization study plan (see Reference 3). Condition S12B.2.b of the NPDES permit requires CGS to submit the characterization study's final report to EFSEC by May 1, 2019.

On March 10, 2019, the National Marine Fisheries Service (NMFS) issued a Biological Opinion pursuant to section 7(a)(2) of the Endangered Species Act as part of the Columbia Generating Station's licensing renewal process by the U.S. Nuclear Regulatory Commission (NRC). On March 23, 2017, the NRC transmitted the Biological Opinion to Energy Northwest (see Reference 3). Condition 2.9.4.4.b of the Biological Opinion requires EN to provide a copy of the final entrainment study report to the NMFS and the NRC.

Energy Northwest began the fish entrainment characterization study in the spring of 2017, but ran into mechanical issues associated with the operation of the fish cages. The fish cages would not meet the capture and fish retention requirement outlined in the study plan. To address this issue, EN personnel spent a number of months over the course of 2017 studying the operation of the fish cages, engineered cage retrofits, and conducted successful trials to ensure that fish capture and retention efficiency was adequate for both cages. Throughout 2017 EN had a number of conversations with EFSEC discussing the issues the facility was experiencing with the fish cages and on January 17, 2018, EN requested an updated study schedule (see Reference 5). On November 19, 2018, EFSEC approved EN's request to delay the start of the two-year study until the spring of 2018. EFSEC required an interim status report to be submitted by May 1, 2019 and the final report to be submitted by May 1, 2020 (see Reference 6). The interim report was submitted to EFSEC on February 7, 2019 (see Reference 7).

Final Results

Attached is the final fish entrainment characterization study report. The report was prepared by Anchor QEA and underwent third-party external review by experts in biological monitoring

and Columbia River aquatic ecology in accordance with the U.S. Environmental Protection Agency Peer Review Guidelines.

Very few fish were entrained over the entire two-year study period. A total of four fish were entrained in 754 hours of monitoring, suggesting the Columbia Generating Station's impact to the fish populations in the Hanford Reach of the Columbia River are minute. Capture

efficiency testing of the entrainment cages was consistently high, providing confidence in the fish entrainment monitoring methods throughout the study period. A well-planned fish entrainment monitoring study design was implemented and multiple potential contributing environmental and CGS operational factors were monitored that showed that the data collected in this study are representative of typical operating conditions, and thus, actual fish entrainment. In addition, the results of this two-year fish entrainment monitoring study are consistent with earlier observations report by Mudge et al. in 1981. Low water elevation was previously identified as a factor that could increase the risk of entrainment, however direct observations did not support this assumption, as no fish were entrained during periods of lowest flows in late August and September. Chinook salmon fry are one of the most vulnerable species owing to their abundance in the Hanford Reach during a relatively short period of the year. At least one, and potentially two, Chinook salmon fry were entrained during this study period, yet this represents a minute proportion of the total population rearing and migrating in the area of the Columbia Generating Station's river water intake structures.

<u>Certification</u>

I certify under penalty of law, that this document and all attachments were prepared under my direction or supervision in accordance with a system designed to assure that qualified personnel gathered and evaluated the information submitted. Based on my inquiry of the person or persons who manage the system or those persons directly responsible for gathering information, the information submitted is, to the best of my knowledge and belief, true, accurate and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for knowing violations.

If you require any additional information regarding this report, please contact WK Whitehead at (509) 377-8794.

Sincerely,

26/02/20 12:32:04 -08:00

X 

Khounnala, Shannon E. , Environme...

Shannon E. Khounnala
Environmental and Regulatory Programs Manager

SEK/np

Attachment: Final CGS Entrainment Study Report 2_18_2020.pdf

cc: Ami Moon – EFSEC
Ellie Ott – Ecology

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February 2020
Columbia Generating Station Fish Entrainment Study

FINAL
Fish Entrainment Characterization Report

Prepared for Energy Northwest

February 2020
Columbia Generating Station Fish Entrainment Study

FINAL
Fish Entrainment Characterization Report

Prepared for
Energy Northwest
P.O. Box 989
Richland, Washington 99352

Prepared by
Anchor QEA, LLC
23 South Wenatchee Avenue, Suite 220
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Project Number: 171376-01.01
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ABBREVIATIONS

CFD	computational fluid dynamics
cfs	cubic feet per second
CGS	Columbia Generating Station
CE	capture efficiency
CI	confidence interval
cm	centimeters
EFSEC	Energy Facility Site Evaluation Council
ESA	Endangered Species Act
fish/m^3	number of fish per cubic meter
ft	feet
fps	feet per second
gpm	gallons per minute
HRFCPPA	Hanford Reach Fall Chinook Protection Program Agreement
kcfs	thousand cubic feet per second
m^3	cubic meters
m^3/s	cubic meters per second
MGD	million gallons per day
mm	millimeter
mmHg	millimeter of mercury
mph	miles per hour
NMFS	National Marine Fisheries Service
NPDES	National Pollutant Discharge Elimination System
RE	routine entrainment
RKM	river kilometer
RM	river mile
SAP	Sampling and Analysis Protocol
SD	standard deviation
Study Plan	*Draft Entrainment Characterization Study Plan for the Columbia Generating Station, Richland, Washington*
TMU	Tower Make-Up System
TSE	Total Seasonal Entrainment
USGS	U.S. Geological Survey
VBSA	Vernita Bar Settlement Agreement
WDFW	Washington Department of Fish and Wildlife

Executive Summary

Energy Northwest's Columbia Generating Station (CGS) is located adjacent to the Columbia River near river mile (RM) 352 (river kilometer 566) approximately 5 miles upstream of the city limits of Richland, Washington. The Columbia River at the CGS site is a migratory pathway for salmonids that reproduce and rear in the upstream reaches and the Hanford Reach (the reach of river extending from the CGS vicinity to upstream Priest Rapids Dam at RM 397.1). The Hanford Reach is heavily used for spawning and rearing by fall-run Chinook salmon (*Oncorhynchus tshawytscha*) and is also spawning and rearing habitat for steelhead (*O. mykiss*).

A reissuance of National Pollutant Discharge Elimination System (NPDES) Permit No. WA002515-1 for Energy Northwest's CGS was published in 2014 by the Washington State Energy Facility Site Evaluation Council. During consultation for the reissuance of the NPDES permit, questions were raised about whether the two 42-inch- (107-centimeter [cm])-diameter cylindrical T-screen intake units currently used to withdraw water from the Columbia River would impinge or entrain fish. To address concerns regarding fish entrainment, NPDES Condition S12.B was included in the permit requiring CGS to prepare an entrainment characterization plan that includes 2 years of fish entrainment monitoring. A *Draft Entrainment Characterization Study Plan for the Columbia Generating Station, Richland, Washington* (Study Plan; Coutant 2014; Appendix A) was developed to guide the implementation of the fish entrainment study. The Study Plan directed the implementation of entrainment sampling paired with monitoring of physical conditions associated with the intakes to provide additional indirect lines of evidence of entrainment and impingement risk.

In addition, the Study Plan directed that a review of existing literature be developed to identify fish species and life stages at risk of entrainment or impingement. This Historical Fish Occurrence Literature Review of the Hanford Reach is briefly summarized in this interim report with the full literature review attached as Appendix E.

The risk of fish impingement associated with the intake screens was monitored per the Study Plan. Of particular interest were any risks posed to downstream-migrating juvenile salmonids. Energy Northwest contracted Alden Research Laboratory, Inc., to analyze the physical flow patterns (i.e., velocity and pressure fields) around the intake screens using 3D computational fluid dynamics (CFD) modeling reported in *Computational Fluid Dynamics Analysis of Perforated Intake Screens at Columbia Generating Station* (Alden 2018). Results of the modeling showed that a bow wave forms at the upstream end of the cylindrical intake screens, which could hydraulically deflect fish and stimulate the fish's behavior to avoid the intake screens. Thus, there is low likelihood of impingement in nearly all river flow and direction cases evaluated due to the generally high ratio of tangential (sweeping) flow to normal (approach) flow toward the screen pores in the boundary layer very near the screen.

Based on the Historical Fish Occurrence Literature Review on entrainment risk and the CFD modeling, a conservative assumption is that some risk exists for some species, even though the CGS intake was designed to bypass most fish. Periods of higher risk of encountering the intake occur when the most vulnerable species are present in highest abundance from March through September. Though hydraulic bypass of fish is facilitated by sweeping velocities that exceed approach velocity year-round, risk of encountering the intake may increase when river flows are more oblique to the intake orientation (Alden 2018), and late in the year when intake submergence depths may fail to meet National Marine Fisheries Service criteria of greater than one screen radius, or 1.75 ft.

This report describes the results of two seasons of the fish entrainment monitoring from mid-March to mid-September in 2018 and 2019. The methodology used to conduct the 2-year fish entrainment study is described in this report, with details provided in the Sampling and Analysis Protocol (Appendix B).

Fish entrainment sampling was conducted weekly from early April in 2018 and mid-March in 2019 to June and approximately every other week from July through mid-September in both years. Variances from the planned schedule occurred due to high river conditions during late May and early June 2018 that prohibited routine entrainment sampling and postponed one capture efficiency test to late June 2018. In 2018, a planned outage prevented sampling from occurring from mid-May to mid-June 2019, and an unplanned safety review required the cancellation of a single routine entrainment event in late August 2019. A total of thirty (30) fish entrainment sampling events occurred over the two-year time period; fifteen (15) in 2018 and fifteen (15) in 2019. A total of six (6) capture efficiency tests were successfully conducted on each pair of fish entrainment cages; three (3) in 2018 and three (3) in 2019.

Across all 30 fish entrainment sampling events observed fish entrainment was extremely low. Over a total of 754 hours of sampling conducted during the 2 study years, a total of four fish were entrained and retrieved from the sampling cages. These included a fall-run Chinook salmon fry recovered on May 3, 2018; a Pacific lamprey (*Lampetra tridentata*) ammocoete recovered on June 22, 2018; an unidentifiable salmonid fry recovered on March 21, 2019; and an adult torrent sculpin (*Cottus rhotheus*) recovered on April 4, 2019. Capture efficiency testing confirmed that fish retention by the cages was high (greater than 0.8) over a 24-hour sampling period.

Average adjusted entrainment rates and total fish entrained each year were calculated at the end of the second year of study following the methods outlined in the Sampling and Analysis Protocol (Appendix B). Total Seasonal Entrainment (TSE) was estimated to be a small fraction of overall fish populations, and the variation associated with the estimates was high because of the small number of fish entrained during sampling events and a conservative approach taken to estimate confidence limits. In 2018, the overall TSE for all species was estimated to be 24 fish with a confidence interval with at least 90% confidence (CI_{90}) estimated to be = 0 to 212 fish. In 2019, the overall TSE for all

species was estimated to be 24 fish with a confidence interval with at least 90% confidence (CI_{90}) estimated to be = 0 to 213 fish. TSE for pacific lamprey was 12 fish based on observations in 2018 (CI_{90} = 0 to 153) and for torrent sculpin TSE was 12 fish based on observations in 2019 (CI_{90} = 0 to 150). For Chinook salmon fry, TSE was also 12 fish per season (CI_{90} = 0 to 150). Based on the estimated abundance of pre-smolts in the Hanford Reach each year (WDFW 2019), the resulting maximum impact to the Hanford Reach fall-run Chinook salmon stock was estimated to be 0.00011% (CI_{90}= 0 to 0.0014%) of the pre-smolts in 2018 and 0.00015% (CI_{90} = 0 to 0.00187%) of the pre-smolts in 2019.

The Study Plan also calls for studies to demonstrate whether clogging of the two Columbia River water intake structure screens occurs due to debris and any associated fish impingement. The two CGS intake structures were visually inspected in situ using underwater video on individual days in September 2018 and October 2019. Algae biofouling was noted in each event where greater than 50% of the screen area was covered by algae or other debris. However, no fish were observed in the vicinity of the intake structures during the video imaging and no impingement of fish or shellfish was observed during any event. These observations were consistent with similar observations in 2016 and 2017 that showed an increase in the amount of biological growth on the intakes between early to late summer, but no evidence of fish impingement.

Clogging of screen openings can cause a short-term draw down of water level in the Tower Make-Up System (TMU) pumphouse, observed as a differential in water elevation between the Columbia River at the intake screens and water elevation within the TMU. Monitoring of hourly water elevations indicated that differentials were variable during the 2018 fish entrainment monitoring period and corresponded closely with the pattern of increasing and decreasing make-up water flow, suggesting that head differential was closely related to changes in pump flow volume. There was no evidence in the hourly head differential data to suggest any blockage of the intake structure screens occurred during the study period.

Debris entrained in the sampling cages during fish entrainment testing in 2018 and 2019 was routinely monitored. Debris type and volume varied throughout the season and included algae clumps, sediment, aquatic insect larvae, and “sponge-like” material. In general, light to medium amounts of debris were observed during the sampling.

Columbia River flow, water temperature, and meteorological data during the 2018 and 2019 field seasons are summarized in this report along with CGS operational data.

Study results show that fish entrainment by the CGS intakes was extremely rare. Entrainment of salmonids was a primary concern prior to study implementation, yet during 754 hours of monitoring that spanned the typical salmonid emergence period, just two fall-run Chinook salmon (one confirmed Chinook salmon, and one presumed to be a Chinook salmon) and no steelhead were

entrained. Expanded estimates of total entrainment across the study season indicated TSE would have a minute effect on fall-run Chinook salmon at the stock level. Entrainment of other small-bodied fishes, including larval lamprey, was another topic of concern, yet only one lamprey ammocoete and one torrent sculpin were observed. It is notable that factors that can increase fish entrainment risk, particularly the low water levels above the intake screens in late August and September, did not appear to increase the frequency of fish entrainment events. Biofouling of the intake screens occurred but had no observed effect on intake screen flow in ways that increased the risk of entrainment or impingement to fish. Generally, so few fish were entrained that the occurrences did not appear related to a specific environmental or operating condition in a way that informs assumptions about specific risk factors or that could be used to predict future entrainment events. Based on these observations, the CGS intakes pose extremely low risk of entrainment and impingement to fish that reside in the Hanford Reach and to the endangered salmonids from upstream populations that migrate through the Hanford Reach.

1 Introduction

Energy Northwest's Columbia Generating Station (CGS) is a boiling-water nuclear power plant located in south-central Washington State in Benton Country, approximately 5 miles upstream of the Richland, Washington city limits, that became operational in December 1984. The CGS is located adjacent to the Columbia River near river mile (RM) 352 (river kilometer [RKM] 566) and withdraws make-up water for its closed-cycle cooling system (cooling tower). The Columbia River at the CGS site is a migratory pathway for salmonids that reproduce and rear in the upstream reaches. The Hanford Reach (the reach of river extending from the CGS vicinity to upstream Priest Rapids Dam at RM 397.1) is heavily used by spawning fall-run Chinook salmon (*Oncorhynchus tshawytscha*) and some steelhead (*O. mykiss*).

On September 30, 2014, the Washington State Energy Facility Site Evaluation Council (EFSEC) published a reissuance of National Pollutant Discharge Elimination System (NPDES) Permit No. WA002515-1 for Energy Northwest's CGS. The final permit, effective November 1, 2014, with a second amendment effective March 19, 2019 was the result of consultations between EFSEC and interested agencies, including the Washington Department of Ecology, Region 10 of the U.S. Environmental Protection Agency, and the National Marine Fisheries Service (NMFS). The March 2019 amendment allowed for improvements to control biological growth in the cooling towers and did not change the fish entrainment and impingement conditions of the permit. Concerns were raised by NMFS and Washington Department of Fish and Wildlife (WDFW) about potential entrainment and impingement of fish by the two 42-inch (1.07 m) diameter cylindrical T-screen intake units currently used to withdraw water from the Columbia River for CGS operations. The existing screens use a design developed prior to the formal development of NMFS engineering design criteria (NMFS 2011) and NMFS and WDFW were especially concerned about the potential risk to Endangered Species Act (ESA)-listed and non-listed salmonids.

To address NMFS's and WDFW's concerns regarding fish entrainment, NPDES Condition S12.B was included in the final permit that became effective on November 1, 2014, requiring CGS to prepare an entrainment characterization study design and submit it to EFSEC for approval by November 1, 2015. The *Draft Entrainment Characterization Study Plan for the Columbia Generating Station, Richland, Washington* (Study Plan, Appendix A) was submitted to EFSEC in October 2015 and approved by EFSEC in June 2016. The approved Study Plan described the general methods for a 2-year fish entrainment monitoring study using entrainment cages specifically built for monitoring the intakes and maintained in place within the CGS Tower Make-Up (TMU) pumphouse since the facility was initially constructed. In addition, the Study Plan also outlined the need for a review of existing literature to identify fish species and life stages at risk of entrainment or impingement. The Historical Fish Occurrence Literature Review of the Hanford Reach is briefly summarized in this report with the full review attached as Appendix E.

The fish entrainment monitoring study was scheduled to begin in spring 2017 and to be completed in fall 2018. As per NPDES Condition S12.B the final report was to be submitted to EFSEC by May 1, 2019. Due to unforeseen mechanical problems with the fish entrainment cages, fish retention in the cages (capture efficiency) was low and the start of the study was delayed 1 year to allow for mechanical improvements to be made. In 2017, EFSEC was informed of the delay and CGS staff spent several months throughout 2017 and early 2018 retrofitting the sampling equipment to ensure that capture efficiency rates of 80% or better were attained for both sampling cages. In January 2018, Energy Northwest requested from EFSEC that the fish entrainment schedule be updated to initiate the study in the spring 2018 and complete the study in the fall 2019, with the final study report to be submitted by May 1, 2020. EFSEC approved the updated entrainment study schedule in November 2018, with the stipulation that an interim report be submitted by May 1, 2019 (EFSEC 2018). The interim report, submitted to EFSEC on February 7, 2019, described the results for the first year of the fish entrainment study, based on data collected from March 11, 2018, through September 15, 2018 (Anchor QEA 2019, CGS correspondence no. GO2-19-035).

To satisfy requirements stipulated by NMFS' Biological Opinion on the Columbia Generating Station and incorporated into NPDES permit requirements, Energy Northwest agreed to investigate the risks of fish impingement associated with the water intake structures by analyzing hydraulic conditions around the intake screens (NMFS 2017, NPDES Permit No. WA002515-1 Condition S12.B). Of particular interest are the risks posed to downstream-migrating juvenile salmonids. Energy Northwest contracted Alden Research Laboratory, Inc., to analyze the physical flow patterns (i.e., velocity and pressure fields) around the intake screens using 3D computational fluid dynamics (CFD) modeling. The modeling allows for interferences to be made about fish interaction with the intake structures based on the modeled velocity and pressure fields and known fish responses from published scientific literature. The modelling effort used a two-phased analysis in which the first phase focused on simulating larger-scale (e.g., the whole intake screen) dynamics around the intake structures, and the second phase focused on simulating smaller-scale (e.g., individual fish size) dynamics in the turbulent boundary layer over the holes of perforated screen areas. The two phases are referred to as "global" and "near-field" models, respectively. The global model supports the hypothesis that the bow wave at the upstream end of the cylindrical intake screens could provide pressure and velocity changes that hydraulically divert fish away from the screen and stimulate screen avoidance behavior by the fish. The global model results also showed that at times of the year when the tangential (sweeping) flow of the river is more oblique, the boundary layer is compressed to within a few inches of the screen on the up-current face and expands the boundary layer on the leeward face to a few feet where the layer blends with the wake region.

In terms of impingement risk, this translates to the highest potential impingement risk associated with the up-current face of the upstream screen and the leeward face of the downstream screen due to high approach velocity and low sweeping velocity, respectively. However, the near-field model

suggests low likelihood of entrainment or impingement in nearly all of the multiple model-input scenarios analyzed due to the generally high ratio of tangential (sweeping) flow in the boundary layer to normal (approach) flow toward the screen pores and low approach velocities through the pores over most of the screen area for most river conditions. Non-uniformity in through-screen flow resulting in regions of concentrated inflow along the screen produced some minor exceedances of near-field approach velocity thresholds given in NMFS guidelines (NMFS 2011). For additional details, see the report entitled, "*Computational Fluid Dynamics Analysis of Perforated Intake Screens at Columbia Generating Station*" (Alden 2018).

This Fish Entrainment Characterization Report satisfies Task 5 of the Study Plan to report the results of actual fish entrainment and debris sampling conducted at CGS in 2018 and 2019, including operations, flow, and other environmental data associated with field monitoring, per the requirements of NPDES Permit Condition S12.B.2.b, implemented as Tasks 2 and 3 of the Study Plan.

This report also includes excerpts of the Historical Fish Occurrence Literature Review (Anchor QEA 2018) to identify fish species and life stages at risk of entrainment or impingement. Findings of the literature review are summarized in Section 2.1 and the complete review is included in Appendix E.

All environmental, fish entrainment, capture efficiency, and debris impingement data that were collected or calculated as part of the Fish Entrainment Characterization study were provided to Energy Northwest as digital files, retained in the CGS Environmental & Regulatory Programs Reference Library under Fish Entrainment Study (Task 4 of the Study Plan, Data Summaries and Analyses).

1.1 Site Description

The study was conducted at the CGS Tower Make-Up (TMU) water pumphouse building, located at RKM 566 (RM 352) on the Columbia River, approximately 300 ft (91 m) shoreward of the river's normal high-water mark. The general layout of the pumphouse, intake pipes, and intake screens is depicted in Figures 1 and 2.

The pumphouse contains three (3) make-up water pumps that withdraw from the pumphouse well. Two pumps are typically in operation. Water is gravity-fed from the Columbia River to the pumphouse well located in the TMU pumphouse through two river water intake structures and two 36-inch (91-cm)-diameter buried pipes that extend 900 ft (274 m) from the pumphouse to the river channel. Water is then pumped from the pumphouse well by the 800-horsepower make-up water pumps designed to each supply 12,500 gallons per minute (gpm) (0.79 cubic meters per second [m^3/s] or 9 million gallons per day [MGD]) or half the system capacity at design head. Two pumps can supply make-up water to the plant with a withdrawal capacity of 25,000 gpm (1.58 m^3/s or 36

MGD) but during normal operating periods, the average make-up-water withdrawal is about 17,000 gpm (1.1 m^3/s or 24.48 MGD). Actual withdrawal rates vary seasonally and hourly.

An intake structure is located in the river at the end of each of the 36-inch diameter buried pipes. The pipes make a 90-degree, upward bend and extend slightly above the surface of the riverbed (Figure 1). Attached to each of the pipes is a 30-ft (9-m)-long, cylindrical screen housing mounted above the riverbed and approximately parallel to the river flow. Each cylinder is composed of two intake screens each 6.5- (2-m)-long and mounted upstream and downstream of a central chamber attached to the buried pipe. Solid cones cap each end of the dual-screen structure. The screens consist of an outer and inner sleeve of perforated pipe. The outer sleeve (forming the wall of the cylinder) is 42 inches (107 centimeters) in diameter with 0.375-inch (9.5-millimeter [mm]) holes comprising 40% of the surface area. The inner sleeve is a 36-inch (91-cm)-diameter cylinder with 0.75-inch (19-mm) holes comprising 7% of the surface area. The double-sleeve intake screens are designed to distribute water flow into the structure evenly along its outer surface.

The pumphouse building has three levels: a ground level where entry is gained and the pumps are housed, a first underground level, and a second, lower underground level where sampling occurs, referred to here as the "Sampling Platform" (Figure 2). Fish are removed from the entrainment sampling cages on the sampling platform. Two identical sampling cages are suspended in the pumphouse well in front of the sluice gates at the terminal end of the 36-inch diameter buried pipes leading from the intake structures in the river (Figures 1 and 2) (Mudge et al. 1981). Each cage is approximately 5.8 ft (1.5 m) long, 5 ft (1.52 m) high, and 3.5 ft (1.07 m) wide. Each cage has an 11.5-square-foot (1.07-square-meter) door for coupling with the 36-inch intake pipe openings. The cages have an aluminum frame and door, while the remainder is made of woven stainless-steel wire mesh with 2.0-mm square openings. Initial investigations in 2017 identified gaps between the cage door openings and the sluice gates at the end of intake pipes, allowing fish to escape the cages. The cages were retrofitted with engineered inserts that extend out from the cage doors to bridge the gap between the cage doors and the sluice gates on the intake pipe outlets. The inserts were needed to provide a close seal with the sluice gate on the incoming pipe from the river (Figure 3). Inserts are configured to rest inside the cage doors while they are being lowered or raised. Each cage insert is equipped with brushes around the outer edge of the insert that adjoin to the uneven surface of the sluice gate when the insert is extended.

The cages are lowered individually approximately 35 ft (10.7 m) into the water of the pumphouse well using electric winches to the sampling position in direct alignment with the sluice gates of the intake pipes. As the cage nears the intake pipe sluice gates the cage door abuts against a fixed stop-block that causes the door to automatically open as the body of the cage continues to descend into position. Once cages are in position at the termination of the intake pipes and cage doors are fully open, the inserts are immediately extended by manually pulling a cable attached to the insert,

bridging the gap between the cage doors and sluice gates with stiff brushes that conform to the shape of the sluice gate openings (Figure 3). A separate cable is used to retract the cage insert immediately prior to closing the doors and raising the cage to the surface. As the cage is raised from the vault, the cage door automatically closes.

1.2 Objectives

The overall objective of this study was to broadly characterize entrainment and impingement risk posed by the CGS intake screens to all fish, and to further address specific concerns about the potential impact on Columbia River salmon and steelhead. The 9.5-mm (0.375-inch) openings of the outer screens of the CGS intake structures are potentially large enough to entrain early life stages of several fish species, including fall-run Chinook salmon and Pacific lamprey (Anchor QEA 2018; Appendix E). Variable environmental conditions in the Columbia River and CGS operations may influence fish entrainment and impingement. River velocity and elevation, water temperature, CGS make-up flow, and debris on the intake screen have been identified as key factors that may affect whether fish present are entrained or impinged. The ways in which these factors affect entrainment or impingement is likely to change over the year with variability in river flow, water temperature, CGS make-up water flow, as well as seasonal change in fish presence, habitat uses, and debris.

The Study Plan specifies four specific tasks that were implemented to meet the overall study objective:

1. Study Plan Task 1: A literature review on the historical fish occurrence was prepared to summarize the large body of existing work on Hanford Reach fish populations and assumptions about the risk of entrainment posed by the CGS intakes.
2. Study Plan Task 2: The primary objective of the fish entrainment study was to quantify fish entrainment through the CGS intake screens over 2 years of monitoring in association with the changing environmental conditions and make-up water flow at the intake.
3. Study Plan Task 3: In addition, potential fish and debris impingement on the intake screens was evaluated by monitoring water surface level differential between the Columbia River and the CGS pumphouse for abnormalities that could indicate clogging of the intake screens. The interpretation of these data was informed by direct visual observations of the screen surface with video monitoring carried out by Energy Northwest.
4. Study Plan Task 4: The routine fish entrainment results, capture efficiency results, and environmental monitoring data were used to quantify a seasonal fish entrainment estimate, and to expand to an estimated impact to the Hanford Reach fall-run Chinook salmon population.

1.3 Contributing Organizations and Personnel

This report and literature review have undergone third-party external review by experts in biological monitoring and Columbia River fish in accordance with the U.S. Environmental Protection Agency

Peer Review Guidelines (EPA 2006). The reviewers were Dr. Charles C. Coutant, retired from a career with Pacific Northwest National Laboratory in Richland, Washington, and Oak Ridge National Laboratory in Oak Ridge, Tennessee, and author of the Study Plan and expert in biological effects of power plants on salmon in the Hanford Reach; Dr. Lyman L. McDonald, an internationally recognized biometrician with long tenure of membership on the Northwest Power and Conservation Council's Independent Scientific Advisory Board for the Columbia River Basin Fish and Wildlife Program and founder of Western EcoSystems Technology (WEST) Inc. Environmental and Statistical Consultants; and Dr. Jared Studyvin, a research biometrician also of WEST Inc.

The following people and organizations contributed to this Fish Entrainment Characterization Study and Report.

Table 1
Contributors to the CGS Entrainment Study and Report

Name	Organization	Role
Dr. Charles Coutant	Coutant Aquatics	Author of the Entrainment Characterization Study Plan and peer reviewer
Kip Whitehead	Energy Northwest	Principal environmental scientist and project manager
Shannon Khounnala	Energy Northwest	Environmental and regulatory program manager
Marshall Schmitt	Energy Northwest	Technical support
Mechanical Maintenance Department	Energy Northwest	Fish cage deployment and retrieval
Fix It Now Department	Energy Northwest	Cage insert optimization
Greg Jaschke	Energy Northwest	Systems engineer, fish cage insert design
Jaime Henle	Energy Northwest	Systems engineer, operational support
Larissa Rohrbach	Anchor QEA	Senior fisheries scientist and project manager
Arial Evans	Anchor QEA	Field technician
Sydney Gonsalves	Anchor QEA	Scientist, data analyst
Kristi Geris	Anchor QEA	Field and project coordination
John Ferguson	Anchor QEA	Principal fisheries scientist, senior review
WDFW	Ringold/Meseberg Hatchery	Source for juvenile steelhead
WDFW	Pasco Field Office, Region 3	Source for Hanford Reach fall-run Chinook fry abundance estimates

Name	Organization	Role
Dr. Lyman McDonald	West, Inc.	Peer statistical review
Dr. Jared Studyvin	West, Inc.	Peer statistical review

2 Literature Review

2.1 Study Plan Task 1: Historical Fish Occurrence

Per the Study Plan (Task 1.A.), a Historical Fish Occurrence Literature Review (Anchor QEA 2018) was prepared that provides a literature review on fish species present in the Hanford Reach, factors that determine fish entrainment, entrainment risk at CGS, and a review of historical spring river elevations and discharges.

Species that are at highest risk of encountering the CGS intake were identified (per Study Plan, Task 1.B.) based on overlapping habitat preference for mid-channel or benthic habitat with river conditions and fish size. The seasonal presence of the species at highest risk are shown in Figure 4. A conservative assumption is that some risk exists for these species even though the CGS intake was designed to bypass most fish. Periods of higher risk of encountering the intake occur when the most vulnerable species are present in highest abundance from March through September, highlighted in yellow in Figure 4. Though hydraulic bypass of fish is facilitated by sweeping velocities that exceed approach velocity year-round, risk of encountering the intake may also increase late in the year when submergence depths may fail to meet NMFS criteria of greater than one screen radius, or 1.75 ft, highlighted in orange in Figure 4.

Concerns were raised by NMFS and WDFW about risk of entrainment and impingement to ESA-listed and non-listed salmonids. Those migrating from upstream spawning and nursery areas include the upper Columbia River spring Chinook salmon (Endangered), upper Columbia River steelhead (Threatened), Wenatchee and Okanogan sockeye salmon (*O. nerka*; not listed), and coho salmon (*O. kisutch*; coho salmon are unlisted, but currently a reintroduction effort exists to reverse historical extirpation from the middle and upper Columbia River Basin). Typically, migratory smolts originating from the upper Columbia River Basin (upstream of Hanford Reach) are a size that would exclude them from becoming entrained through the CGS intake screens (greater than 75 mm in length, correlating with a body depth greater than the 9.5 mm screen pore width; Bell 1990). In addition, smolts from the upper Columbia River Basin tend to behave in ways that greatly minimize their risk of impingement: their peak emigration timing is in spring and summer, concurrent with high river discharge and peak sweeping velocities (shown in Figure 4); they tend to migrate near the surface, placing them approximately 7 to 12 ft from the intake screens at this time of year; and they would have burst swimming capacities greater than 2.5 ft per second (fps; Taylor and McPhail 1985), which greatly exceed the bulk flow approach velocities of 0.07 fps through the CGS intakes. Based on these biological factors, the risk of entrainment or impingement to migrating smolts from the upper Columbia River Basin is negligible for the CGS intake structures.

Salmon and steelhead that emerge and rear within the Hanford Reach have higher potential risk due to their small size and potential exposure to the intake during early development. Hanford Reach

fall-run Chinook salmon are the salmonid species at highest risk due to their proximity and abundance near the CGS intakes. Figure 5 shows determining factors of entrainment that are evaluated individually relative to the biological characteristics of Hanford Reach fall-run Chinook salmon (discussed in detail in the Historical Occurrence report, Appendix E) to characterize the level of risk created by each individual factor. The entrainment factors that create the most risk for fall-run Chinook salmon are their presence in proximity to the intake structure, their habitat preference that causes them to move away from nearshore areas as they grow, and their small size relative to the external screen pore size. These characteristics put fall-run Chinook salmon at relatively higher risk in April and May when large numbers of fry are both small in size and starting to move away from nearshore areas.

Extreme low water elevations are one factor that can increase risk of fish entrainment. Historical water elevations during the March to June emergence period of juvenile Chinook salmon were evaluated to assess when this risk has been elevated in the past (per Study Plan, Task 1.C). Risk may increase if water levels are lower than one screen radius above the intake screen (NMFS 2011), a depth of 21 inches or 343.05 ft (104.56 m) mean sea level for the CGS intake. A critical minimum flow to protect salmon is maintained each year by agreements that apply to operation of Priest Rapids Dam, to provide water elevations that keep salmon redds submerged and minimize the magnitude of flow fluctuations during the rearing period within the Hanford Reach (Grant PUD 2004). Modeled river elevation at the CGS intake site from March 1976 to January 2016 (Niehus et al. 2014; Perkins et al. 2018) encompasses the periods prior to implementation of the Vernita Bar Settlement Agreement (VBSA) in 1984, after implementation of the VBSA, and after initial application of the Hanford Reach Fall Chinook Protection Program Agreement (HRFCPPA) in 1999. Figure 6 displays the number of low water events and event duration in hours for each of these three historical periods. Extreme low water elevations occurred more frequently prior to the VBSA (52 events in 9 years compared to 54 events in 32 years). However, the mean duration of such events is highest in the post-HRFCPPA period. Low-flow events lasted on average 24.1 hours during the 1999 to 2015 period. In 2001 and 2002, five events exceeded 40 hours, with one event lasting longer than 80 hours. It is notable that the HRFCPPA was not finalized until 2004, and since then, there has only been one extreme low-flow event of short duration (2 hours) in 2015. Since implementation of the HRFCPPA, the lowest flows in the Hanford Reach typically occur in September and October, a time of year when most fall-Chinook salmon fry have out-migrated from the Hanford Reach, and any that remain are likely to have grown to a size that exceeds the CGS intake pore width (Dauble et al. 1989).

Entrainment factors that effectively minimize the risk to fall-run Chinook salmon are facilitated by orientation of the intake in a relatively high-velocity, mid-channel location, parallel to flow that creates sweeping velocities that exceeds maximum approach velocity by a factor of 10. It can also be assumed that fall-run Chinook salmon can effectively avoid entrainment given their ability to sense

rapid changes in acceleration and burst swimming capacity that also exceeds maximum approach velocity by a factor of 10.

3 Sampling and Analysis Methods

The Sampling and Analysis Protocol (SAP; Appendix B) provides detailed descriptions of the mobilization, communication, sample collection, sample processing and identification, data management, Quality Assurance and Quality Control procedures and documentation, and health and safety protocols associated with the entrainment monitoring and other sampling conducted at CGS in 2018 and 2019. Further details for safe and effective handing of sampled fish are described in *Tower Make-Up System (TMU) Fish Cages – Operational Considerations* (EN 2018). A short summary of the sampling methods used is provided in the following sections.

3.1 Task 2: Fish Entrainment Sampling

Fish entrainment sampling incorporated three components used to estimate overall fish entrainment rates: routine fish entrainment monitoring, capture efficiency testing of entrainment cages, and ancillary data collection to identify environmental or operational conditions associated with fish entrainment.

3.1.1 Task 2.A. Routine Fish Entrainment

Routine fish entrainment sampling involved intercepting and capturing entrained fish over a 24-hour sampling period using specially designed cages located at the end of the two submerged intake pipes within the CGS pumphouse (Figures 1 through 3). Sampling was carried out weekly from mid-March through mid-June and every-other-weekfrom July through September in each of 2 years (2018 and 2019) when intake pumps were operating at 60% of capacity or greater.

The Study Plan states that if more than 20 individual fish were captured during a routine sampling session, contingency sampling is required, consisting of immediate redeployment of the sampling cages for two sequential 12-hour “day” and “night” periods to monitor any diel variation in entrainment. Due to low numbers of fish entrained in any one event, no contingency sampling events were required.

3.1.2 Task 2.B. Capture Efficiency Testing

The efficacy of the sampling cages for capturing and retaining fish (capture efficiency) was estimated and used as a correction factor to develop adjusted entrainment rate estimates. The minimum requirement for capture efficiency is 0.80, per the SAP (Anchor QEA 2018).

Capture efficiency was evaluated using juvenile hatchery fish of similar size to wild Hanford Reach Chinook salmon fry in three trials conducted each sampling year (six total trials in 2018 and 2019). Hatchery-reared juvenile steelhead (*O. mykiss*) were obtained from Ringold/Meseberg Hatchery in Mesa, Washington, and transported to the CGS pumphouse. The appropriate Fish Transport Applications were obtained from WDFW prior to transfer (Permits Nos. 7675-01-05-18 and 7972-01-31-19; Appendix F). A direct test of entrainment and retention of the intake structure by releasing fish

into the intake structure was not feasible due to safety concerns of working in swift water near the intake and inability to access the intake pipes directly; therefore, fish were released into the cages that intercept fish at the terminal end of the intake pipe as a direct test of the ability of the cages to retain fish (and other material) once captured. Exactly 100 hatchery fry were released into each cage, cages were deployed for 24 hours, and the proportion of fry remaining after 24 hours was recorded as the capture efficiency of each cage. Hatchery fry were marked with Bismarck brown dye to differentiate them from any fish that may have become entrained from the river. Fish were removed and cages were deployed for an additional 24 hours to re-capture any fish that may have moved into the intake pipes. No fish were re-captured during the second 24-hour monitoring periods.

3.1.3 Task 2.C. Ancillary Data Collection

Ancillary data were collected hourly from mid-March through mid-September to characterize river flow and elevation, direction of river stage (rising or falling), river water temperature, number and duration of pumps operating, make-up water flow, weather, and any abnormal operating or river conditions.

3.1.4 General Fish Sampling Methods and Schedule

Two sampling cages were used for entrainment sampling. The cages were individually lowered and raised into position at the terminal end of the intake pipes. The cages were designated as “Cage 1” and “Cage 2” based on the south-north orientation depicted in Figure 7.

CGS staff lowered both sampling cages from the Sampling Platform approximately 35 ft into the pumphouse sump directly in alignment with the openings of the inlet pipes. The cage doors automatically opened and the cage inserts were extended to intercept any fish coming out of the terminal end of the intake pipes. The date and time that each cage was lowered into the pumphouse sump was recorded. Field data for the entire study are provided in Appendix C.

Cages were retrieved after a 24-hour sampling period. One sampling cage at a time was raised to retrieve any fish present. Cages were visually inspected and cleaned of entrained fish and debris.

The following data were recorded for fish retrieved from the sampling cages:

- Identification of species and life stage
- Weight (grams)
- Fork Length (mm)
- Description of any outward signs of damage or disease

In addition, the relative debris load was noted qualitatively.

As discussed with the EFSEC, Energy Northwest began the fish entrainment characterization study in spring 2017; however, mechanical issues associated with the operation of the fish cages caused

concern about capture efficiency (the efficacy of the cages for capturing and retaining fish). It was discovered that there was a gap between each fish entrainment cage and the sluice gate at the outlet of the intake pipe that was wide enough for entrained fish or any fish placed in a cage during an efficiency test to easily escape into the pumphouse well. To address this issue, Energy Northwest spent several months in 2017 observing the operation of the fish cages and engineering cage retrofits. Trials were conducted in 2017 and early 2018 to ensure that fish capture and retention was adequate for both cages. The first year of the 2-year entrainment characterization study began in the spring of 2018 (Table 2).

From early-April to mid-June in 2018, and early-March to mid-June in 2019, routine entrainment (RE) sampling was scheduled to occur once per week, then every other week until mid-September. Cages were deployed by CGS staff at approximately 9:00 a.m. and cage retrieval occurred 24 hours later. No events entrained more than one fish and so no contingency sampling was required following the 24-hour sample. Three separate capture efficiency (CE) tests were scheduled to be conducted each year during the typical fall-run Chinook salmon emergence period. After each capture efficiency test, cages were deployed for an additional 24-hour period to recapture any fish that may have moved into the intake pipes; the weekly routine sampling was carried out concurrently with the second 24-hours of deployment for capture efficiency testing.

Table 2
Fish Monitoring Events Timeline

Sample Event	Event Type	Sampling Dates	
		Start	Finish
CE-1	Capture efficiency	Tuesday April 3, 2018	Wednesday, April 4, 2018
RE-2018-1	Capture efficiency follow-up + routine	Wednesday April 4, 2018	Thursday, April 5, 2018
RE-2018-2	Routine	Wednesday, April 11, 2018	Thursday, April 12, 2018
RE-2018-3	Routine	Wednesday, April 18, 2018	Thursday, April 19, 2018
CE-2	Capture efficiency	Tuesday, April 24, 2018	Wednesday, April 25, 2018
RE-2018-4	Capture efficiency follow-up + routine	Wednesday, April 25, 2018	Thursday, April 26, 2018
RE-2018-5	Routine	Wednesday, May 2, 2018	Thursday, May 3, 2018
RE-2018-6	Routine	Wednesday, May 9, 2018	Thursday, May 10, 2018
--	High water; no sampling[1]	Wednesday, May 16, 2018	Thursday, May 17, 2018
--	High water; no sampling[1]	Thursday, May 17, 2018	Friday, May 18, 2018
--	High water; no sampling[1]	Wednesday, May 23, 2018	Thursday, May 24, 2018
--	High water; no sampling[1]	Wednesday, May 30, 2018	Thursday, May 31, 2018
--	High water; no sampling[1]	Wednesday, June 6, 2018	Thursday, June 7, 2018
RE-2018-7	Routine	Wednesday, June 13, 2018	Thursday, June 14, 2018

Sample Event	Event Type	Sampling Dates	
		Start	Finish
RE-2018-8	Routine	Wednesday, June 20, 2018	Thursday, June 21, 2018
CE-3	Capture efficiency	Tuesday, June 26, 2018	Wednesday, June 27, 2018
RE-2018-9	Capture efficiency follow-up + routine	Wednesday, June 27, 2018	Thursday, June 28, 2018
RE-2018-10	Capture efficiency (Cage 2 only)	Wednesday, July 11, 2018	Thursday, July 12, 2018
CE-3b	Capture efficiency	Tuesday, July 17, 2018	Wednesday, July 18, 2018
RE-2018-11	Capture efficiency follow-up + routine	Wednesday, July 18, 2018	Thursday, July 19, 2018
RE-2018-12	Routine	Wednesday, August 1, 2018	Thursday, August 2, 2018
RE-2018-13	Routine	Wednesday, August 15, 2018	Thursday, August 16, 2018
RE-2018-14	Routine	Wednesday, August 29, 2018	Thursday, August 30, 2018
RE-2018-15	Routine	Wednesday, September 12, 2018	Thursday, September 13, 2018
CE-4	Capture efficiency	Tuesday, March 12, 2019	Wednesday, March 13, 2019
RE-2019-1	Capture efficiency follow-up + routine	Wednesday, March 13, 2019	Thursday, March 14, 2019
RE-2019-2	Routine	Wednesday, March 20, 2019	Thursday, March 21, 2019
RE-2019-3	Routine	Wednesday, March 27, 2019	Thursday, March 28, 2019
--	Test fish mortalities; no sampling[2]	Tuesday, April 2, 2019	Thursday, April 3, 2019
RE-2019-4	Routine	Wednesday, April 3, 2019	Thursday, April 4, 2019
CE-5	Capture efficiency	Tuesday, April 9, 2019	Wednesday, April 10, 2019
RE-2019-5	Capture efficiency follow-up + routine	Wednesday, April 10, 2019	Thursday, April 11, 2019
RE-2019-6	Routine	Wednesday, April 17, 2019	Thursday, April 18, 2019
CE-6	Capture efficiency	Tuesday, April 23, 2019	Wednesday, April 24, 2019
RE-2019-7	Capture efficiency follow-up + routine	Wednesday, April 24, 2019	Thursday, April 25, 2019
RE-2019-8	Routine	Wednesday, May 1, 2019	Thursday, May 2, 2019
RE-2019-9	Routine	Wednesday, May 8, 2019	Thursday, May 9, 2019
--	Outage; no sampling[3]	Wednesday, May 15, 2019	Thursday, May 16, 2019
--	Outage; no sampling[3]	Wednesday, May 22, 2019	Thursday, May 23, 2019
--	Outage; no sampling[3]	Wednesday, May 29, 2019	Thursday, May 30, 2019
--	Outage; no sampling[3]	Wednesday, June 5, 2019	Thursday, June 6, 2019
--	Outage; no sampling[3]	Wednesday, June 12, 2019	Thursday, June 13, 2019
RE-2019-10	Routine	Wednesday, June 26, 2019	Thursday, June 27, 2019
RE-2019-11	Routine	Wednesday, July 10, 2019	Thursday, July 11, 2019
RE-2019-12	Routine	Wednesday, July 24, 2019	Thursday, July 25, 2019
RE-2019-13	Routine	Wednesday, August 7, 2019	Thursday, August 8, 2019

Sample Event	Event Type	Sampling Dates	
		Start	Finish
--	Safety review; no sampling[4]	Wednesday, August 21, 2019	Thursday, August 22, 2019
RE-2019-14	Routine	Wednesday, September 4, 2019	Thursday, September 5, 2019
RE-2019-15	Routine	Wednesday, September 18, 2019	Thursday, September 19, 2019

Notes:

1. Sampling in 2018 was suspended from mid-May through early June due to high Columbia River level and flooding of the CGS TMU pumphouse.
2. Capture efficiency sampling was canceled due to mortalities among test fish during transport from the hatchery.
3. Sampling in 2019 was suspended from mid-May to mid-June for a scheduled CGS maintenance outage.
4. No sampling was carried out on Wednesday, August 21, 2019, due to a safety review of CGS pumphouse conditions and operations related to the study.

3.1.4.1 Deviations from the Study Plan

Planned and unplanned variances from the planned sampling schedule occurred in both 2018 and 2019.

Flood conditions in 2018 during extremely high spring runoff conditions from early-May to early-June 2018 submerged the pumphouse sampling platform, preventing access for entrainment sampling. Routine entrainment sampling was canceled from May 16 to June 6, 2018. One capture efficiency test was postponed until June 26, 2018 (Table 2). From July to early-September 2018, additional routine sample dates were added and the routine sampling schedule was adjusted to compensate for the lost sampling events. A low capture efficiency value for Cage 2 was observed on June 27, 2018, (49 of 100 dyed fish retained) following high water levels that inundated the sampling platform and cages for 5 weeks. The efficacy of Cage 2 was restored by repairing and modifying cable attachments following the high-water event. A capture efficiency test was repeated on Cage 2 on July 17, 2018, to confirm that this cage was operating with adequate efficiency. Water elevation in the river and TMU pumphouse exceeded the capacity of CGS gauges resulting in a period from May 6 to June 6 during which water elevation data were inaccurate for the pumphouse well and the river adjacent to the site. In addition, at approximately 7 a.m. on May 18, 2018, CGS was disconnected from the power grid (SCRAM) due to a problem with the No. 1 transformer. The plant was offline for 6 days and synched back with the grid at approximately 11 a.m. on May 24, 2018, at 65% power output. At the request of the Bonneville Power Administration, the plant operated at 65% power until June 10, 2018, due to surplus power production at nearby hydropower dams caused by the high river water levels. This period of reduced power output corresponds with reduced demand for make-up flow.

In 2019, field sampling activities were suspended from May 15 to June 13, 2019, to accommodate a planned maintenance outage. Every 2 years CGS shuts down to conduct a refueling outage, during which time cooling towers are taken out of service and offline maintenance tasks are performed throughout the facility. There is no demand for make-up water during planned outages, the amount

of water pumped from the river is drastically reduced, and sampling cannot be performed. Also in 2019, a capture efficiency test was attempted on Tuesday April 2 but canceled due to mortality of approximately 10% of the test fish during transport of the test fish from the hatchery to the CGS facility; the test was rescheduled to Tuesday April 9. A routine monitoring test on Wednesday August 21, 2019, was canceled due to the need to review the safety of fish entrainment study methods for preventing worker injury.

A total of six capture efficiency tests were carried out over 2 years to be used in calculating an average capture efficiency. Fifteen routine monitoring events were carried out each year to be used in calculating annual fish entrainment rates.

3.2 Task 3: Fish Impingement and Debris Monitoring

In addition to monitoring fish entrainment, the Study Plan calls for studies to demonstrate any clogging of the water intake screens by debris and associated fish impingement (Study Plan, Task 3). CFD modelling suggests low likelihood of impingement due to the generally high ratio of sweeping flow in the boundary layer to approach flow toward screen pores (Alden 2018). There is, however, variation in this ratio among modeled locations on the screen unit and with angle of incident river flow that suggest variations in impingement risk across the screen units.

Cleaning of the intake screens was conducted before the study began in the fall of 2017 and again in September 2018 using a 2,500-pounds-per-square-inch pressure washer fitted with a 6-foot wand. CGS Operations personnel isolated one intake structure at a time before the perforated sections were cleaned and videoed. CGS Operations also conducts a back-flush of the intake screens every two years.

To demonstrate whether the clogging of pores could affect through-screen (approach) velocities of non-clogged pores in a way that influences fish impingement, the intake screens were inspected annually by Energy Northwest or other contractors. Inspections during the study period occurred in September 2018 and October 2019, at a time of year when flows were low and velocities slow enough to work safely around the intakes. Similar inspections took place prior to the study period in June 2016 and October 2017. The two CGS intake screens were inspected in situ using a GoPro digital camera accordance with NPDES permit condition S12.A.3 and in support of permit condition S12.B.

In addition, water-level elevation in the pumphouse was constantly monitored for evidence of a sudden drawdown in the pumphouse that could be attributed to clogging of the intake screens. The water surface elevation differential between the pumphouse and river was calculated on an hourly basis to identify sudden increases in the differential from hour-to-hour and to identify trends over longer periods of time.

If clogged screen pores were observed or clogging was suspected to have occurred based on an increase in the water surface differential, the SAP states that velocity through the screen pores (entrance velocity) should be calculated to determine the potential magnitude of the effect of the clogged pores on entrainment velocities. No indication of intake screen pore clogging was evident in the water surface differential data nor in visual inspections, so any effect on water velocity could not be calculated.

3.3 Task 4: Data Summaries and Fish Entrainment Analyses

The SAP (Appendix B) provides detailed descriptions of the data that were summarized, and analyses carried out to characterize entrainment and the operating conditions and environmental variables that may interact with entrainment.

Operational and environmental data were collected in order to summarize conditions that may influence fish entrainment and quantify fish entrainment across the study season. Data collected across each study season from mid-March through mid-September are summarized in Table 3.

Table 3
Data Sources Used for Data Summaries and Entrainment Analyses

Data	Data Source	Application
Weekly/every-other-week fish sampling data (species capture information)	Anchor QEA	Daily, weekly, and seasonal entrainment estimates (fish/m^3)
Pump operation (number of pumps running out of 3 pumps, 2 on is typical)	CGS	Cross reference with make-up water volume pumped and use to calculate screen velocity
Make-up water volume pumped (cfs and m^3)	CGS	Expansion of daily, weekly, and seasonal entrainment estimates (fish/m^3)
Pumphouse water elevation at well (ft and m)	CGS	Estimate screen blockage by calculating the differential between pumphouse water elevation and Columbia River water elevation at pumphouse
Columbia river water elevation at pumphouse intake (ft and m)	CGS	Estimate screen blockage by calculating the differential between pumphouse water elevation and Columbia River water elevation near pumphouse
Qualitative debris observations	CGS Anchor QEA	Visual observations of screen blockage; qualitative description of the amount of debris held by fish cages during each weekly/bi-weekly sampling session
Columbia River discharge (kcfs and m^3)	USGS[1]	Characterize patterns of expected fish presence/distribution related to flow
Columbia River stage (ft and m; hourly)	CGS	Derive from river elevation at pumphouse intake; characterize patterns of expected fish presence/distribution related to stage
Change in river stage (ft and m; hourly derived)	CGS	Derive from change in river elevation at pumphouse intake; characterize patterns of expected fish presence/distribution

Data	Data Source	Application
River temperature (°F and °C)	Grant County Public Utility District[2]	Characterize patterns of expected fish presence/distribution related to temperature
Abnormal operational conditions	CGS	Relate to observed entrainment data
Weather (air temperature, wind speed, barometric pressure)	CGS	Relate to observed entrainment data
Hanford Reach fall-run Chinook salmon spawning escapement	WDFW	Estimate the number of fry produced in the Hanford Reach to estimate entrainment impacts

Notes:

1. USGS Monitoring Station 12472800 at Columbia River below Priest Rapids Dam, Washington
2. Grant County Public Utility District, Priest Rapids Dam tailrace

The following metrics were calculated and used to expand any observed entrainment into estimates of the total number of fish entrained for the period from mid-March to mid-September within each monitoring year:

Capture efficiency: the number of test fish recovered in sampling cages divided by the number of test fish released in each of six trials (three trials per year with two replicate cages). The average capture efficiency ($\overline{CE}$) was calculated as the average of the six trial capture efficiencies.

Entrainment rate (ER_i): calculated for each routine sampling event as the number of fish entrained during a 24-hour sampling event out of the volume of make-up water (Q_i) pumped into the CGS facility (fish per m^3 in a 24-hours event).

Average adjusted entrainment rate (ER_{adj}): entrainment rate averaged across all routine sampling events for the period from mid-March to mid-September study season within each study year ($\overline{ER}$) and adjusted by the average capture efficiency ($\overline{CE}$).

Total Seasonal Entrainment (*TSE*): the total number of fish entrained in a season, calculated by multiplying the average adjusted entrainment rate (ER_{adj}) by average intake flow ($\bar{Q}$) and the number of weeks in a season (n). The average intake flow ($\bar{Q}$), was calculated as the average of the weekly intake flow rates, Q_i.

Percent Hanford Reach fall-run Chinook salmon entrained (% Entrainment): to estimate the impact on Hanford Reach fall-run Chinook salmon specifically, the total seasonal entrainment estimate (*TSE*) was divided by the modeled number of fry produced in the reach for each study year (*R*), a metric that is estimated by WDFW on an annual basis using two different methods (WDFW 2019).

Generally, standard error or standard deviation are reported around the average (mean) values reported to describe the distribution of the data around the mean. In the case of estimating TSE, the

data contain many zeros and are not normally distributed, which must be considered when reporting the precision of the estimate. During the development of the SAP, alternative methods for estimating a confidence interval for the precision of the TSE estimate were proposed for non-normally distributed data; however, in practice, with so few fish entrained compared to such a large fish population, it was determined that the use of statistics to provide a confidence interval was unnecessary. Instead, the limits around TSE for each season are expressed as an asymmetric confidence interval with 90% or greater confidence, taking into account that the total number of fish entrained cannot be less than 0. A simple and conservative approach was used for calculating an upper confidence interval for TSE using three times the standard error (SE) of the mean as the upper bound and zero as the lower bound.

4 Results

The following sections discuss the observations and analyses related to the three major tasks directed by the Study Plan: fish entrainment monitoring, fish impingement and debris monitoring, and data summaries and analyses. In the first two of these tasks, observations on direct fish entrainment monitoring and evidence for debris accumulation on the intake screens are described. In the third of these sections, analyses are carried out to expand the observed number of fish entrained to season-wide estimates of all fish entrained, and impacts to the Hanford Reach fall-run Chinook salmon population.

4.1 Task 2: Fish Entrainment Sampling

The following sections discuss the results and observations for each of three fish entrainment sampling tasks directed by the Study Plan: routine fish entrainment monitoring, capture efficiency testing, and ancillary environmental and operations data used to identify conditions that could affect risk of entrainment or impingement.

4.1.1 Task 2.A. Routine Fish Entrainment

Fish entrainment sampling resulted in a total of four (4) fish becoming entrained and retrieved from the sampling cages among 754 hours of monitoring across thirty (30) sampling events and 2 years of study (Table 4). A Chinook salmon fry and Pacific lamprey ammocoete were recovered in early May and mid-June 2018, respectively. A salmonid fry was recovered in late March 2019, but its body condition was degraded, and its species was not identifiable. A torrent sculpin was recovered in early April 2019. All fish except the unidentified salmonid fry were recovered alive.

No contingency sampling was required because the number of fish entrained did not exceed twenty (20) fish in a single entrainment event (contingency sampling would have required immediate redeployment of the sampling cages for two sequential 12-hour "day" and "night" periods to monitor any diel variation in entrainment).

The Chinook salmon fry and the unidentified salmonid fry were of a size consistent with the fall-run stock that originates from the Hanford Reach. Fall-run Chinook salmon are known to be abundant near the CGS intake structure from mid-March to mid-July (Anchor QEA 2018). Based on the most recent available data, WDFW estimated the number of Hanford Reach fry to be as many as 56.4 million in 2018. Emergent fry use shallow, shoreline habitats with mean water velocities less than 1.5 fps. Older subyearlings are found in water depths of 4.9 to 19.4 ft, and velocities between 0.6 and 2.6 fps, mainly in nearshore areas, but can be found across the entire river channel and water column. Fall-run Chinook salmon are not a listed species but are native in origin and are a local species of interest for this study. The unidentified salmonid fry could have been an ESA-listed steelhead (Threatened), however, for the purposes of estimating broader impacts, it was considered

a Chinook salmon to conservatively estimate the maximum impact to the Hanford Reach fall Chinook salmon population, one of the main objectives of the study.

Pacific lamprey ammocoetes are present in the Hanford Reach year-round and prefer mid-channel benthic habitat with silty substrate for rearing. Pacific lamprey is a native fish that is a federal Species of Concern (USFWS 2019) and is recognized by the State of Washington as a species of tribal importance (WDFW 2008).

Torrent sculpin are common in the reach year-round and occupy areas of swift current, in association with rubble or boulder substrates for cover. They mature at approximately 50 mm in length, and adults are commonly 75 to 100 mm in length.

Table 4
Summary of Entrained Fish

Sampling Event Date	Species	Life Stage	Length (mm)	Weight (gram)	Protected Status	Abundance and Habitat Description
May 2–3, 2018	Chinook salmon (*Oncorhynchus tshawytscha*)	Juvenile (Age 0)	37	0.4	Species of interest to the study	Abundant from mid-March to mid-July. Use mid-channel and nearshore habitat for rearing.
June 13–14, 2018	Pacific lamprey (*Lampetra tridentata*)	Ammocoete	129	3.7	Species of Concern (Federal)	Common year-round. Use benthic habitat with soft, silty substrate for rearing.
March 20–21, 2019	Unidentified salmonid sp. (presumed Chinook salmon)	Juvenile (Age 0)	33	0.3	Species of interest to the study	Abundant from mid-March to mid-July. Use mid-channel and nearshore habitat for rearing.
April 3–4, 2019	Torrent sculpin	Adult	80	6.4	None	Common year-round. Use swift-water, benthic habitat in association with rubble or boulders for rearing.

4.1.2 Task 2.B. Capture Efficiency Testing

Three trials in 2018 and three trials in 2019 were successful in evaluating the efficacy of the two sampling cages for capturing and retaining fish (Table 5). The purpose of these trials is to create a correction factor that can be applied to the entrainment rate estimate to account for less than 100% fish retention. (Table 6).

Table 5
Capture Efficiency Testing Results

Sample Event	Deployment Day	Retrieval Day	Total Minutes Deployed	Cage Number	Capture Efficiency (*CE*)	Number of Fish Entrained from River
CE-1	4/3/2018	4/4/2018	1,427	1 (South)	91%	0
			1,422	2 (North)	88%	0
CE-2	4/24/2018	4/25/2018	1,440	1 (South)	94%	0
			1,436	2 (North)	94%	0
CE-3a	6/26/2018	6/27/2018	1,432	1 (South)	86%	0
CE-3b	7/17/2018	7/18/2018	1,431	2 (North)	86%	0
CE-4	3/12/2019	3/13/2019	1,440	1 (South)	96%	0
			1,447	2 (North)	93%	0
CE-5	4/9/2019	4/10/2019	1,449	1 (South)	83%	0
			1,450	2 (North)	98%	0
CE-6	4/23/2019	4/24/2019	1,449	1 (South)	83%	0
			1,450	2 (North)	94%	0

Note: The Cage 2 was repaired after 5-weeks of high water had impaired its operation and capture efficiency. That cage was retested on July 17, 2018 (Sample event CE-3b).

Testing confirmed that capture efficiency was adequate (greater than 0.8) during the periods of fish entrainment monitoring, and that capture efficiency was equivalent between the two replicate cages.

The capture efficiency values were averaged for the two cages within a single date, resulting in three independent capture efficiency trials for 2018. Average capture efficiency across the three trials was 90% with a 95% confidence interval (CI) of 85% to 94%.

For 2019 the efficiency value was averaged for the two cages within a single date, resulting in three independent capture efficiency trials. Average capture efficiency across the three trials was 91% with a 95% confidence interval (CI) of 88% to 95%

For the entire study, the mean capture efficiency was 91% with a 95% confidence interval (CI) of 88% to 93%.

Table 6
Capture Efficiency

Variable Description	Symbol	Capture Efficiency Values		
		2018	2019	Overall
Number of independent capture efficiency trials	m	3	3	6
Average capture efficiency	$\overline{CE}$	0.898 (90%)	0.912 (91%)	0.905 (91%)
Standard error of capture efficiency trials	$SE_{\overline{CE}}$	0.023	0.018	0.013
Capture efficiency 95% CI	$\overline{CE} \pm 1.96 \times SE_{\overline{CE}}$	0.853–0.944 (85–94%)	0.877–0.946 (88–95%)	0.879–0.931 (88–93%)

Note:
Calculated per SAP Equations 2 through 5.

4.1.3 Task 2.C. Ancillary Data: Environmental Summaries

4.1.3.1 Priest Rapids Dam Total Discharge

Flow in the Hanford Reach can be measured by discharge from Priest Rapids Dam. Mean flow conditions reflect a combination of the seasonal runoff from the Upper Columbia Basin and flows released for power generation, including regulation at Priest Rapids Dam, but also driven by releases from Grand Coulee Dam and passed through several run-of-river hydroprojects upstream of Priest Rapids Dam. The weekly minimum and maximum flows reflect major climactic events and power generation patterns at Priest Rapids Dam. These data are summarized in Table 7 and Figure 4.

More detailed flow data across the study season are shown in Figure 8 as the 12-hour rolling mean of Priest Rapids Outflow for 2018 and 2019 individually (blue and orange lines, respectively), and compared to recent historic median outflows from 2004 to 2017 (green line). The two study years encompass flows that are both higher and lower than the mean of the 2004 to 2017 record, bracketing the range of likely impacts of river discharge on entrainment.

An unusually large snowpack from the La Niña event during the 2017 to 2018 winter was followed by rapid warming in May 2018, resulting in spring runoff flows that were well-above typical flows from late April to early June 2018 (British Columbia River Forecast Center 2018). In 2018, mean daily discharge ranged from 122.5 thousand cubic feet per second (kcfs) during the first study week of March 11, increasing to 361.72 kcfs during the week of May 13, and declining to 67.5 kcfs during the last week of the study season starting September 9. (Table 7, Figure 8). Discharge in 2018 was largely influenced by high flow conditions in May to early June that were nearly 80% higher than the previous 10 years over a period of 35 days. The river reached its seasonal peak 2 weeks earlier than observed over the past 10 years in the Hanford Reach below Priest Rapids Dam, and on May 14,

2018, the river crested at its flood stage of 32 ft and 413 kcfs (Figure 8, USGS 2019). Spring precipitation events in the Idaho panhandle and western Montana also resulted in higher than normal downstream Columbia River elevations in central Washington in late May and June 2018 (Culverwell 2018).

Snowpack was highly variable across the Upper Columbia Basin in 2019 with a cold and snowy February that made up for poor snowpack earlier in the season, followed by persistent dry weather and warming in late March (British Columbia River Forecast Center 2019). In 2019, mean daily discharge ranged from 75.8 kcfs during the first study week, increasing to 163.0 kcfs the week of May 25 during the planned outage period, and declining to 54.6 kcfs during the last week of the study season starting September 15. (Table 7, Figure 8). Flows in 2019 were generally low during the spring and summer compared to conditions over the previous 10 years. Flows in 2019 were less influenced by basin-level climactic conditions in the March to April period as water was retained to counteract the variable snowpack and projected drought conditions in the interior Cascades. The spring peak flows occurred in mid-May again in 2019, 1 to 2 weeks earlier than normal. The spring peak flows were of a typical magnitude in the Hanford Reach, peaking at 22 ft and 205 kcfs on May 17, 2019; however, flow declined over a shorter period of time than has been observed in the past 10 years, with the freshet ending by mid-June (Figure 8).

Table 7
Priest Rapids Dam Outflow and Water Temperature by Study Week

Study Week	Fish Monitoring Event	Start of Week	End of Week	Weekly River Flow (kcfs)				Weekly River Temperature (°C)	
				Average	SD	Minimum	Maximum	Average	SD
2018-1	None	3/11/2018	3/17/2018	122.5	19.6	61.4	155.0	4.4	0.2
2018-2	None	3/18/2018	3/24/2018	110.9	22.8	63.8	163.8	5.0	0.2
2018-3	None	3/25/2018	3/31/2018	111.3	15.4	68.5	133.8	5.1	0.2
2018-4	CE-1, RE-2018-1	4/1/2018	4/7/2018	128.6	13.9	95.4	151.7	5.5	0.1
2018-5	RE-2018-2	4/8/2018	4/14/2018	130.9	13.9	101.2	149.8	6.0	0.3
2018-6	RE-2018-3	4/15/2018	4/21/2018	165.9	19.3	122.2	208.9	6.9	0.2
2018-7	CE-2, RE-2018-4	4/22/2018	4/28/2018	184.9	15.9	135.4	230.3	8.0	0.4
2018-8	RE-2018-5	4/29/2018	5/5/2018	226.9	27.9	150.1	287.9	9.1	0.2
2018-9	RE-2018-6	5/6/2018	5/12/2018	286.3	38.7	168.0	361.3	10.0	0.4
2018-10	None (High water)	5/13/2018	5/19/2018	361.7	23.8	250.4	419.8	11.4	0.4
-	*None (High water)*	*5/20/2018*	*5/26/2018*	*339.6*	*19.3*	*294.2*	*390.0*	*12.4*	*0.4*
-	*None (High water)*	*5/27/2018*	*6/2/2018*	*278.6*	*28.5*	*209.8*	*341.6*	*13.2*	*0.2*
-	*None (High water)*	*6/3/2018*	*6/9/2018*	*227.3*	*23.6*	*165.0*	*278.5*	*13.6*	*0.4*
2018-11	RE-2018-7	6/10/2018	6/16/2018	179.8	22.6	136.8	227.7	14.3	0.3
2018-12	RE-2018-8	6/17/2018	6/23/2018	150.8	14.6	111.9	177.1	15.6	0.6
2018-13	CE-3a, RE-2018-9	6/24/2018	6/30/2018	189.3	23.3	126.2	258.4	16.6	0.2
2018-14	None	7/1/2018	7/7/2018	126.3	23.1	65.5	175.1	16.3	0.4
2018-15	RE-2018-10	7/8/2018	7/14/2018	132.5	25.7	59.2	183.2	17.6	0.4

Study Week	Fish Monitoring Event	Start of Week	End of Week	Weekly River Flow (kcfs)				Weekly River Temperature (°C)	
				Average	SD	Minimum	Maximum	Average	SD
2018-16	CE-3b, RE-2018-11	7/15/2018	7/21/2018	132.8	15.8	90.1	199.6	18.6	0.1
2018-17	None	7/22/2018	7/28/2018	130.3	25.3	69.3	177.3	19.2	0.3
2018-18	RE-2018-12	7/29/2018	8/4/2018	110.4	34.0	40.6	167.3	19.6	0.2
2018-19	None	8/5/2018	8/11/2018	110.5	36.1	40.8	164.5	20.3	0.4
2018-20	RE-2018-13	8/12/2018	8/18/2018	98.1	39.0	38.5	165.1	19.9	0.2
2018-21	None	8/19/2018	8/25/2018	112.2	30.5	39.3	152.7	19.5	0.4
2018-22	RE-2018-14	8/26/2018	9/1/2018	89.8	33.0	39.9	153.9	18.9	0.2
2018-23	None	9/2/2018	9/8/2018	76.2	28.6	40.6	138.5	19.4	0.2
2018-24	RE-2018-15	9/9/2018	9/15/2018	67.5	20.3	40.6	117.0	19.2	0.3
2019-1	CE-4, RE-2019-1	3/10/2019	3/16/2019	75.8	12.8	68.8	140.7	2.9	0.3
2019-2	RE-2019-2	3/17/2019	3/23/2019	73.2	5.3	68.7	90.1	4.1	0.5
2019-3	RE-2019-3	3/24/2019	3/30/2019	70.1	1.1	69.3	74.7	5.2	0.3
2019-4	RE-2019-4	3/31/2019	4/6/2019	69.1	0.9	67.1	70.2	6.3	0.4
2019-5	CE-5, RE-2019-5	4/7/2019	4/13/2019	67.7	0.3	67.2	68.4	6.9	0.1
2019-6	RE-2019-6	4/14/2019	4/20/2019	74.9	8.9	67.6	97.8	7.3	0.5
2019-7	CE-6, RE-2019-7	4/21/2019	4/27/2019	110.2	22.4	69.9	160.6	8.0	0.1
2019-8	RE-2019-8	4/28/2019	5/4/2019	121.0	10.3	95.7	144.3	8.1	0.2
2019-9	RE-2019-9	5/5/2019	5/11/2019	122.6	18.3	90.7	183.9	9.5	0.6
-	*None (Outage)*	*5/12/2019*	*5/18/2019*	*160.7*	*20.2*	*119.8*	*216.4*	*10.7*	*0.2*
-	*None (Outage)*	*5/19/2019*	*5/25/2019*	*163.0*	*17.9*	*135.3*	*208.8*	*11.0*	*0.3*
-	*None (Outage)*	*5/26/2019*	*6/1/2019*	*159.5*	*16.3*	*125.3*	*195.1*	*12.5*	*0.5*
-	*None (Outage)*	*6/2/2019*	*6/8/2019*	*131.4*	*14.8*	*106.9*	*160.6*	*13.9*	*0.2*

Study Week	Fish Monitoring Event	Start of Week	End of Week	Weekly River Flow (kcfs)				Weekly River Temperature (°C)	
				Average	SD	Minimum	Maximum	Average	SD
-	*None (Outage)*	*6/9/2019*	*6/15/2019*	*129.9*	*15.2*	*98.8*	*162.4*	*14.5*	*0.3*
-	*None (Outage)*	*6/16/2019*	*6/22/2019*	*108.5*	*27.7*	*44.5*	*203.0*	*15.6*	*0.3*
2019-10	RE-2019-10	6/23/2019	6/29/2019	110.1	23.9	56.3	160.1	15.8	0.2
2019-11	None	6/30/2019	7/6/2019	93.1	29.9	0.7	159.0	16.3	0.4
2019-12	RE-2019-11	7/7/2019	7/13/2019	94.8	20.7	58.8	148.2	17.6	0.4
2019-13	None	7/14/2019	7/20/2019	99.6	24.0	47.0	156.2	18.0	0.2
2019-14	RE-2019-12	7/21/2019	7/27/2019	96.2	29.7	45.5	165.5	18.6	0.3
2019-15	None	7/28/2019	8/3/2019	112.6	31.0	48.8	169.6	19.1	0.3
2019-16	RE-2019-13	8/4/2019	8/10/2019	104.0	31.7	47.7	175.5	19.8	0.2
2019-17	None	8/11/2019	8/17/2019	94.1	33.6	40.1	166.8	20.0	0.2
2019-18	None (Safety)	8/18/2019	8/24/2019	91.0	37.3	40.2	167.2	19.9	0.2
2019-19	None	8/25/2019	8/31/2019	92.3	34.3	40.4	161.1	19.9	0.2
2019-20	RE-2019-14	9/1/2019	9/7/2019	67.4	31.5	40.7	129.0	20.2	0.2
2019-21	None	9/8/2019	9/14/2019	57.0	20.5	41.0	120.3	20.1	0.2
2019-22	RE-2019-15	9/15/2019	9/21/2019	54.6	22.0	39.5	136.8	19.3	0.3

Notes:
Grey italic data is presented for completeness but these weeks are not included as study weeks in statistical analyses as CGS was not operating at normal capacity. 5/20/2018 to 6/9/2018 corresponds to a period of high Columbia River flow releases from Priest Rapids dam, when intakes were operating was 45% or less of capacity, or data was unreliable. 5/12/2019 to 6/22/2019 corresponds to a period when CGS was not in operation for planned maintenance.

Water temperature data is typically reported from Priest Rapids tailrace, with the following exceptions: 1) from 3/14/2018 to 3/19/2018 130 hours of water temperature are reported from Priest Rapids forebay. One hour of data on 7/19/2018 is also from Priest Rapids forebay; 2) from 9/3/2018 to 9/10/2018 161 hours of water temperature data are reported from Wanapum tailrace; 3) from 9/10/2018 to 9/14/2018 96 hours of water temperature data are reported from Rock Island tailrace; 4) 56 hours from 3/12/2019 to 3/14/2019, 114 hours from 4/16/2019 to 4/21/2016, 275 hours from 5/10/2019 to 5/22/2019, and 67 hours from 9/5/2019 to 9/8/2019 of temperature data are reported from Priest Rapids forebay. Water temperature data are only reported from other sources if Priest Rapids tailrace data is unavailable.

4.1.3.2 Conditions for the Hanford Reach Fall Chinook Protection Program Agreement

As described above, outflow from Priest Rapids Dam reflects climactic conditions and power generation, but is also constrained by the Hanford Reach Fall Chinook Protection Program Agreement (HRFCPPA) to maintain conditions that support incubating salmon eggs and newly emerged fry. The critical minimum flow levels are determined on a year-to-year basis depending on the water levels at which Hanford Reach fall-run Chinook salmon spawn and accumulated temperature units that determine the emergence timing of the fry.

Water temperature is driven by climate and flow regulation from upstream dams and is important for driving transitions between fish life history stages, behavior, and occurrence near the TMU intake structures. The effect of temperature on early fish development is typically described in Accumulated Temperature Units representing the cumulative effect of temperature over time, defined as one degree of temperature for a 24-hour period. Emergence and rearing periods are defined in the HRFCPPA specifically for the purpose of maintaining adequate flows for juvenile fall-run Chinook salmon. "Emergence" is defined as

> the point at which the water over eggs in Redds at Vernita Bar or other areas [in the Hanford Reach] … have accumulated 1,000 (°C) Temperature Units after the Initiation of Spawning (HRFCPPA 2004)

Similarly, "Rearing Period" is defined as

> the time period beginning with the start of the Emergence Period and continuing thereafter until 400 (°C) Temperature Units have been accumulated at Vernita Bar after the end of Emergence Period (HRFCPPA 2004)

Sections C.3.b.1-6 of the HRFCPPA prescribe various flow criteria through the Hanford Reach, including mean daily minimum outflow, the delta (variability) of daily outflow, and mean daily minimum flows for Monday through Thursday of each study week. The required flows for 2018 and 2019 are summarized in Table 8 as they relate to the HRFCPPA criteria.

Table 8
Hanford Reach Fall Chinook Protection Program Agreement Requirements for Priest Rapids Dam Flow Operations 2018 to 2019

Life Stage	Criteria	Year	Dates	Required Flows
Emergence	Section C.2.b Maintains protection level flow at or above the critical elevation set by the monitoring team	2018	March 23 to May 15	60 kcfs minimum
		2019	March 13 to May 14	65 kcfs minimum
Rearing	Section C.3.b.1-4 Controls the variation in flow within a day (delta) depending on the previous day's (a) weekday inflow from Wanapum Dam or (b) weekend outflow from Chief Joseph Dam	2018	March 23 to June 25	Δ20-60 kcfs per day
		2019	March 13 to June 15	Δ20-60 kcfs per day
	Section C.3.b.5 Requires minimum daily flow when previous day's (a) weekday inflow from Wanapum Dam or (b) weekend outflow from Chief Joseph Dam is greater than 170 kcfs	2018	April 18 to June 15	150 kcfs minimum
		2019	March 16 to June 4	150 kcfs minimum
	Section C.3.b.6 Requires minimum daily flow equivalent to the average of daily hourly minimum flow from Monday to Thursday.	2018	Weekends; April 28 to May 20	Ranged from 150.9 to 316.0 kcfs minimum
		2019	Weekends; dates TBD	Ranged from 94.2 to 148.3 kcfs minimum

Source: Grant PUD 2018, 2019

Water temperature affects the rate of emergence and early development and the accumulated temperature units over time is used as a proxy for determining the duration of the emergence and rearing life stages. The 12-hour rolling mean of Priest Rapids Dam discharge and hourly mean water temperature are shown in Figure 9 in relation to key fall-run Chinook salmon life-stage time periods and the minimum flow levels required by the HRFCPPA for each year (shown as a green line in Figure 9). Conditions in 2018 are shown in the top panel, and in the bottom panel for 2019.

Generally, temperature conditions during the crucial emergence and rearing periods were similar between the two study years. In 2018, mean weekly Columbia River temperatures for the fall-run Chinook salmon emergence period (mid-March to mid-May) increased from 4.5°C to 10°C (weekly standard deviation [SD] between 0.1°C and 0.4°C) (Table 9). Water temperatures during the subsequent rearing period (mid-May to mid-July) increased from 11.4°C to 17.6°C (weekly SD between 0.2°C and 0.6°C). In 2019, mean weekly Columbia River temperatures for the fall-run Chinook salmon emergence period (mid-March to mid-May) increased from 2.9°C to 10.7°C (weekly SD between 0.1°C and 0.6°C). Water temperatures during the subsequent rearing period (mid-May to mid-July) increased from 11.0°C to 17.6°C (weekly SD between 0.2°C and 0.5°C). In both years, temperatures plateaued at 19°C to 20°C by mid-July, remaining elevated through mid-September,

the remainder of the study season. Although the 2 years differed in accumulated temperature units over time, and the resulting periods of emergence and rearing were slightly different, few fish were caught in either year. This indicates that temperature, as it affects developmental stage and the potential start of the migration period, was not a determining factor of entrainment.

4.1.3.3 Meteorological Conditions

Meteorological data for air temperature, wind speed and direction, and barometric pressure during the 2018 and 2019 study periods were provided by the Columbia Generating Station's Meteorological station (located at 33 ft above ground level) are summarized by study week in Table 9. The mean daily low and high air temperatures in May 2018 were approximately 5°F warmer than historical (1981 to 2010) published data for the Richland, Washington area, whereas temperatures were similar to the historic averages in 2019 (U.S. Climate Data 2019). Winds generally blew from a west-northwesterly direction. Maximum wind gusts of 61 miles per hour (mph) was recorded in July of 2018, and 73.9 mph in September of 2019, but average wind speeds were less than 8 mph throughout the two seasons of the study. Atmospheric pressure was stable.

Table 9
Meteorological Data by Study Week

Study Week	Start of Week	End of Week	Mean Low Air Temp (°C)	Mean High Air Temp (°C)	Mean Wind Speed (mph)	Min. Wind Speed (mph)	Max. Wind Speed (mph)	Median Wind Direction (0° N)	Mean Pressure (mmHg)	Min Pressure (mmHg)	Max Pressure (mmHg)
2018-1	3/11/2018	3/17/2018	36.3	58.8	6.6	0.0	16.1	315.0	29.4	29.2	29.8
2018-2	3/18/2018	3/24/2018	34.3	55.7	7.1	0.3	26.0	222.7	29.4	29.0	29.7
2018-3	3/25/2018	3/31/2018	37.9	59.7	8.5	0.0	23.8	242.5	29.7	29.4	29.8
2018-4	4/1/2018	4/7/2018	40.9	56.7	7.1	0.0	18.6	269.0	29.4	28.9	29.6
2018-5	4/8/2018	4/14/2018	45.4	61.6	11.8	1.3	23.9	204.0	29.5	29.1	29.8
2018-6	4/15/2018	4/21/2018	43.5	62.5	10.3	0.0	27.9	235.9	29.5	29.0	29.8
2018-7	4/22/2018	4/28/2018	44.0	73.4	6.3	0.0	20.2	322.6	29.6	29.1	29.9
2018-8	4/29/2018	5/5/2018	49.4	73.8	7.8	0.2	19.1	188.3	29.5	29.3	29.6
2018-9	5/6/2018	5/12/2018	54.9	75.0	7.4	0.1	20.8	293.1	29.5	29.3	29.6
2018-10	5/13/2018	5/19/2018	56.2	81.0	6.8	0.2	19.2	317.6	29.4	29.2	29.5
-	*5/20/2018*	*5/26/2018*	*59.6*	*83.1*	*6.6*	*0.1*	*21.1*	*284.5*	*29.3*	*29.1*	*29.5*
-	*5/27/2018*	*6/2/2018*	*52.0*	*77.4*	*7.7*	*0.4*	*25.3*	*205.5*	*29.5*	*29.2*	*29.7*
-	*6/3/2018*	*6/9/2018*	*53.7*	*79.1*	*8.2*	*0.1*	*22.6*	*242.8*	*29.4*	*29.2*	*29.5*
2018-11	6/10/2018	6/16/2018	51.1	74.9	9.3	0.0	24.2	271.1	29.4	29.2	29.7
2018-12	6/17/2018	6/23/2018	62.7	85.3	8.8	0.0	35.4	291.7	29.4	29.3	29.6
2018-13	6/24/2018	6/30/2018	57.9	82.5	9.7	0.1	30.4	260.5	29.4	29.1	29.6
2018-14	7/1/2018	7/7/2018	60.9	84.7	9.4	0.7	24.8	279.5	29.5	29.4	29.7
2018-15	7/8/2018	7/14/2018	64.7	93.1	10.1	0.0	61.0	301.3	29.5	29.3	29.6
2018-16	7/15/2018	7/21/2018	63.3	94.5	7.3	0.1	21.4	279.0	29.4	29.3	29.6
2018-17	7/22/2018	7/28/2018	64.9	95.4	4.3	0.0	11.4	338.2	29.5	29.3	29.7
2018-18	7/29/2018	8/4/2018	64.9	94.8	7.1	0.3	19.8	295.3	29.4	29.2	29.5
2018-19	8/5/2018	8/11/2018	65.2	97.5	5.1	0.0	19.7	274.8	29.4	29.2	29.6
2018-20	8/12/2018	8/18/2018	61.6	89.6	3.9	0.0	12.3	305.5	29.5	29.3	29.6

Study Week	Start of Week	End of Week	Mean Low Air Temp (°C)	Mean High Air Temp (°C)	Mean Wind Speed (mph)	Min. Wind Speed (mph)	Max. Wind Speed (mph)	Median Wind Direction (0° N)	Mean Pressure (mmHg)	Min Pressure (mmHg)	Max Pressure (mmHg)
2018-21	8/19/2018	8/25/2018	59.2	85.4	7.7	0.0	17.8	308.4	29.4	29.3	29.6
2018-22	8/26/2018	9/1/2018	56.6	79.7	6.4	0.0	20.2	250.8	29.4	29.2	29.6
2018-23	9/2/2018	9/8/2018	57.5	82.8	5.6	0.0	23.0	307.4	29.5	29.3	29.6
2018-24	9/9/2018	9/15/2018	55.2	75.1	6.0	0.0	16.6	198.8	29.4	29.3	29.5
2019-1	3/10/2019	3/16/2019	24.3	38.1	3.6	0.4	9.8	299.5	29.8	29.3	30.0
2019-2	3/17/2019	3/23/2019	35.2	60.6	4.4	0.3	17.6	297.4	29.6	29.4	29.9
2019-3	3/24/2019	3/30/2019	39.6	57.2	7.0	0.6	26.5	287.4	29.6	29.4	29.9
2019-4	3/31/2019	4/6/2019	44.5	65.2	7.7	0.5	24.8	239.6	29.4	29.2	29.8
2019-5	4/7/2019	4/13/2019	46.3	57.9	9.5	1.0	31.2	258.7	29.5	29.3	29.7
2019-6	4/14/2019	4/20/2019	46.9	66.4	7.7	0.9	24.8	256.6	29.4	29.2	29.7
2019-7	4/21/2019	4/27/2019	47.7	69.6	13.1	1.4	39.4	284.6	29.6	29.4	29.7
2019-8	4/28/2019	5/4/2019	41.6	66.6	7.4	1.0	17.6	287.6	29.5	29.2	29.7
2019-9	5/5/2019	5/11/2019	54.5	80.3	6.4	0.6	14.9	339.3	29.4	29.2	29.6
-	*5/12/2019*	*5/18/2019*	*51.7*	*72.2*	*7.2*	*0.4*	*21.0*	*201.2*	*29.3*	*29.0*	*29.5*
-	*5/19/2019*	*5/25/2019*	*55.3*	*71.8*	*8.4*	*0.5*	*21.2*	*340.7*	*29.2*	*29.1*	*29.5*
-	*5/26/2019*	*6/1/2019*	*61.0*	*82.8*	*6.8*	*0.9*	*23.1*	*206.6*	*29.4*	*29.2*	*29.5*
-	*6/2/2019*	*6/8/2019*	*55.4*	*78.0*	*7.8*	*1.4*	*23.3*	*214.7*	*29.4*	*29.1*	*29.8*
-	*6/9/2019*	*6/15/2019*	*60.1*	*88.0*	*6.3*	*0.7*	*23.3*	*258.1*	*29.5*	*29.1*	*29.9*
-	*6/16/2019*	*6/22/2019*	*59.8*	*80.8*	*10.5*	*1.4*	*27.4*	*268.2*	*29.5*	*29.3*	*29.6*
2019-10	6/23/2019	6/29/2019	54.9	78.3	7.6	1.3	26.0	232.2	29.4	29.2	29.6
2019-11	6/30/2019	7/6/2019	59.9	84.6	7.2	0.9	23.6	221.4	29.4	29.3	29.6
2019-12	7/7/2019	7/13/2019	62.9	85.2	6.6	0.6	18.7	229.2	29.4	29.3	29.6
2019-13	7/14/2019	7/20/2019	61.3	82.8	8.1	1.1	24.6	250.1	29.4	29.3	29.6
2019-14	7/21/2019	7/27/2019	61.8	90.8	7.2	0.7	20.9	287.0	29.5	29.3	29.7
2019-15	7/28/2019	8/3/2019	63.4	89.9	6.6	1.1	17.5	215.5	29.4	29.3	29.7
2019-16	8/4/2019	8/10/2019	66.3	93.3	6.6	0.8	17.8	324.5	29.3	29.2	29.5

Study Week	Start of Week	End of Week	Mean Low Air Temp (°C)	Mean High Air Temp (°C)	Mean Wind Speed (mph)	Min. Wind Speed (mph)	Max. Wind Speed (mph)	Median Wind Direction (0° N)	Mean Pressure (mmHg)	Min Pressure (mmHg)	Max Pressure (mmHg)
2019-17	8/11/2019	8/17/2019	61.6	84.5	6.6	0.9	17.2	213.8	29.5	29.3	29.6
2019-18	8/18/2019	8/24/2019	61.9	87.4	6.4	1.0	21.5	231.8	29.3	29.2	29.4
2019-19	8/25/2019	8/31/2019	62.9	88.1	5.9	0.5	18.7	273.8	29.4	29.3	29.7
2019-20	9/1/2019	9/7/2019	61.8	87.7	5.6	0.9	17.6	312.7	29.4	29.2	29.5
2019-21	9/8/2019	9/14/2019	60.6	77.7	7.8	1.1	73.9	215.2	29.4	29.2	29.7
2019-22	9/15/2019	9/21/2019	52.9	71.6	7.4	0.9	19.2	202.1	29.4	29.2	29.6

Note:
Grey italic data is presented for completeness, but these weeks are not considered study weeks. 5/20/2018 to 6/9/2018 corresponds to a period of high Columbia River flow releases from Priest Rapids dam, when intake at CGS was 45% or less or data was unreliable. 5/12/2019 to 6/22/2019 corresponds to a period when CGS was not in operation for maintenance.

4.1.3.4 River Level at Columbia Generating Station Intake Structure

Mean river flow rates and Columbia River water elevation at the CGS TMU pumphouse for the two study seasons are shown in Figures 10 and 11, respectively, overlaid with the dates of capture efficiency tests (green bars), routine entrainment sampling (orange bars), and routine sampling with fish captures (blue bars) to show river conditions in relation to fish entrainment events. Figures 10 and 11 also show when sampling was suspended (grey shading) during peak flow events in 2018 (top panels) and the planned outage in 2019 (bottom panels).

Across the sampling periods, river elevations ranged from approximately 345 ft to greater than 355 ft during the 2018 high-water periods (Figure 11), translating to water depths over the top of the cylindrical CGS intake structures ranging from 3.5 ft in September 2019 to greater than 14 ft. Water levels were held stable at critical minimum levels in mid-March to mid-April 2019 with water depths of 4 to 5 ft over the intakes until the onset of the 2019 freshet. Capture efficiency testing took place across a range of river flow levels between 68 and 189 kcfs, translating to water levels of 345.8 to 353.3, and depths over the intake of 4.3 to 11.8 ft of water.

The mean weekly river elevation as it relates to the depth of the water over the intakes is shown in Table 10.

Table 10
River Elevation by Study Week

Study Week	Fish Monitoring Event	Start of Week	End of Week	River Elevation (ft)		Depth to Intakes at 341.4 ft Elevation				
				Mean	SD	Mean	SD	Median	Minimum	Maximum
2018-1	None	3/11/2018	3/17/2018	349.6	1.04	8.1	1.0	8.5	4.9	9.4
2018-2	None	3/18/2018	3/24/2018	348.8	1.16	7.3	1.2	7.3	4.6	9.3
2018-3	None	3/25/2018	3/31/2018	348.8	0.96	7.3	1.0	7.4	4.7	8.7
2018-4	CE-1, RE-2018-1	4/1/2018	4/7/2018	349.7	0.88	8.2	0.9	8.4	6.0	9.8
2018-5	RE-2018-2	4/8/2018	4/14/2018	350.1	0.79	8.6	0.8	8.8	6.8	9.9
2018-6	RE-2018-3	4/15/2018	4/21/2018	351.9	0.89	10.4	0.9	10.6	8.1	12.0
2018-7	CE-2, RE-2018-4	4/22/2018	4/28/2018	352.8	0.51	11.3	0.5	11.3	10.3	12.6
2018-8	RE-2018-5	4/29/2018	5/5/2018	354.8	0.91	13.3	0.9	13.4	11.1	15.0
2018-9	RE-2018-6	*5/6/2018*	*5/12/2018*	*355.9*	*0.51*	*14.4*	*0.5*	*14.5*	*11.1*	*15.2*
2018-10	None (High water)	*5/13/2018*	*5/19/2018*	*356.2*	*0.55*	*14.7*	*0.5*	*14.7*	*13.6*	*15.7*
-	*None (High water)*	*5/20/2018*	*5/26/2018*	*355.4*	*0.25*	*13.9*	*0.3*	*13.8*	*13.6*	*14.6*
-	*None (High water)*	*5/27/2018*	*6/2/2018*	*355.3*	*0.25*	*13.8*	*0.3*	*13.7*	*13.1*	*15.3*
-	*None (High water)*	*6/3/2018*	*6/9/2018*	*354.4*	*0.87*	*12.9*	*0.9*	*13.1*	*10.9*	*14.8*
2018-11	RE-2018-7	6/10/2018	6/16/2018	352.7	0.96	11.2	1.0	11.1	9.5	13.3
2018-12	RE-2018-8	6/17/2018	6/23/2018	351.5	0.62	10.0	0.6	10.0	7.5	11.2
2018-13	CE-3a, RE-2018-9	6/24/2018	6/30/2018	353.3	0.84	11.8	0.8	11.8	9.3	13.1
2018-14	None	7/1/2018	7/7/2018	350.0	1.22	8.5	1.2	8.3	6.3	11.2
2018-15	RE-2018-10	7/8/2018	7/14/2018	350.4	1.18	8.9	1.2	9.2	5.6	11.1
2018-16	CE-3b, RE-2018-11	7/15/2018	7/21/2018	350.7	0.90	9.2	0.9	9.3	7.4	10.8

Study Week	Fish Monitoring Event	Start of Week	End of Week	River Elevation (ft)		Depth to Intakes at 341.4 ft Elevation				
				Mean	SD	Mean	SD	Median	Minimum	Maximum
2018-17	None	7/22/2018	7/28/2018	350.6	1.23	9.1	1.2	9.4	5.9	11.0
2018-18	RE-2018-12	7/29/2018	8/4/2018	349.2	1.98	7.7	2.0	8.2	3.7	10.7
2018-19	None	8/5/2018	8/11/2018	349.4	1.84	7.9	1.8	8.0	4.5	11.3
2018-20	RE-2018-13	8/12/2018	8/18/2018	348.1	1.84	6.6	1.8	6.6	2.9	10.1
2018-21	None	8/19/2018	8/25/2018	349.1	1.53	7.6	1.5	8.0	3.7	9.9
2018-22	RE-2018-14	8/26/2018	9/1/2018	347.6	1.75	6.1	1.7	6.0	2.9	9.6
2018-23	None	9/2/2018	9/8/2018	346.7	1.23	5.2	1.2	5.1	2.1	7.7
2018-24	RE-2018-15	9/9/2018	9/15/2018	345.8	0.92	4.3	0.9	4.2	2.2	6.4
2019-1	CE-4, RE-2019-1	3/10/2019	3/16/2019	346.6	0.99	5.1	1.0	4.7	4.0	8.7
2019-2	RE-2019-2	3/17/2019	3/23/2019	346.3	0.32	4.8	0.3	4.7	4.1	5.7
2019-3	RE-2019-3	3/24/2019	3/30/2019	346.0	0.24	4.5	0.2	4.5	4.0	5.0
2019-4	RE-2019-4	3/31/2019	4/6/2019	345.9	0.29	4.4	0.3	4.4	3.8	5.2
2019-5	CE-5, RE-2019-5	4/7/2019	4/13/2019	345.8	0.25	4.3	0.3	4.3	3.4	4.7
2019-6	RE-2019-6	4/14/2019	4/20/2019	346.2	0.65	4.7	0.6	4.5	3.6	6.2
2019-7	CE-6, RE-2019-7	4/21/2019	4/27/2019	348.4	1.50	6.9	1.5	7.3	3.9	9.1
2019-8	RE-2019-8	4/28/2019	5/4/2019	349.4	0.41	7.9	0.4	7.9	7.1	8.9
2019-9	RE-2019-9	5/5/2019	5/11/2019	349.4	0.81	7.9	0.8	7.7	6.4	10.0
-	*None (Outage)*	*5/12/2019*	*5/18/2019*	*350.9*	*0.85*	*9.4*	*0.9*	*9.6*	*7.8*	*10.9*
-	*None (Outage)*	*5/19/2019*	*5/25/2019*	*351.2*	*0.78*	*9.7*	*0.8*	*9.8*	*8.4*	*11.1*
-	*None (Outage)*	*5/26/2019*	*6/1/2019*	*351.0*	*0.71*	*9.5*	*0.7*	*9.5*	*8.2*	*10.7*
-	*None (Outage)*	*6/2/2019*	*6/8/2019*	*349.4*	*0.70*	*7.9*	*0.7*	*8.0*	*6.6*	*9.1*
-	*None (Outage)*	*6/9/2019*	*6/15/2019*	*349.2*	*0.77*	*7.7*	*0.8*	*7.7*	*6.3*	*9.2*
-	*None (Outage)*	*6/16/2019*	*6/22/2019*	*348.2*	*1.51*	*6.7*	*1.5*	*6.3*	*4.0*	*11.4*
2019-10	RE-2019-10	6/23/2019	6/29/2019	348.8	0.93	7.3	0.9	7.5	5.3	9.4
2019-11	None	6/30/2019	7/6/2019	348.2	1.15	6.7	1.1	6.8	4.1	9.1
2019-12	RE-2019-11	7/7/2019	7/13/2019	347.9	0.86	6.4	0.9	6.3	4.3	8.3

Study Week	Fish Monitoring Event	Start of Week	End of Week	River Elevation (ft)		Depth to Intakes at 341.4 ft Elevation				
				Mean	SD	Mean	SD	Median	Minimum	Maximum
2019-13	None	7/14/2019	7/20/2019	348.3	0.78	6.8	0.8	7.0	4.8	8.4
2019-14	RE-2019-12	7/21/2019	7/27/2019	348.3	1.20	6.8	1.2	6.9	4.4	9.4
2019-15	None	7/28/2019	8/3/2019	349.2	1.54	7.7	1.5	7.7	4.9	10.7
2019-16	RE-2019-13	8/4/2019	8/10/2019	349.0	1.29	7.5	1.3	7.3	4.4	10.2
2019-17	None	8/11/2019	8/17/2019	347.9	1.46	6.4	1.5	6.3	3.8	9.4
2019-18	None (Safety)	8/18/2019	8/24/2019	347.9	1.69	6.4	1.7	6.4	3.0	9.9
2019-19	None	8/25/2019	8/31/2019	347.6	1.85	6.1	1.8	6.4	2.7	9.1
2019-20	RE-2019-14	9/1/2019	9/7/2019	346.4	1.63	4.9	1.6	4.4	2.6	8.1
2019-21	None	9/8/2019	9/14/2019	345.2	1.00	3.7	1.0	3.4	2.3	7.2
2019-22	RE-2019-15	9/15/2019	9/21/2019	345.0	1.23	3.5	1.2	3.2	2.0	6.9

Notes:
Grey italic data is presented for completeness but these weeks are not included as study weeks in statistical analyses as CGS was not operating at normal capacity. 5/20/2018 to 6/9/2018 corresponds to a period of high Columbia River flow releases from Priest Rapids Dam, when intakes were operating was 45% or less of capacity, or data was unreliable.

5/12/2019 to 6/22/2019 corresponds to a period when CGS was not in operation for planned maintenance.

During study weeks 2018-9 and 2018-10 CGS operations continued at approximately 60% intake flow capacity and two entrainment monitoring events occurred. However, river elevation gauges become unreliable starting 5/6/2018 as river elevation exceeded 355 ft. Grey italicized data are provided for completeness but should be considered unreliable.

During the periods of highest risk to fall Chinook salmon juveniles from mid-March to June (Anchor QEA 2018), the mean water depth over the CGS intakes ranged from 7.3 to 13.25 ft in 2018 and 4.3 to 9.7 ft in 2019 (Table 10). Water depth over the CGS intakes remained above the 1.75 ft (one screen radius) during the study periods, the water depth directed by NMFS guidance for the protection of fish (NMFS 2011). The annual minimum depths recorded during the study period occurred in September of each year; minimum levels of water over the intakes were 2.14 ft on September 8, 2018 and 1.99 ft on September 18, 2019. No fish were entrained during the lowest seasonal flows August and September of 2018 or 2019.

Total discharge from Priest Rapids Dam influences water velocity at the CGS intakes, which determines risk for entrainment. Based on Pacific Northwest National Laboratory 2D MASS2 model simulation of the Columbia River (Perkins and Richmond 2007) centered at RM 352.13, water velocities at the intake likely ranged between 5 and 7 fps from March to mid-August 2018, dropping to about 4 fps in late August and early September (Perkins et al. 2018).

Fish were entrained on four occasions over the two study seasons across a broad range of river conditions (Table 11) with river flow levels ranging from 70 to 233 kcfs, temperatures from 4.1°C to 15.9°C, and water depths ranging from 4.8 to 14.6 ft over the intakes.

Table 11
River Conditions During Fish Entrainment Events

Deployment Day	Species	Priest Rapids Tailrace Temperature (°C)				Priest Rapids Discharge (kcfs)				River Elevation (ft)			Depth to Intake (ft)		
		Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	Min	Max	Mean	Min	Max
5/2/2018	Chinook salmon fry	9.1	0.1	8.9	9.2	233.5	29.9	150.1	280.7	355.6	354.9	356.1	14.6	13.9	15.1
6/13/2018	Pacific lamprey ammocoete	14.4	0.1	14.2	14.5	157.9	3.7	153.8	174.3	351.8	351.3	352.7	10.8	10.3	11.7
3/20/2019	Unidentified salmonid sp. fry	4.1	0.1	3.8	4.2	73.1	3.3	70.6	87.3	346.5	346.0	346.9	5.5	5.0	5.9
4/3/2019	Adult Sculpin	6.4	0.1	6.3	6.5	70.0	0.1	69.9	70.2	345.8	345.5	346.3	4.8	4.5	5.3

Note:
The unidentified salmonid fry may have been a fall-run Chinook salmon or steelhead as described in Section 4.1.1.

4.1.4 Task 2.C. Ancillary Data: Make-Up System Operations Summaries

4.1.4.1 CGS Tower Make-Up System Pump Operations

CGS TMU pump operation is monitored by tracking the electrical current (amperage) flow to each of the three pumps (1A, 1B, and 1C). All three pumps were active during both study seasons; however, use was reduced during periods of lower demand or shutdowns.

Pump operations are summarized in Table 12 in terms of percent of time in use during a given study week and average amperes by study week.

Table 12
Summary of Tower Make-Up System Pump Operation by Study Week

Study Week	Start of Week	End of Week	Pump in Use (% of time in week)			Pump Amperes		
			1A	1B	1C	1A	1B	1C
2018-1	3/11/2018	3/17/2018	0.0	100.0	100.0	0.0	75.2	81.3
2018-2	3/18/2018	3/24/2018	0.0	99.4	99.4	0.0	75.2	81.6
2018-3	3/25/2018	3/31/2018	0.0	100.0	100.0	0.0	75.2	81.5
2018-4	4/1/2018	4/7/2018	0.0	100.0	100.0	0.0	75.7	81.9
2018-5	4/8/2018	4/14/2018	0.0	100.0	100.0	0.0	76.8	82.9
2018-6	4/15/2018	4/21/2018	0.0	100.0	100.0	0.0	77.0	82.9
2018-7	4/22/2018	4/28/2018	0.0	100.0	100.0	0.0	76.6	82.6
2018-8	4/29/2018	5/5/2018	0.0	100.0	100.0	0.0	77.5	83.5
2018-9	5/6/2018	5/12/2018	0.0	100.0	100.0	0.0	77.2	83.1
2018-10	5/13/2018	5/19/2018	0.0	100.0	83.9	0.0	79.8	70.8
-	*5/20/2018*	*5/26/2018*	*82.7*	*44.1*	*0.0*	*63.5*	*32.9*	*0.0*
-	*5/27/2018*	*6/2/2018*	*100.0*	*100.0*	*0.0*	*69.6*	*71.8*	*0.0*
-	*6/3/2018*	*6/9/2018*	*100.0*	*100.0*	*0.0*	*69.8*	*71.5*	*0.0*
2018-11	6/10/2018	6/16/2018	100.0	100.0	0.0	73.6	76.2	0.0
2018-12	6/17/2018	6/23/2018	100.0	100.0	16.7	75.7	78.6	12.7
2018-13	6/24/2018	6/30/2018	100.0	100.0	100.0	68.2	71.3	77.1
2018-14	7/1/2018	7/7/2018	100.0	100.0	100.0	69.1	72.0	78.1
2018-15	7/8/2018	7/14/2018	100.0	100.0	100.0	68.8	71.7	77.7
2018-16	7/15/2018	7/21/2018	100.0	100.0	100.0	69.2	72.3	78.6
2018-17	7/22/2018	7/28/2018	100.0	100.0	100.0	69.4	72.1	78.9
2018-18	7/29/2018	8/4/2018	100.0	100.0	100.0	69.8	73.0	79.1
2018-19	8/5/2018	8/11/2018	100.0	100.0	100.0	70.1	73.0	79.9
2018-20	8/12/2018	8/18/2018	100.0	100.0	100.0	69.9	71.7	78.4
2018-21	8/19/2018	8/25/2018	100.0	100.0	100.0	69.0	71.7	78.9

Study Week	Start of Week	End of Week	Pump in Use (% of time in week)			Pump Amperes		
			1A	1B	1C	1A	1B	1C
2018-22	8/26/2018	9/1/2018	39.9	100.0	88.1	27.8	75.9	73.2
2018-23	9/2/2018	9/8/2018	0.0	100.0	100.0	0.0	77.6	86.5
2018-24	9/9/2018	9/15/2018	0.0	100.0	100.0	0.0	77.9	86.1
2019-1	3/10/2019	3/16/2019	100.0	100.0	0.0	75.3	74.8	0.0
2019-2	3/17/2019	3/23/2019	100.0	100.0	0.0	76.2	75.2	0.0
2019-3	3/24/2019	3/30/2019	100.0	100.0	0.0	84.2	81.3	0.0
2019-4	3/31/2019	4/6/2019	100.0	100.0	0.0	78.8	77.5	0.0
2019-5	4/7/2019	4/13/2019	100.0	100.0	0.0	77.1	76.2	0.0
2019-6	4/14/2019	4/20/2019	100.0	100.0	0.0	87.3	84.7	0.0
2019-7	4/21/2019	4/27/2019	100.0	100.0	0.0	78.2	76.8	0.0
2019-8	4/28/2019	5/4/2019	100.0	100.0	0.0	77.1	76.2	0.0
2019-9	5/5/2019	5/11/2019	94.6	100.0	0.0	72.3	76.6	0.0
-	*5/12/2019*	*5/18/2019*	*0.0*	*70.2*	*13.7*	*0.0*	*53.6*	*11.1*
-	*5/19/2019*	*5/25/2019*	*89.3*	*0.0*	*11.3*	*66.9*	*0.0*	*9.0*
-	*5/26/2019*	*6/1/2019*	*100.0*	*0.0*	*0.0*	*75.8*	*0.0*	*0.0*
-	*6/2/2019*	*6/8/2019*	*100.0*	*0.0*	*0.0*	*76.0*	*0.0*	*0.0*
-	*6/9/2019*	*6/15/2019*	*100.0*	*13.7*	*0.0*	*78.6*	*8.8*	*0.0*
-	*6/16/2019*	*6/22/2019*	*100.0*	*0.0*	*63.1*	*72.5*	*0.0*	*50.7*
2019-10	6/23/2019	6/29/2019	100.0	95.8	4.8	79.8	75.6	3.8
2019-11	6/30/2019	7/6/2019	100.0	100.0	38.1	75.6	75.7	29.4
2019-12	7/7/2019	7/13/2019	100.0	100.0	100.0	70.0	71.8	78.0
2019-13	7/14/2019	7/20/2019	100.0	100.0	100.0	70.4	72.0	78.4
2019-14	7/21/2019	7/27/2019	100.0	100.0	100.0	70.7	72.0	78.9
2019-15	7/28/2019	8/3/2019	100.0	100.0	100.0	70.7	71.8	78.8
2019-16	8/4/2019	8/10/2019	100.0	100.0	100.0	71.2	72.5	79.4
2019-17	8/11/2019	8/17/2019	100.0	100.0	100.0	70.9	72.3	79.1
2019-18	8/18/2019	8/24/2019	100.0	100.0	100.0	70.2	72.2	79.2
2019-19	8/25/2019	8/31/2019	100.0	100.0	100.0	71.1	72.6	80.3
2019-20	9/1/2019	9/7/2019	100.0	100.0	100.0	71.6	72.7	80.0
2019-21	9/8/2019	9/14/2019	100.0	100.0	100.0	70.8	71.9	79.7
2019-22	9/15/2019	9/21/2019	100.0	100.0	76.8	71.8	73.1	59.9

4.1.4.2 Circulating Water Make-Up Flow

Circulating water make-up flow is used to extrapolate season-wide entrainment rates at the conclusion of the entrainment sampling study at the end of 2019. Season-wide entrainment rates are based on the number of fish entrained and flow that occurred while sampling cages were in the water.

Throughout most of the study period in both 2018 and 2019, circulating water make-up flow to the cooling towers from the Columbia River operated at approximately 60% to 80% (15,000 to 20,000 gpm) of maximum intake flow of 25,000 gpm, with the exception of the outage periods noted (Table 13). Generally, mean make-up flow was relatively stable across the season, with the lowest flows occurring in March, increasing slowly to the highest rates in July and August. During the period of high flow on the Columbia River from mid-May to late-June 2018, make-up water flow to the circulating water system was approximately 40% of maximum operating conditions, corresponding with the period of 65% power output from the plant (Figure 12). Make-up flow fell to 0 during the planned outage in 2019. Aside from the high flow period in 2018 and planned outage period in 2019, weekly mean make-up water flow to the circulating water system ranged from a minimum of 13,807 gpm the week of May 13, 2018 during peak Columbia River flow, to a maximum of 19,624.64 gpm the week of July 22, 2018 (Table 13). Both intake structures were in use throughout the 2018 and 2019 study periods.

Table 13
CGS Circulating Water System Make-Up Flow by Study Week

Study Week	Start of Week	End of Week	Make-up Flow (gpm)				
			Mean	Median	SD	Minimum	Maximum
2018-1	3/11/2018	3/17/2018	15,438	15,587	1,399	11,075	18,069
2018-2	3/18/2018	3/24/2018	15,461	15,407	1,591	11,198	19,208
2018-3	3/25/2018	3/31/2018	15,571	15,905	1,829	9,645	19,119
2018-4	4/1/2018	4/7/2018	15,532	15,731	1,381	11,501	18,144
2018-5	4/8/2018	4/14/2018	15,756	15,861	1,308	11,669	18,656
2018-6	4/15/2018	4/21/2018	15,802	15,905	1,489	11,941	18,591
2018-7	4/22/2018	4/28/2018	16,120	16,240	2,127	8,370	20,885
2018-8	4/29/2018	5/5/2018	16,396	16,817	1,931	11,419	21,259
2018-9	5/6/2018	5/12/2018	16,614	16,935	2,503	0	20,760
2018-10	5/13/2018	5/19/2018	13,806	16,072	6,519	0	22,271
-	*5/20/2018*	*5/26/2018*	*7,977*	*9,277*	*4,317*	*412*	*14,298*
-	*5/27/2018*	*6/2/2018*	*11,287*	*11,259*	*1,995*	*4,927*	*20,674*
-	*6/3/2018*	*6/9/2018*	*11,315*	*11,259*	*1,600*	*7,882*	*15,008*
2018-11	6/10/2018	6/16/2018	15,298	16,085	2,681	8,334	20,908
2018-12	6/17/2018	6/23/2018	17,383	17,319	2,059	9,166	20,815
2018-13	6/24/2018	6/30/2018	17,047	17,158	1,284	12,295	20,041
2018-14	7/1/2018	7/7/2018	17,088	17,667	3,248	6,197	22,936
2018-15	7/8/2018	7/14/2018	18,187	18,377	1,671	12,129	22,623
2018-16	7/15/2018	7/21/2018	19,137	18,854	2,376	13,927	22,800
2018-17	7/22/2018	7/28/2018	19,624	19,604	2,024	13,494	22,995

Study Week	Start of Week	End of Week	Make-up Flow (gpm)				
			Mean	Median	SD	Minimum	Maximum
2018-18	7/29/2018	8/4/2018	19,350	19,438	2,509	13,062	23,479
2018-19	8/5/2018	8/11/2018	19,499	19,737	2,860	13,129	23,836
2018-20	8/12/2018	8/18/2018	18,593	19,208	2,153	10,228	22,070
2018-21	8/19/2018	8/25/2018	18,085	17,937	2,121	13,763	23,449
2018-22	8/26/2018	9/1/2018	17,095	17,219	1,407	10,029	20,036
2018-23	9/2/2018	9/8/2018	17,223	17,426	2,137	8,356	20,436
2018-24	9/9/2018	9/15/2018	16,836	17,004	1,937	9,707	19,694
2019-1	3/10/2019	3/16/2019	14,727	15,015	1,255	11,656	16,752
2019-2	3/17/2019	3/23/2019	15,820	15,822	1,497	10,910	19,186
2019-3	3/24/2019	3/30/2019	16,416	16,534	2,054	4,843	20,214
2019-4	3/31/2019	4/6/2019	17,208	17,025	1,834	12,979	21,876
2019-5	4/7/2019	4/13/2019	16,576	16,798	1,635	9,481	19,311
2019-6	4/14/2019	4/20/2019	17,075	17,226	1,548	10,678	20,975
2019-7	4/21/2019	4/27/2019	16,950	17,074	1,307	12,890	19,089
2019-8	4/28/2019	5/4/2019	16,784	16,742	1,363	11,969	20,520
2019-9	5/5/2019	5/11/2019	14,945	16,480	5,104	3,444	22,306
-	*5/12/2019*	*5/18/2019*	*3,727*	*32*	*8,428*	*0*	*31,568*
-	*5/19/2019*	*5/25/2019*	*44*	*0*	*264*	*0*	*2,283*
-	*5/26/2019*	*6/1/2019*	*0*	*0*	*2*	*0*	*13*
-	*6/2/2019*	*6/8/2019*	*0*	*0*	*0*	*0*	*2*
-	*6/9/2019*	*6/15/2019*	*3,073*	*3,885*	*2,525*	*0*	*15,114*
-	*6/16/2019*	*6/22/2019*	*7,819*	*5,971*	*5,794*	*0*	*21,279*
2019-10	6/23/2019	6/29/2019	17,223	17,147	1,416	12,881	19,581
2019-11	6/30/2019	7/6/2019	18,860	18,690	1,979	13,986	24,426
2019-12	7/7/2019	7/13/2019	18,006	18,511	2,660	10,293	23,921
2019-13	7/14/2019	7/20/2019	18,731	18,723	1,435	14,335	21,208
2019-14	7/21/2019	7/27/2019	19,065	19,108	1,457	14,870	21,954
2019-15	7/28/2019	8/3/2019	18,827	19,011	1,677	13,832	22,556
2019-16	8/4/2019	8/10/2019	19,408	19,560	1,663	14,108	22,260
2019-17	8/11/2019	8/17/2019	18,843	19,241	1,702	14,085	21,547
2019-18	8/18/2019	8/24/2019	19,125	19,379	1,628	13,336	21,635
2019-19	8/25/2019	8/31/2019	19,355	19,418	1,829	13,616	22,856
2019-20	9/1/2019	9/7/2019	19,289	19,340	1,698	14,883	21,830
2019-21	9/8/2019	9/14/2019	18,730	18,998	1,568	12,788	21,051
2019-22	9/15/2019	9/21/2019	17,324	17,614	1,824	12,282	22,326

Note:
Weeks without a study week designation are not included in season wide statistical analysis. In 2018 three weeks of low operational capacity and unreliable data occurred because of high Columbia River flow. In 2019 the CGS was shut down for six weeks for a maintenance outage. The make-up flow status gauge indicated that data are unreliable for 2 hours on May 17, 2018 and continuously from May 20 00:00:00 to May 22 06:00 2018, and June 03 02:00 to June 04 10:00, 2018.

During the 24-hour routine entrainment events in which a fish was entrained, make-up flow ranged from 52% to 83% of pump capacity, with intake flows ranging from 13,011 to 20,815gpm (Table 14). Neither the mean, minimum, nor maximum make-up flow rates differed between weeks in which fish were entrained versus those in which no fish were entrained.

Table 14
Make-Up Flow During Fish Entrainment Events

Deployment Day	Species	Make-Up Water Pump Capacity				Make-Up Water Intake Flow (gpm)			
		Mean	SD	Min	Max	Mean	SD	Min	Max
5/2/2018	Chinook fry	68%	7%	52%	77%	17,017	1,780	13,011	19,292
6/13/2018	Pacific lamprey ammocoete	65%	3%	59%	71%	16,209	780	14,646	17,681
3/20/2019	Unidentified salmon sp. fry	64%	4%	54%	71%	16,121	1,049	13,487	17,866
4/3/2019	Adult sculpin	64%	6%	52%	76%	16,117	1,590	12,979	19,080

Note:
The unidentified salmonid may be a fall-run Chinook salmon or steelhead as described in Section 4.1.1.

4.2 Task 3 Fish Impingement and Debris Monitoring

Hypothetical and observed river elevation data at the CGS TMU pumphouse on the Columbia River are shown in Figure 13 with observations from 2018 on the left and 2019 on the right. Observed river elevation data closely follows hypothetical simulations developed by Niehus et al. (2014) for RM 352.13 until approximately 250 kcfs mean daily flow, at which point the elevation of the Columbia River at the TMU pumphouse reaches an asymptote relative to discharge from Priest Rapids Dam. Based on conversations with CGS operators, the asymptote is indicative of a failure of TMU pumphouse gauges to accurately measure river elevation above bank-full conditions of approximately 355 ft of river elevation.

Visual inspection of the CGS intake for debris and signs of fish and shellfish impingement occurred on June 16, 2016, October 13, 2017, September 17, 2018, and October 10, 2019. A GoPro digital camera was used to record underwater video of both outer intake screens and structures. Algae biofouling was noted in the perforated and non-perforated areas of both intake structures during each inspection event. Visual estimation of the perforated area covered by algae was greater than 50% based on a post-monitoring visual assessment of images taken of the perforated areas. No fish

were observed in the vicinity of the intake structures, and no impingement of fish or shellfish was observed during any inspection event. The Impingement Evaluation reports are included in Appendix G to this document.

Debris entrained in the sampling cages during fish entrainment testing was routinely monitored. Debris type and volume varied throughout the season and included algae clumps, other organic material such as leaves and small wood debris, sediment, larval aquatic insects, and sponge-like material suspected to be a freshwater sponge (Table 15). Debris particles were small in size, on the order of the size of the intake screen pores. In general, light to medium amounts of debris were observed during the sampling, with the amount of debris increasing as the season progressed. Heavy debris levels were associated with high flows. The qualitative descriptions of debris level are summarized in Table 15 by month, and reflect the amount of debris relative to all sampling events across the season (daily debris levels recorded during sampling events are provided in Appendix C).

Table 15
Entrained Debris Summary

Month	Description
March	Light debris
April	Light to medium debris, light sand
May	Light to medium debris, high water levels
June	Light to heavy debris, aquatic insect larvae
July	Aquatic insect larvae (possibly caddisfly), light to medium debris
August	Sponge-like material, light to medium other debris
September	Sponge-like material, light to heavy other debris

Clogging of screen pores can also cause a short-term drawdown of water level in the TMU system pumphouse, observed as a differential in water elevation of the Columbia River at the intake screens compared to water level within the TMU system pumphouse well. A sudden change or excessive increase in water elevation differential is an indication that the intake structure screens are clogged or are becoming clogged. Water elevation differential between the Columbia River and the TMU pumphouse was variable during the 2018 fish entrainment monitoring period (Figure 14). Water elevation differential was at its minimum in late May when there was flooding of the pumphouse well and surrounding area and approximately no difference between the river and pumphouse; however, the gauges were submerged, and accurate data are unavailable for that time period. Maximum water elevation differential was greater than 2 ft in August 2018. Differential varied within days across the

sampling period; for the entire sampling period for which reliable data exist, the mean change in height over a 24-hour period was 0.92 ft. The maximum monthly SD in depth differential was approximately 0.5 ft or less, suggesting that water elevation differential was generally stable during that sampling period.

One overall pattern in the data was that water elevation differential during CGS operational periods trended higher during summer until August (2018) or September (2018) followed by a decline (Table 16, Figure 14) corresponding closely with the pattern of increasing and decreasing make-up flow in these same periods (Figure 12). In general, trends in water level elevation tracked closely with make-up flows at all time-scales examined (hourly, weekly, seasonally), indicating that water elevation differential was driven by the power plant operations that influence make-up flow.

Per the SAP, no periods of sudden and unexplained differences in water surface elevation or blockages were identified that required calculation of the change in velocity through the screen pores (entrance velocity).

Table 16
Hourly Differences in Pumphouse to Columbia River Water Depth

Study Week	Start of Week	End of Week	Pumphouse to River Elevation Difference (ft)		Pumphouse to River Elevation Change per Hour (ft)		
			Mean	SD	Mean	SD	Maximum
2018-1	3/11/2018	3/17/2018	0.48	0.19	0.001	0.110	0.322
2018-2	3/18/2018	3/24/2018	0.49	0.22	-0.001	0.144	0.577
2018-3	3/25/2018	3/31/2018	0.50	0.24	0.000	0.167	0.542
2018-4	4/1/2018	4/7/2018	0.49	0.19	0.002	0.138	0.429
2018-5	4/8/2018	4/14/2018	0.54	0.18	-0.001	0.107	0.329
2018-6	4/15/2018	4/21/2018	0.53	0.21	-0.001	0.135	0.574
2018-7	4/22/2018	4/28/2018	0.59	0.30	0.000	0.153	0.830
2018-8	4/29/2018	5/5/2018	0.60	0.27	0.001	0.149	0.840
2018-9	5/6/2018	5/12/2018	0.66	0.31	0.009	0.209	1.935
2018-10	5/13/2018	5/19/2018	0.93	0.53	-0.003	0.151	0.632
-	*5/20/2018*	*5/26/2018*	*0.18*	*0.26*	*-0.001*	*0.099*	*0.311*
-	*5/27/2018*	*6/2/2018*	*0.07*	*0.22*	*0.001*	*0.172*	*1.296*
-	*6/3/2018*	*6/9/2018*	*0.08*	*0.19*	*-0.001*	*0.145*	*0.840*
2018-11	6/10/2018	6/16/2018	0.64	0.39	0.001	0.151	0.551
2018-12	6/17/2018	6/23/2018	1.00	0.39	0.005	0.194	0.860
2018-13	6/24/2018	6/30/2018	0.90	0.23	0.000	0.114	0.384
2018-14	7/1/2018	7/7/2018	0.96	0.54	0.001	0.361	1.986
2018-15	7/8/2018	7/14/2018	1.09	0.34	0.001	0.149	0.694
2018-16	7/15/2018	7/21/2018	1.30	0.51	0.001	0.177	0.932

Study Week	Start of Week	End of Week	Pumphouse to River Elevation Difference (ft)		Pumphouse to River Elevation Change per Hour (ft)		
			Mean	SD	Mean	SD	Maximum
2018-17	7/22/2018	7/28/2018	1.33	0.40	0.004	0.171	0.861
2018-18	7/29/2018	8/4/2018	1.37	0.51	-0.007	0.239	0.754
2018-19	8/5/2018	8/11/2018	1.41	0.58	0.004	0.246	0.830
2018-20	8/12/2018	8/18/2018	1.20	0.39	-0.002	0.219	1.050
2018-21	8/19/2018	8/25/2018	1.10	0.42	0.000	0.221	0.815
2018-22	8/26/2018	9/1/2018	0.97	0.25	0.002	0.146	0.934
2018-23	9/2/2018	9/8/2018	1.07	0.40	-0.002	0.218	0.763
2018-24	9/9/2018	9/15/2018	0.93	0.33	-0.001	0.204	0.772
2019-1	3/10/2019	3/16/2019	0.56	0.18	0.004	0.120	0.379
2019-2	3/17/2019	3/23/2019	0.68	0.20	0.000	0.096	0.282
2019-3	3/24/2019	3/30/2019	0.70	0.23	-0.002	0.101	0.479
2019-4	3/31/2019	4/6/2019	0.75	0.29	0.002	0.134	0.497
2019-5	4/7/2019	4/13/2019	0.61	0.22	-0.004	0.102	0.349
2019-6	4/14/2019	4/20/2019	0.59	0.22	0.000	0.119	0.547
2019-7	4/21/2019	4/27/2019	0.52	0.18	0.000	0.089	0.431
2019-8	4/28/2019	5/4/2019	0.50	0.20	0.002	0.081	0.263
2019-9	5/5/2019	5/11/2019	0.46	0.39	-0.004	0.152	0.414
-	*5/12/2019*	*5/18/2019*	*-0.09*	*0.04*	*0.000*	*0.050*	*0.330*
-	*5/19/2019*	*5/25/2019*	*-0.10*	*0.06*	*0.000*	*0.076*	*0.590*
-	*5/26/2019*	*6/1/2019*	*-0.11*	*0.04*	*0.002*	*0.051*	*0.385*
-	*6/2/2019*	*6/8/2019*	*-0.11*	*0.01*	*0.000*	*0.016*	*0.164*
-	*6/9/2019*	*6/15/2019*	*-0.09*	*0.13*	*0.000*	*0.148*	*0.992*
-	*6/16/2019*	*6/22/2019*	*0.18*	*0.57*	*0.009*	*0.277*	*1.364*
2019-10	6/23/2019	6/29/2019	0.82	0.31	-0.004	0.125	0.602
2019-11	6/30/2019	7/6/2019	1.15	0.42	0.002	0.163	0.532
2019-12	7/7/2019	7/13/2019	0.92	0.44	-0.002	0.213	1.079
2019-13	7/14/2019	7/20/2019	1.02	0.30	0.000	0.115	0.337
2019-14	7/21/2019	7/27/2019	1.16	0.36	0.004	0.118	0.404
2019-15	7/28/2019	8/3/2019	1.19	0.40	-0.003	0.150	0.513
2019-16	8/4/2019	8/10/2019	1.30	0.40	-0.001	0.342	2.916
2019-17	8/11/2019	8/17/2019	1.19	0.40	-0.002	0.134	0.375
2019-18	8/18/2019	8/24/2019	1.23	0.37	0.003	0.132	0.552
2019-19	8/25/2019	8/31/2019	1.31	0.44	-0.003	0.161	0.654
2019-20	9/1/2019	9/7/2019	1.36	0.43	0.003	0.150	0.721
2019-21	9/8/2019	9/14/2019	1.34	0.35	-0.002	0.157	0.632
2019-22	9/15/2019	9/21/2019	1.07	0.36	-0.001	0.149	0.531

Note:
Weeks without a study week designation are not included in season wide statistical analysis. In 2018 three weeks of low operational capacity and unreliable data occurred because of high Columbia River flow. In 2019 the Columbia Generating Station was shut down for six weeks for operational maintenance.

4.3 Task 4: Data Summaries and Fish Entrainment Analyses

A summary of fish entrainment sampling events and associated make-up flow conditions is provided in Table 17. Four fish were entrained across all 30 sampling events. No fish were entrained from the river during the six capture efficiency trials. Weekly entrainment rates, used to calculate Total Seasonal Entrainment (TSE), ranged between 0 and 1.09×10^{-05} fish per cubic meter of intake water for all species (Table 17).

Fish entrainment rate statistics are summarized for the entire study period in Table 18. In 2018, the overall TSE for all species was estimated to be 24 fish with a conservative confidence interval with at least 90% confidence (CI_{90}) estimated to be = 0 to 212 fish. In 2019, the overall TSE for all species was estimated to be 24 fish with a conservative confidence interval with at least 90% confidence (CI_{90}) estimated to be = 0 to 213 fish. TSE for pacific lamprey was 12 fish based on observations in 2018 (CI_{90} = 0 to 153) and for torrent sculpin TSE was 12 fish based on observations in 2019 (CI_{90} = 0 to 150). For Chinook salmon fry, TSE was also 12 fish per season (CI_{90} = 0 to 150). The variation associated with the estimated TSE was high because of the small number of fish entrained during sampling events and the conservative approach taken to estimate a confidence interval around TSE. The resulting impact to the total population of juvenile (pre-smolt) fall Chinook salmon that originate from the Hanford Reach was estimated to be 0.00011% (CI_{90} = 0 to 0.0014%) of the pre-smolts in 2018 and 0.00015% (CI_{90} = 0 to 0.00187%) of the pre-smolts in 2019.

Table 17
Weekly Entrainment Rates

Sample Event	Deployment Day	Retrieval Day	Average Hourly CGS Make-up Flow (gpm)	Average Hourly CGS Make-up Flow (m^3/min)	Number of Cages Deployed	Total Hours Deployed	Total Minutes Deployed	Species	Cage of Entrainment	Weekly Entrainment Rate, ER_i (fish/m^3)
RE-2018-1	4/4/2018	4/5/2018	15,521	58.75	2	24	1440			0
RE-2018-2	4/11/2018	4/12/2018	15,366	58.17	2	25	1500			0
RE-2018-3	4/18/2018	4/19/2018	15,975	60.47	2	25	1500			0
RE-2018-4	4/25/2018	4/26/2018	17,076	64.64	2	25	1500			0
RE-2018-5	5/2/2018	5/3/2018	17,017	64.42	2	25	1500	Fall Chinook salmon	2 (North)	1.03E-05
RE-2018-6	5/9/2018	5/10/2018	15,345	58.09	2	25	1500			0
RE-2018-7	6/13/2018	6/14/2018	16,209	61.36	2	26	1560	Pacific lamprey	2 (North)	1.04E-05
RE-2018-8	6/20/2018	6/21/2018	18,456	69.87	2	25	1500			0
RE-2018-9	6/27/2018	6/28/2018	16,933	64.10	2	24	1440			0
RE-2018-10	7/11/2018	7/12/2018	17,609	66.66	2	25	1500			0
RE-2018-11	7/18/2018	7/19/2018	19,760	74.80	2	27	1620			0
RE-2018-12	8/1/2018	8/2/2018	19,231	72.80	2	25	1500			0
RE-2018-13	8/15/2018	8/16/2018	18,622	70.49	2	29	1740			0
RE-2018-14	8/29/2018	8/30/2018	17,642	66.78	2	25	1500			0
RE-2018-15	9/12/2018	9/13/2018	16,315	61.76	2	25	1500			0
RE-2019-1	3/13/2019	3/14/2019	15,313	57.97	2	25	1500			0
RE-2019-2	3/20/2019	3/21/2019	16,121	61.03	2	25	1500	Unidentified salmon sp.	1 (South)	1.09E-05
RE-2019-3	3/27/2019	3/28/2019	15,489	58.63	2	25	1500			0
RE-2019-4	4/3/2019	4/4/2019	16,117	61.01	2	25	1500	Torrent sculpin	2 (North)	1.09E-05
RE-2019-5	4/10/2019	4/11/2019	16,228	61.43	2	25	1500			0
RE-2019-6	4/17/2019	4/18/2019	16,772	63.49	2	25	1500			0

Sample Event	Deployment Day	Retrieval Day	Average Hourly CGS Make-up Flow (gpm)	Average Hourly CGS Make-up Flow (m^3/min)	Number of Cages Deployed	Total Hours Deployed	Total Minutes Deployed	Species	Cage of Entrainment	Weekly Entrainment Rate, ER_i (fish/m^3)
RE-2019-7	4/24/2019	4/25/2019	16,682	63.15	2	25	1500			0
RE-2019-8	5/1/2019	5/2/2019	16,396	62.07	2	25	1500			0
RE-2019-9	5/8/2019	5/9/2019	15,228	57.65	2	25	1500			0
RE-2019-10	6/26/2019	6/27/2019	17,370	65.75	2	24	1440			0
RE-2019-11	7/10/2019	7/11/2019	18,043	68.30	2	25	1500			0
RE-2019-12	7/24/2019	7/25/2019	18,468	69.91	2	25	1500			0
RE-2019-13	8/7/2019	8/8/2019	19,424	73.53	2	25	1500			0
RE-2019-14	9/4/2019	9/5/2019	18,797	71.15	2	25	1500			0
RE-2019-15	9/18/2019	9/19/2019	16,802	63.61	2	25	1500			0

Table 18
Average Adjusted Entrainment Rate Metrics

Variable Description	Symbol	2018			2019		
		All 2018	Chinook Fry	Pacific Lamprey	All 2019	Chinook Fry[1]	Sculpin
Number of Study Weeks, k	k	24	24	24	22	22	22
Number of Routine Entrainment Sample Weeks	n	15	15	15	15	15	15
Average Unadjusted Entrainment Rate (fish per m^3)	$\overline{ER}$	1.39E-06	6.90E-07	6.96E-07	1.46E-06	7.28E-07	7.28E-07
Standard Error of Average Unadjusted Entrainment Rate	$SE_{\overline{ER}}$	9.45E-07	6.90E-07	6.96E-07	9.93E-07	7.28E-07	7.28E-07
Capture Efficiency	$\overline{CE}$	0.905	0.905	0.905	0.905	0.905	0.905
Average Adjusted Entrainment Rate (fish per m^3)	ER_{adj}	1.53E-06	7.62E-07	7.70E-07	1.61E-06	8.05E-07	8.05E-07
Standard Error of Average Adjusted Entrainment Rate	$SE_{ER_{adj}}$	4.04E-06	2.95E-06	2.98E-06	4.25E-06	3.12E-06	3.12E-06
Average Weekly Intake Flow (m^3 per week)	$\bar{Q}$	646,709.15	646,709.15	646,709.15	675,046.55	675,046.55	675,046.55
TSE (number of fish)	TSE	24	12	12	24	12	12
Standard Error of TSE	SE_{TSE}	63	45	46	63	46	46
Coefficient of Variation, TSE	CV_{TSE}	264%	387%	387%	264%	387%	387%

Variable Description	Symbol	2018			2019		
		All 2018	**Chinook Fry**	**Pacific Lamprey**	**All 2019**	**Chinook Fry**[1]	**Sculpin**
Lower Confidence Limit of TSE	Lower CI_{90}	0	0	0	0	0	0
TSE Upper Confidence Interval[3]	Upper CI_{90}	212	150	153	213	150	150
Estimated Number of Hanford Reach Fall Chinook Pre-smolts[4]	R	-	Method 1: 56,443,476 or Method 2: 10,678,675	-	-	Method 1: 29,964,889 or Method 2: 8,069,040	-
Estimated Percent Entrainment of Hanford Reach Fall Chinook Fry	% Ent	-	0.00002% or 0.00011%	-	-	0.00004% or 0.00015%	-
Estimated Maximum Percent Entrainment of Hanford Reach Fall Chinook Fry	Max % Ent		0.00027% or 0.00140%			0.00050% or 0.00187%	

Note: Values calculated as specified in the Sampling and Analysis Plan (Anchor QEA 2018) unless noted below.

1. The unidentifiable salmonid fry that was entrained in 2019 was conservatively assumed to be a Chinook salmon.
2. Standard Error of Total Seasonal Entrainment was larger than estimated Total Seasonal Entrainment, therefore the lower confidence limit was determined to be 0.
3. Entrainment data were not normally distributed therefore the upper limit to the confidence interval was conservatively calculated as TSE + (3*SE_{TSE}). This represents a greater than 90% confidence interval.
4. The estimate of pre-smolts, , was provided by WDFW (2019).

5 Conclusions

Fish entrainment monitoring at Energy Northwest's CGS intake was conducted in 2018 and 2019 in accordance with the EFSEC-approved Study Plan. Few fish were entrained over the two observation seasons that occurred from mid-March to mid-September, with only four fish observed during 30 independent, 24-hour sampling events. The small number of fish entrained is consistent with the findings of previous monitoring (Mudge et al. 1981).

Based on the few entrained fish that were observed in the study monitoring, an estimate of the overall Total Seasonal Entrainment (TSE) for all species based on the number of fish entrained per given volume of make-up water was expanded from the 24-hour sample periods to the entire monitoring period from mid-March to mid-September. Overall TSE was estimated to be 24 fish in 2018 and 24 fish in 2019. For a given species, TSE for Pacific lamprey was estimated to be 12 fish in 2018, for torrent sculpin TSE was estimated to be 12 fish in 2019, and TSE for fall-run Chinook salmon was estimated to be 12 fish per season. The resulting impact to the total population of juvenile (pre-smolt) fall-run Chinook salmon that originate from the Hanford Reach was estimated to be only as high as 0.00011% of the pre-smolts in 2018 and to 0.00015% of the pre-smolts in 2019.

It is notable that while the CGS intakes can entrain small-bodied fishes observed in the study, based on just the relative sizes of fish and the pore sizes of the intake, very few of the available fish of suitable size in the river are actually entrained. This finding is consistent with the risk analysis based on CFD modeling of the hydraulic patterns near and at the intake (Alden 2018). Note that lamprey ammocoetes are at higher risk of entrainment than other species due to their body shape and narrow body depth, yet only one was observed in the study. Thus, the overall impact to the fish populations in the Hanford Reach, especially to the Hanford Reach fall-run Chinook salmon, is minute.

These conclusions are robust despite river-flow variations and periods without sampling. Discharge from the upper Columbia River Basin and Priest Rapids Dam was exceptionally high in 2018 and peak flows occurred in May, approximately 1 month earlier than average, causing an interruption in typical make-up water flow rates and fish entrainment monitoring activities. Discharge from Priest Rapids Dam in 2019 was generally low compared to typical conditions observed over the past 10 years, with peak water levels in mid-May to early June. The fish entrainment monitoring undertaken in March and April prior to the high flows experienced in 2018 and the planned CGS maintenance outage in 2019 coincided with the typical peak emergence period for Hanford Reach fall-run Chinook salmon. The monitoring provided representative, weekly sampling for entrainment during this key time of year.

Visual inspections of the intake screens by video showed no fish impingement or signs of impingement. Biofouling by algae was observed in late summer and fall; however, monitoring of the

water-level differential between the Columbia River and the TMU system pumphouse well showed no evidence of clogged screen pores, a condition that could increase the risk of fish impingement. There was no increase in fish entrainment associated with biofouling of the screens. The relative amount of debris entrained in the cages appeared to be related to the degree of biofouling of the intakes, which is assumed to have increased over the summer season, and did not appear to be related to large and sudden accumulations of debris becoming impinged on the intake.

The few fish entrained did not appear related to any of the metrics we obtained. Despite the broad range of flow conditions observed during the two study seasons, fish entrainment did not appear to coincide with specific river flows or water elevations. The fish were entrained on days when environmental conditions were typical relative to seasonal trends in river conditions and plant operations. Fish entrainment did not appear related to the other metrics monitored which included river temperatures, water depth over the intake structure screens, or circulating make-up flows. No fish were entrained during the mid- to late summer months, among the ten 24-hour samplings conducted from July through mid-September in 2018 and 2019, combined. This suggests that fish entrainment may be more frequent in the spring and early summer, and related to the greater abundance of salmon fry and other small fish emerging and migrating through the reach during that time of year, rather than specific environmental conditions.

Hydrodynamic modeling of the CGS intakes specifically indicated that sweeping velocities are more likely to pass fish and debris around the intakes than for debris or fish to become impinged on the intake or entrained (Alden 2018). An exception noted was during times of the year when the dominant river flows are slightly more oblique to the intake structure screens. However, the entrainment study did not measure the direction of river flow at the site or fine scale measures of velocity, and any effect of the direction of the flow on the actual debris and fish impingement and entrainment remains uncertain. It is notable that the hydrodynamic modeling also demonstrated at a fine scale that depending on river conditions, the effective pore size of the intake screens was considerably smaller than the physical pore size of 9.5 mm due to turbulence at the pore opening (an assessment of the risk the structure poses to fish entrainment is discussed further in the Historical Fish Occurrence and Risk Assessment, Appendix E).

A detailed literature review and evaluation of species and life stages potentially at risk indicated that listed salmonid stocks from the upper Columbia River Basin were not at risk of entrainment or impingement due to their large size and strong swimming ability upon reaching the CGS intake structure screens. The primary vulnerable salmonid species and life stages are fall-run Chinook salmon and steelhead fry originating from the Hanford Reach, in relatively close proximity to the CGS intakes. However, this risk is minimized by the hydraulic conditions around the intake structure screens (Alden 2018). Overall, the published literature supports the observations from the fish entrainment monitoring that a low probability of impingement and entrainment exists for the CGS

intake in this reach of the Columbia River and that the magnitude of the impact to the total population is extremely low.

In summary, very few fish (4 fish) were entrained in 754 hours of monitoring, suggesting the impact to fish populations in the Hanford Reach are minute. Capture efficiency testing of the entrainment cages was consistently high, providing confidence in the fish entrainment monitoring methods. A well-planned fish entrainment monitoring study design was implemented and multiple potential contributing environmental and operational factors were monitored that showed that the data collected in this study are representative of typical operating conditions, and thus, actual fish entrainment. However, trends in environmental or plant operating conditions and fish entrainment are difficult to evaluate since only 4 fish were captured. In addition, the results of two years of fish entrainment monitoring are consistent with earlier observations (Mudge et al. 1981). Low water elevation was previously identified as a factor that could increase the risk of entrainment, however direct observations did not support this assumption, as no fish were entrained during the periods of lowest flows in late August and September. No evidence of debris nor fish impingement was observed in once-per-year direct visual surveys, nor using indirect methods to identify sudden changes in intake performance. Chinook salmon fry are one of the most vulnerable species owing to their abundance in the Hanford Reach during a relatively short period of the year. At least one, and potentially two, Chinook salmon fry were entrained, yet this represents a minute proportion of the total population rearing and migrating in the area of the intakes.

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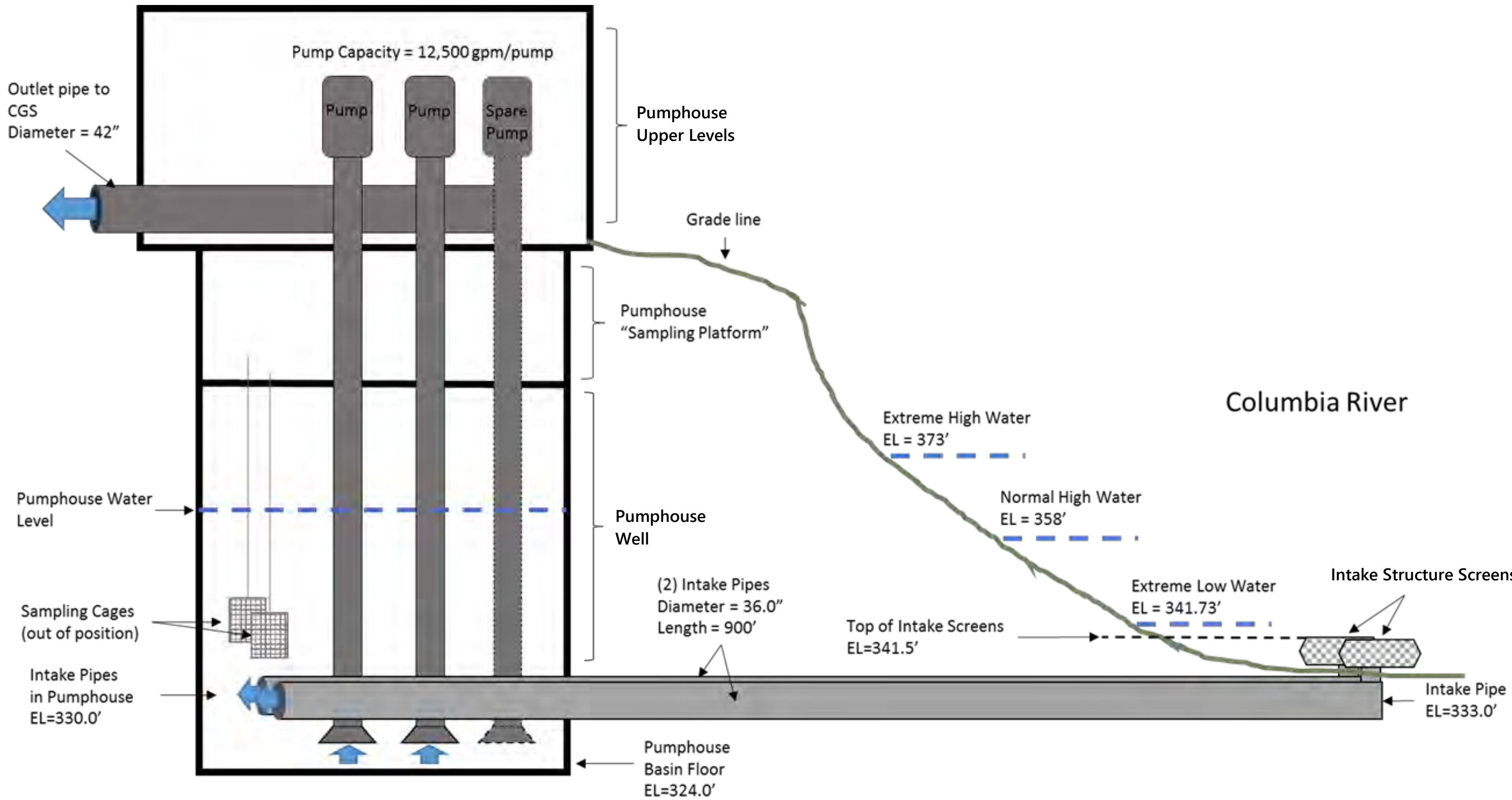
Figures



Notes: Drawings are not to scale and are intended to highlight the general orientation of the facility relative to the intakes and screens.
Large blue arrows depict the direction of pumped water conveyed through the pumphouse building.

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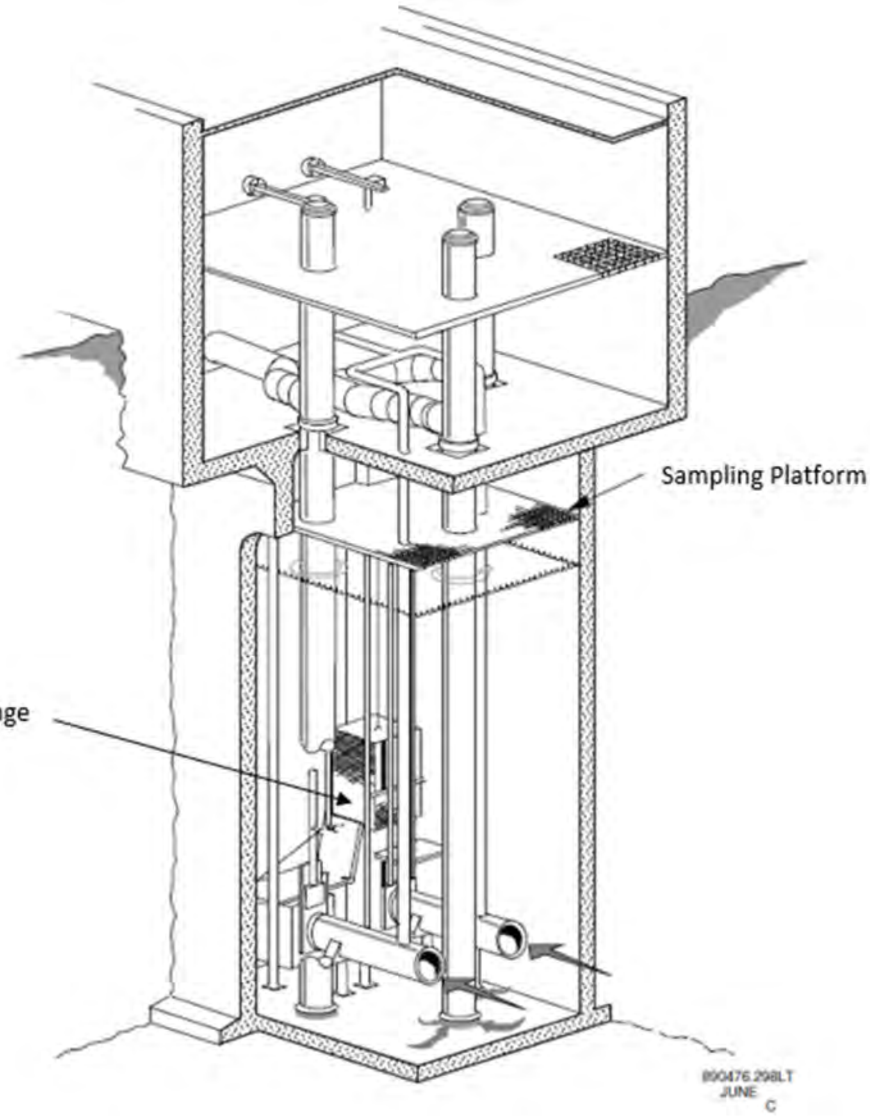
Figure 1
General Layout of Columbia Generating Station Make-Up Water Pumphouse Building

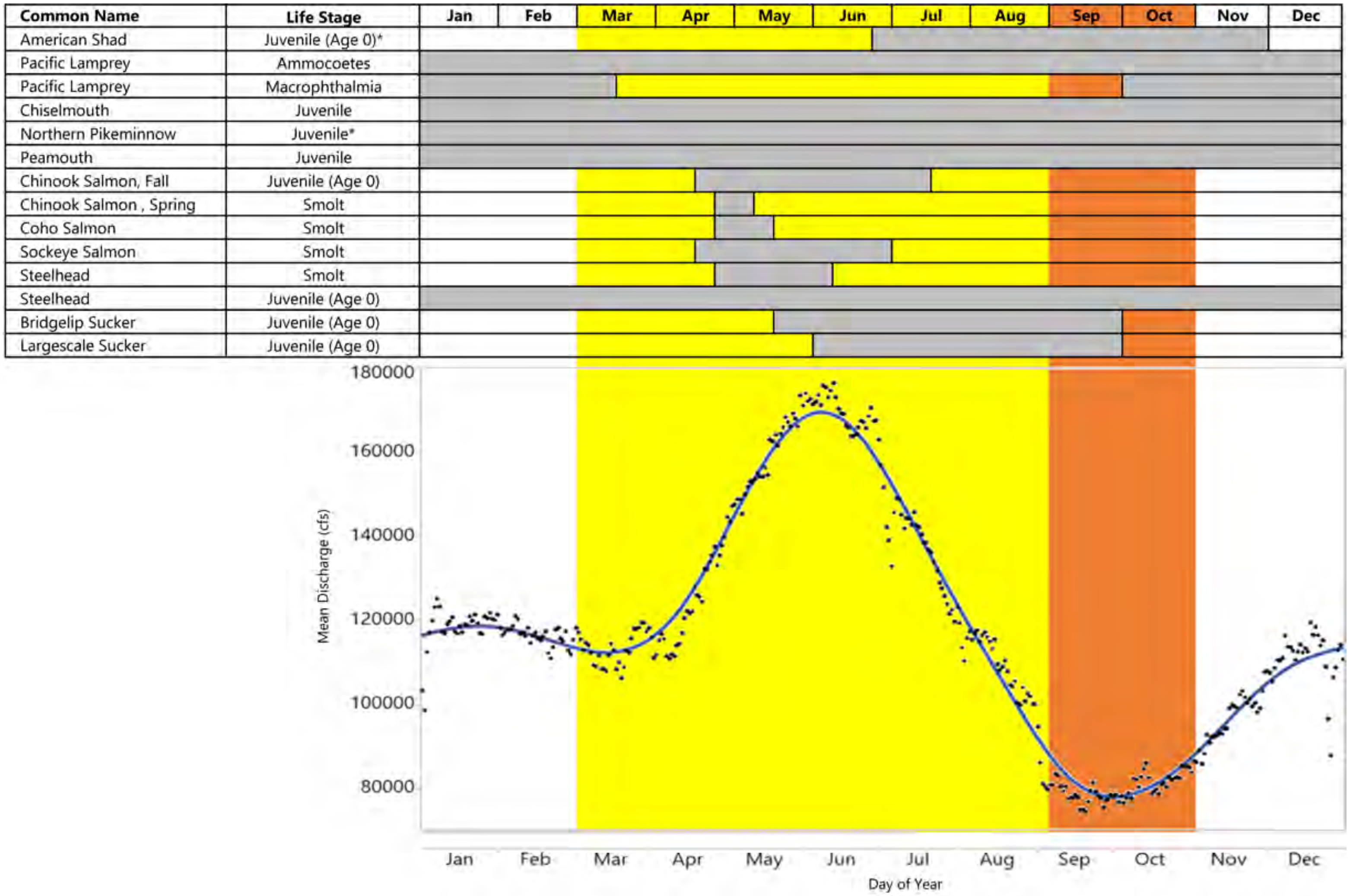


Filepath: I:\Projects\Energy_Northwest\04-Deliverables\2019 Final Study Report\final_report_figures\Word files\Figure2_Schematic of the Fish Entrainment Sampling Cage.docx

Figure 2
Schematic of the Fish Entrainment Sampling Cage and Platform at the Columbia Generating Station Make-Up Water Pumphouse

Note: Cage is shown with door removed. Added gap-bridging insert provides a close seal with incoming pipe from the river.

Figure 3
Sampling Cage with Gap-Bridging Insert



Notes:
** Eggs may drift, or larvae have a drifting pelagic phase vulnerable to entrainment by the CGS intake*
Mean Daily Discharge shows the daily mean discharge below Priest Rapids Dam with each day represented by a black dot and the overall seasonal trend represented by the blue line. Data were collected from January 1975 through January 2016.

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Figure 4
Seasonal Occurrence of Fish Species at Risk of Entrainment in Relation to Average Daily River Discharge

Fish Entrainment Characterization Report
Columbia Generating Station Fish Entrainment Study

Entrainment Factor	Review of Literature Summary	Risk Level Created by Each Determining Factor of Entrainment by Month						
		Mar	Apr	May	Jun	Jul	Aug	Sep
Presence in Hanford Reach	Fry emerge from mid-March through mid-May, redistribute to shallow nearshore areas through early summer, and migrate downstream from early June through mid-August.	*M*	*H*	*H*	*H*	*H*	*M*	*L*
Habitat preference	Emergent fry use shallow, shoreline habitats with mean water velocities less than 1.5 fps. Older subyearlings are found in water depths of 4.9 to 19.4 feet and velocities between 0.6 to 2.6 fps, mainly in nearshore areas, but can be found across the entire river channel and water column.	*L*	*L*	*H*	*H*	*H*	*H*	*H*
Fish size	37 to 44 mm at emergence, 70 to 110 mm by early June, and 105 to 125 mm by mid-August	*H*	*H*	*H*	*M*	*M*	*L*	*L*
Hydraulic bypass	Mean sweeping velocity ranges from 4 to 5 fps during the months that emerging fry and subyearlings are present and exceeds the typical bulk flow approach velocity of 0.07 fps by at least a factor of 50.	*L*	*L*	*L*	*L*	*L*	*L*	*L*
Behavioral avoidance	Burst swimming capacity of 3.5 fps exceeds the typical approach velocity of 0.07 fps by a factor of 50.	*L*	*L*	*L*	*L*	*L*	*L*	*L*
Exclusion	Salmon larger than approximately 75 mm excluded from outer screen pores that are 9.5 mm in diameter. Most subyearlings reach 75 mm by June.	*H*	*H*	*H*	*M*	*L*	*L*	*L*
Sweep-off or impingement	Sweeping velocities that exceed approach velocities contribute to sweep-off. Blocked screen pores may contribute to higher and uneven approach velocities and increase the potential for impingement; river debris is likely to be swept off; however, biofouling of screen pores may increase across the summer.	*L*	*L*	*L*	*L*	*M*	*M*	*M*
Combination of all entrainment factors	**Low risk for one factor negates the risk posed by subsequent factors**	***L***	***L***	***L***	***L***	***L***	***L***	***L***

Notes: Each entrainment risk factor and relevant biological characteristic is briefly summarized on the left-hand side of the table, and the relative level of risk is shown on the right side of the table, by month, as red, yellow, and green, representing the range from high (H), to moderate (M), to low (L) risk. The overall risk created by the combination of entrainment factors is depicted in the bottom row, representing the outcome of the sequence of entrainment factors.
fps: feet per second
mm: millimeter

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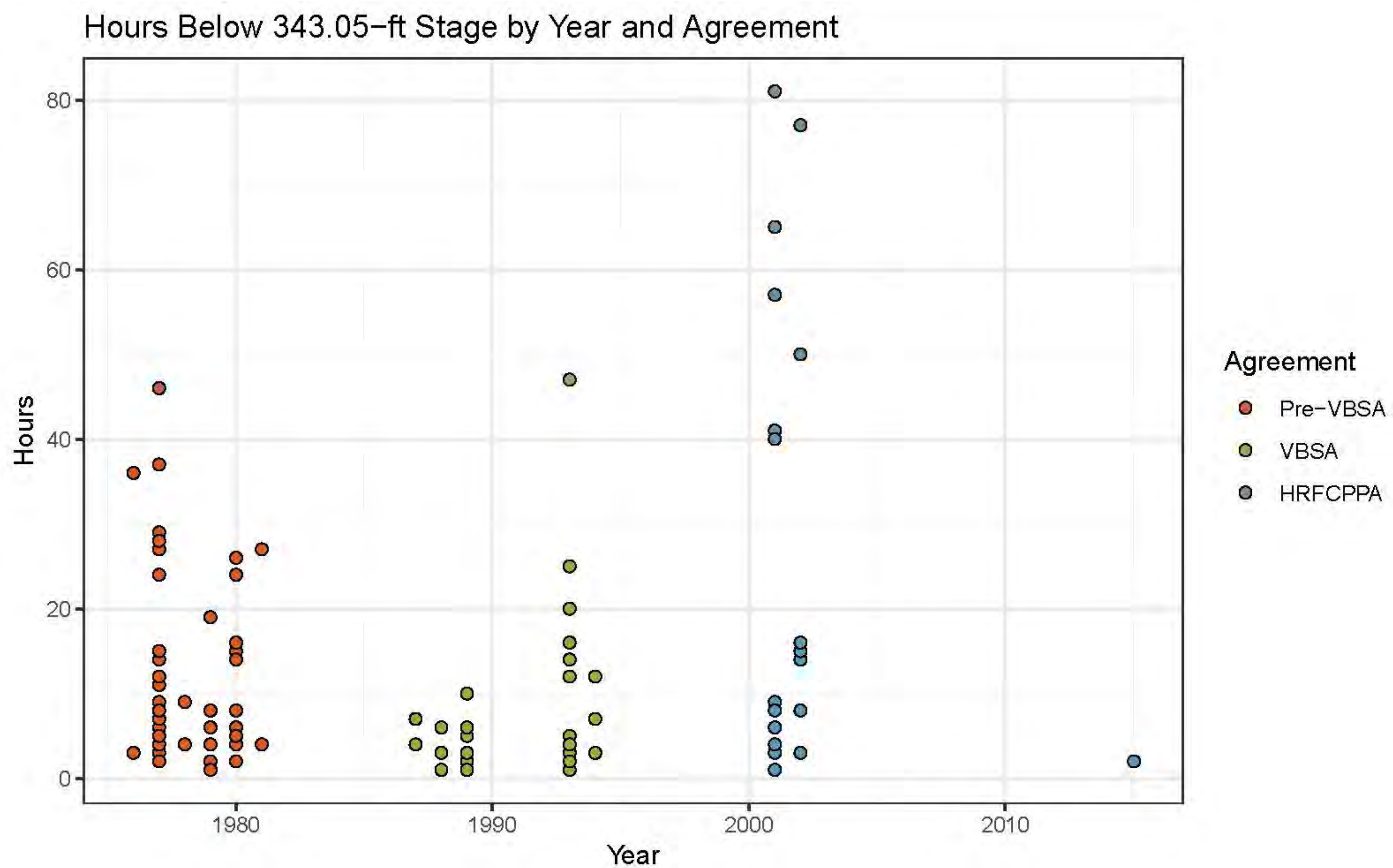
Figure 5
Risk to Fall-Run Chinook Salmon Created by the Columbia Generating Station Intake Structure by Entrainment Factor and Month



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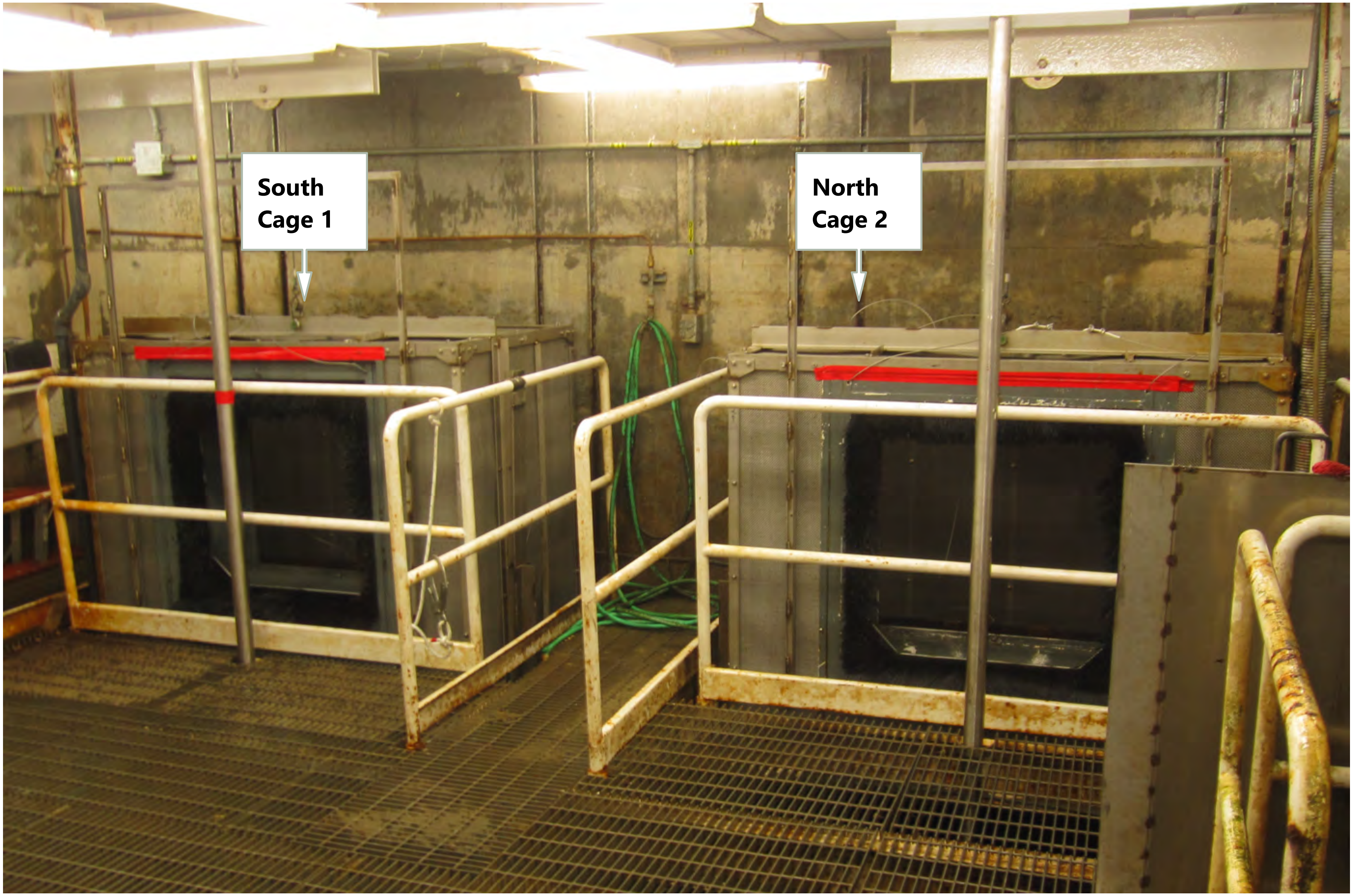

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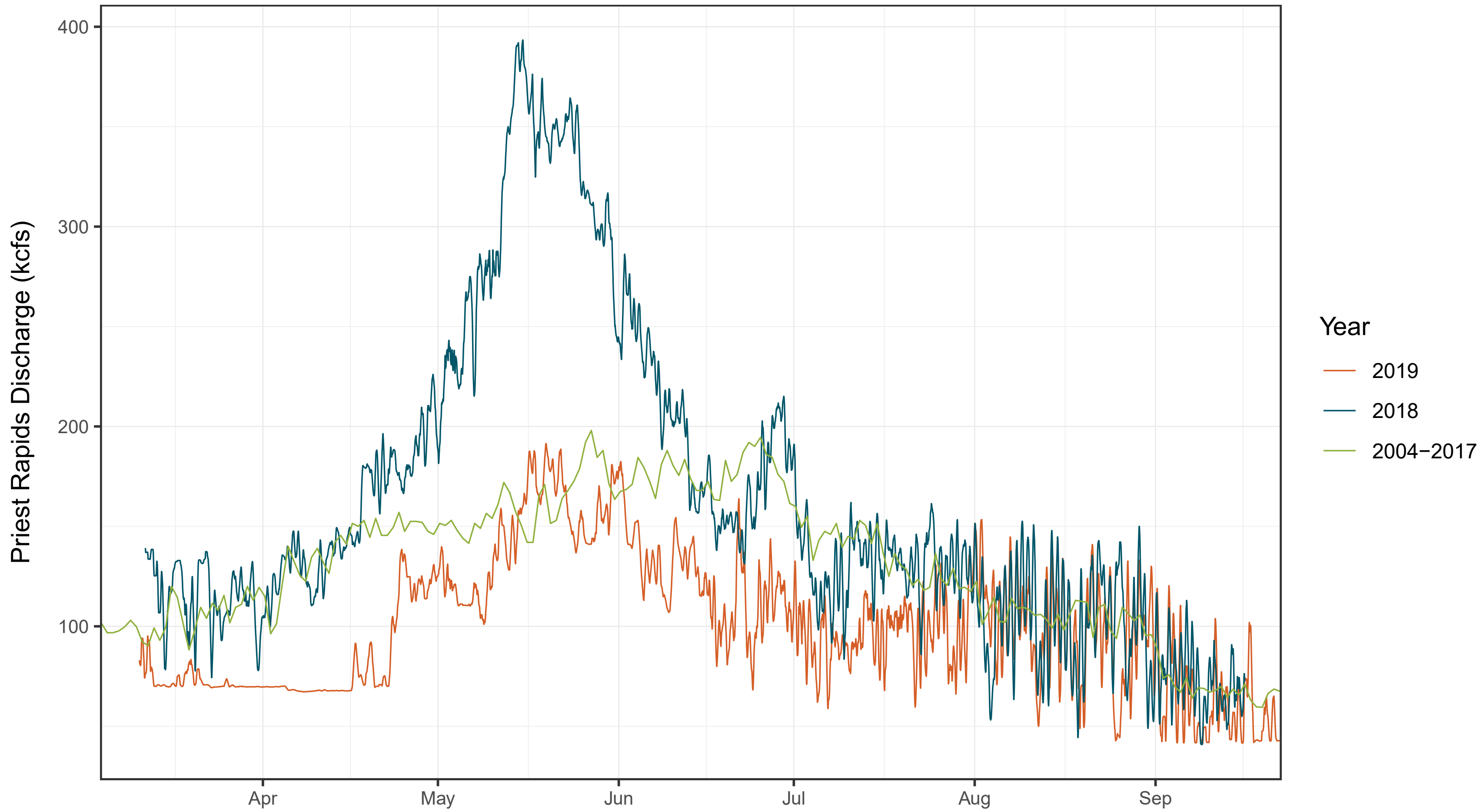
Figure 7
Sampling Cage Locations at Sampling Platform
Fish Entrainment Characterization Report
Columbia Generating Station Fish Entrainment Study



Notes: Priests Rapids discharge data for fish entrainment study seasons (2018-2019) was provided by the Army Corps of Engineers and obtained from the Fish Passage Center River Database (FPC 2019; http://www.fpc.org/river/flowspill/flowspill_Query.html). The 12-hour rolling mean is shown. Priest Rapids discharge data for 2004 through 2017 was obtained from the USGS Water Database for gage number 12472800 (USGS 2019; https://waterdata.usgs.gov). The daily median flow for the time period is shown. The period from 2004 to present is the period for which the HRFCPPA has been implemented.

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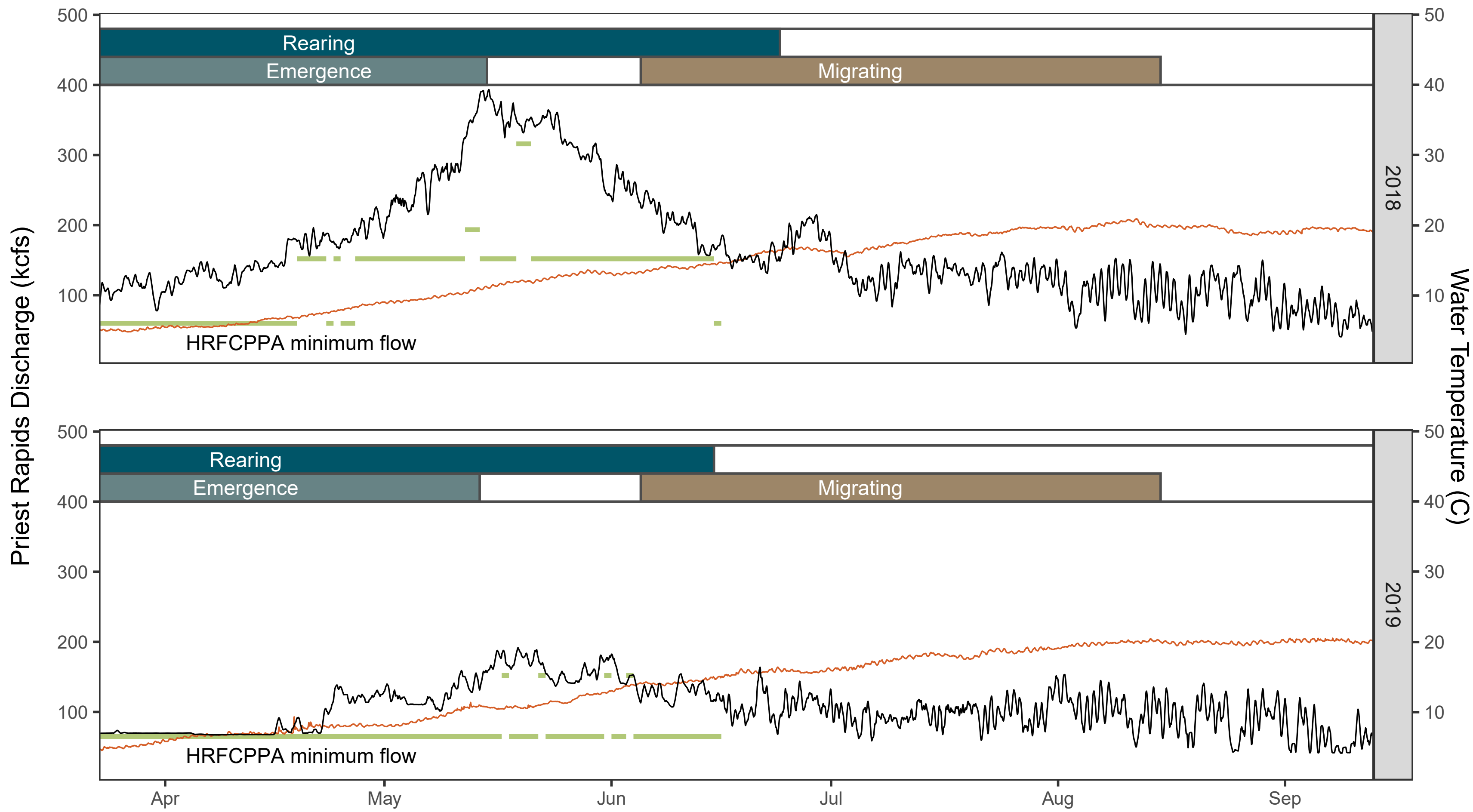
Figure 8

Priest Rapids Outflow for Study Years with Historic Median Outflow



Notes: Priest Rapids discharge for study seasons 2018 and 2019 is shown in black as a 12-hour rolling mean. Hourly mean water temperature is shown in red. Salmon lifestage periods are taken from the Hanford Reach Fall Chinook Protection Plan Agreement (HRFCPPA). The green line represents the HRFCPPA annual critical flow requirement for Priest Rapids based on redd surveys at Vernita Bar the previous fall (GCPUD 2018, 2019).

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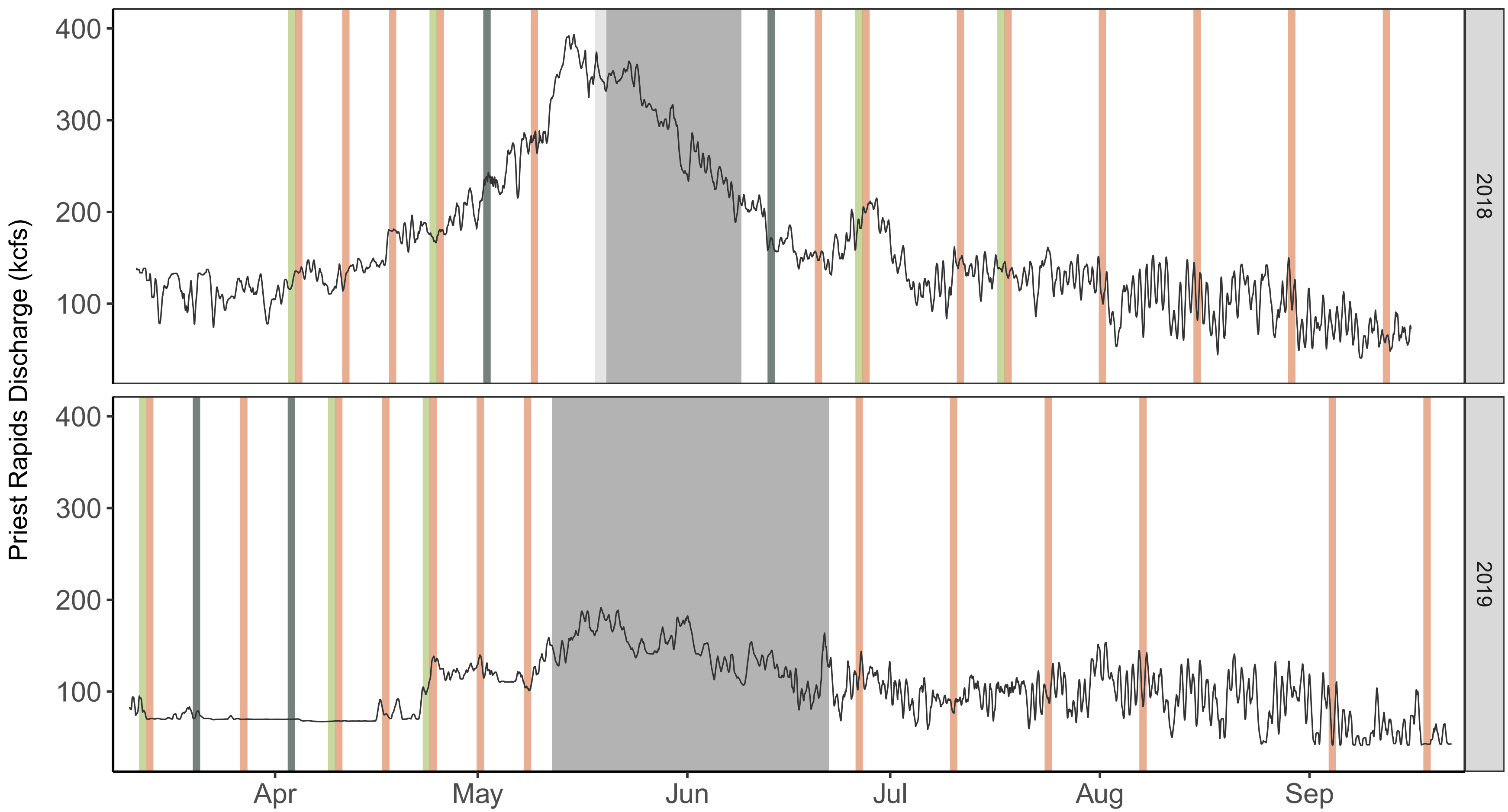

Notes: Priest Rapids discharge for study seasons 2018 and 2019 is shown in black as a 12-hour rolling mean. Orange bars represent routine entrainment tests. Blue bars represent a routine entrainment test in which a fish was entrained. Green bars represent cage efficacy tests that began one day prior to routine entrainment tests. Dark grey shaded areas represent periods of limited or non-operation of the Columbia Generating Station. In 2018, three weeks (from 5/20/2018 to 6/9/2018) of low operational capacity and unreliable data occurred because of high Columbia River flow. Additionally, the lighter shaded grey area shows a period from 5/18/2018 to 5/20/2018 during which operations were limited, but make-up flow sensors were reliable. In 2019, dark grey shading shows the period when the Columbia Generating Station was shut down for six weeks (from 5/12/2019 to 6/22/2019) for operational maintenance.

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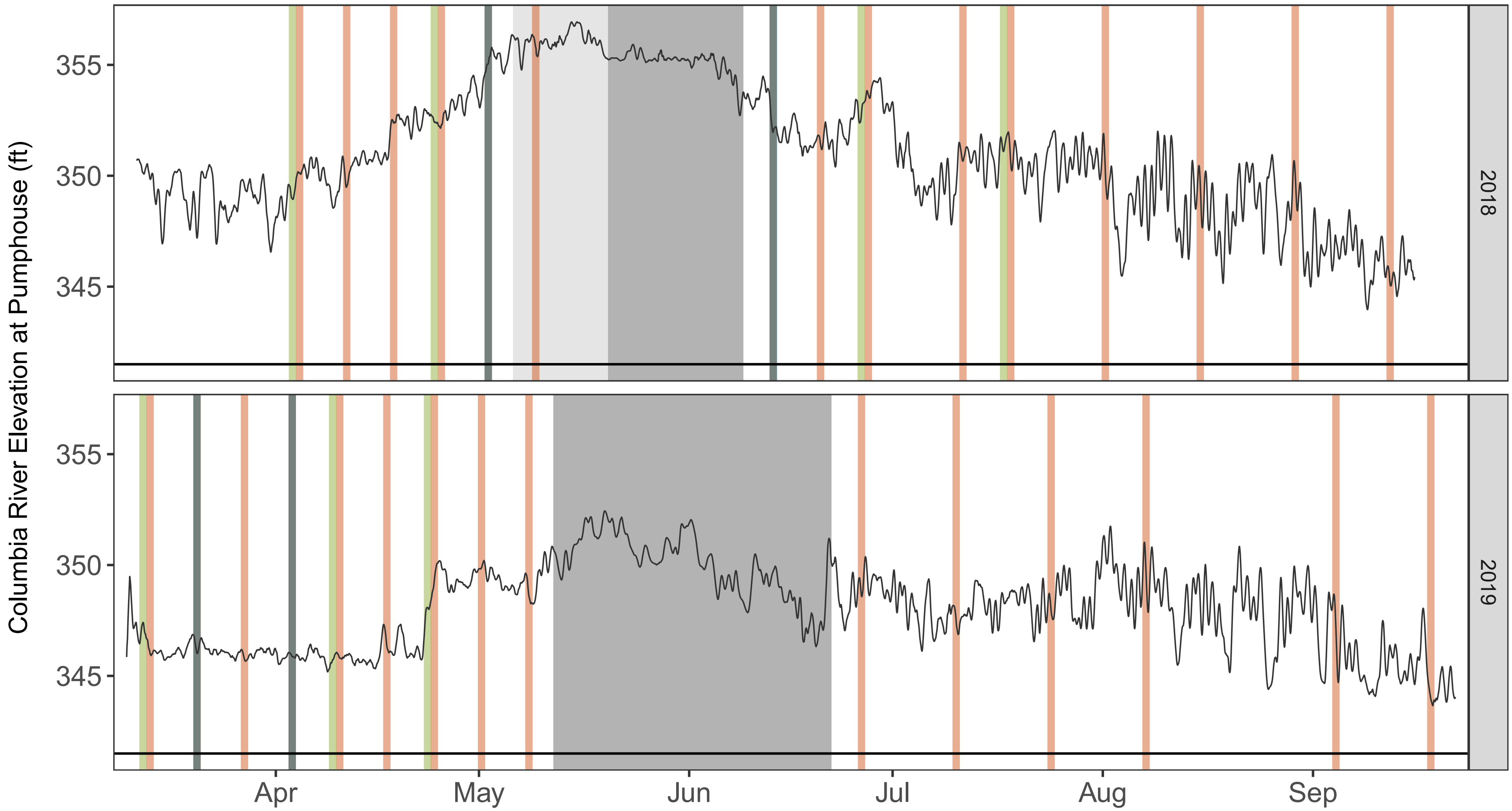
Figure 10

Priest Rapids Outflow with Columbia Generating Station Fish Monitoring Events



Notes: Columbia River elevation at the CGS intakes for study seasons 2018 and 2019 is shown as a 12-hour rolling mean in black. Orange bars represent routine entrainment tests. Blue bars represent a routine entrainment test in which a fish was entrained. Green bars represent cage efficacy tests that began one day prior to routine entrainment tests. Dark grey shaded areas represent periods of limited or non-operation of the Columbia Generating Station. In 2018, three weeks (from 5/20/2018 to 6/9/2018) of low operational capacity and unreliable data occurred because of high Columbia River flow. Additionally, the lighter shaded grey area shows a period from 5/6/2018 to 5/20/2018 during pumphouse water level sensors were unreliable. In 2019, dark grey shading shows the period when the Columbia Generating Station was shut down for six weeks (from 5/12/2019 to 6/22/2019) for operational maintenance.

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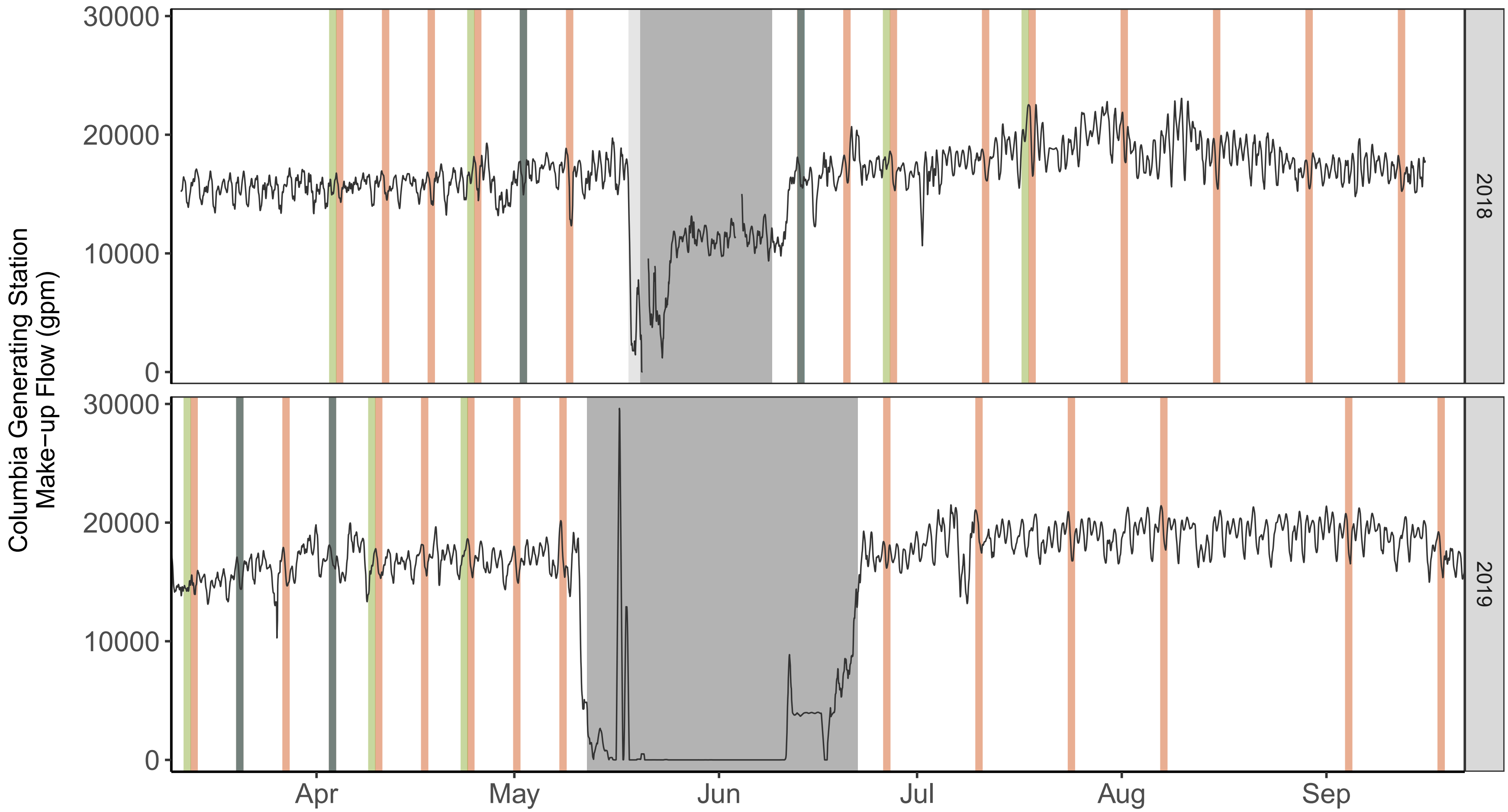
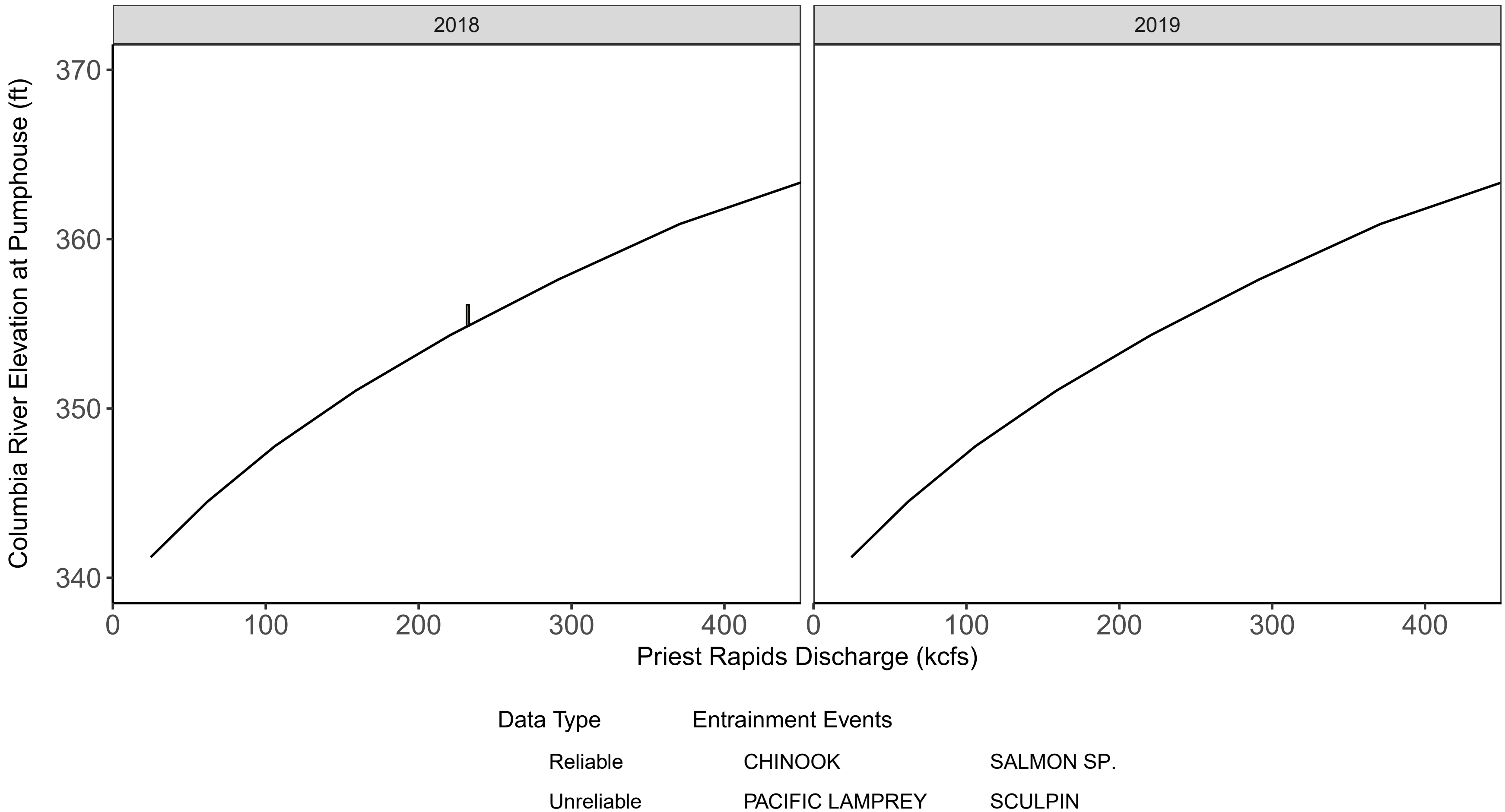
Figure 11
Columbia River Elevation at the Columbia Generating Station Pumphouse



Notes: Columbia Generating Station make-up flow for study seasons 2018 and 2019 is shown as a 12-hour rolling mean in black. Orange bars represent routine entrainment tests. Blue bars represent a routine entrainment test in which a fish was entrained. Green bars represent cage efficacy tests that began one day prior to routine entrainment tests. Dark grey shaded areas represent periods of limited or non-operation of the Columbia Generating Station. In 2018, three weeks (from 5/20/2018 to 6/9/2018) of low operational capacity and unreliable data occurred because of high Columbia River flow. Additionally, the lighter shaded grey area shows a period from 5/18/2018 to 5/20/2018 during which operations were limited, but make-up flow sensors were reliable. In 2019, dark grey shading shows the period when the Columbia Generating Station was shut down for six weeks (from 5/12/2019 to 6/22/2019) for operational maintenance.



Notes: Priests Rapids discharge data for fish entrainment study seasons (2018-2019) was provided by the Army Corps of Engineers and obtained from the Fish Passage Center River Database (FPC 2019; http://www.fpc.org/river/flowspill/flowspill_Query.html). Columbia river elevation was measured directly at the Columbia Generating Station pumphouse during the 2018 and 2019 study seasons. The hypothetical stage-discharge curve is based on 2D MASS2 model results by PNNL.

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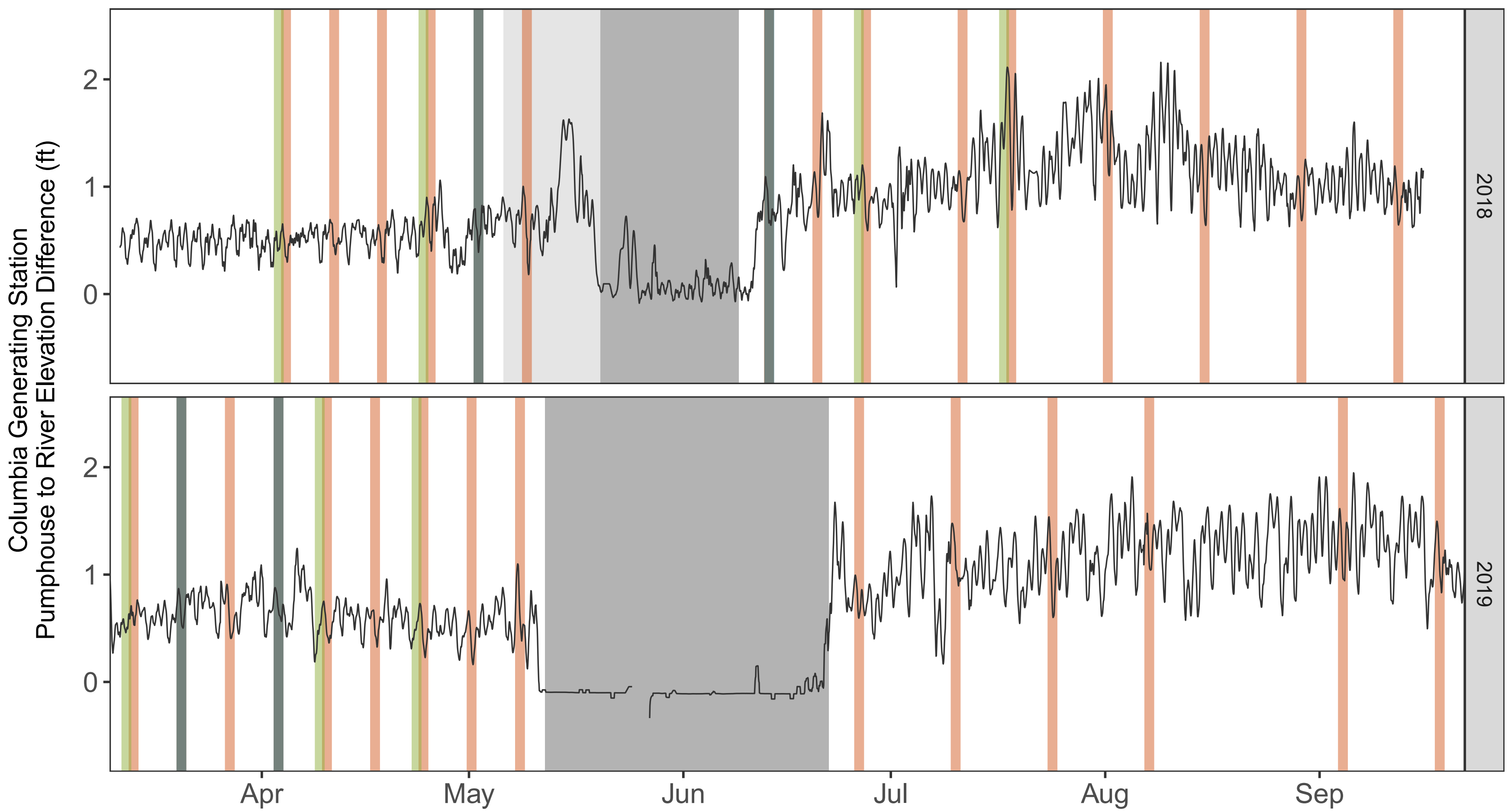

Notes: Columbia Generating Station pumphouse to river elevation difference for study seasons 2018 and 2019 is shown as a 12-hour rolling mean in black. Orange bars represent routine entrainment tests. Blue bars represent a routine entrainment test in which a fish was entrained. Green bars represent cage efficacy tests that began one day prior to routine entrainment tests. Dark grey shaded areas represent periods of limited or non-operation of the Columbia Generating Station. In 2018, three weeks (from 5/20/2018 to 6/9/2018) of low operational capacity and unreliable data occurred because of high Columbia River flow. Additionally, the lighter shaded grey area shows a period from 5/6/2018 to 5/20/2018 during pumphouse water level sensors were unreliable. In 2019, dark grey shading shows the period when the Columbia Generating Station was shut down for six weeks (from 5/12/2019 to 6/22/2019) for operational maintenance.

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Figure 14
Columbia Generating Station Pumphouse to River Elevation Difference

Appendix A
2014 Draft Entrainment Characterization Study Plan for the Columbia Generating Station, Richland, Washington

Entrainment Characterization Study Plan for the Columbia Generating Station Richland, Washington

For National Pollutant Discharge Elimination System (NPDES) Permit No. WA002515-1, Effective November 1, 2014

Energy Northwest
P. O. Box 968
Richland, WA 99352
Attention: Shannon E. Khounnala
sekhounnala@energy-northwest.com

DRAFT

Prepared by
Charles C. Coutant, PhD
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ABSTRACT

This study plan for characterizing fish entrainment at the Columbia Generating Station was prepared in response to stipulation in the reissue of National Pollutant Discharge Elimination System (NPDES) permit No. WA-002515-1 for Energy Northwest's (EN) Columbia Generating Station (CGS). This Permit includes operation of a water intake in the Columbia River for make-up water for the CGS's cooling, fire protection, and potable water systems. The Permit was issued September 30, 2014 (for implementation November 1, 2014) by the Washington State Energy Facility Site Evaluation Council (EFSEC) in coordination with the Washington Department of Ecology, Region 10 of the U.S. Environmental Protection Agency (EPA), and the U.S. National Marine Fisheries Service (NMFS). These agencies had questions about the water intake structure and its efficacy for excluding entrainment of fish, particularly early life stages of Chinook salmon and Steelhead. Extensive consultations were conducted between EN and the NMFS as a consequence of the existing water intake not conforming to NMFS' screening criteria, which were developed primarily from screening of irrigation canals and other intakes unlike the CGS intake. Two entrainment studies conducted at CGS's commissioning in the 1980s were deemed out of date and the present intake screens do not meet current NMFS's screening guidelines.

The proposed Study Plan provides an overview of the CGS; a general description and operating characteristics of the intake system for cooling tower makeup-water on the Columbia River upstream of Richland, Washington; general methods for conducting an updated entrainment characterization study; data management and analysis; and reporting. Methods include sampling period and frequency, general sample collection protocols, and ancillary data collection (e.g., river temperature, river elevation). The study plan includes characterization of the fish present in the area of influence of the intake structure based on a long history of fish studies in the Hanford Reach and near the intake location, and monitoring of entrainment into the cooling system's pump well. EN's standard health & safety, quality assurance, and quality control procedures will be followed for sampling in the CGS pump well. Detailed sampling, data management and analysis protocols will be developed by EN environmental staff and a fisheries contractor following approval of the overall Study Plan by the EFSEC. Although the water withdrawal rate by CGS is lower than the 125 MGD that requires existing power plants to conduct such an entrainment study, this Study Plan is informed by the requirements of the final EPA Clean Water Act §316(b) Rule published August 15, 2014 and follows relevant guidance in the Rule (quoted in Appendix A).

Keywords

Columbia Generating Station
Entrainment
Columbia River
Salmon
Cooling Water Intake Structures
NPDES Permit
Study Plan

PEER REVIEW

A draft of this Entrainment Study Plan was peer reviewed by three experts in biological monitoring and Columbia River fish in accordance with the EPA Peer Review Guidelines (EPA 2006). The reviewers were Dr. Dennis D. Dauble, Dr. Lyman L. McDonald and Mr. Goeff A. McMichael, all who have had extensive experience with Columbia River salmon, including conduct of field studies in the Hanford Reach (Dauble, McMichael) and an internationally recognized biometrician with long tenure of membership on the Northwest Power and Conservation Council's Independent Scientific Advisory Board for the Columbia River Basin Fish and Wildlife Program (McDonald). A summary of their expertise follows. Comments relevant to this draft Study Plan have been incorporated. Following that peer review, a revised draft Study Plan was reviewed by relevant agencies, including the Energy Facility Site Evaluation Council, Washington Department of Ecology, Washington Department of Fish and Wildlife, the Environmental Protection Agency Region 10, and the National Marine Fisheries Service (and others as requested). As a result of that informal review, the scope of the Study has been narrowed to two main components: (1) a summary of fish species and life stage presence and vulnerability to entrainment, and (2) entrainment sampling in the water withdrawn from the intake. The final Study Plan will/does incorporate the formal agency comments on this draft, which will be/are included as Appendix B.

Dr. Dennis D. Dauble. Dr. Dauble retired in 2009 after a 35-year career as a fisheries scientist at Pacific Northwest National Laboratory in Richland, Washington where he focused on Endangered Species issues, fish passage and behavior and aquatic ecological monitoring. He has participated in and directed field studies of salmonids and other species in the Hanford Reach of the Columbia River. He is currently an adjunct professor at the Washington State University branch campus in the Tri-Cities. Since retirement, he has participated in expert science panels on issues relating to salmon survival and water export for the San Joaquin/Sacramento River delta; influence of flow fluctuations on productivity of Hanford Reach fall Chinook salmon; and impacts of potential mining activities on salmon ecosystems of Bristol Bay, Alaska. He is a member of the Independent Scientific Review Panel for the Northwest Power Planning Council and a member of the Monitoring Panel for the Salmon Recovery Board of Washington State.

Dr. Lyman L. McDonald. Dr. McDonald is an internationally known biometrician with over 40 years of experience in the application of statistical methods to design, conduct, and analyze field and laboratory studies. Initially on the faculty of the University of Wyoming, he was a founder and now Senior Biometrician of Western Ecosystems Technology, Inc. (WEST) environmental and statistical consultants. He designed and managed both large and small environmental impact assessments and monitoring programs in terrestrial and aquatic ecosystems including marine environments. He had appointments to regional and national technical advisory and review committees including the Independent Scientific Advisory Board for the Northwest Power Planning Council, the Columbia River Inter-Tribal Fish Commission, and NOAA Fisheries.

Mr. Goeff A. McMichael. Mr. McMichael is a consulting fishery biologist who was employed at the Pacific Northwest National Laboratory (PNNL) between September 1999 and May 2014. Prior to forming Mainstem Fish Research, Mr. McMichael worked on a wide variety of aquatics

projects at PNNL, most recently development and implementation of a new acoustic telemetry system for use on very small fish. Mr. McMichael has been a Project Manager and Principal Investigator for acoustic telemetry projects using the newly-developed Juvenile Salmon Acoustic Telemetry System (JSATS). These projects have addressed critical uncertainties regarding juvenile Chinook salmon and steelhead survival and passage behavior in the Snake and Columbia rivers and in the near shore Pacific Ocean. He has also been Principal Investigator in comprehensive studies of the effects of hydropower operations on the fall Chinook salmon populations in the mid-Columbia River. Extensive evaluations of fish screen performance criteria, and ADCP surveys of water velocities upstream of Grand Coulee Dam are particularly relevant to the CGS entrainment study. Geoff has also been active in other research areas including ecological interactions between hatchery and wild salmonids, behavioral ecology, fish population monitoring, fish capture methods development, input to Ecosystem Diagnosis and Treatment modeling efforts, predator-prey interactions, and electrofishing injury. He managed over $30M in research over the past 15 years and has published over 100 technical reports and papers, including the most cited paper in *Fisheries* for the past three years.

CONTENTS

LIST OF FIGURES

INTRODUCTION

Purpose

This document presents an Entrainment Characterization Study Plan for the Columbia Generating Station (CGS) in accordance with the requirements of a re-issued National Pollutant Discharge Elimination System (NPDES) Permit. On September 30, 2014 the Washington State Energy Facility Site Evaluation Council (EFSEC) published a reissuance of NPDES Permit No. WA-002515-1 for Energy Northwest's (EN) Columbia Generating Station. The final Permit, effective November 1, 2014, was the result of consultations between EFSEC and interested agencies, including the Washington State Department of Ecology, Region 10 of the U.S. Environmental Protection Agency (EPA), and the U.S. National Oceanographic and Atmospheric Administration's National Marine Fisheries Service (NMFS). These agencies had questions about the water intake structure and its efficacy for excluding entrainment (withdrawal) of fish, particularly early life stages of Chinook salmon and Steelhead, through the intake screens (Atkinson 2014). Extensive consultations were conducted between EN and the NMFS through a physical meeting, letters, and e-mail as a consequence of the existing water intake not conforming to NMFS' screening criteria, which were developed primarily from screening of irrigation canals and other intakes unlike the CGS intake (NMFS 2011; Coutant 2014b). Entrainment studies conducted at CGS's commissioning in 1979-80 (Mudge et al. 1981) and 1985 (WPPSS 1985) were considered by NMFS as out of date.

The Columbia River at the CGS site is a migratory pathway for salmonids that reproduce and rear in the upstream reaches. The Hanford Reach (the reach of river extending from the CGS vicinity to upstream Priest Rapids Dam at RM 397.1) is heavily used by spawning fall race of Chinook salmon *Oncorhynchus tshawytscha* and some Steelhead *O. mykiss*. The Hanford Reach is home to one of the most productive stocks of fall Chinook salmon anywhere (Harnish et al. 2014) and is so abundant that there is concern for density dependent limitations to population growth (McMichael and James 2015). These fall Chinook salmon spawn largely in October-November mostly in the upper reaches of the Hanford Reach although some spawn closer to CGS near Ringold (Dauble and Watson 1997; Annual monitoring reports available from the U.S. Department of Energy, Mission Support Alliance Project). Early life stages occupy near-shore rearing areas throughout the Reach mostly April-June. Steelhead spawn in spring, primarily in the discharge of the Ringold hatchery and a nearby irrigation return canal (approximately 2.5 miles or 4 km upstream of the CGS intake and on the opposite shore), but rarely in the main river (Wagner et al. 2014). Early life stages after the emergent fry stage rear in the area in summer. No Steelhead spawning has been identified immediately upstream of the CGS intake. Bull trout *Salvelinus confluentus* occupy the river rarely, limited by the species' requirement for especially cold water (Jeff Chen, USFWS, Section 10 permit unnecessary for Bull Trout per telecom to Shannon Khounnala, May 2012). Sockeye salmon *O. nerka* migrate past the CGS area to upriver hatcheries, spawning and rearing zones while yearling or older juvenile Sockeye salmon migrate downstream past it. Coho salmon *O. kisutch* also migrate past the area to hatchery release locations and habitats upstream of the CGS, with yearling or older smolts migrating downstream. Of these species, three have been identified as federally Threatened (T) or Endangered (E): Upper Columbia River spring Chinook salmon (E), Upper Columbia River Steelhead (T), and bull trout (T) (NRC 2011). The abundant Hanford fall Chinook salmon are not a listed species.

The anadromous Pacific lamprey *Entophenus tridentatus*, with potentially entrainable juvenile stages, is known to spawn and rear in the Hanford Reach and migrate near the CGS intake (Dauble et al. 2006). It is not a listed species.

The reissued Permit requires EN to conduct an Entrainment Characterization Study of its existing cooling-water intake system, with emphasis on potential entrainment of early life stages of Chinook salmon and Steelhead and any threatened or endangered species. A related operational monitoring stipulation requires evaluation of impingement. An entrainment Study Plan is to be submitted to EFSEC for approval by November 1, 2015. Because the CGS uses a closed-cycle cooling system of mechanical draft cooling towers, it is assumed that any fish entrained in the intake structure will not survive in the cooling system. The re-issued NPDES Permit in its entirety is located at:
http://www.efsec.wa.gov/Columbia%20Generating%20Station/EFSEC/CGS-NPDESPermit-Final-ElectronicSignature.pdf

The requirement for an Entrainment Characterization Study states (Page 26):

S12.B. Entrainment Characterization Study
The Permittee must prepare and conduct an entrainment characterization study consistent with the content requirements in 40 CFR 122.21(r) (9).
1. Study design
The Permittee must:
a. Prepare documentation of the proposed entrainment characterization study design and submit it to EFSEC for approval by November 1, 2015. The Permittee must submit a paper copy and an electronic copy (preferably in a portable document format (PDF)).
2. Study implementation
The Permittee must:
a. Following EFSEC approval of the study design referenced in S12.B.1, conduct the entrainment characterization study according to the approved design.
b. Submit the final entrainment characterization study to EFSEC by May 1, 2019. The Permittee must submit a paper copy and an electronic copy (preferably in a portable document format (PDF)).

The results of the Entrainment Characterization Study will be taken into account by the EFSEC for review and possible revision of the existing permit or for application to the next NPDES permit cycle.

Entrainment Studies Under Clean Water Act Section 316(b)

At about the same time as the renewed Permit was being finalized the EPA published (August 15, 2014) the final Clean Water Act §316(b) Rule for cooling-system intake structures at existing power plants. The final Rule presents the compliance options EPA requires for impingement and entrainment control at cooling-water intake systems for existing power plants and other industrial facilities. One of the requirements is for an Entrainment Characterization Study (40 CFR 122.21(r)(9)). The EPA Rule applies to owners and operators of any existing facility that withdraws greater than 125 million gallons per day (MGD) of actual intake flow. This flow rate

is much greater than the maximum 36 MGD of cooling-tower make-up water that is withdrawn by the CGS. Also, legal challenges to the Rule can be expected. Nonetheless, the Rule can be taken as general guidance for any study of entrainment. The Rule's study requirements thus inform the content of an entrainment study plan for the CGS. The EPA's requirements for an Entrainment Characterization Study (40 CFR 122.21(r)(9)) are provided in Appendix A. Details of the full final Rule are available at the EPA website located at http://water.epa.gov/lawsregs/lawsguidance/cwa/316b/index.cfm.

Salient points of the EPA Rule for this Entrainment Study Plan include:

- A minimum of two years of entrainment data collection;
- Documentation of data collection period and frequency;
- Identification of fish that occur in the vicinity of the cooling-water intake structure and are susceptible to entrainment, including any species protected under Federal, State or Tribal law with habitat ranges that include waters in the vicinity of the intake structure;
- Biological collections that are representative of the entrainment in the subject intake;
- Description of spatial and temporal characteristics of fish abundance in the vicinity of the intake (can be based on historical data);
- Description of annual, seasonal, and diel variations in entrainment as related to climate, weather, spawning, feeding and water column migration;
- Entrainment collections that are representative of current operation of the facility (e.g., flows) and biological conditions at the site;
- Documentation of all assumptions and methods used to calculate the total entrainment for the facility;
- Documentation of all study methods and quality assurance/control procedures for data collection and analysis that are suitable for a quantitative survey.

Previous Studies

Studies of salmon spawning, rearing and migration in the Hanford Reach of the Columbia River have been conducted since the early 1950s by the U.S. Department of Energy and its predecessor agencies operating the Hanford Works (e.g., Becker 1970, 1973, 1985, 1990; Becker and Gray 1989; Dauble et al. 1989; Geist et al. 2000; Geist and Dauble 1998; Gray and Dauble 1977a, 2001; and annual monitoring reports available from the U.S. Department of Energy Mission Support Alliance Project, Richland Operations). These studies have documented a generally increasing density of fall Chinook salmon spawning in the Reach as nearly all other reaches of the river were impounded and natural riverine features were flooded (Dauble and Watson 1997; Visser et al. 2002). In the late 1970s, considerable effort was expended on characterizing the fish community, particularly in the vicinity of water intakes for the N Reactor, the adjacent power-production facility, and the site of the planned CGS intake (then called WNP-2; Gray and Dauble 1976, 1977b, 1977c, 1978, 1979a, 1979b; Page et al. 1974). Spatial and temporal distributions were identified, particularly for fall Chinook salmon. These studies also identified salmonids from upper reaches of the Columbia River basin that migrate through the Hanford Reach. These numerous reports have been catalogued and copies are publicly available. Many are cited in NRC 2011. Reports cited here are a partial listing of studies; the Study Plan includes synthesis of these and related documents for relevance to entrainment of fish at the CGS water intake.

Fish entrainment studies have been conducted previously at the CGS. Beak Consultants conducted entrainment studies in May 1979 to May 1980 as part of the Preoperational Environmental Monitoring Program for what was then called the Washington Public Power Supply System (WPPSS) Nuclear Project No. 2 (WNP-2) (Beak 1980; Mudge et al. 1981). No juvenile salmonids were entrained. As a result of review by the EFSEC, WPPSS was required to conduct additional studies during one spring (April-June) out-migration of naturally spawned juvenile salmon when the facility was at or above 75% power load (EFSEC Resolution 214 issued in 1982). Further review by NMFS (Evans 1983) established the study period would extend to September 15 (Sorensen 1983), although recent studies in the Hanford Reach indicate that entrainment sampling to this late date is not biologically relevant. The facility reached approximately 75% thermal (power) load in November 1984 and the studies were conducted in 1985 to fulfill the requirements set forth in EFSEC Resolution No. 214 and to address the concerns of NMFS. The entrainment sampling equipment for each study was the same as described in Mudge et al. (1981) and is largely the same for the current plan. During times when Chinook salmon juveniles were confirmed present in the vicinity by beach seining there were no fish, fish eggs or larvae collected during 294 hours of entrainment sampling with an average sampling period of just under 12 hours per sample (WPPSS 1985).

Fish impingement and biofouling at the intakes were also studied in 1985 using SCUBA divers (WPPSS 1985). On nine occasions between March 13 and December 3 (six of which took place in April-September when juvenile salmonids were likely present) divers inspected and reported any fish impingement on or interaction with the intake structure, the need for maintenance, accumulation of submerged debris and plugging of orifices by attached growths. Videotape logs were made in spring and fall. Although resident fish were seen around the intakes structures, there were no impinged fish found and no fouling by algae, insects, sponges or debris occurred that would impact proper operation of the intakes.

The U.S. Nuclear Regulatory Commission recently prepared a combined biological assessment (BA) and essential fish habitat assessment (EFH) to address the effects of renewing the CGS's operation license on endangered or threatened species or their designated habitat (NRC 2011). This assessment summarized relevant information for NRC's consultation with federal agencies as required by the Endangered Species Act of 1973 and the Magnuson-Stevens Fishery Conservation and Management Act as amended by the Sustainable Fisheries Act of 1996. The combined BA/EFH Assessment examined the potential impacts of the proposed re-licensing action by the NRC on federally listed aquatic species within the NMFS and U.S. Fish and Wildlife Service (USFWS) jurisdictions as well as the designated and revised critical habitat and the EFH. It also described any proposed conservation measures to avoid, minimize or otherwise offset potential adverse effects on designated EFH resulting from the re-licensing. The report's conclusions for species under the Endangered Species Act were: Bull Trout- "no effect"; Upper Columbia River Spring Chinook Salmon and Upper Columbia River Steelhead - "may affect, but is not likely to adversely affect". For other downstream-migrating juveniles from upstream hatcheries or habitats (Upper Columbia River Chinook Salmon and Coho Salmon), the report concluded that the CGS "will have minimal adverse effect." Sockeye salmon and Pacific lamprey were not mentioned. The report considered the CGS's cooling tower system to be "the most reasonable way to mitigate the number of aquatic organisms entrained and impinged" in

comparison with other power plant cooling systems. The NRC's assessment provides valuable background for this Entrainment Study Plan.

This document presents the Entrainment Characterization Study Plan for the CGS in accordance with the requirements of the NPDES Permit. The Study Plan provides an overview of the CGS; a general description and operating characteristics of the cooling-water make-up intake system on the Columbia River upstream of Richland, Washington; general methods for conducting the entrainment characterization study; data management and analysis; and reporting. Methods include sampling period and frequency, general data collection protocols, and ancillary data collection (e.g., river temperature, river elevation). Detailed sampling, data management and analysis protocols will be developed by a fisheries contractor and EN environmental staff following approval of the overall Study Plan by the EFSEC. The Study Plan includes characterization of the fish present in the area of influence of the intake structure, and monitoring of entrainment into the cooling system's pump well. EN's standard health & safety, quality assurance and quality control procedures will be implemented for sampling by EN operations staff and a fisheries contractor at the CGS pump well.

The entrainment monitoring study will concentrate on entrainment of fall Chinook salmon fry. Through consultations with NMFS it is mutually recognized that newly emerged Chinook salmon derived from spawning beds in the Hanford Reach are the species and life stage most likely to be entrained. This is not an ESA-listed species but its population's proximity to CGS, its abundance and its seasonal sizes near the CGS intake make it a useful surrogate for all entrainable fish. It is also in NMFS's regulatory authority through the Magnuson-Stevens Act. Although other species and life stages of fish occur in the vicinity of the CGS intake (as will be identified in the study's literature review), most salmonids including those with ESA listing are large enough that entrainment through the 3/8th-inch diameter pores of the intake would not be possible (Bell 1990; Nordlund 2013a). For example, downstream-migrating juveniles of Chinook (underyearlings >75 mm long and 12 mm deep), Steelhead (wild pre-smolt >125 mm long and 22 mm deep), Sockeye (89-127 mm long) and Coho salmon (yearling or older 89-114 mm) from populations spawning and rearing upstream in or upstream of the Hanford Reach would be excluded by a 3/8-inch mesh (for sizes sampled in the Hanford Reach see Dauble et al. 1989 and other Hanford reports cited above). The effective opening of a 3/8-inch pore that is positioned parallel with a high sweeping flow >1 m/s is likely less than 3/8-inch for passage of particles such as small fish.

STUDY AREA

Plant Description

The Columbia Generating Station is located in south-central Washington State in Benton County adjacent to the Columbia River near River Mile (RM) 352 approximately five miles upstream of the city limits of Richland, Washington **(Figures 1 and 2).** The site is located on leased land in the southeastern portion of the U.S. Department of Energy's Hanford Site. The Columbia River bounds the CGS site on the east side.

The CGS is a single-unit, 1,170-megawatt boiling-water nuclear power plant that began commercial operation in December 1984 (EN 2010; NRC 2011). The reactor produces heat that boils water, producing steam for direct use in a steam turbine, which generates electricity for the Pacific Northwest grid. Steam that exits the turbine is condensed with cool water from a closed-cycle cooling system consisting of six mechanical-draft cooling towers that remove heat from the circulating water and transfer the heat to the atmosphere. A portion of the water in the circuit is lost by evaporation and drift of droplets entrained in air. The evaporative and drift losses lead to concentration of dissolved salts in the cooling circuit, necessitating a gradual replacement of water in the circuit by release of so-called "blowdown" water to the Columbia River. The combined losses from evaporation, drift and blowdown are replenished by so-called "make-up" water pumped from the Columbia River. It is the water intake for the make-up water that is the subject of this Entrainment Study Plan.

The make-up-water pump house is located 3 miles (5 km) east of the CGS reactor complex and approximately 300 ft. (91 meters) shoreward of the river's normal high-water mark at RM 352 **(Figures 3 and 4).** It houses three 800-horsepower make-up water pumps situated in a pump well. The pump well is connected to intake structures in the river by two 36-inch (91-cm) diameter buried pipes that extend 900 ft. (274 m) from the pump house. Entrainment sampling will be conducted in this pump house.

The pumps are designed to each supply 12,500 gallons per minute (gpm) (0.79 m^3/s or 9 million gallons per day [MGD]) or half the system capacity at design head. Two pumps can supply make-up water to the plant with a withdrawal capacity of 25,000 gpm (1.58 m^3/s or 36 MGD) but during normal operating periods, the average make-up-water withdrawal is about 17,000 gpm (1.1 m^3/s or 24.48 MGD). This contrasts with the average mean annual discharge of the Columbia River near the site of 117,823 cfs (3,336 m^3/s or 76.2 BGD) and a minimum mean annual discharge of 80,650 cfs (2,284 m^3/s or 52.1 BGD) (USGS 2010). The average make-up-water withdrawal of 17,000 gpm is thus about 0.03 percent of the average mean annual discharge and 0.05 percent of the minimum mean annual discharge of the river. The period of most concern, mid-March to mid-June when recently emerged Chinook salmon fry of entrainable size are present, is normally the period of highest river discharge, and thus the smallest percentage of river water withdrawn. At these times, 10-year average daily river flows downstream of Priest Rapids Dam (Hanford Reach; 2005-2014) rose fairly steadily from about 100 cfs near March 15 to 190-210 cfs in late May and early June (Columbia Basin Research query on July 23, 2015). The average make-up water withdrawal of 17,000 gpm would have ranged from 0.036% in late March to 0.018-0.020 in late May and early June of this recent 10-year period.

Withdrawal rates actually vary seasonally and hourly. In the April-September period when juvenile fall Chinook salmon of progressively increasing sizes are present in the Hanford Reach, the 2014 monthly average withdrawal rates compared to CGS's maximum withdrawal capacity were: April- 63%, May- 62%, June- 69%, July 75%, August-60% and September- 66%. On a daily basis, water withdrawal rates are highest during the warm hours whereas downstream-migrating Chinook salmon juveniles pass mostly at night (Dauble et al. 1989).

Water velocities within the two 36-inch-diameter intake pipes, with which all make-up water is shared equally, vary with pumping rate. The calculated velocities inside each pipe at a range of flows are (http://irrigation.wsu.edu/Content/Calculators/General/Pipe-Velocity.php):

Flow Rate (GPM), Total System	Flow rate (GPM), Per Pipe	Water Velocity (feet per second)
10000	5000	1.64
15000	7500	2.47
20000	10000	3.29
25000	12500	4.11

Make-up Water Intake Structure

An intake structure is located at the end of each of the buried pipes. The pipes make a 90-degree, upward bend and extend slightly above the surface of the riverbed **(Figures 4 and 5**). Attached to each of the pipes is a 30 ft. (9 m)-long, cylindrical screen housing mounted above the riverbed and approximately parallel to the river flow. Each cylinder is composed of two intake screens each 6.5 ft. (2 m) long and mounted upstream and downstream of a central chamber attached to the buried pipe. Solid cones cap each end of the dual-screen structure **(Figure 6).** The screens consist of an outer and inner sleeve of perforated pipe. The outer sleeve (forming the wall of the cylinder) is 42-in in diameter (107 cm) with 3/8-in (9.5 mm) holes comprising 40 percent of the surface area. The inner sleeve is a 36-in (91-cm)-diameter cylinder with 3/4-in (19-mm) holes comprising 7 percent of the surface area. The double-sleeve intake screens are designed to distribute water flow into the structure evenly along its outer surface.

The dual intake cylinders are located approximately in the main channel of the Columbia River, which is flowing north to south **(Figure 7).** The river at this point has a western main channel and an eastern side channel separated by an island. Upstream of this island the river flow shifts from an eastern channel to the western channel via an area of very swift water. This zone is a minor spawning area for the fall race of Chinook salmon (Dauble and Watson 1997). A small area of suitable habitat for Steelhead spawning has been identified but no spawning activity has been documented there (G. McMichael, peer review comment). The nearest Steelhead spawning occurs in the outflow channel of the Ringold Springs fish hatchery, approximately 2.5 miles (4 km) upstream of the CGS intake and on the opposite shore.

The screens were designed for low through-screen velocities to minimize impingement and entrainment. Under maximum (abnormal) intake operating conditions of 25,000 gpm withdrawn through only one of the two intake structures there was a calculated entrance velocity at each screen pore of 0.50 to 1.1 ft./s (0.2 to 0.34 m/s) (WPPSS 1985). Under minimum operating conditions when 12,500 gpm would be withdrawn from both intake structures the entrance velocities were calculated to be 0.15 ft./s (0.05 m/s). These through-screen velocities compare to measured river velocities (sweeping velocities) of 4 to 5 ft/s (1.22 to 1.53 m/s) across the screen faces and perpendicular to flow into the screen pores.

Entrainment Sampling Location and Operation

Entrainment sampling will be conducted in sampling cages suspended in the intake pump well at the termination of the buried pipes leading from the intake structures in the river **(Figure 8)** (Mudge et al. 1981). Two sampling cages are available, each 1.5 m (5.8 ft.) long, 1.52 m (5 ft.) high and 1.07 m (3.5 ft.) wide. Each cage has a 1.07 m^2 door for coupling with the pipe outlets. The cages have an aluminum frame and door, while the remainder is made of woven stainless steel wire mesh with 2.0-mm square openings. The existing sampling cages will be thoroughly refurbished, as needed, for this study. The cages will be lowered approximately 35 ft. (10.7 m) into the water of the pumphouse sump to the sampling position in direct alignment with the openings of the 36-inch inlet pipes. The cage door automatically opens as it nears the inlet pipe and closes upon initiation of cage retrieval. After the designated sampling time, the cages will be raised the approximately 35 ft. to a Fish Monitoring Access Platform in the pump well where the contents are processed. Tests for the apparatus' effectiveness for capturing entrained fish will be conducted with hatchery fish of approximately the same size as concurrently found in the river that will be added experimentally to the sampling cage and retrieved after the designated sampling interval (as was done in previous studies; Mudge et al. 1981). There is no provision for testing latent mortality (as prescribed in EPA rule for 316(b) entrainment studies) because it is assumed any fish entering the closed-cycle cooling tower system would not survive.

STUDY TASKS AND METHODS

This study plan outlines the tasks and general methods for a 2-year monitoring study focusing on early juvenile Chinook salmon but documenting other entrainable species and life stages, as well. A literature review of abundant prior research in the Hanford Reach will lay the background for the presence and abundance of entrainable fish species and life stages. Samples of entrained fish will be taken weekly mid March through mid June (the risk window for early juvenile Chinook salmon) in the intake pump well and biweekly from July-September in each of two years when the power station is operating at >90% load (intake pumps are generally operating at 60% of the 25,000 gpm capacity or greater at these loads based on recent historical data). One of the two years may exclude a period of reactor outage, which usually occurs from early May through mid June. An independent contractor will conduct the literature review; entrainment sampling will be conducted by EN's Operations personnel (operation of sampling baskets) and an independent fisheries contractor (fish handling and data collection) with oversight and potential participation by staffs of NMFS, and relevant state agencies such as WDFW. The general approach and methods presented here will be augmented by a detailed sampling and analysis protocol (Standard Operating Procedure; SOP) to be developed by EN and its selected study contractor. That protocol will receive additional peer review focusing on statistical issues for sampling and analysis.

Task 1--Historical Fish Occurrence

Identification of fish that are, or likely to be, in the vicinity of the cooling-water intake structure and susceptible to entrainment.

Task 1.A. Using all existing and relevant literature resources and historical data that are reasonably obtainable, document the species, life stages, size classes, seasonal occurrence and general habitat preference of all fish species that do, or likely would, occur in the general vicinity of the CGS intake, including all ESA listed species and all salmonids. Although the monitoring will focus on juvenile fall Chinook salmon, this synthesis will not be as limited. The seasonal and diel abundance and size classes of juvenile Chinook salmon and many other species have been demonstrated in numerous prior studies, so this would be strictly a literature synthesis directed specifically at fishes in the CGS intake vicinity. Suggested sources: field research in the Hanford Reach and near CGS (as referenced above), a compendium of fishes in the Columbia Basin (Dauble 2009) and Washington State (Wydoski and Whitney 2003), and Moser et al. (2015) on lamprey.

Task 1.B. Based on life-stage sizes and proximity to the CGS intake and the physical structure of the intake in relation to river morphology (e.g., vertical and horizontal placement of the intake in the river, hydraulics of flow around a cylinder such as the CGS intakes, pore size of the CGS screens, flow velocities into the CGS screen pores, sweeping river flows at the intakes) identify the species, life stages, size classes, and timing of fish susceptible or vulnerable to entrainment through the outer screen pores. Although not strictly part of the Entrainment Study Plan, identify risks from fish impingement on the screens, also. Published habitat-utilization data from the Hanford Reach and elsewhere can be used to estimate whether fall Chinook fry or parr would be expected to be found in the water flowing 1-3 m/s at the intake. Suggested sources: Bell 1990; NMFS 2011; Nordlund 2013a, b, c; Coutant 2014a including references therein. Particular attention should be given to recent laboratory studies of hydraulic bypass of juvenile (larval) fish around a cylindrical screen oriented parallel to rapidly flowing water (NAI and ASA 2011a, b; ASA and NAI 2012). Recent studies of capped fall Chinook spawning beds in the Hanford Reach showed that fry emerged at sizes of 36 to 42 mm fork length (McMichael et al. 2005; McMichael reviewer).

Task 1.C. Obtain and summarize, via table or figure, the historical water surface elevations and river discharges during the March-June period of potential juvenile Chinook salmon vulnerability to define the occurrence and frequency of extreme low water elevations that could affect entrainment (part of NMFS screen criteria).

Task 2--Fish Entrainment Sampling

Demonstration of the species, life stages and numbers of fish entrained.

The following study features are expected, pending completion of a detailed SOP by a selected fisheries contractor and EN staff.

Task 2.A. Samples of entrained fish will be taken weekly mid March through mid June and biweekly from July-September in each of two years when the intake pumps are operating at 60% capacity or greater (although previous studies required >75% power load, this study uses >60% of maximum pumping capacity since it is water withdrawal rate that influences entrainment). One of the two years may exclude a period of reactor outage, which usually occurs for a few

weeks in May and early June. Each sampling will include both collection cages (as near to concurrent as possible), with data maintained separately for each cage. A sample will consist of a 24-hour collection. Starting and ending times will be coordinated with the facility's shift times, but maintained consistent throughout the study. Following processing (defined below), live fish will be allowed to recover from anesthesia and then returned to the river. Dead fish will be disposed of as organic waste through the CGS Sanitary Waste Treatment system or garbage disposal system. Any identifiable parts of dead fish will be tallied.

Additionally, two sequential 12-hour samples will be taken during normal sampling weeks when there are >20 fish appearing in the entrainment samples. This will identify any differences between daylight and dark entrainment (diel variation). Starting and stopping times will be at approximately dawn and dusk.

Fish collected will be anesthetized and then processed with the following information recorded:

- identification to species and life stage (fish of questionable identity will be preserved in 70% alcohol and referred to a qualified taxonomist for verification)
- lengths of individual fish to nearest mm (if >50 of a species, then a sample of 50 can be taken)
- weights of individual fish to nearest gram (if >50 of a species, then a sample of 50 can be taken)
- any outward signs of damage or disease, which should be described

Task 2.B. The efficacy of the cages for capturing and retaining fish (capture efficiency) is to be established by tests with juvenile hatchery fish twice during each annual sampling period (also see section on Quality Control and Quality Assurance). Juvenile Chinook salmon of the sizes found concurrently in the river will be used. Special arrangements will be made with a supply hatchery to ensure the proper sizes at the test times (to adequately represent the size of fish in the wild, hatchery fish may need to be grown at cooler temperatures and/or lower feed levels than at local production hatcheries). All test fish will be marked (e.g., coded fin clip). For these tests, an open container of at least 100 hatchery fish will be placed in each sampling cage immediately prior to its lowering into the sampling position. These fish will escape the container when the cage is submerged in the pump well and attached to the end of the intake pipe. After the regular sampling time of 24 hours the cage will be raised and the number of marked fish remaining in the cage will be counted. The sampling cage will be deployed for the next 24 hours (as part of regular sampling) and any marked fish that appear (presumed to have moved into the intake pipe during the test of capture efficiency) will be added to the catch in the capture efficiency test. It is unlikely that either entrained fish or control fish will remain in the piping from the intake to the pump well due to the high water velocities in the pipe (velocities are about 3 ft/sec at the typical withdrawal volume for the total system of about 17,000 gpm; see table above). Although visual monitoring of escaped fish with video cameras or DIDSON has been suggested, mounting the equipment in the pump well would be physically difficult and unlikely to be allowed with Nuclear Regulatory Commission regulations for existing water intakes. All regular capture data will be adjusted upward by the percentage of introduced fish not recaptured (i.e., if only 90% of the hatchery fish are recaptured in the efficacy tests, the number of fish in monitoring collections will be increased by 10%).

Task 2.C. Ancillary data will be collected hourly by CGS for each sampling period including river elevation and discharge, direction of change of river stage (rising or falling), river water temperature, number and duration of pumps operating, make-up-water volume pumped, weather, and any abnormal operating or riverine conditions. River stage is routinely monitored by the CGS; river temperature will be monitored at the City of Richland's Snyder Street potable water intake located about 3 miles downstream of the CGS with backup data from the USGS monitoring station 12514400 at the Hwy 395 bridge at Pasco, WA. Hourly and daily withdrawal volumes will be provided for the entire April-September period in order that the sampled entrainment can be extrapolated to total annual entrainment and per unit volume of water pumped.

Task 3--Fish Impingement and Debris Monitoring

Demonstration of any clogging of the screens by fish impingement or debris.

A separate Operations and Maintenance Plan for the CGS includes periodic observations to detect impinged fish and debris on the intake screens. In addition to these observations, there will be at least hourly comparison of water elevations of the river (Task 2.C.) and in the pump house well (routinely monitored; real time and historical data are available) to identify any abnormal differential that could be attributed to clogging of the intake screens. Significant clogging would likely influence the through-screen velocities by increasing velocities of non-clogged pores, which would affect likelihood of fish being entrained or impinged. This task would consist of making these O&M observations available for analysis and reporting with the entrainment data.

Task 4--Data Summaries and Analyses

Raw data for each entrainment sampling event will be assembled in electronic logs using Microsoft Excel or equivalent spreadsheet suitable for sharing with agencies. Tabular summaries will be prepared that include total numbers and relative abundance by species, life stage and size class. Plant-supplied operating data will be summarized hourly for each entrainment-sampling event. Water-withdrawal volumes also will be summarized on a weekly basis for the April-June and biweekly for July-September. Data will be preserved on electronic media (e.g., external hard drive).

Depending on the final set of methods established with a fisheries contractor, additional detail will be necessary in the SOP to clearly describe how data will be processed and analyzed, and expanded or extrapolated to species and life stages of interest. Protocols are needed for sampling and analyses. The planned SOP will be reviewed for acceptable precision (e.g., are sample sizes large enough, what coefficients of variation are expected, statistical procedures). These details will be reviewed by Dr. McDonald.

Loss estimates from the entrainment sampling will be placed in the context with the prolific and well-studied Hanford Reach fall Chinook salmon population. This will be done using recent redd counts, anticipated yield from each redd, and estimated numbers of Chinook salmon fry exposed to the CGS intake. Entrainment of other species will also be placed in the context of population sizes, to the extent possible.

Task 5--Reporting

An Entrainment Characterization Report, due to EFSEC on or before May 1, 2019, will document the current entrainment of all life stages of fish and any fish species protected under Federal, State, or Tribal law (including threatened or endangered species). Recognizing the general importance of the EPA §316(b) Rule for such studies, the report will [italics quote the Rule]:

- identify and document *"all methods and quality assurance/quality control procedures for data collection and data analysis";*
- present and discuss all ancillary data, including "*the flows associated with the data collection*";
- describe the fish composition in the entrainment samples, "*including a description of their abundance and their temporal and spatial characteristics in the vicinity of the cooling water intake structure(s)*";
- note the presence of any fish species protected under Federal, State, or Tribal law (including threatened or endangered species, and in this case including the fall Chinook salmon), "*including a description of their abundance and their temporal and spatial characteristics in the vicinity of the cooling water intake structure(s)*" and put loss estimates from entrainment into context with this presence and abundance;
- provide size (length) distributions for the commonly entrained species;
- provide entrainment estimates for all species combined and by species and life stage, and "*identify and document all assumptions and calculations used to determine the total entrainment*";
- assume 100 percent mortality for all taxa entrained;
- "*characterize annual, seasonal, and diel variations in entrainment*"; and
- provide appendices with (or otherwise make available) all raw data, including plant operating and other ancillary data.

PERMITS

Energy Northwest will request appropriate permits from regulatory agencies in a timely manner. The following permit is expected to be required for the study plan: WDFW Transport Permit (for hatchery fish to be used for tests of capture efficiency of the sampling baskets).

QUALITY ASSURANCE AND QUALITY CONTROL

Quality Assurance (QA) is an integrated system of management activities that involves planning, implementation, assessment, reporting, and quality improvement to ensure that data are of the type and quality necessary for application to their intended use. Quality control (QC) is the

system of activities that measures the QA program activities to verify that they meet project specifications. In addition to requiring QA/QC procedures, the EPA Rule has set some objectives for data quality by stating that the sampling and analytical methods must be appropriate for a quantitative survey.

This study plan for CGS provides the site-specific document that presents the study design, methodologies, and guidance from sample collection and processing through data analysis and reporting, as well as the QA/QC activities and health and safety concerns. It provides the mechanism whereby EN, its contractors, peer reviewers and responsible agencies may raise and resolve questions and concerns pertaining to the study design (e.g., methodologies, gear specifications, data analysis, reporting content/format) prior to the start of the study, thereby minimizing the potential for disagreements and misunderstandings after the study is completed.

The SOP manual will be established prior to collecting entrainment and other samples. This study plan will form the basis of the SOP and will be augmented by the addition of project-specific checklists, datasheets, forms, and instructions on how to fill them out, review them, and store them. The SOP will also provide a more detailed ("cookbook") approach for mobilization, communication, sample collection, sample processing and identification, data management, QA/QC procedures and documentation, and health and safety. The SOP will be written in a concise, step-by-step, easy-to-read format. Information will be conveyed clearly and explicitly to remove any doubt as to what is required. The following sections provide general discussions of key components for the QA/QC section of the SOP.

All equipment used during the entrainment characterization study will be calibrated and/or maintained according to established procedures or manufacturer's recommendations. Calibrations will be appropriately documented and maintained in the project file. Equipment for this study that will require calibration includes, at least, the pump house fish monitoring facilities (see Task 2).

All sampling personnel, whether EN staff, contractors or participating agencies (e.g., NMFS or WDFW), will be expected to have read and have on hand at all times a copy of the SOP. The SOP will provide all sample collection procedures, and an equipment checklist so that the personnel have all the appropriate equipment needed for sampling. All sampling personnel and/or other visitors will be in the presence of EN's Operation and E&RP personnel who are required to brief on relevant health and safety information, including emergency response actions (see Health and Safety Section).

Data will be managed to avoid errors and loss. Hard copy field and in-plant data sheets will be entered into an appropriate (e.g., Microsoft Access) database and then imported into a statistical (e.g., SAS) database if needed. SAS (or equivalent) programs will be used to create proof sets that will be double checked against the hard copy field and laboratory data sheets. This process will be documented on a data processing log sheet and kept as part of the project file. Only documented programs will be used to generate tabular summaries that will be imported into a Microsoft Office (Excel) product to produce tables and figures for the report.

A senior scientist familiar with entrainment characterization will write the Entrainment Characterization Report. This will be an EN contractor. The report will undergo a three-step

review process before being provided to the EFSEC: 1) contractor senior technical review, 2) at least two external peer reviewers (if available, the same reviewers who reviewed the study plan), and 3) EN technical and management review.

HEALTH AND SAFTY

EN and contractor personnel may potentially be exposed to a variety of hazards because of the industrialized nature of the study area. Safety is of the utmost importance to EN, therefore no personnel will be required to or instructed to work in surroundings or under conditions that are unsafe or dangerous to his or her health. At least one EN staff member will be present for all sampling/data collection events. All EN employees and contractor personnel will be responsible for complying with EN's applicable safety requirements, wearing prescribed safety equipment such as Personal Protective Equipment (PPE), and preventing avoidable accidents. In particular, when personnel are on plant property, appropriate safety gear (e.g., hard hats, safety glasses, ear protection) will be used as prescribed by EN.

Any chemicals brought into the study areas (e.g., formalin, alcohol) will be handled in accordance with EN's Chemical Management procedures and their respective material safety data sheet (MSDS), which will be included in an appendix of the SOP. Work will not be conducted or will be suspended if a chemical spill occurs that contaminates the work area.

All personnel will be expected to follow all safety procedures applicable to CGS. Applicable requirements in EN Industrial Safety Program Manual (ISPM) will be incorporated specifically or by reference in the SOP. Additionally all sampling personnel and/or other visitors will be in the presence of EN's Operation and E&RP personnel for each sampling visit and will be briefed on relevant health and safety information, including emergency response actions.

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FIGURES

Figure 1 Location of CGS, 50-mi (80-km) Region

(Source: EN, 2010)

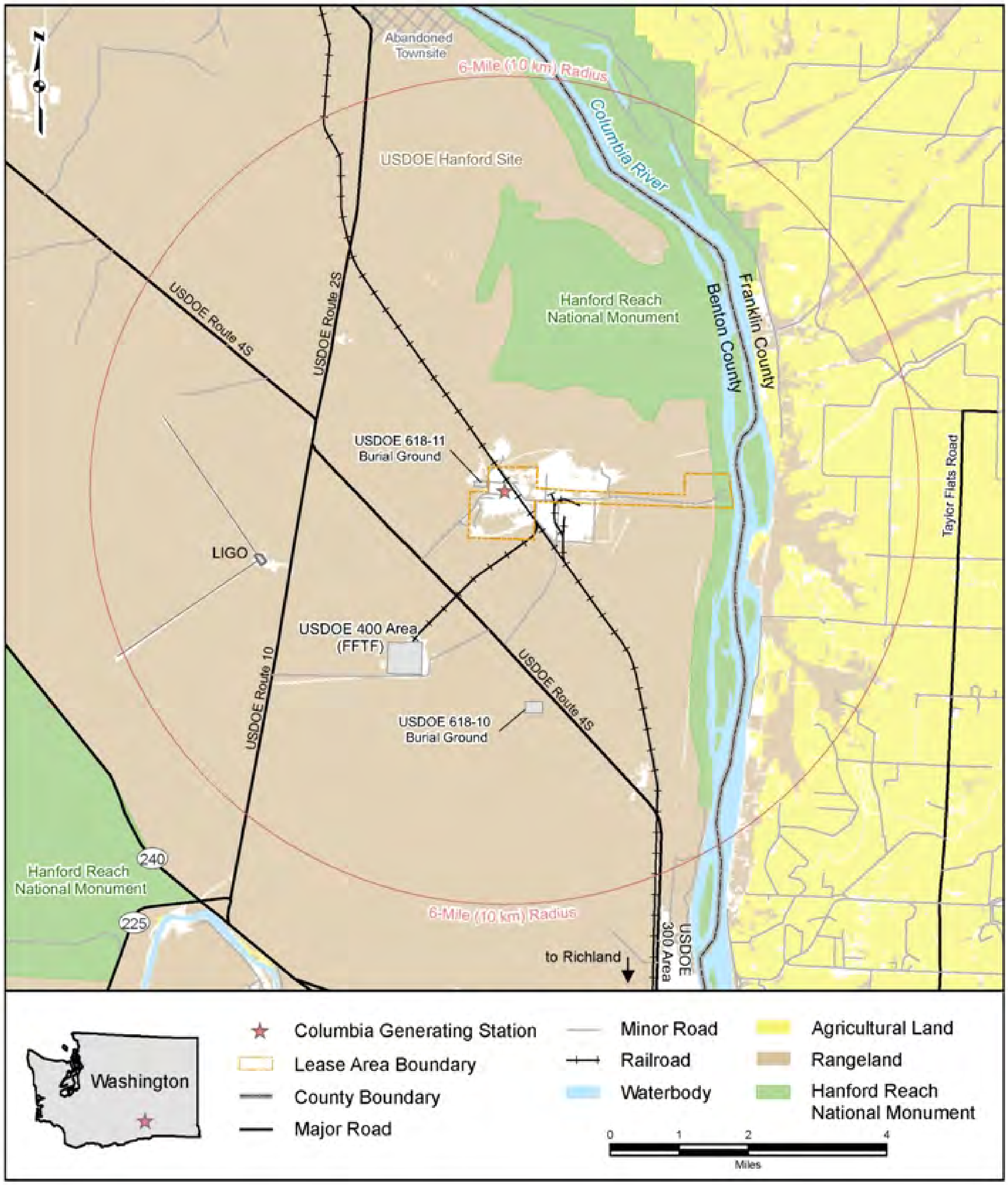

Figure 2 Location of CGS, 6-mi (10-km) Region

(Source: EN, 2010)

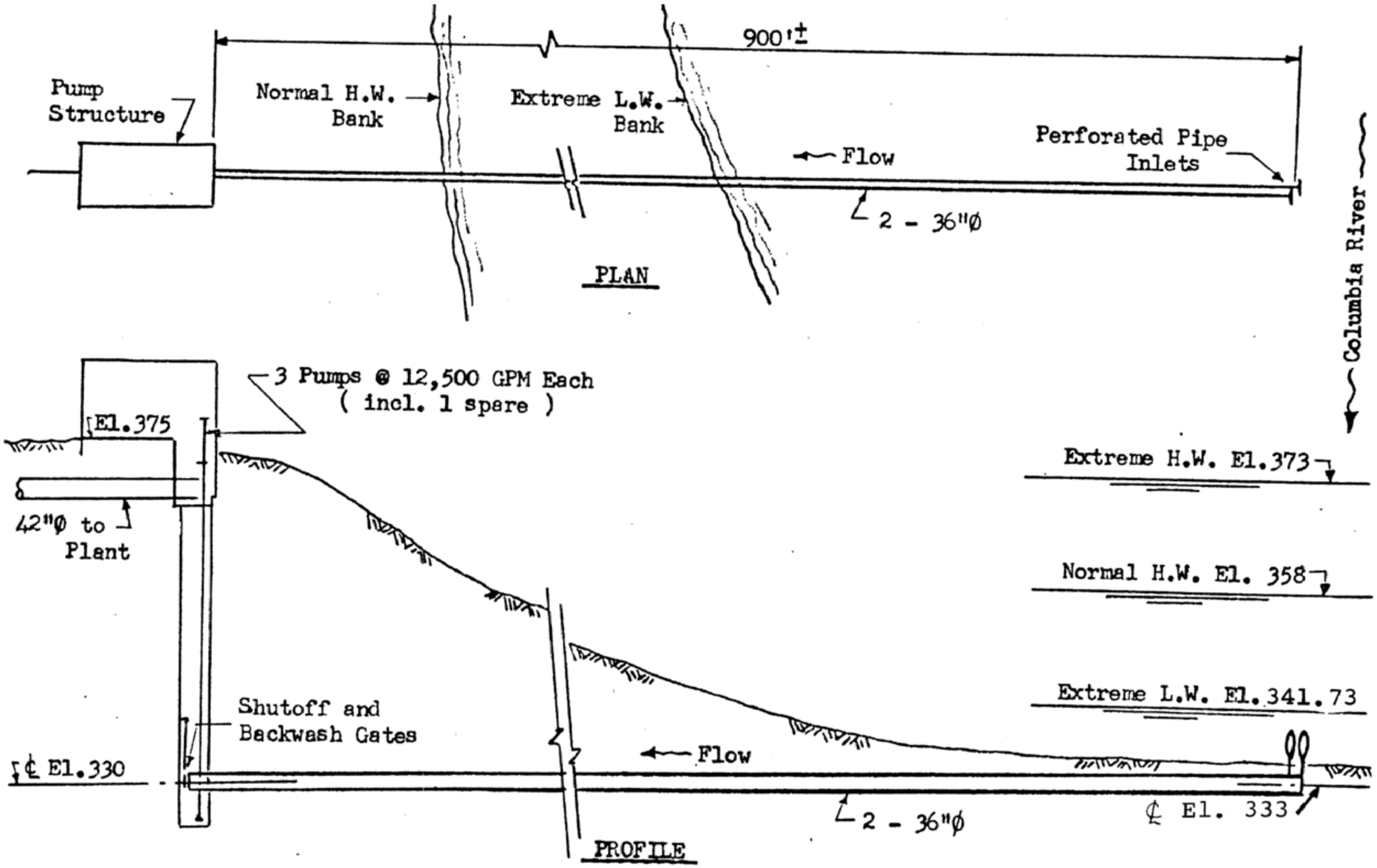

Figure 3 Intake system plan and profile

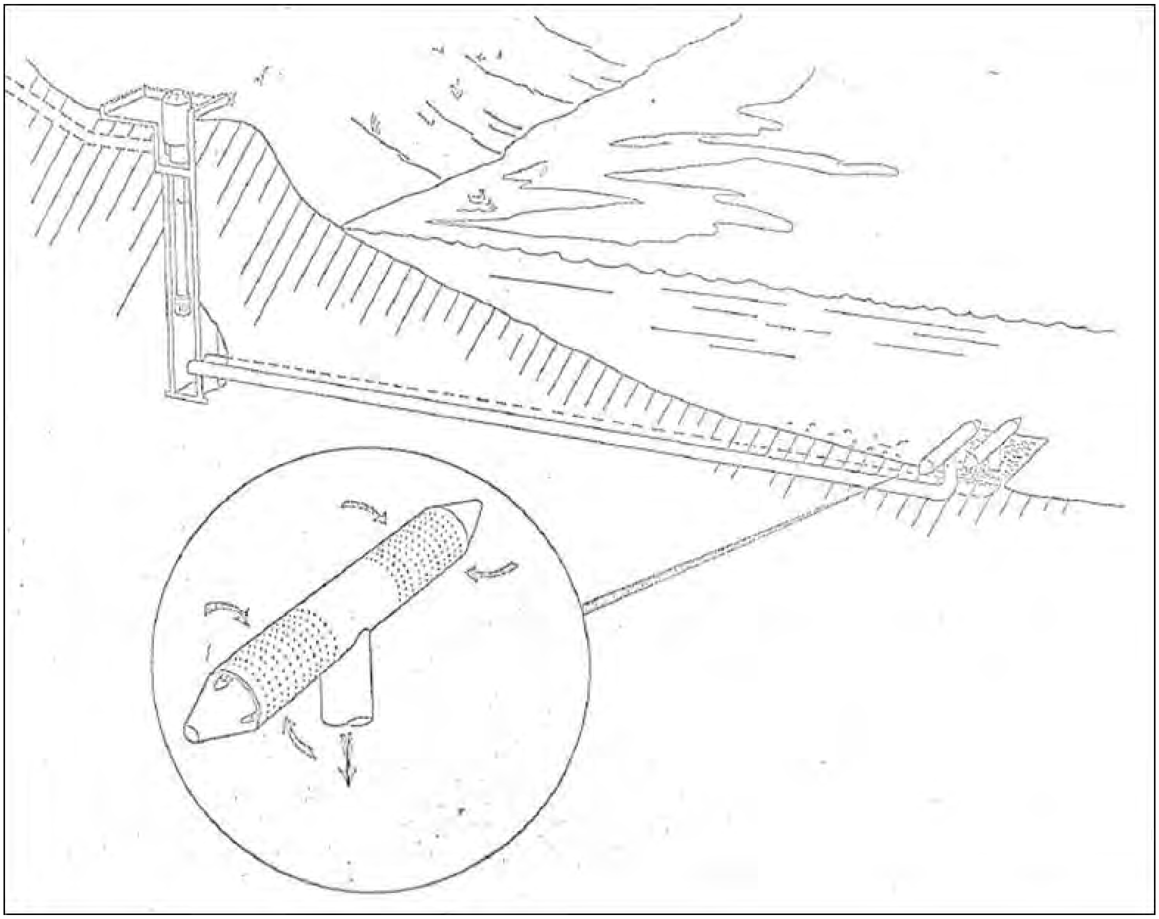

Figure 4. Artists rendering of the cooling-water intake system of the Columbia Generating Station from the in-river intake screens to the pump house.

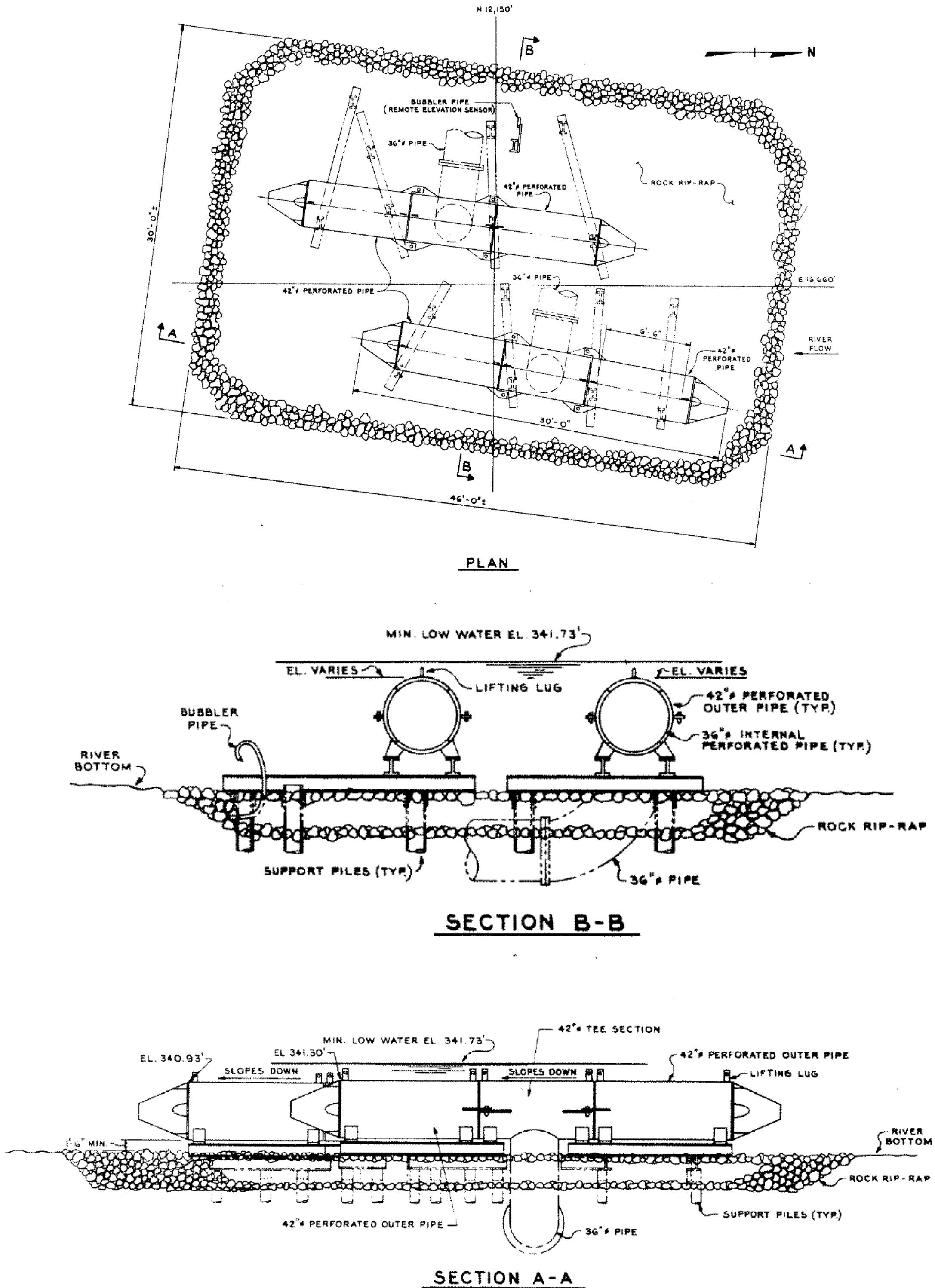

Figure 5 Perforated intake plan and section

Source: (WPPSS, 1980)

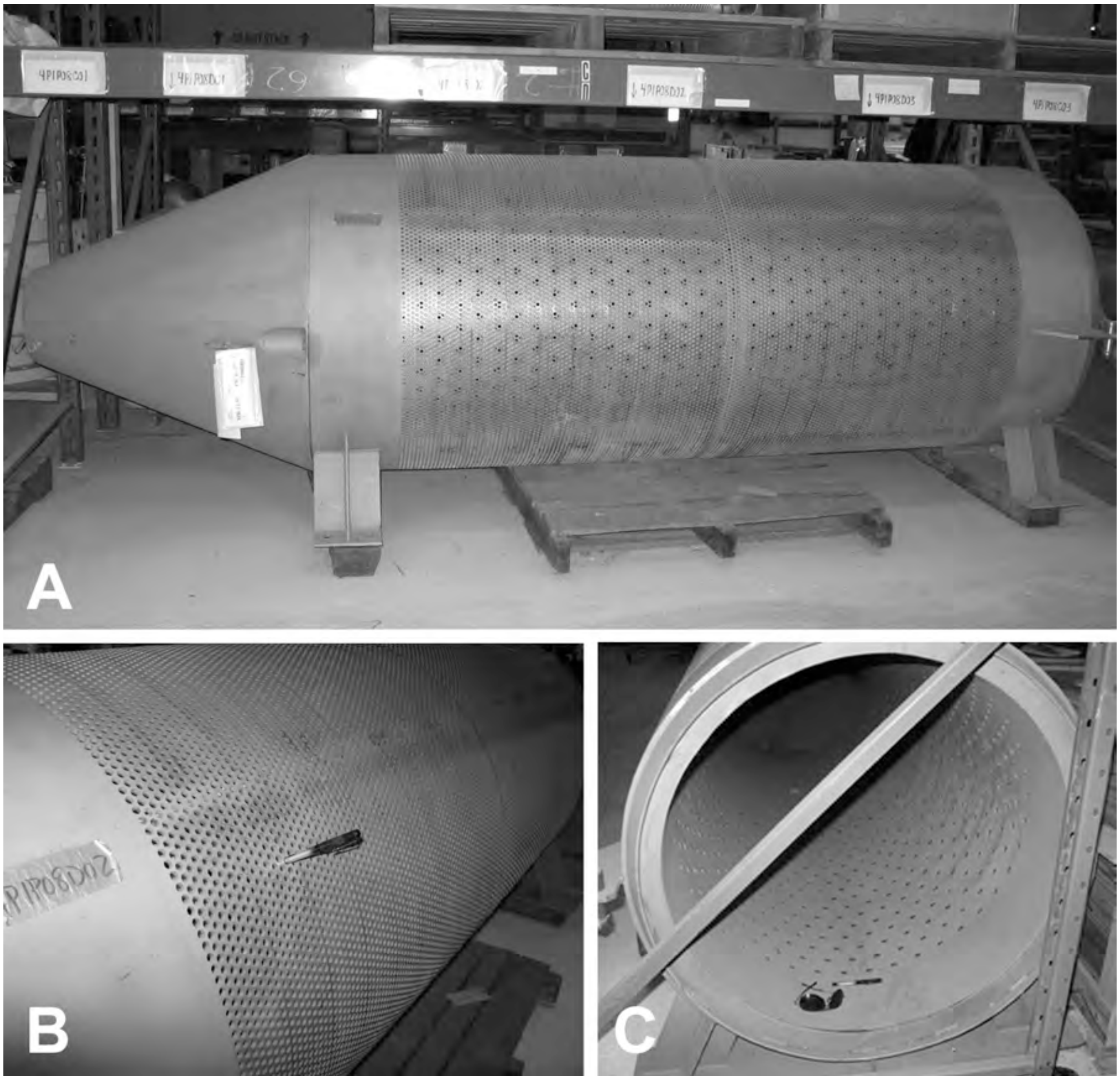

Figure 6 Spare perforated pipe for the intake screen at CGS. "A" side view; "B" close up of outer sleeve; and "C" end view showing inner sleeve of perforated pipe.

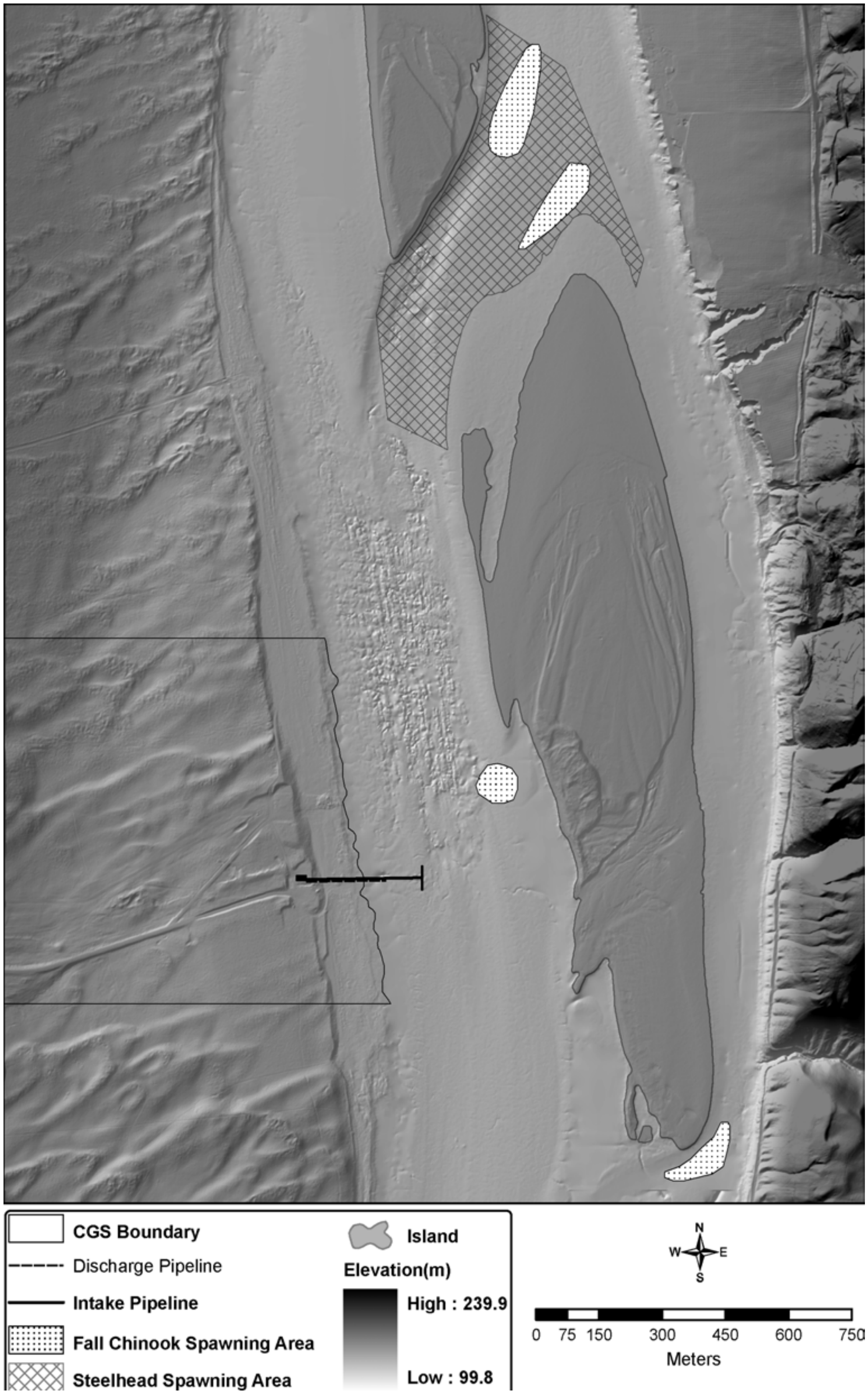

Figure 7 Location of pumphouse, pipelines, intakes, and outfalls showing historical steelhead and fall Chinook salmon spawning locations

Source: (Gambhir, 2010), (Poston, et al., 2008)

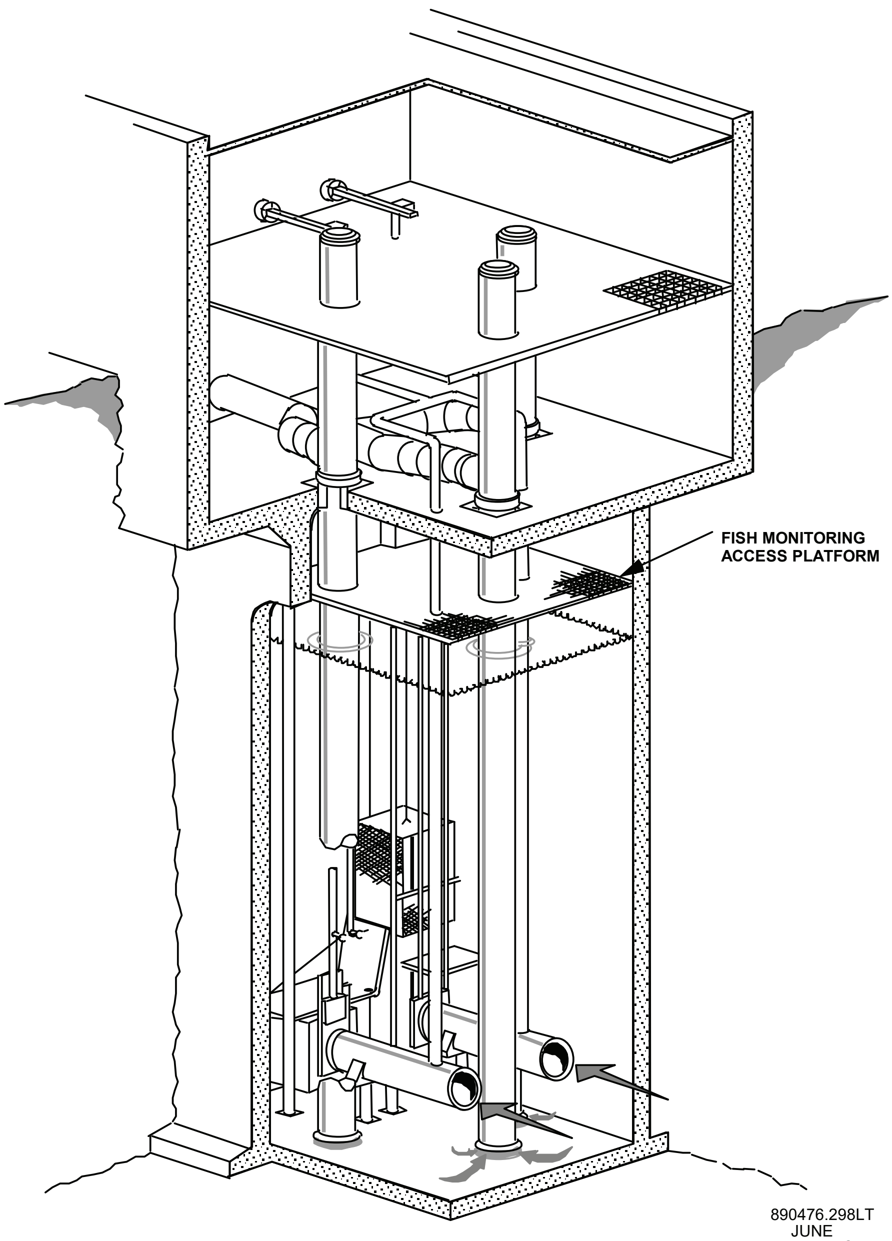

Figure 8--Diagram of fish entrainment monitoring cages in CGS pumphouse.
Fish sampling cages attached to the terminal ends of the buried pipes carrying water from the in-river intake structures and are raised to a monitoring platform above the water surface for fish counting.

APPENDIX A. EPA §316(b) RULE REQUIREMENTS FOR AN ENTRAINMENT CHARACTERIZATION STUDY

The final EPA Rule for implementing Clean Water Act Section 316(a) contains a number of requirements for an Entrainment Characterization Study (§122.21(r)(9)) that inform the CGS study plan (although not required due to lower water withdrawal by the closed-cycle cooling system):

> "*[t]he owner or operator of an existing facility that withdraws greater than 125 mgd AIF [actual intake flow], where the withdrawal of cooling water is measured at a location within the cooling water intake structure that the Director deems appropriate, must develop for submission to the Director an Entrainment Characterization Study that includes a minimum of two years of entrainment data collection. The Entrainment Characterization Study must include the following components:*
>
> *(i) Entrainment Data Collection Method. The study should identify and document the data collection period and frequency. The study should identify and document organisms collected to the lowest taxon possible of all life stages of fish and shellfish that are in the vicinity of the cooling water intake structure(s) and are susceptible to entrainment, including any organisms identified by the Director, and any species protected under Federal, State, or Tribal law, including threatened or endangered species with a habitat range that includes waters in the vicinity of the cooling water intake structure. Biological data collection must be representative of the entrainment at the intakes subject to this provision. The owner or operator of the facility must identify and document how the location of the cooling water intake structure in the waterbody and the water column are accounted for by the data collection locations;*
>
> *(ii) Biological Entrainment Characterization. Characterization of all life stages of fish, shellfish, and any species protected under Federal, State, or Tribal law (including threatened or endangered species), including a description of their abundance and their temporal and spatial characteristics in the vicinity of the cooling water intake structure(s), based on sufficient data to characterize annual, seasonal, and diel variations in entrainment, including but not limited to variations related to climate and weather differences, spawning, feeding, and water column migration. This characterization may include historical data that are representative of the current operation of the facility and of biological conditions at the site. Identification of all life stages of fish and shellfish must include identification of any surrogate species used, and identification of data representing both motile and non-motile life-stages of organisms;*
>
> *(iii) Analysis and Supporting Documentation. Documentation of the current entrainment of all life stages of fish, shellfish, and any species protected under Federal, State, or Tribal law (including threatened or endangered species). The documentation may include historical data that are representative of the current operation of the facility and of biological conditions at the site. Entrainment data to support the facility's calculations must be collected during periods of representative operational flows for the cooling water intake structure, and the flows associated with the data collection must be documented. The method used to determine latent mortality along with data for specific*

organism mortality or survival that is applied to other life-stages or species must be identified. The owner or operator of the facility must identify and document all assumptions and calculations used to determine the total entrainment for that facility together with all methods and quality assurance/quality control procedures for data collection and data analysis. The proposed data collection and data analysis methods must be appropriate for a quantitative survey."

APPENDIX B. AGENCY COMMENTS ON DRAFT STUDY PLAN

Appendix B
Sampling and Analysis Protocol

March 2018
Columbia Generating Station Entrainment Investigation

Sampling Analysis Protocol

Prepared for Energy Northwest

March 2018

Columbia Generating Station Entrainment Investigation

Sampling Analysis Protocol

Prepared for
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23 South Wenatchee Avenue
Wenatchee WA, 98801

Project Number: 171376-01.01

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ABBREVIATIONS

CGS	Columbia Generating Station
ISPM	Industrial Safety Program Manual
m^2	square meter
m^3	cubic meter
m/s	meter per second
mm	millimeter
MS-222	Tricaine Methanesulfonate
O&M	Operations and Maintenance
QA/QC	Quality Assurance and Quality Control
SAP	Sampling and Analysis Protocol definition
USGS	U.S. Geological Survey

1 Introduction

The Sampling and Analysis Protocol (SAP) is intended to provide a detailed ("cookbook") approach for mobilization, communication, sample collection, sample processing and identification, data management, Quality Assurance and Quality Control (QA/QC) procedures and documentation, and health and safety associated with entrainment monitoring and other sampling at the Columbia Generating Station (CGS). The SAP is organized to address these topics.

2 Sampling Design and Methods

Sampling and design methods were developed to be consistent with those described in Coutant (2014) and build upon entrainment studies conducted for CGS's commissioning in 1979-1980 (Mudge et al. 1981) and in 1985 (WPPSS 1985).

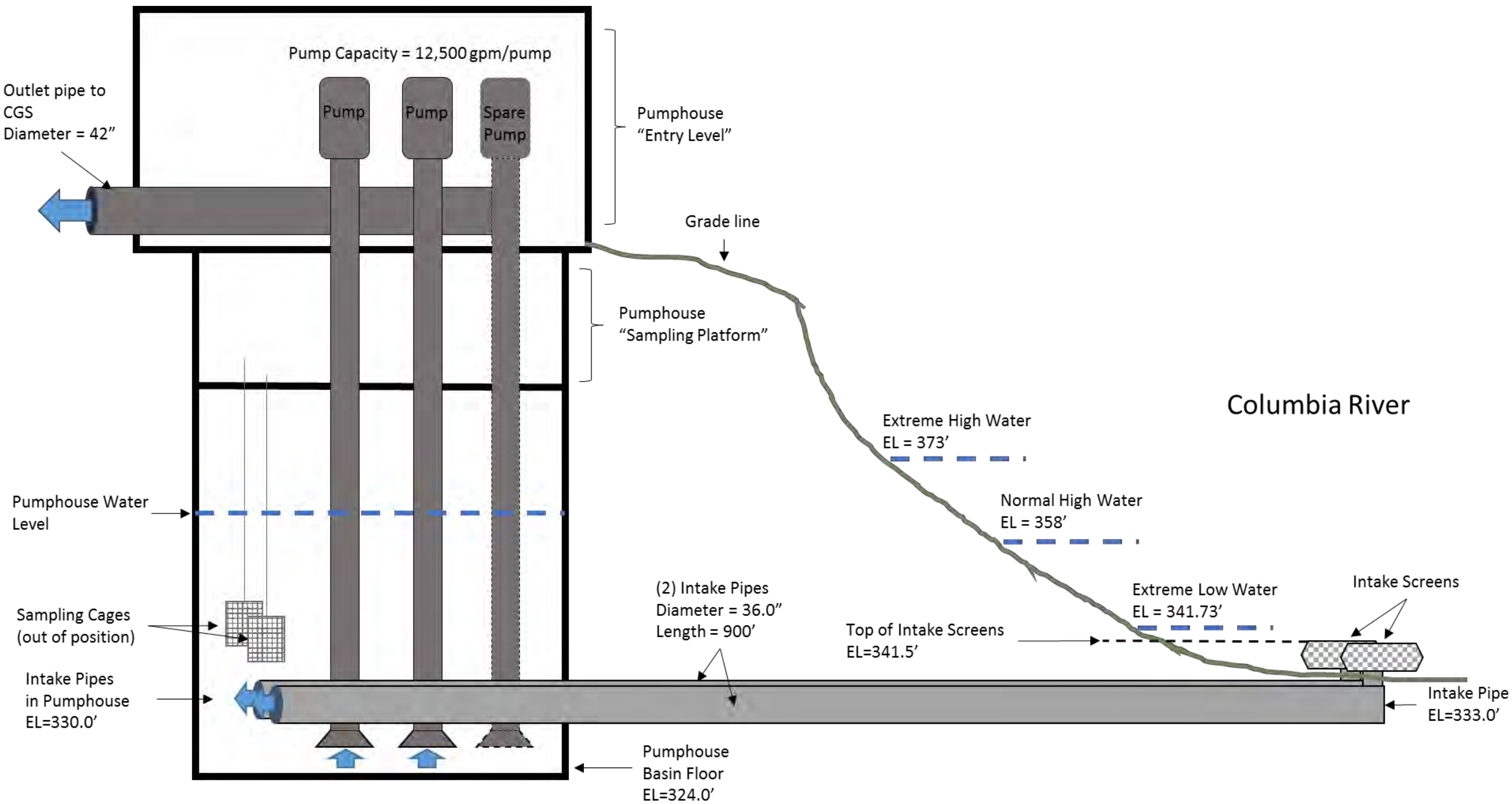
2.1 Fish Entrainment Sampling

The SAP covers three different sampling protocols (1) "Routine Entrainment Sampling," which provides raw weekly and biweekly capture data to estimate entrainment rates; (2) "Contingency Sampling," which provides an expanded characterization of diel entrainment patterns; and (3) "Cage Efficacy Sampling," which is used to generate a correction factor for entrainment rates based on the retention efficiency of the cages. These three protocols and related analyses are described below.

2.1.1 Routine Entrainment Sampling

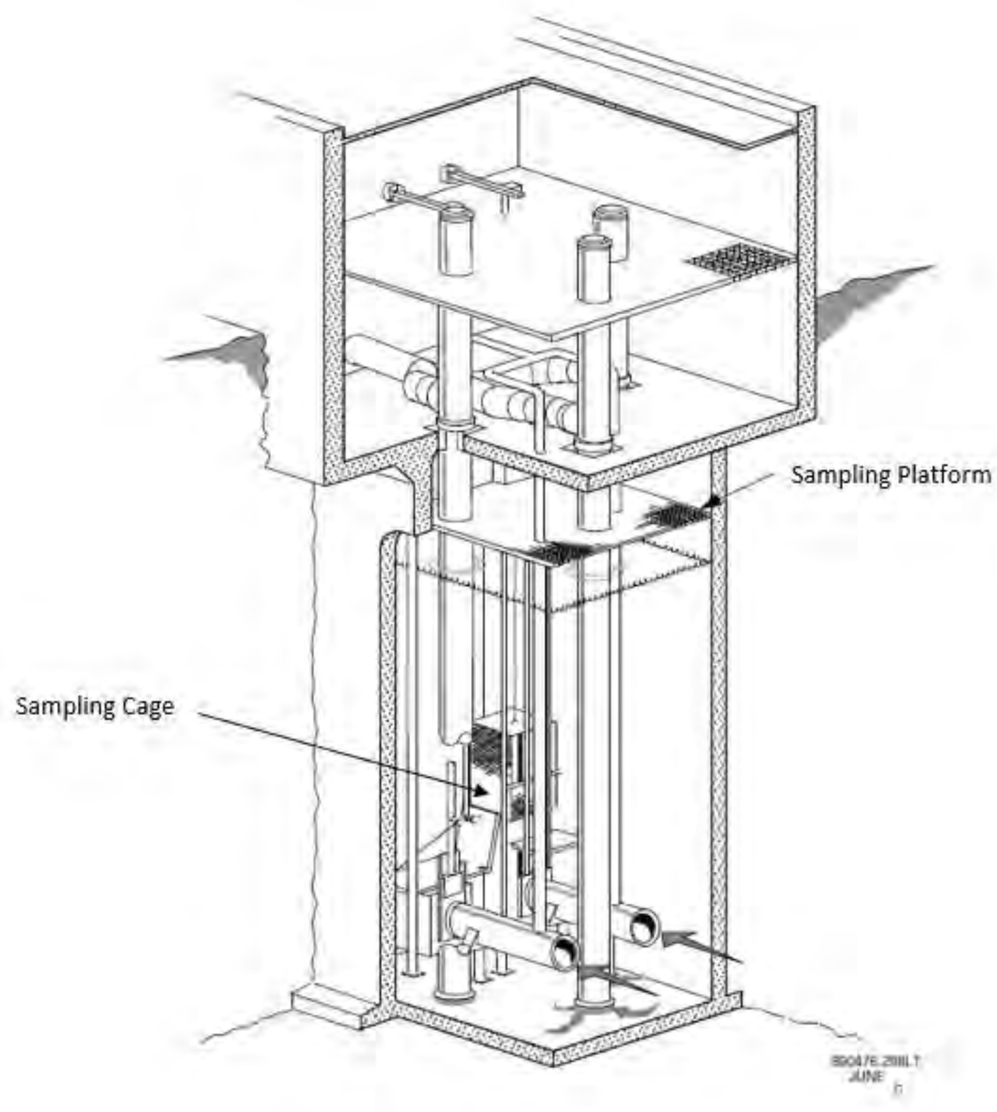
Entrainment sampling will be conducted at the CGS make-up water pumphouse building, located at River Mile 352 on the Columbia River. The pumphouse building has two levels: an upper level, referred to here as the "Entry Level"; and a lower level where sampling occurs, referred to here as the "Sampling Platform." The general layout of the pumphouse, intake pipes, and screens is depicted in Figures 1 and 2.

Figure 1
General Layout of Columbia Generating Station Make-up Water Pumphouse Building



Notes:
Drawings are not to scale and are intended to highlight the general orientation of the facility relative to intakes and screens.
Large blue arrows depict the direction of pumped water conveyed through the pumphouse building.

Figure 2
Detail of Sampling Cage in Columbia Generating Station Make-up Water Pumphouse Depicting the Relative Location of Cages to Intake Pipes



2.1.1.1 Methods

Two sampling cages will be used for entrainment sampling. Cages will be lowered and raised (Figure 2) with electric motors; the door to each cage will be raised and lowered via a rope connected to the top of the door. The cages will be designated as "Cage 1" and "Cage 2" based on the orientation depicted in Figure 3.

Figure 3
Sampling Cage Locations at Sampling Platform

Schedule

Routine entrainment sampling in 2018 will occur once per week during the early-April to mid-June period; during the July to early September period, sampling will occur once every other week. CGS staff will deploy the cages on Wednesday mornings (approximately 9 a.m.), with cage retrieval to occur 24 hours later on Thursday mornings. In the event more than 20 fish are captured in any sampling event (based on the combined count from both cages) additional contingency sampling will commence (Section 2.1.2).

Three separate cage efficacy tests will be conducted concurrently with routine sampling on dates that span the typical fall-Chinook emergence period (Table 1). The methods for cage efficacy sampling are described in Section 2.1.3 below.

Routine Entrainment and Cage Efficacy sampling in 2019 will occur during the mid-March to September period at the same weekly/biweekly frequency; however, specific dates will be identified closer to the 2019 sampling period to align with CGS operations.

Table 1
2018 Proposed Sampling Schedule

Sampling Dates[a]		
Start	**Finish**	**Notes**
Wednesday, April 4, 2018	Thursday, April 5, 2018	Cage Efficacy
Thursday, April 5, 2018	Friday, April 6, 2018	Efficacy Follow-up + Routine
Wednesday, April 11, 2018	Thursday, April 12, 2018	Routine
Wednesday, April 18, 2018	Thursday, April 19, 2018	Routine
Wednesday, April 25, 2018	Thursday, April 26, 2018	Cage Efficacy
Thursday, April 26, 2018	Friday, April 27, 2018	Efficacy Follow-up + Routine
Wednesday, May 2, 2018	Thursday, May 3, 2018	Routine
Wednesday, May 9, 2018	Thursday, May 10, 2018	Routine
Wednesday, May 16, 2018	Thursday, May 17, 2018	Cage Efficacy
Thursday, May 17, 2018	Friday, May 18, 2018	Efficacy Follow-up + Routine
Wednesday, May 23, 2018	Thursday, May 24, 2018	Routine
Wednesday, May 30, 2018	Thursday, May 31, 2018	Routine
Wednesday, June 6, 2018	Thursday, June 7, 2018	Routine
Wednesday, June 13, 2018	Thursday, June 14, 2018	Routine
Wednesday, June 27, 2018	Thursday, June 28, 2018	Routine
Wednesday, July 11, 2018	Thursday, July 12, 2018	Routine
Wednesday, July 25, 2018	Thursday, July 26, 2018	Routine
Wednesday, August 8, 2018	Thursday, August 9, 2018	Routine
Wednesday, August 22, 2018	Thursday, August 23, 2018	Routine
Wednesday, September 5, 2018	Thursday, September 6, 2018	Routine

Note:
a. Contingency sampling will occur if more than 20 individual fish are captured during a routine sampling session.

Cage Deployment and Retrieval

On the Wednesday morning of a sampling event, CGS staff will lower both sampling cages from the Sampling Platform approximately 35 feet into the pumphouse sump directly in alignment with the openings of the inlet pipes. The cage doors will then be opened to allow access for any fish entrained in the intake pipes. A clipboard will be located on the Entry Level adjacent to the ladder that accesses the Sampling Platform to record the date and time that each cage is lowered (see data forms in Appendix B) into the pumphouse sump.

After a 24-hour sampling period (i.e., Thursday morning), Anchor QEA staff will meet with CGS staff at the pumphouse to conduct fish retrieval and sampling activities. Prior to retrieving the sampling cages, Anchor QEA and CGS staff will set up a small sampling station on the Entry Level of the

pumphouse where fish identification and other sampling activities will be conducted. Sampling at this location will minimize the risk of having fish or sampling materials fall through the grated floor of the Sampling Platform.

After the sampling station is set up on the Entry Level of the pumphouse, CGS and Anchor QEA staff will descend to the Sampling Platform (Figure 3) to retrieve fish from the cages.

Accessing the Sampling Platform will require walking on surfaces that may be wet or uneven. Special care should be taken to ensure solid footing. In addition, there is a ladder that is used to climb down from the Entry Level to Sampling Platform. Special caution should be used to ensure hand and foot placement during travel up or down the ladder. A visual inspection of travel routes inside the pumphouse will be important to avoid any tripping hazards or colliding with low hanging pipes. The transport of any gear up and down the ladder will be planned in advance and discussed with CGS operators to ensure that the gear is secured properly and doesn't interfere with hand or foot placement.

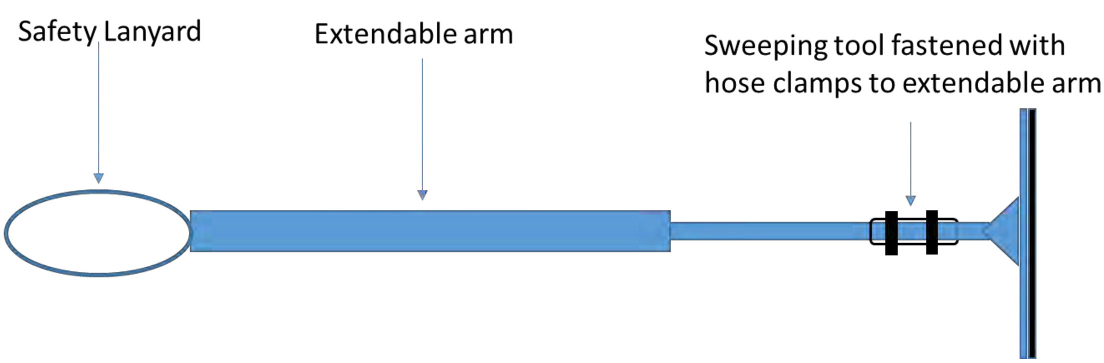
All personnel will empty pockets and remove loose items from their person such as jewelry, wallets, keys, cell phones, and other items not necessary to perform the job, and leave in a tray at the sampling station. In addition to the required personal protective equipment (work boots, hard hat, gloves, eye protection, and hearing protection), the ear plug type hearing protection must have attached lanyards to prevent the ear plug from becoming foreign material. The lanyards are not to be cut or removed. Clear plastic or glass items are not to be taken down to the Sampling Platform unless deemed necessary to perform the work. Items are to be conspicuously marked so they can be clearly seen in the area, including if submerged in water. A CGS supplied floor covering will be spread across the deck of the Sampling Platform near the cages so that nothing will fall through the grating.

One sampling cage at a time will be raised to inspect the interior and retrieve any fish that are present. After the cage is pulled to the surface, Anchor QEA and CGS personnel will verify that the cage locking pin is in place (Figure 4). This is a critical step to ensure that the cage does not unexpectedly drop while fish are being sampled.

Fish will be retrieved from the cages with sweeping, vacuum, or grabbing tools mounted on extension poles (Figure 5). Cages will be sprayed down with pressurized water or air to dislodge debris and move fish into areas within the cage that are accessible. The purpose of this approach is to maximize safety by minimizing the need to physically bring hands, arms or clothing into the cage.

Figure 4
Image of the Cage Locking Pin Securely Placed

Figure 5
Diagram of Extendable Fish Retrieval Tool



All fish retrieved from the cages will be placed in a 5-gallon bucket and transported to the sampling station on the Entry Level of the pumphouse. Fish will be processed from one cage at a time. If no fish are observed in Cage 1 or counting has been completed for Cage 1, Cage 2 will be raised and

the identical protocol will be followed. Once sampling is completed, Anchor QEA and CGS staff will visually inspect the cages to ensure trap integrity and the cages will be stored in place until the next test date.

Data Collection

Fish retrieved from the sampling cages will be transferred from a 5-gallon bucket to a container with Tricaine Methanesulfonate (MS-222) to be euthanized. Anchor QEA staff will collect the following measurements on the Fish Entrainment Form (Appendix B):

- Identification of species and life stage
- Weight (grams) for the first 50 of a species
- Fork Length (mm) for the first 50 of a species
- Notation of any outward signs of damage or disease and a description

Fish identification will follow a hierarchical approach where focal taxa are always identified to the species level and other fish are identified to genus level (Table 2).

Table 2
Fish Identification Hierarchy

Fish Encountered	Identification Level
Focal Species • Bull trout • Steelhead • Chinook salmon • Lamprey • Sturgeon • All other salmonids	Species Level
Other fish species	Genus Level

Any fish of questionable identity will be photographed and then preserved in 70% ethanol and subsequently examined in a lab setting for distinguishing morphological or meristic characteristics using regional fish identification keys (e.g., Pollard et al. 1997 or PSMFC 2009).

Fish that are not retained for further identification will be disposed of as organic waste through the CGS Sanitary Waste Treatment or garbage disposal systems.

Equipment Required

The following equipment will be located on the Sampling Platform for fish sampling:

- Five-gallon buckets

- A rope or chain for fastening the bucket to the rail and preventing the bucket from being dropped in the sump
- Long-handled tools to remove the fish from the sampling cages
- Floor cover to prevent fish or material from falling through the grating into the vault

The following equipment will be used on the Entry Level of the pumphouse for sampling:

- Sampling station (table)
- MS-222
- Small mesh aquarium nets for transferring fish
- Sampling tubs for anesthetic and fresh water
- Measuring boards
- Weighing scales

Communication

All sampling activities will be coordinated between Anchor QEA staff and Energy Northwest Staff. Anchor QEA will provide a weekly email update on routine sampling activities and will contact Energy Northwest directly if there are any changes or deviations from the regular sampling schedule or activities. The project representatives and contact information is described in Table 3 below.

Table 3
Project Representative Contact Information

Organization	Representative	Contact Information
Energy Northwest	Shannon Khounnala Department Manager	Work Phone: (509) 377- 8639 Cell phone: (509) 619-8338 Email: sekhounnala@energy-northwest.com
	Wayde (Kip) Whitehead Project Manager	Work Phone: (509) 377-8794 Cell phone: (801) 989-1844 Email: wkwhitehead@energy-northwest.com
Anchor QEA	Larissa Rohrbach Project Manager	Cell Phone: (253) 820-3467 Email: lrohrbach@anchorqea.com
	Kristi Geris Field Lead	Cell Phone: (360) 220-3988 Email: kgeris@anchorqea.com
	Arial Evans Field Biologist	Cell Phone: (747 242-0951 Email: aevans@anchorqea.com

2.1.2 Contingency Sampling

If more than twenty fish total are captured in a 24-hour routine sampling event, contingency sampling will occur. Immediately after the fish are processed as in Section 2.1.1, the sampling cages

will be redeployed. Instead of a 24-hour sampling period, however, fish will be collected in two sequential 12-hour shifts representing a "day" period and "night" period to identify any diel variation in entrainment. The purpose is to determine if there are diel differences in entrainment rates. Sampling would correspond to the following time periods, and most likely occur from Thursday morning until Friday morning:

- "Day" Period: Dawn to dusk (approximately 12 hours; cages will be raised, sampled, and redeployed)
- "Night" Period: Dusk to dawn (approximately 12 hours; cages will be raised, sampled, inspected, and stored until the next sampling event)
- Sampling methods will be identical to those described in Section 2.1.1, with the exception of sampling timing

2.1.3 Cage Efficacy Sampling

The efficacy of the sampling cages for capturing and retaining fish will be evaluated with juvenile hatchery fish during three trials conducted during each sampling year (2018 and 2019). The purpose of this sampling is to create a correction factor that can be applied to the seasonal entrainment estimate (Section 4).

2.1.3.1 Methods

Cage efficacy trials will be conducted during the period between March and June when wild juvenile fall Chinook salmon (*Oncorhynchus tshawytscha*) are expected to be abundant in the Hanford Reach. Individual trials will occur concurrently with scheduled routine entrainment sampling events (Table 1).

Anchor QEA will coordinate with the hatchery supplying the trial fish in 2018-19 and it is anticipated that the Ringold or Columbia Basin Hatchery, operated by the Washington Department of Fish and Wildlife, will be the primary source. Juvenile salmonids of similar size to juvenile fall Chinook salmon found concurrently in the Columbia River will be used for the trials. Rainbow trout (*O. mykiss*) and Chinook salmon (*O. tshawytscha*) are expected to be available and small enough to appropriately represent the size of juvenile fall Chinook salmon expected to be in the study area.

The size of juvenile fall Chinook salmon in the vicinity of the CGS intake can be inferred by examining previous studies. Work conducted by Harnish et al. (2014), Hoffarth et al. (2003) Dauble et al. (1989) collected juvenile fall Chinook salmon from the Hanford Reach in nearshore areas using a variety of sampling approaches including seines. Dauble et al. (1989) also collected juveniles in deeper, mid-river areas using fyke nets. Each of these studies had an implicit goal of documenting the representative size of juvenile Chinook salmon in the Hanford Reach to support analyses concerning broader population-based questions. Additionally, these studies temporally overlapped with the focal period of the current proposed CGS entrainment study where post emergent fall Chinook salmon are expected to be present (March to June).

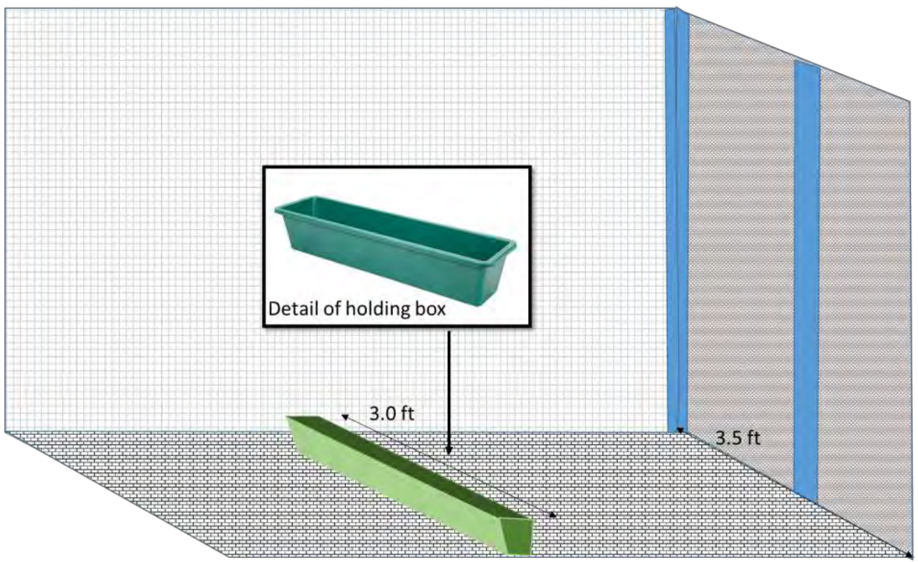
Based on a review of these literature sources, the average size of natural fall Chinook salmon in the study area is expected to be less than 50 millimeters (mm). These results were observed in both nearshore and deeper portions of the Hanford Reach. For the purpose of testing the efficacy of the CGS traps, fish at or below 50 mm best represent the size of fish expected to present near the CGS intake.

In 2018, juvenile salmonids[1] that are 40 to 50 mm in length will be obtained from Ringold Hatchery for implementation of the cage efficacy trials. Juveniles will be marked at the Hatchery with Bismark brown dye prior to conducting cage efficacy trials. Anchor QEA staff will coordinate with the staff at the hatchery to ensure that fish are thermally tempered based on the estimated water temperature in the pumphouse. The temperature in the pumphouse will be estimated by reviewing the water temperature at the U.S. Geological Survey (USGS) Monitoring Station 12472800 at the Columbia River below Priest Rapids Dam. In addition, after the fish are delivered to the CGS facility, the water temperature will be checked in the transport container and the pumphouse and any differences between the two water sources will be recorded. If necessary, on-site tempering will be performed through the serial addition of pumphouse water to the fish transport container water until the temperatures are within 2°C. Tempering will reduce the likelihood of shock or mortality occurring when fish are placed in the cages and introduced to the intake water.

Following tempering, fish will be counted into and transported via 5-gallon buckets from the transport container to the Sampling Platform. Each cage will be outfitted with one holding box placed on the floor of the cage (Figure 6). A total of 100 marked salmonids will be transferred to the holding box within each cage using a water-to-water conveyance system that consists of a large diameter funnel and hose (Figure 7). The cage door will be closed at this time and will remain closed until the cage is lowered the approximate 35 feet into the sump area and attached to the ends of the intake pipes, when the cage door will be opened. The date, time, cage number, and number of marked fish will be recorded. Once the first cage is deployed, the process will be repeated for the second sampling cage. Identical information will be recorded for the second cage as it is deployed.

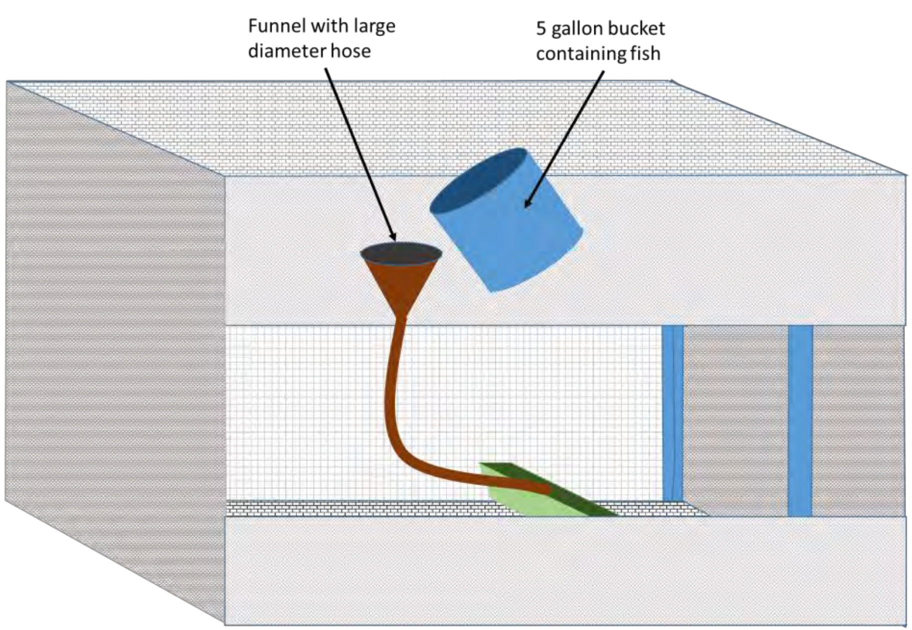
[1]Rainbow trout or Chinook salmon are expected to be available and in the size range needed to support the cage efficacy trials

Figure 6
Cut-away Interior View of Sampling Cage Illustrating the Approximate Placement of Holding Boxes on the Cage Floor



Notes:
Holding box volume = 1728 cubic inches = 7.48 gallons

Figure 7
Interior View of Sampling Cage Illustrating Transfer of Fish from 5-gallon Bucket to Holding Box



After being deployed for 24 hours, the cages will be retrieved and the remaining marked fish will be enumerated. Fish will be retrieved from each cage and transported to the Entry Level for counting and data recording. All of the marked fish used in the cage efficacy trial will be euthanized. No salmonids will be released into the Columbia River.

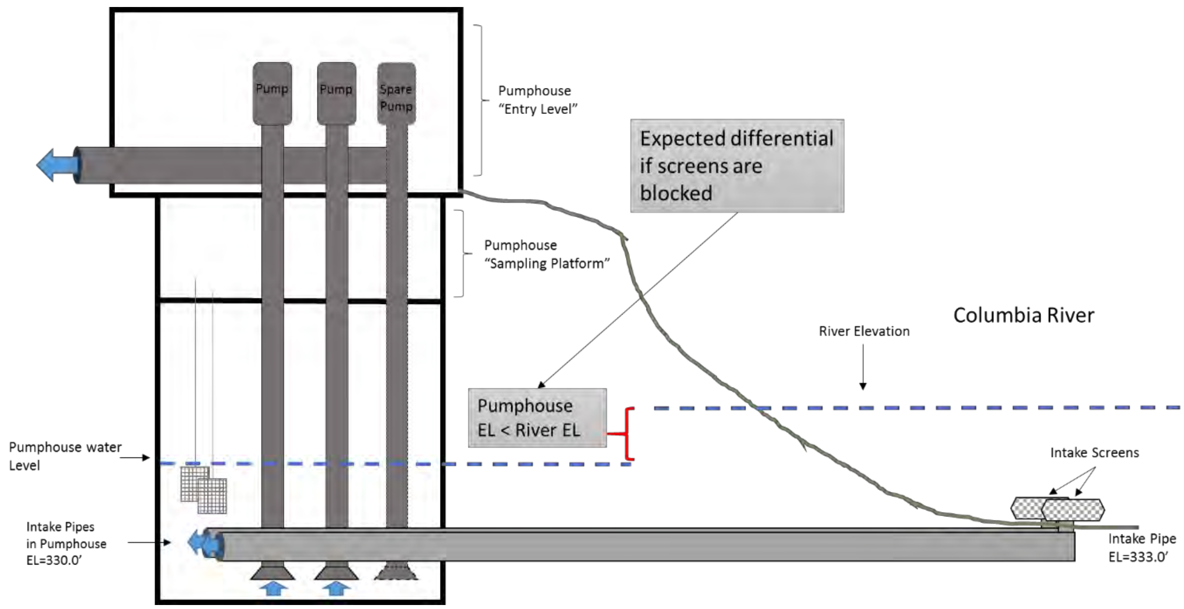
The sampling cages will be re-deployed for the next 24-hours as part of routine weekly sampling and any marked fish that appear may be added to the catch of the cage efficacy test (presumed to have moved into the intake pipe during the test of capture efficiency).

The results of the three cage efficacy trials conducted each year will be used to confirm adequate (>80%) and equivalent cage efficacy rates between the two replicate cages and to develop a single averaged correction factor (*C*) that will be applied to calculations of entrainment (Section 4.3.1).

3 Fish Impingement and Debris Monitoring

A separate Operations and Maintenance (O&M) Plan for CGS includes periodic observations to detect impinged fish and debris at the intake screens. Data to be collected include, at a minimum, real time and historical hourly comparisons of water surface elevations in the Columbia River and the pumphouse well. Differences in elevations (Figure 8) could indicate intake screen clogging, which could result in higher velocities in unclogged areas.

Figure 8
Simplified Diagram of Expected Differential between Pumphouse Water Elevation and Columbia River Elevation when Screens are Blocked



The estimated blockage of the screen will be characterized using the observations from the separate CGS debris monitoring study and differentials in water elevations between the pumphouse and Columbia River. The interaction between assumed screen blockage and estimated pore velocity at the screen at an observed intake flow will be graphed relative to NOAA Fisheries-screening criteria. Figure 9 depicts this hypothetical relationship based on Equation 1.

A qualitative log of the amount of debris retained on cages over the 24-hour sampling events will be kept.

As part of the fish impingement study, the Columbia Generating Station also evaluates the intake structure twice per year for evidence of impinged fish, algae growth and accumulated debris on the intake structure's screens located in the Columbia River. This information will be obtained as an aid to evaluate the amount of debris accumulated on the intake screens.

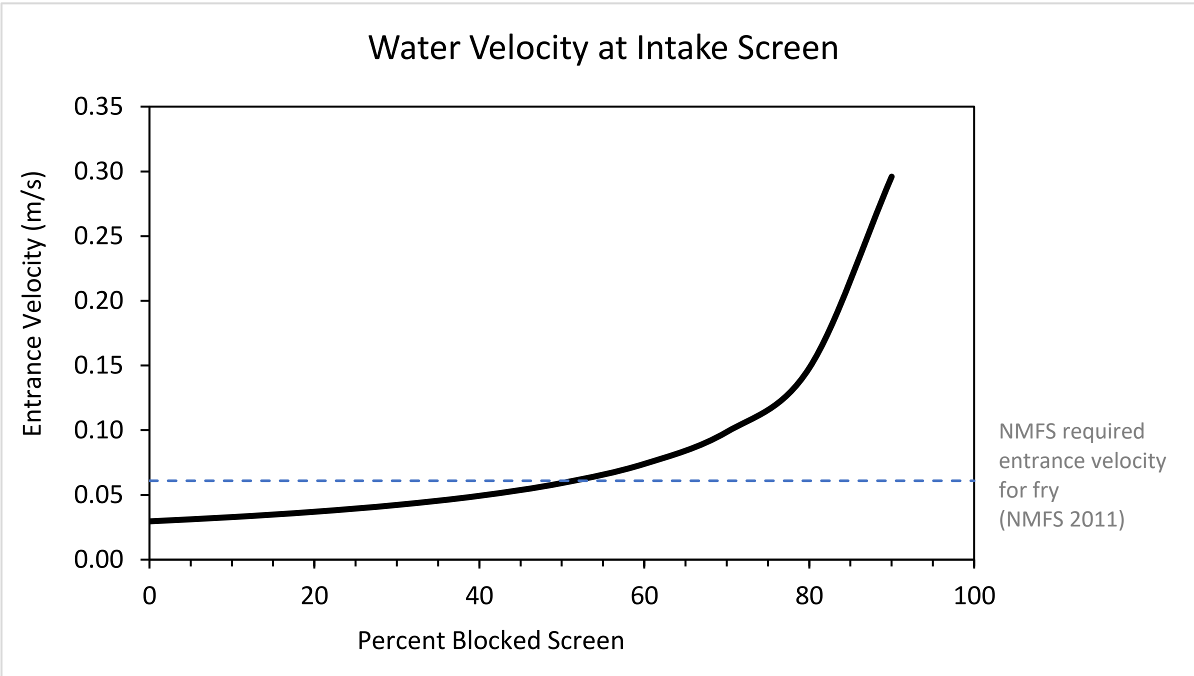
Equation 1

$$V_{ent} = \frac{Q}{A_{eff} * (1 - b)}$$

where:

A_{eff}	=	effective screen area (square meters [m^2])
b	=	proportion screen area blockage
Q	=	intake flow (cubic meters per second [m^3/s])
V_{ent}	=	entrance velocity (meters per second [m/s])

Figure 9
Generalized Relationship Between Screen Blockage and Entrance Velocity at Constant Intake Volume



Notes:
m/s: meters per second

4 Data Summaries and Analyses

This section of the SAP describes the data summaries and analyses that will be provided to characterize entrainment and the operating conditions and environmental variables that may interact with entrainment.

4.1 Data Management and QA/QC

Spreadsheet forms for entering data collected during fish entrainment sampling will be designed prior to the start of field work and will include field validation to enforce data integrity rules (e.g., enforce correct data types and values). Field personnel will be instructed in correct data entry protocols and data entries will be checked for quality control after each field event. Once checked the field forms will be stored on a server on Anchor QEA's network that is backed up daily to protect against data loss due to file corruption or disk failure. Operational and environmental data provided by CGS or obtained from the USGS website will be obtained in spreadsheet or delineated text file (e.g., CSV) format. Once these files are acquired, they will also be stored on a secured location on Anchor QEA's network. At the end of each field season project data will be compiled in a Microsoft Access relational database. Reporting queries will be developed to extract data from the database in tabular format for analysis and reporting (Table 4).

4.2 Data Summaries

In addition to fish sampling data, other operational and environmental data will be collected and characterized to provide data summaries and analyses related to entrainment. These data and their sources and applications are described in Table 4. Operational and environmental data summaries will be provided for each sampling event.

Table 4
Data Sources Used for Entrainment Analyses and Data Summaries

Data	Data Source	Application
Weekly/biweekly fish sampling data (species capture information)	Anchor QEA	Daily, weekly, and seasonal entrainment estimates (fish/m^3)
Pump operation (number of pumps running out of 3 pumps, 2 on is typical)	CGS	Cross reference with make-up water volume pumped and use to calculate screen velocity
Make-up water volume pumped (cfs and m^3)	CGS	Expansion of daily, weekly, and seasonal entrainment estimates (fish/m^3)
Pumphouse water elevation at well (feet and meters)	CGS	Estimate screen blockage by calculating the differential between pumphouse water elevation and Columbia River water elevation at pumphouse
Columbia river water elevation at pumphouse intake (feet and meters)	CGS	Estimate screen blockage by calculating the differential between pumphouse water elevation and Columbia River water elevation near pumphouse

Data	Data Source	Application
Qualitative debris observations	CGS Anchor QEA	Correlate with screen blockage estimate Qualitative description of the amount of debris held by fish cages during each weekly/bi-weekly sampling session.
Columbia River discharge (kcfs and m3)	USGS[a]	Characterize patterns of expected fish presence/distribution related to flow
Columbia River stage (feet and meters; hourly)	CGS	Derive from river elevation at pumphouse intake. Characterize patterns of expected fish presence/distribution related to stage
Change in river stage (feet and meters; hourly derived)	CGS	Derive from change in river elevation at pumphouse intake. Characterize patterns of expected fish presence/distribution
River temperature (°F and °C)	Grant County PUD Priest Rapids Dam tailrace[b]	Characterize patterns of expected fish presence/distribution related to temperature
Abnormal operational conditions	CGS	Correlate with observed entrainment data
Weather	CGS	Correlate with observed entrainment data
Hanford Reach Fall Chinook Salmon Spawning Escapement	WDFW	Estimate the number of fry produced in the Hanford Reach to estimate entrainment impacts

Notes:

a. USGS Monitoring Station 12472800 at Columbia River below Priest Rapids Dam, Washington
b. Grant County PUD

CGS: Columbia Generating Station
cfs: cubic feet per second
fish/m^3: number of fish per cubic meter
kcfs: kilo cubic feet per second
m^3: cubic meters
USGS: U.S. Geological Survey
WDFW: Washington Department of Fish and Wildlife

4.3 Analyses

4.3.1 Entrainment

Entrainment rate estimates will be performed for each sampling session (week) and these results will be used to estimate average entrainment rates for a season and total entrainment for a season. The specific equations that will be used to make the estimates are described below.

4.3.1.1 Average cage efficacy

For each trial, cage efficacy, CE_j, is the number of test fish recovered divided by the number of test fish released in trial j, where j = 1,2,….,m and m=6 trials (3 trials per year with 2 replicate cages) as described in section 2.1.3.1. The average cage efficacy, $\overline{CE}$, can be computed as the average of the

trial capture efficiencies (Equation 2). The sample variance, s_{CE}^2, of the m values are calculated as shown in Equation 3 and the variance, $var(\overline{CE})$, and standard error, $SE_{\overline{CE}}$, of average cage efficacy are estimated by Equations 4 and 5.

Equation 2

$$\overline{CE} = \frac{\sum_j^m CE_j}{m}$$

Equation 3

$$s_{CE}^2 = \frac{\sum_j^m (CE_j - \overline{CE})^2}{m-1}$$

Equation 4

$$var(\overline{CE}) = \frac{s_{CE}^2}{m}$$

Equation 5

$$SE_{\overline{CE}} = \sqrt{var(\overline{CE})}$$

where:

$\overline{CE}$	=	average cage efficacy
CE_j	=	number of test fish recovered/number of test fish released in trial *j* in each cage
m	=	number of trials per cage (6 trials)
s^2	=	sample variance
var	=	overall variance
SE	=	standard error

4.3.1.2 Unadjusted Entrainment Rates for 24-Hour Sampling Events

The entrainment rate (ER_i) for one 24-hour sampling event (one per week) will be calculated using Equation 6. Fish captured in both cages will be pooled into a single sample for each 24-hour event. The calculation will incorporate flow (*Q*), time (*t*), and entrainment rate. Results will be presented as *numbers of fish per cubic meter*. ER_i is not corrected for cage efficacy in this step.

For each sampling season (2018 and 2019) the entrainment rate is (ER_i) for week i =1, 2, ..., *n*, where *n* is the number of weeks in the sampling season of interest.

Equation 6

$$ER_i = \frac{(N_i)}{Q_i * t} = \frac{No.of\ fish}{m^3}$$

where:

N_i	=	number of fish caught in the two cages for either a 24-hour sampling period in week *i*.
Q_i	=	60-100% of pump capacity flow rate, 56.8-94.6 m^3/minute (15,000-25,000 gallons per minute)
t	=	24 hours of sampling (24 hr x 60 min/hr = 1,440 min)

The average unadjusted entrainment rate ($\overline{ER}$), will be calculated as the average of the weekly entrainment rates (Equation 7). The variance, s_{ER}^2, of the *n* weekly values are calculated as shown in Equation 8 and the variance, $var(\overline{ER})$, and standard error, $SE_{\overline{ER}}$, of average entrainment rate are estimated by Equations 9 and 10.

Equation 7

$$\overline{ER} = \frac{\sum_i^n ER_i}{n}$$

Equation 8

$$s_{ER}^2 = \frac{\sum_i^m (ER_i - \overline{ER})^2}{n-1}$$

Equation 9

$$var(\overline{ER}) = \frac{s_{ER}^2}{n}$$

Equation 10

$$SE_{\overline{ER}} = \sqrt{var(\overline{ER})}$$

where:

$\overline{ER}$	=	average entrainment rate
n	=	number of weekly values
s^2	=	sample variance
var	=	overall variance
SE	=	standard error

4.3.1.3 Seasonal Entrainment Rate Adjusted for Average Cage Efficacy

The seasonal entrainment rate adjusted for average cage efficacy, ER_{adj}, is computed by Equation 11 and it's variance, $var(ER_{adj})$, is approximated by the formula in Equation 12 and it's standard error, $SE_{ER_{adj}}$, by Equation 13 (Stuart and Ord 1998).

Equation 11

$$ER_{adj} = \frac{\overline{ER}}{\overline{CE}}.$$

Equation 12

$$var(ER_{adj}) = (ER_{adj})^2 \left[\frac{s_{ER}^2}{(\overline{ER})^2} + \frac{s_{CE}^2}{(\overline{CE})^2}\right].$$

Equation 13

$$SE_{ER_{adj}} = \sqrt{var(ER_{adj})}$$

where:

$\overline{ER}$	=	average entrainment rate
$\overline{CE}$	=	average cage efficacy
s^2	=	sample variance
var	=	overall variance
SE	=	standard error

4.3.1.4 Total Seasonal Entrainment

Total entrainment for each sampling season will be calculated using Equation 14. The calculation for *TSE* will multiply the adjusted seasonal entrainment rate (ER_{adj}) by average intake flow ($\bar{Q}$) and the number of weeks in a season (*n*) to yield the total number of fish entrained in a season. The average intake flow ($\bar{Q}$), will be calculated as the average of the weekly intake flow rates, Q_i (Equation 15). The sample variance, s_Q^2, of the *n* weekly values are calculated as shown in Equation 16 and the variance, $var(\bar{Q})$, and standard error, $SE_{\bar{Q}}$, of average flow rate are estimated by Equations 17 and 18.

Equation 14

$$TSE = (ER_{adj})(\bar{Q})(n).$$

Equation 15

$$\bar{Q} = \frac{\sum_i^n Q_i}{n}$$

Equation 16

$$s_Q^2 = \frac{\sum_i^m (Q_i - \bar{Q})^2}{n-1}$$

Equation 17

$$var(\bar{Q}) = \frac{s_Q^2}{n}$$

Equation 18

$$SE_{\bar{Q}} = \sqrt{var(\bar{Q})}.$$

where:

$\overline{ER}_{adj}$	=	seasonal entrainment rate
Q_i	=	weekly intake flow rates
n	=	number of weekly Q_i values
$\bar{Q}$	=	average intake flow
s^2	=	sample variance
var	=	overall variance
SE	=	standard error

4.3.1.5 Precision of Total Seasonal Entrainment

Precision of the estimated total entrainment for each season can be expressed as the limits of an approximate 90% confidence interval, assuming an approximate normal distribution for the statistic *TSE*[2]. The variance, $var(TSE)$, standard error, SE_{TSE}, and coefficient of variation, COV_{TSE}, of total entrainment for each season are calculated using Equations 19-21 and the 90% confidence interval,

[2] Depending on the distribution of the entrainment data, a more robust method of estimating precision of total seasonal entrainment may be proposed at the end of the study using a resampling method such as bootstrapping.

CI_{90}, is applied by Equation 22. An approximate 95% confidence interval on TSE can be obtained by replacing 1.645 with 1.96 in Equation 15.

Equation 19[3]

$$var(TSE) = var(ER_{adj}) * (\bar{Q})^2(n)^2$$

Equation 20

$$SE_{TSE} = \sqrt{var(TSE)}$$

Equation 21

$$COV_{TSE} = \frac{SE_{TSE}}{TSE}$$

Equation 22

$$CI_{90} = TSE \ \pm 1.645 * SE_{TSE}$$

4.3.2 Entrainment Impact on Hanford Reach Fall Chinook

The seasonal impact of entrainment on the total production of Hanford Reach Fall Chinook salmon will be estimated by dividing the total seasonal entrainment estimate, *TSE*, by the modeled number of presmolts (Harnish et al. 2014b).

Equation 23

$$\%\ \text{Entrainment} = \frac{TSE}{R}$$

where:

TSE	=	total seasonal entrainment
R	=	modeled total number of pre-smolts given estimated egg escapement

The modeled number of presmolts (*R*) from Equation 5 is calculated from Equation 6 which was obtained from Harnish et al. (2014b).

[3] The method for estimating the variance of TSE will be re-evaluated at the end of the season. If Q_i, and therefore $\bar{Q}$, varies randomly, variance of TSE may be estimated by the equation $var(TSE) = \left[var(ER_{adj})(\bar{Q})^2 + var(\bar{Q})(ER_{adj})^2 + var(ER_{adj})var(\bar{Q})\right] * (n)^2$ if $\bar{Q}$ is treated as a random variable.

Equation 24

From Harnish et al. 2014b, Table 3 and Figure 6:

$$ln\left(\frac{R}{S}\right) = \hat{y} = ln(\tau + \alpha) + \beta S = -.244 - 4.98 \times 10^{-9} S$$

$(SE_{\tau} = 0.234, Adj. R^2 = 0.341, p = 0.024)$

where:

R	=	total number of pre-smolts in a year
S	=	egg escapement in a year
$\hat{y}$	=	natural log of presmolts produced per egg
τ + α	=	non-density dependent productivity accounting for modeled time period
β	=	linear slope for most recent modeled time period (1999-2004, -4.98×10^{-9}) 1/β represents the estimate of spawners associated with max recruitment
ln(τ + α)	=	linear intercept of line for most recent modeled time period (1999-2004, −.244)

4.3.3 Characterizing Screen Pore Velocity at Different Intake Volumes

To determine the potential impact of different pumping rates (e.g., intake volumes) on entrainment, the pore velocity at the observed pumping rate (i.e., during sampling) will be characterized using Equation 25.

Equation 25

$$V_{ent} = \frac{Q}{A_{screen}} = \frac{Q}{(\pi * OD * L * n)}$$

where:

A_{screen}	=	total area of screen (m^2)
L	=	length (meters)
n	=	number of screens
OD	=	outer diameter (meters)
Q	=	volumetric flow rate (m^3/s)
V_{ent}	=	pore entrance velocity (m/s)

5 Health and Safety

All personnel will be expected to follow all safety procedures applicable to CGS. Applicable requirements in Energy Northwest's Industrial Safety Program Manual (ISPM) will be incorporated specifically or by reference in the SAP. In addition, all sampling personnel and visitors will be in the presence of Energy Northwest's Operation personnel for each sampling visit and will be briefed on relevant health and safety information, including emergency response actions.

Anchor QEA staff will adhere to all CGS health and safety requirements. Additionally, Anchor QEA staff will comply with the internal Health and Safety Plan (Appendix A), but will defer to CGS protocols where there is overlap.

6 Project Schedule

Task	Date
Sample Analysis Protocol Final	Mar. 21, 2018
Test Run Sampling	Dec. 2017 – Mar. 2018
2018 Entrainment Sampling	Mar. 14 – Sept. 5, 2018
2019 Entrainment Sampling	Mar. – Aug. 2019
Preliminary Report	May 2019
Final Entrainment Report	Dec. 2020

7 References

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Appendix A
Health and Safety Plan

Appendix B
Data Forms

Cage Deployment and Retrieval Log

CGS Cage Deployment and Retrieval Information						Page ________
Deployment			Retrieval			
Date (MM/DD/YY)	Time	Notes	Date (MM/DD/YY)	Time	Debris Load	Notes

Routine Fish Sampling Form

CGS Fish Entrainment Sampling **Page** ______

Deployed

Date	
Time	

Retrieved

Date	
Time	

Cage 1 (check)

Cage 2 (check)

Fish No.	Species	Life Stage	Length (mm)	Weight (g)	Survival	Health	Injury Comment
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
11							
12							
13							
14							
15							
16							
17							
18							
19							
20							
					0 - Alive 1 - Dead	0 - No injuries 1 - Injuries 2 - Disease	

Appendix C
Safety Data Sheets

Appendix C
Fish Entrainment Complete Dataset

Table C-1
Fish Entrainment Monitoring Data

CAGE DEPLOY DATETIME	CAGE RETRIEVE DATETIME	SAMPLE EVENT	CAGE NUMBER	FISH NUMBER	SPECIES	LIFE STAGE	LENGTH MM	WEIGHT G	SURVIVAL	HEALTH	DEBRIS LOAD	COMMENT	CAPTURE EFFICIENCY
4/3/2018 11:43	4/4/2018 11:30	CE-1	1	0	ND	ND	ND	ND	ND	ND	ND	CE test 1	0.91
4/3/2018 11:56	4/4/2018 11:38	CE-1	2	0	ND	ND	ND	ND	ND	ND	ND	CE test 1	0.88
4/4/2018 12:53	4/5/2018 11:47	RE-2018-1	1	0	ND	ND	ND	ND	ND	ND	Light debris	Paired with CE test 1	NA
4/4/2018 12:56	4/5/2018 11:58	RE-2018-1	2	0	ND	ND	ND	ND	ND	ND	Light debris	Paired with CE test 1	NA
4/11/2018 11:01	4/12/2018 10:50	RE-2018-2	1	0	ND	ND	ND	ND	ND	ND	Light debris	NONE	NA
4/11/2018 10:35	4/12/2018 10:40	RE-2018-2	2	0	ND	ND	ND	ND	ND	ND	Light debris	NONE	NA
4/18/2018 9:18	4/19/2018 9:17	RE-2018-3	1	0	ND	ND	ND	ND	ND	ND	Light debris, sand	NONE	NA
4/18/2018 9:10	4/19/2018 9:11	RE-2018-3	2	0	ND	ND	ND	ND	ND	ND	Light debris, sand	NONE	NA
4/24/2018 10:35	4/25/2018 10:35	CE-2	1	0	ND	ND	ND	ND	ND	ND	ND	CE test 2	0.94
4/24/2018 10:44	4/25/2018 10:40	CE-2	2	0	ND	ND	ND	ND	ND	ND	ND	CE test 2	0.94
4/25/2018 11:08	4/26/2018 11:04	RE-2018-4	1	0	ND	ND	ND	ND	ND	ND	Light debris	Paired with CE test 2	NA
4/25/2018 11:17	4/26/2018 11:12	RE-2018-4	2	0	ND	ND	ND	ND	ND	ND	Light debris	Paired with CE test 2	NA
5/2/2018 9:20	5/3/2018 9:06	RE-2018-5	1	0	ND	ND	ND	ND	ND	ND	Light debris	NONE	NA
5/2/2018 9:10	5/3/2018 9:16	RE-2018-5	2	1	CHINOOK	FRY	37	0.4	ALIVE	GOOD	Light debris	NONE	NA
5/9/2018 9:15	5/10/2018 9:14	RE-2018-6	1	0	ND	ND	ND	ND	ND	ND	Medium debris, high water	NONE	NA
5/9/2018 9:25	5/10/2018 9:24	RE-2018-6	2	0	ND	ND	ND	ND	ND	ND	Medium debris, high water	NONE	NA
6/13/2018 9:54	6/14/2018 10:08	RE-2018-7	1	0	ND	ND	ND	ND	ND	ND	Heavy debris	NONE	NA
6/13/2018 10:01	6/14/2018 10:19	RE-2018-7	2	1	PACIFIC LAMPREY	AMMOCOETE	129	3.7	ALIVE	GOOD	Heavy debris	NONE	NA
6/20/2018 9:45	6/21/2018 9:41	RE-2018-8	1	0	ND	ND	ND	ND	ND	ND	Aquatic invertebrate larvae (possibly caddisfly), light to medium debris	NONE	NA
6/20/2018 9:35	6/21/2018 9:31	RE-2018-8	2	0	ND	ND	ND	ND	ND	ND	Aquatic invertebrate larvae (possibly caddisfly), light to medium debris	NONE	NA
6/26/2018 9:31	6/27/2018 9:23	CE-3a	1	0	ND	ND	ND	ND	ND	ND	ND	CE test 3a	0.86
6/26/2018 9:40	6/27/2018 9:31	CE-3a	2	0	ND	ND	ND	ND	ND	ND	ND	CE test 3a - repeated, not used in analyses	0.49
6/27/2018 10:34	6/28/2018 9:28	RE-2018-9	1	0	ND	ND	ND	ND	ND	ND	Aquatic invertebrate larvae (possibly caddisfly), medium to heavy debris	Paired with CE test 3a	NA

CAGE DEPLOY DATETIME	CAGE RETRIEVE DATETIME	SAMPLE EVENT	CAGE NUMBER	FISH NUMBER	SPECIES	LIFE STAGE	LENGTH MM	WEIGHT G	SURVIVAL	HEALTH	DEBRIS LOAD	COMMENT	CAPTURE EFFICIENCY
6/27/2018 10:28	6/28/2018 9:34	RE-2018-9	2	0	ND	ND	ND	ND	ND	ND	Aquatic invertebrate larvae (possibly caddisfly), medium to heavy debris	Paired with CE test 3a	NA
7/11/2018 9:30	7/12/2018 9:21	RE-2018-10	1	0	ND	ND	ND	ND	ND	ND	Aquatic invertebrate larvae (possibly caddisfly), light to medium debris	NONE	NA
7/11/2018 9:11	7/12/2018 9:13	RE-2018-10	2	0	ND	ND	ND	ND	ND	ND	Aquatic invertebrate larvae (possibly caddisfly), light to medium debris	NONE	NA
7/17/2018 9:29	7/18/2018 9:20	CE-3b	2	0	ND	ND	ND	ND	ND	ND	ND	CE test 3b	0.86
7/18/2018 10:01	7/19/2018 10:15	RE-2018-11	1	0	ND	ND	ND	ND	ND	ND	Medium debris	NONE	NA
7/18/2018 10:09	7/19/2018 12:10	RE-2018-11	2	0	ND	ND	ND	ND	ND	ND	Medium debris	Paired with CE test 3b	NA
8/1/2018 9:07	8/2/2018 9:16	RE-2018-12	1	0	ND	ND	ND	ND	ND	ND	Light debris	NONE	NA
8/1/2018 9:15	8/2/2018 9:28	RE-2018-12	2	0	ND	ND	ND	ND	ND	ND	Light debris	NONE	NA
8/15/2018 9:47	8/16/2018 9:29	RE-2018-13	1	0	ND	ND	ND	ND	ND	ND	Sponge-like material, light other debris	NONE	NA
8/15/2018 9:13	8/16/2018 13:40	RE-2018-13	2	0	ND	ND	ND	ND	ND	ND	Sponge-like material, light other debris	NONE	NA
8/29/2018 9:35	8/30/2018 9:25	RE-2018-14	1	0	ND	ND	ND	ND	ND	ND	Sponge-like material, medium other debris	NONE	NA
8/29/2018 9:30	8/30/2018 9:16	RE-2018-14	2	0	ND	ND	ND	ND	ND	ND	Sponge-like material, medium other debris	NONE	NA
9/12/2018 9:18	9/13/2018 9:22	RE-2018-15	1	0	ND	ND	ND	ND	ND	ND	Sponge-like material, medium other debris	NONE	NA
9/12/2018 9:10	9/13/2018 9:16	RE-2018-15	2	0	ND	ND	ND	ND	ND	ND	Sponge-like material, medium other debris	NONE	NA
3/12/2019 10:24	3/13/2019 10:24	CE-4	1	0	ND	ND	ND	ND	ND	ND	Very light debris	CE test 4	0.96
3/12/2019 10:40	3/13/2019 10:47	CE-4	2	0	ND	ND	ND	ND	ND	ND	Very light debris	CE test 4	0.93
3/13/2019 11:37	3/14/2019 11:27	RE-2019-1	1	0	ND	ND	ND	ND	ND	ND	Light debris	Paired with CE test 4	NA
3/13/2019 11:49	3/14/2019 11:41	RE-2019-1	2	0	ND	ND	ND	ND	ND	ND	Light debris	Paired with CE test 4	NA
3/20/2019 9:40	3/21/2019 9:43	RE-2019-2	1	1	SALMON SP.	FRY	33	0.3	MORTALITY	MORTALITY; NO SPP ID DUE TO BODY DECOMPOSITION	Light debris	NONE	NA

CAGE DEPLOY DATETIME	CAGE RETRIEVE DATETIME	SAMPLE EVENT	CAGE NUMBER	FISH NUMBER	SPECIES	LIFE STAGE	LENGTH MM	WEIGHT G	SURVIVAL	HEALTH	DEBRIS LOAD	COMMENT	CAPTURE EFFICIENCY
3/20/2019 9:53	3/21/2019 9:59	RE-2019-2	2	0	ND	ND	ND	ND	ND	ND	Light debris	NONE	NA
3/27/2019 9:27	3/28/2019 9:31	RE-2019-3	1	0	ND	ND	ND	ND	ND	ND	Light debris	NONE	NA
3/27/2019 9:44	3/28/2019 9:39	RE-2019-3	2	0	ND	ND	ND	ND	ND	ND	Light debris	NONE	NA
4/3/2019 10:45	4/4/2019 10:40	RE-2019-4	1	0	ND	ND	ND	ND	ND	ND	Light debris	NONE	NA
4/3/2019 10:56	4/4/2019 10:46	RE-2019-4	2	1	TORRENT SCULPIN	ADULT	43	6.4	LIVE	GOOD	Light debris	NONE	NA
4/9/2019 9:25	4/10/2019 9:34	CE-5	2	0	ND	ND	ND	ND	ND	ND	Medium debris	CE test 5	0.83
4/9/2019 9:32	4/10/2019 9:42	CE-5	1	0	ND	ND	ND	ND	ND	ND	Medium debris	CE test 5	0.98
4/10/2019 10:27	4/11/2019 10:17	RE-2019-5	1	0	ND	ND	ND	ND	ND	ND	Light debris	Paired with CE test 5	NA
4/10/2019 10:36	4/11/2019 10:21	RE-2019-5	2	0	ND	ND	ND	ND	ND	ND	Light debris	Paired with CE test 5	NA
4/17/2019 9:10	4/18/2019 9:26	RE-2019-6	1	0	ND	ND	ND	ND	ND	ND	Light debris	NONE	NA
4/17/2019 9:20	4/18/2019 9:34	RE-2019-6	2	0	ND	ND	ND	ND	ND	ND	Light debris	NONE	NA
4/23/2019 9:06	4/24/2019 9:15	CE-6	1	0	ND	ND	ND	ND	ND	ND	Medium debris	CE test 6	0.83
4/23/2019 9:12	4/24/2019 9:22	CE-6	1	0	ND	ND	ND	ND	ND	ND	Medium debris	CE test 6	0.94
4/24/2019 10:03	4/25/2019 10:06	RE-2019-7	1	0	ND	ND	ND	ND	ND	ND	Not reported	Paired with CE test 6	NA
4/24/2019 10:10	4/25/2019 10:12	RE-2019-7	2	0	ND	ND	ND	ND	ND	ND	Not reported	Paired with CE test 6	NA
5/1/2019 9:15	5/2/2019 9:06	RE-2019-8	1	0	ND	ND	ND	ND	ND	ND	Light debris	NONE	NA
5/1/2019 9:26	5/2/2019 9:14	RE-2019-8	2	0	ND	ND	ND	ND	ND	ND	Light debris	NONE	NA
5/8/2019 9:23	5/9/2019 9:10	RE-2019-9	1	0	ND	ND	ND	ND	ND	ND	Light debris	NONE	NA
5/8/2019 9:33	5/9/2019 9:17	RE-2019-9	2	0	ND	ND	ND	ND	ND	ND	Light debris	NONE	NA
6/26/2019 10:10	6/27/2019 9:11	RE-2019-10	1	0	ND	ND	ND	ND	ND	ND	Heavy debris	NONE	NA
6/26/2019 10:20	6/27/2019 9:20	RE-2019-10	2	0	ND	ND	ND	ND	ND	ND	Heavy debris	NONE	NA
7/10/2019 9:05	7/11/2019 9:10	RE-2019-11	1	0	ND	ND	ND	ND	ND	ND	Medium debris	NONE	NA
7/10/2019 9:15	7/11/2019 9:16	RE-2019-11	2	0	ND	ND	ND	ND	ND	ND	Medium debris	NONE	NA
7/24/2019 9:23	7/25/2019 9:15	RE-2019-12	1	0	ND	ND	ND	ND	ND	ND	Medium debris	NONE	NA
7/24/2019 9:29	7/25/2019 9:23	RE-2019-12	2	0	ND	ND	ND	ND	ND	ND	Medium debris	NONE	NA
8/7/2019 9:24	8/8/2019 9:13	RE-2019-13	1	0	ND	ND	ND	ND	ND	ND	Medium debris	NONE	NA
8/7/2019 9:33	8/8/2019 9:23	RE-2019-13	2	0	ND	ND	ND	ND	ND	ND	Medium debris	NONE	NA
9/4/2019 9:21	9/5/2019 9:13	RE-2019-14	1	0	ND	ND	ND	ND	ND	ND	Heavy debris, aquatic invertebrate larvae (possibly caddisfly), sponge-like material	NONE	NA
9/4/2019 9:32	9/5/2019 9:23	RE-2019-14	2	0	ND	ND	ND	ND	ND	ND	Heavy debris, aquatic invertebrate larvae (possibly caddisfly), sponge-like material	NONE	NA

CAGE DEPLOY DATETIME	CAGE RETRIEVE DATETIME	SAMPLE EVENT	CAGE NUMBER	FISH NUMBER	SPECIES	LIFE STAGE	LENGTH MM	WEIGHT G	SURVIVAL	HEALTH	DEBRIS LOAD	COMMENT	CAPTURE EFFICIENCY
9/18/2019 9:30	9/19/2019 9:10	RE-2019-15	1	0	ND	ND	ND	ND	ND	ND	Heavy debris, aquatic invertebrate larvae (possibly caddisfly), sponge-like material	NONE	NA
9/18/2019 9:32	9/19/2019 9:23	RE-2019-15	2	0	ND	ND	ND	ND	ND	ND	Heavy debris, aquatic invertebrate larvae (possibly caddisfly), sponge-like material	NONE	NA

Notes: A low capture efficiency value for Cage 2 was observed on June 27, 2018, (49 of 100 fish retained) due to damage that occurred during 5 weeks of high water levels that inundated the sampling platform and cages; this value was not used in analyses. The efficiency of Cage 2 was restored by modifying cable attachments following the high-water event. A capture efficiency test was repeated on Cage 2 from July 17, 2018, to confirm that this cage was operating with adequate efficiency.

Table C-2
Hanford Reach Egg to Fry Estimates

																Value is mean of 1997-2004 Spawning Population					**Literature Cited**
																Value is mean of 1997-2004 PR Hatchery Return					
Escapement Year	2018	2017	2011	2010	2009	2008	2007	2006	2005	2004	2003	2002	2001	2000	1999	1998	1997	1996	1995	1994	
Emergence Year	2019	2018	2012	2011	2010	2009	2008	2007	2006	2005	2004	2003	2002	2001	2000	1999	1998	1997	1996	2000	
Method 1																					
Adult Fall Chinook Escapement	42,277	71,303	80,408	26,346	23,361	13,887	47,095	64,355	79,464	89,312	69,117	44,140	36,027	27,012	29,410	34,007	37,548	38,381	48,857	30,650	Hanford Reach Carcass Survey, Watson & Brock
Female (%)	57.4%	65.4%	33.9%	45.4%	36.3%	46.6%	45.9%	53.0%	45.3%	50.9%	40.4%	36.5%	54.2%	46.1%	46.4%	60.9%	48%	48%	48%	48%	Hanford Reach Sport Fishery, Watson & Brock
Fecundity	4,200	4,117	4,462	4,575	3,904	4,057	4,200	4,204	4,224	4,422	4,003	4,418	4,794	4,371	4,200	4,420	4,357	4,357	4,357	4,357	Priest Rapids Hatchery, Rodgers & Pearson
# of spawning females	24,267	46,632	27,258	11,961	8,480	6,471	21,617	34,108	35,997	45,460	27,923	16,111	19,527	12,453	13,646	20,710	17,868	18,241	23,219	14,566	
Potential eggs	101,921,392	191,984,611	121,626,588	54,721,959	33,106,088	26,254,234	90,789,741	143,390,663	152,052,139	201,023,271	111,776,842	71,178,840	93,610,683	54,430,017	57,314,208	91,539,362	77,842,615	79,465,044	101,154,834	63,458,576	
Egg Retention	2.00%	2.00%	0.50%	0.50%	0.50%	0.50%	0.50%	0.50%	0.50%	0.50%	0.50%	0.50%	0.50%	0.50%	0.50%	0.50%	0.50%	0.50%	0.50%	0.50%	Hanford Reach Carcass Survey, Watson & Brock
Total eggs deposited	99,882,964	188,144,919	121,018,455	54,448,350	32,940,557	26,122,963	90,335,792	142,673,709	151,291,878	200,018,155	111,217,958	70,822,946	93,142,630	54,157,867	57,027,637	91,081,666	77,453,402	79,067,719	100,649,059	63,141,283	
Egg to fry survival @ 30%	**29,964,889**	**56,443,476**	**36,305,537**	**16,334,505**	**9,882,167**	**7,836,889**	**27,100,738**	**42,802,113**	**45,387,563**	**60,005,446**	**33,365,387**	**21,246,884**	**27,942,789**	**16,247,360**	**17,108,291**	**27,324,500**	**23,236,021**	**23,720,316**	**30,194,718**	**18,942,385**	Pacific Salmon Life Histories
Method 2																					
PNNL Aerial Redd count			8,817	4,996	5,618	4,018	6,508	7,891	8,468	9,465	8,041	6,248	5,507	6,086	5,368	7,600					
Expansion (70% of redds observed)	6,404	8,646	12,596	7,137	8,026	5,740	9,297	11,273	12,097	13,521	11,487	8,926	7,867	8,694	7,669	10,857					
Fecundity	4,200	4,117	4,462	4,575	3,904	4,057	4,200	4,204	4,224	4,422	4,003	4,418	4,794	4,371	4,200	4,420					
Potential eggs	26,896,800	35,595,582	56,202,077	32,652,429	31,332,389	23,287,180	39,048,000	47,391,091	51,098,331	59,791,757	45,983,033	39,433,806	37,715,083	38,002,723	32,208,000	47,988,571					
Egg to fry survival @ 30%	**8,069,040**	**10,678,675**	**16,860,623**	**9,795,729**	**9,399,717**	**6,986,154**	**11,714,400**	**14,217,327**	**15,329,499**	**17,937,527**	**13,794,910**	**11,830,142**	**11,314,525**	**11,400,817**	**9,662,400**	**14,396,571**					
Mean of Two Estimates	**19,016,965**	**33,561,075**	**26,583,080**	**13,065,117**	**9,640,942**	**7,411,521**	**19,407,569**	**28,509,720**	**30,358,531**	**38,971,487**	**23,580,149**	**16,538,513**	**19,628,657**	**13,824,089**	**13,385,346**	**20,860,536**					
Subyearling Passage Index at McNary											10,561,371*	8,372,688	10,782,663	10,667,690	7,643,679	11,428,630					

* McNary smolt monitoring was discontinued on Oct 1 and sampling occurred on an every other day basis from April 1 through June 28

																	Value is mean of 1997-2004 Spawning Population				Literature Cited
																	Value is mean of 1997-2004 PR Hatchery Return				
Passage was doubled for the period of alternate day sampling to make passage index roughly comparable																					
Hatchery Releases of Fall Chinook								6,599,835		6,814,560	12,255,089	10,913,482	11,976,344	12,293,934	11,870,800	11,924,206					
Priest Rapids Hatchery								6,814,560	6,599,835	6,814,560	6,777,605	6,779,035	6,862,550	6,856,000	6,504,800	6,737,600					
Ringold Springs Hatchery											3,322,946	2,283,020	2,974,905	3,436,897	3,484,000	3,491,207					
Yakama Tribe (Prosser Acclimation)											2,154,538	1,851,427	2,138,889	2,001,037	1,882,000	1,695,399					
Lyons Ferry Hatchery																					
Fry Production Using Alternate Egg to Smolt Ratios																					
Method 1																					
Egg to Fry survival @ 63%		**118,531,299**	**76,241,627**	**34,302,460**	**20,752,551**	**16,457,467**	**56,911,549**	**89,884,437**	**95,313,883**	**126,011,437**	**70,067,313**	**44,618,456**	**58,679,857**	**34,119,456**	**35,927,411**	**57,381,449**					
Fry to Smolt survival @ 75%		88,898,474	57,181,220	25,726,845	15,564,413	12,343,100	42,683,662	67,413,328	71,485,413	94,508,578	52,550,485	33,463,842	44,009,893	25,589,592	26,945,558	43,036,087					
Method 2																					
Egg to Fry survival @ 63%		**22,425,217**	**35,407,309**	**20,571,030**	**19,739,405**	**14,670,923**	**24,600,240**	**29,856,388**	**32,191,949**	**37,668,807**	**28,969,311**	**24,843,298**	**23,760,502**	**23,941,715**	**20,291,040**	**30,232,800**					
Fry to Smolt survival @ 75%		16,818,912	26,555,481	15,428,273	14,804,554	11,003,193	18,450,180	22,392,291	24,143,962	28,251,605	21,726,983	18,632,473	17,820,377	17,956,287	15,218,280	22,674,600					

Source: WDFW 2019

Entrainment Events with Environmental and Operations Conditions

Table C-3a
Entrainment Events with Pump Operations

YEAR	FISH SAMPLING EVENT	DEPLOY DAY	SPECIES	P1A_VAL (AMPS)				P1B_VAL (AMPS)				P1C_VAL (AMPS)			
				MEAN	SD	MIN	MAX	MEAN	SD	MIN	MAX	MEAN	SD	MIN	MAX
2018	RE-2018-5	5/2/2018	CHINOOK	0.0	0.0	0.0	0.0	77.5	2.8	74.0	80.0	83.7	3.8	79.0	87.0
2018	RE-2018-8	6/13/2018	PACIFIC LAMPREY	75.1	1.4	74.0	77.0	77.7	1.0	77.0	79.0	0.0	0.0	0.0	0.0
2019	RE-2019-2	3/20/2019	SALMON SP.	76.5	1.9	74.0	78.0	74.9	1.5	73.0	76.0	0.0	0.0	0.0	0.0
2019	RE-2019-5	4/3/2019	SCULPIN	76.2	1.0	74.0	77.0	75.8	0.7	74.0	76.0	0.0	0.0	0.0	0.0

Table C-3b
Entrainment Events with Make-Up Intake Flow

YEAR	FISH SAMPLING EVENT	DEPLOY_DAY	SPECIES	MAKE-UP_CAPACITY				MAKE-UP INTAKE FLOW (GPM)			
				MEAN	SD	MIN	MAX	MEAN	SD	MIN	MAX
2018	RE-2018-5	5/2/2018	CHINOOK	0.68	0.07	0.52	0.77	17017.28	1780.58	13011.43	19292.00
2018	RE-2018-8	6/13/2018	PACIFIC LAMPREY	0.65	0.03	0.59	0.71	16209.80	780.37	14646.25	17681.48
2019	RE-2019-2	3/20/2019	SALMON SP.	0.64	0.04	0.54	0.71	16121.45	1049.21	13487.48	17866.11
2019	RE-2019-5	4/3/2019	SCULPIN	0.64	0.06	0.52	0.76	16117.17	1590.10	12979.12	19080.34

Table C-3c
Entrainment Events with Water Depth

YEAR	FISH SAMPLING EVENT	DEPLOY_DAY	SPECIES	PUMPHOUSE WATER LEVEL (FT)				PUMPHOUSE TO RIVER DIFFERENTIAL (FT)				RIVER WATER LEVEL (PUMPHOUSE + DIFF [FT])			
				MEAN	SD	MIN	MAX	MEAN	SD	MIN	MAX	MEAN	SD	MIN	MAX
2018	RE-2018-5	5/2/2018	CHINOOK	30.9	0.21	30.4	31.1	0.7	0.26	0.1	1.1	31.6	0.3	30.9	32.1
2018	RE-2018-8	6/13/2018	PACIFIC LAMPREY	27.1	0.35	26.7	27.7	0.8	0.13	0.5	1.0	27.8	0.4	27.3	28.7
2019	RE-2019-2	3/20/2019	SALMON SP.	21.8	0.21	21.5	22.2	0.7	0.15	0.4	1.0	22.5	0.2	22.0	22.9
2019	RE-2019-5	4/3/2019	SCULPIN	21.3	0.02	21.2	21.3	0.6	0.22	0.2	1.0	21.8	0.2	21.5	22.3

Table C-3d
Entrainment Events with Columbia River Elevation

YEAR	FISH SAMPLING EVENT	DEPLOY_DAY	SPECIES	RIVER ELEVATION (RIVER WATER + PUMPHOUSE ELEV, 324FT)			DEPTH TO INTAKE (AT 341 FT)		
				MEAN	MIN	MAX	MEAN	MIN	MAX
2018	RE-2018-5	5/2/2018	CHINOOK	355.6	354.9	356.1	14.6	13.9	15.1
2018	RE-2018-8	6/13/2018	PACIFIC LAMPREY	351.8	351.3	352.7	10.8	10.3	11.7
2019	RE-2019-2	3/20/2019	SALMON SP.	346.5	346.0	346.9	5.5	5.0	5.9
2019	RE-2019-5	4/3/2019	SCULPIN	345.8	345.5	346.3	4.8	4.5	5.3

Table C-3e
Entrainment Events with Columbia River Conditions at Priest Rapids Dam

YEAR	FISH SAMPLING EVENT	DEPLOY_DAY	SPECIES	PRIEST RAPIDS TAILRACE TEMPERATURE(°C)				PRIEST RAPIDS DISCHARGE (KCFS)			
				MEAN	SD	MIN	MAX	MEAN	SD	MIN	MAX
2018	RE-2018-5	5/2/2018	CHINOOK	9.1	0.1	8.9	9.2	233.5	29.9	150.1	280.7
2018	RE-2018-8	6/13/2018	PACIFIC LAMPREY	14.4	0.1	14.2	14.5	157.9	3.7	153.8	174.3
2019	RE-2019-2	3/20/2019	SALMON SP.	4.1	0.1	3.8	4.2	73.1	3.3	70.6	87.3
2019	RE-2019-5	4/3/2019	SCULPIN	6.4	0.1	6.3	6.5	70.0	0.1	69.9	70.2

Table C-3f
Entrainment Events with Weather Conditions

YEAR	FISH SAMPLING EVENT	DEPLOY_DAY	SPECIES	OUTDOOR AIR TEMPERATURE (°F)				WIND SPEED (MPH)				WIND DIRECTION (AZIMUTH)				BARROMETRIC PRESSURE (INHG)			
				MEAN	SD	MIN	MAX	MEAN	SD	MIN	MAX	MEAN	SD	MIN	MAX	MEAN	SD	MIN	MAX
2018	RE-2018-5	5/2/2018	CHINOOK	63.10	9.14	48.23	75.75	8.02	5.06	0.16	15.56	195.57	57.34	117.18	315.47	29.50	0.04	29.43	29.57
2018	RE-2018-8	6/13/2018	PACIFIC LAMPREY	65.88	10.08	49.29	79.01	12.39	7.21	1.57	22.75	235.28	45.53	166.21	337.24	29.37	0.09	29.26	29.50
2019	RE-2019-2	3/20/2019	SALMON SP.	49.66	8.72	38.40	63.93	4.36	2.71	0.88	9.32	296.45	71.41	135.25	378.31	29.51	0.03	29.46	29.58
2019	RE-2019-5	4/3/2019	SCULPIN	55.48	7.80	43.74	66.21	10.44	8.57	1.82	24.77	210.74	44.39	109.37	306.55	29.41	0.07	29.32	29.50

Cage Deployment and Retrieval Log

CGS Cage Deployment and Retrieval Information					Page 1
Deployment			**Retrieval**		
Date (MM/DD/YY)	**Time**	**Notes**	**Date (MM/DD/YY)**	**Time**	**Notes**
03/22/17	09:24 A 09:29 A	CAGE 1 CAGE 2	03/23/17	09:08A 09:14A	CAGE 2 – HATCH DOESN'T CAGE 1 – OPEN ALL THE WAY
04/05/17	08:31 A 08:33A	CAGE 1 CAGE 2	04/06/17	08:45A 08:40A	Began Retrieving both NOTE: CAGE HATCHS TOP REALIGNED on 4/4/17 AND OPENS ALL THE WAY
04/12/17	09:16A 09:19 A	CAGE 1 CAGE 2	04/13/17	09:20A 09:24A	cages @ 08:34 (switch) timecolumn = open cage door
5/12/17	09:30A	SOUTH CAGE	5/12/17	09:41P	SOUTH CAGE
7/26/17	10:10A 10:00A	CAGE 1 CAGE 2	7/27/17	10:10A 10:00A	CAGE 1 CAGE 2
2/6/18	11:10A	NORTH CAGE	2/7/18	11:10	NORTH CAGE
3/7/18	10:45A	CAGE1 CAGE2	3/8/18	10:45	Cage 1 Cage 2
~~3/8/18~~	~~10:45~~				
4/3/18	11:43 11:56	cage 1 cage 2	4/4/18	1130 1138	CAGE 1(SOUTH) CAGE 2(NORTH)
~~4/4/18~~	~~11:30~~	~~SOUTH CAGE Retrieve~~			kg 4/4/18
4/4/18	12:53 12:56	CAGE 1 (SOUTH) CAGE 2 (NORTH)	4/4/18	11:47 11:58	CAGE 1 (SOUTH) CAGE 2 (NORTH)
4/11/18	10:35 11:01	CAGE 2 (NORTH) CAGE 1 (SOUTH)	4/12/18	10:40 10:50	CAGE 2 (NORTH) CAGE 1 (SOUTH)
4/18/2018	09:10 09:18	CAGE 2 (NORTH) CAGE 1 (SOUTH)	4/19/2018	09:11 09:17	CAGE 2 (NORTH) CAGE 1 (SOUTH)
4/24/2018	10:35 10:44	CAGE 1 (S) CAGE 2 (N)	4/25/2018	10:35 10:40	CAGE 1 (SOUTH) CAGE 2 (NORTH)
4/25/2018	11:08 11:17	CAGE 1 (S) CAGE 2 (N)	4/26/2018	11:04 11:12	CAGE 1 (SOUTH) CAGE 2 (NORTH)
5/2/2018	9:20A 9:10A	CAGE 1 (S) CAGE 2 (N)	5/3/2018	9:06 9:16	CAGE 1 CAGE 2
5/9/2018	9:15A 9:25A	CAGE 1 (S) CAGE 2 (N)	5/10/2018	9:14 9:24	CAGE 1 (STH) CAGE 2 (NTH)
6/13/2018	9:54 10:01	CAGE 1 (S) CAGE 2 (N)	6/14/2018	10:08 10:19	CAGE 1 (STH) CAGE 2 (NTH)
6/20/2018	9:35 9:45	Cage 2 (N) Cage 1 (S)	6/21/2018	9:31 9:41	CAGE 2 (NTH) CAGE 1 (STH)

Cage Deployment and Retrieval Log

CGS Cage Deployment and Retrieval Information					Page 2
Deployment			**Retrieval**		
Date (MM/DD/YY)	**Time**	**Notes**	**Date (MM/DD/YY)**	**Time**	**Notes**
6/26/2018	9.31 9.40	CAGE 1 CAGE 2	6/27/2018	9:23 9:31	CAGE 1 (STH) CAGE 2 (NTH)
6/27/2018	10:34 10:28	CAGE 1 CAGE 2	6/28/2018	10.28 10:34	CAGE 1 (STH) CAGE 2 (NTH)
entered backwards 7/11/2018	9:16 9:30	CAGE 1 (South) CAGE 2 (North)	7/12/2018	9:13 9:21	CAGE 2 (NTH) CAGE 1 (STH)
7/17/2018	9:29	CAGE 2 (NORTH)	7/18/2018	9:20	CAGE 2 (NTH)
7/18/2018	10:01 10:09	CAGE 1 (STH) CAGE 2 (NTH)	7/19/2018	10:15 12:10	CAGE 1 (STH) CAGE 2 (NTH)
8/1/2018	9:07 9:15	CAGE 1 (South) CAGE 2 (North)	8/2/2018	0916 0928	Cage 1 (SOUTH) CAGE 2 (NORTH)
8/15/2018	9:13 9:47	CAGE 2 (north) CAGE 1 (South)	8/16/2018	09:29 01:40 PM	CAGE ~~NORTH~~ CAGE 1 (SOUTH) CAGE 2 (NORTH) UNABLE TO RETRACT INSERT - CAGE STILL IN WATER
8/29/2018	9:30 9:35	CAGE 2 (North) CAGE 1 (South)	8/30/2018	9:16 9:25	CAGE 2 (NTH) CAGE 1 (STH)
9/12/2018	9:10A 9:18A	CAGE 2 (NORTH) CAGE 1 (SOUTH)	9/13/2018	9:16 9:22	CAGE 2 (NTH) CAGE 1 (STH)

retreived no Fish. 8/11/18 ms

Cage Deployment and Retrieval Log 2019 LOG

CGS Cage Deployment and Retrieval Information							Page 1
Deployment			**Retrieval**				
Date (MM/DD/YY)	**Time**	**Notes**	**Date (MM/DD/YY)**	**Time**	**Debris Load**	**Notes**	
3/12/2019	10:24 10:40	CAGE 1 (S) CAGE 2 (N)	3/13/2019	10:24 10:47	LIGHT	CAGE 1 (S) CAGE 2 (N)	
3/13/2019	11:37 11:49	CAGE 1 (S) CAGE 2 (N)	3/14/2019	11:27 11:41	LIGHT	CAGE 1 (S) CAGE 2 (N)	
3/20/2019	9:40 9:53	CAGE 1 (S) CAGE 2 (N)	3/21/2019	9:43 9:59	LIGHT	CAGE 1 (S) CAGE 2 (N)	
3/27/19	9:27 9:44	CAGE 1 (S) CAGE 2 (N)	3/28/2019	9:31 9:39	LIGHT	CAGE 1 (S) CAGE 2 (N)	
* 4/2/2019	9:43 9:52	CAGE 1 (S) CAGE 2 (N)	4/3/2019	9:46 9:56	LIGHT	CAGE 1 (S) CAGE 2 (N)	* 9:46 9:55
4/3/2019	10:45 10:56	CAGE 1 (S) CAGE 2 (N)	4/4/2019	10:40 10:46	LIGHT	CAGE 1 (S) CAGE 2 (N)	
4/9/2019	9:25 9:32	CAGE 2 (N) CAGE 1 (S)	4/10/2019	9:34 9:42	MEDIUM	CAGE 2 (N) CAGE 1 (S)	
4/10/2019	10:27 10:36	CAGE 1 (S) CAGE 2 (N)	4/11/2019	10:17 10:21	LIGHT	CAGE 1 (S) CAGE 2 (N)	
4/17/2019	9:10 9:20	CAGE 1 (S) CAGE 2 (N)	4/18/2019	9:26 9:34	LIGHT	CAGE 1 (S) CAGE 2 (N)	
4/23/2019	9:06 9:12	CAGE 1 (S) CAGE 2 (N)	4/24/2019	9:15 9:22	MEDIUM	CAGE 1 (S) CAGE 2 (N)	
4/24/2019	[illegible]	10:03 CAGE 1 (S) 10:10 CAGE 2 (N)	4/25/2019	10:06 10:12	HEAVY	CAGE 1 (S) CAGE 2 (N)	
5/1/2019	9:15A 9:26A	CAGE 1 (S) CAGE 2 (N)	5/2/2019	9:06 9:14	LIGHT	CAGE 1 (S) CAGE 2 (N)	
5/8/2019	9:23A 9:33A	CAGE 1 (S) CAGE 2 (N)	5/9/2019	9:10 9:17	LIGHT	CAGE 1 (S) CAGE 2 (N)	
6/26/2019	9:10A 9:20A	CAGE 1 (S) CAGE 2 (N)	6/27/2019	9:11 9:20	HEAVY	CAGE 1 (S) 9:11 CAGE 2 (N) 9:20	
7/10/2019	9:05A 9:15A	CAGE 1 (S) CAGE 2 (N)	7/11/2019	9:10 9:16	MEDIUM	CAGE 1 (S) CAGE 2 (N)	
7/24/2019	9:23A 9:29A	CAGE 1 (S) CAGE 2 (N)	7/25/2019	9:15 9:23	MEDIUM	CAGE 1 (S) CAGE 2 (N)	
8/7/2019	9:24A 9:33A	CAGE 1 (S) CAGE 2 (N)	8/8/2019	9:13 9:25	MEDIUM	CAGE 1 (S) CAGE 2 (N)	
9/4/2019	9:21A 9:32A	CAGE 1 (S) CAGE 2 (N)	9/5/2019	9:13 9:23	HEAVY	CAGE 1 (S) CAGE 2 (N)	
9/18/2019	9:30A 9:32A	CAGE 1 (S) CAGE 2 (N)	9/19/2019	9:10 9:23	HEAVY	CAGE 1 (S) CAGE 2 (N)	

* INVALID EFFICACY TEST - 11 DEAD FISH IN (S) CAGE AND
12 " " " (N) CAGE
AT START OF TEST

Appendix D
Example Entrainment Calculations

Entrainment rate estimates were performed for each sampling week, and these results were used to estimate average entrainment rate for a season and total entrainment of a given species for a season.

The equations shown are documented in the Sampling and Analysis Plan that was developed prior to implementation of the fish entrainment monitoring study (Anchor QEA 2018; included as Appendix B of the Fish Entrainment Characterization Report).

The following demonstrates how entrainment statistics were calculated for one example, Chinook salmon entrained in 2018. Similar statistics were calculated for all species individually, and for all fish entrained in each year of study (2018 and 2019). The complete results are reported in Section 4.3 of the Fish Entrainment Characterization Report.

Average Capture Efficiency (2018)

Average capture efficiency is the average of the six (6) trial capture efficiencies (Equation 2 of the SAP).[1] Variance and standard error around average capture efficiency shows the accuracy and spread of the data (Equations 3 through 5).

[1] Equation numbering from the Columbia Generating Station Fish Entrainment Study Sampling and Analysis Plan (Appendix A, this document) is used.

Equation 2

$$\overline{CE} = \frac{\sum_j^m CE_j}{m}$$

Equation 3

$$s_{CE}^2 = \frac{\sum_j^m (CE_j - \overline{CE})^2}{m-1}$$

Equation 4

$$var(\overline{CE}) = \frac{s_{CE}^2}{m}$$

Equation 5

$$SE_{\overline{CE}} = \sqrt{var(\overline{CE})}$$

where:

$\overline{CE}$	=	average capture efficiency
$\overline{CE_j}$	=	number of test fish recovered/number of test fish released in trial *j* in each cage
m	=	number of trials per cage
s^2	=	sample variance
var	=	overall variance
SE	=	standard error

Table C-1
Capture Efficiency Trials Results for 2018 and 2019

Trial (m)	Date	CE	$\overline{CE}$	$(CE - \overline{CE})^2$
1	4/03/2018	0.895	0.9050	0.000100
2	4/24/2018	0.940	0.9050	0.0001230
3	6/26/2018 and 7/17/2018	0.860	0.9050	0.002025
4	3/12/2019	0.945	0.9050	0.001600
5	4/9/2019	0.905	0.9050	0.000000
6	4/23/2019	0.885	0.9050	0.000400
			Sum(Σ):	**0.005350**

Where m = 6 capture efficiency trials

Average Capture Efficiency = (0.90 + 0.94 + 0.86 + 0.95 + 0.91 + 0.89)/6 = 5.43/6 = 0.905 ≈ **91%**

Sample Variance = Σ $(CE - \overline{CE})^2$/(6-1) = 0.005350/(6-1) = 0.001070

Variance of Capture Efficiency = 0.001070/6 = 0.000178

Standard Error of Capture Efficiency = 0.013354 ≈ **0.013**

Unadjusted Weekly Entrainment Rates

The unadjusted weekly entrainment rate is the entrainment rate (ER_i) for one 24-hour sampling event (Equation 6). The calculation incorporates the number of fish captured in both cages for the observed flow (*Q*), and time (*t*), reported in the number of fish per cubic meter. ER_i is not corrected for capture efficiency in this step. Variance and standard error around the unadjusted weekly entrainment rate shows the accuracy and spread of the data (Equations 7 through 10).

Equation 6

$$ER_i = \frac{(N_i)}{Q_i * t} = \frac{No.of\ fish}{m^3}$$

where:

N_i	=	number of fish caught in either of the two cages during a 24-hour sampling period in week i
Q_i	=	flow rate
t	=	24 hours of sampling (hours x 60 minutes/hour [=] minutes)

Equation 7

$$\overline{ER} = \frac{\sum_i^n ER_i}{n}$$

Equation 8

$$s_{ER}^2 = \frac{\sum_i^m (ER_i - \overline{ER})^2}{n-1}$$

Equation 9

$$var(\overline{ER}) = \frac{s_{ER}^2}{n}$$

Equation 10

$$SE_{\overline{ER}} = \sqrt{var(\overline{ER})}$$

where:

$\overline{ER}$	=	average entrainment rate
m	=	number of weekly values
s^2	=	sample variance
var	=	overall variance
SE	=	standard error

Table C-2
Fish Entrainment and Intake Flows Used in Calculating Entrainment Rate

Entrainment Sample Event	Deployment Day	Hours	Minutes	Chinook Entrained	Q_i (m^3/min)	ER_i (fish/m^3)	$(ER_i-\bar{E}\bar{R})^2$
1	4/4/2018	24	1440	0	58.75484	0	
2	4/11/2018	25	1500	0	58.16746	0	
3	4/18/2018	25	1500	0	60.47251	0	
4	4/25/2018	25	1500	0	64.64034	0	
5	5/2/2018	25	1500	1	64.4174	1.03×10^{-05}	
6	5/9/2018	25	1500	0	58.08828	0	
7	6/13/2018	26	1560	0	61.36079	0	
8	6/20/2018	25	1500	0	69.86632	0	
9	6/27/2018	24	1440	0	64.10091	0	
10	7/11/2018	25	1500	0	66.65765	0	
11	7/18/2018	27	1620	0	74.80318	0	
12	8/1/2018	25	1500	0	72.79992	0	
13	8/15/2018	29	1740	0	70.49494	0	
14	8/29/2018	25	1500	0	66.78243	0	
15	9/12/2018	25	1500	0	61.76179	0	
					Sums (Σ)	**1.03492×10^{-05}**	**9.996498×10^{-11}**

Notes:
m^3: cubic meters
min: minutes

Where n = 19 weeks of fish entrainment monitoring events

Average unadjusted entrainment rate = ΣER_i = $1.03492^{-5}/15 = 6.89945 \times 10^{-07} \approx$ **6.90×10^{-07} fish/m^3**

Sample Variance = $\Sigma(ER_i - \bar{E}\bar{R})^2/(n-1) = 9.996498 \times 10^{-11}/(15-1) = 7.14036 \times 10^{-12}$

Variance of unadjusted entrainment rate = $7.14036 \times 10^{-12}/15 = 4.76024 \times 10^{-13}$

Standard error of unadjusted entrainment rate = $\sqrt{(4.76024 \times 10^{-13})} = 6.89945 \times 10^{-07} \approx$ **6.90×10^{-07}**

Average Adjusted Entrainment Rate

The average adjusted entrainment rate ER_{adj}, is adjusted for average capture efficiency (Equation 11). Variance and standard error around the average adjusted entrainment rate shows the accuracy and spread of the data (Equations 12 and 13).

Equation 11

$$ER_{adj} = \frac{\overline{ER}}{\overline{CE}}.$$

Equation 12

$$var(ER_{adj}) = (ER_{adj})^2 \left[\frac{s_{ER}^2}{(\overline{ER})^2} + \frac{s_{CE}^2}{(\overline{CE})^2}\right].$$

Equation 13

$$SE_{ER_{adj}} = \sqrt{var(ER_{adj})}$$

where:

$\overline{ER}$	=	average entrainment rate
$\overline{CE}$	=	average capture efficiency
s^2	=	sample variance
var	=	overall variance
SE	=	standard error

$\overline{ER}$ = 6.90 x 10^{-07}

$\overline{CE}$ = 0.905

Average adjusted entrainment rate, adjusted = 6.90 x 10^{-07}/0.905 = **7.623698 x 10^{-07}** ≈ **7.62 x 10^{-07} fish/m^3**

Variance of average adjusted entrainment rate = (7.62 x $10^{-07})^2$ [(7.14036 x $10^{-12})^2$/(6.90 x $10^{-07})^2$ + 0.001070/0.905^2] = 8.718875 x 10^{-12} ≈ 8.72 x 10^{-12}

Standard error of average adjusted entrainment rate = sqrt(8.72 x 10^{-12}) = 2.952774 x 10^{-06} ≈ 2.95 x 10^{-06}

Total Seasonal Entrainment[2]

Total seasonal entrainment (TSE) is the expansion of the average adjusted entrainment rate (ER_{adj}) by average intake flow ($\bar{Q}$) and the number of weeks in a season (k) to yield the total number of fish entrained in a season (Equation 14). The average intake flow ($\bar{Q}$), is calculated as the average of the

[2] In Equations 14-19 the notation *n* from the SAP is replaced by notation *k* to distinguish the total number of weeks in the season from the number of weeks of entrainment testing.

weekly intake flow rates, Q_i (Equation 15). Variance and standard error around the average adjusted entrainment rate shows the accuracy and spread of the data (Equations 16 through 18).

Equation 14

$$TSE = (ER_{adj})(\bar{Q})(k).$$

Equation 15

$$\bar{Q} = \frac{\sum_i^n Q_i}{k}$$

Equation 16

$$s_{\bar{Q}}^2 = \frac{\sum_i^m (Q_i - \bar{Q})^2}{k-1}$$

Equation 17

$$var(\bar{Q}) = \frac{s_{\bar{Q}}^2}{k}$$

Equation 18

$$SE_{\bar{Q}} = \sqrt{var(\bar{Q})}.$$

where:

$\overline{ER}_{adj}$	=	average adjusted entrainment rate
Q_i	=	weekly intake flow rates
k	=	number of weekly Q_i values
$\bar{Q}$	=	average intake flow
s^2	=	sample variance
var	=	overall variance
SE	=	standard error

Where k = 24 weeks of continuous intake flow monitoring, excluding power plant outage periods

Table C-3
Weekly Intake Flows Used in Calculating Total Seasonal Entrainment

Study Week	Start of Week	End of Week	Average weekly intake flow, Q_i (gpm)	Average weekly intake flow, Q_i (m^3/min)	Minutes per Week	Average weekly intake flow, Q_i (m^3/week)	$(Q_i - \bar{Q})^2$
2018-1	3/11/2018	3/17/2018	15,438.83	58.44	10,020	585,592.1	3,735,289,612

Study Week	Start of Week	End of Week	Average weekly intake flow, Q_i (gpm)	Average weekly intake flow, Q_i (m^3/min)	Minutes per Week	Average weekly intake flow, Q_i (m^3/week)	$(Qi - \bar{Q})^2$
2018-2	3/18/2018	3/24/2018	15,461.00	58.53	10,020	586,433.0	3,633,217,180
2018-3	3/25/2018	3/31/2018	15,571.74	58.95	10,080	594,170.1	2,760,355,331
2018-4	4/1/2018	4/7/2018	15,532.05	58.80	10,080	592,655.8	2,921,767,127
2018-5	4/8/2018	4/14/2018	15,756.75	59.65	10,080	601,229.6	2,068,392,462
2018-6	4/15/2018	4/21/2018	15,802.00	59.82	10,080	602,956.0	1,914,342,579
2018-7	4/22/2018	4/28/2018	16,120.17	61.02	10,080	6150,96.6	999,356,378.1
2018-8	4/29/2018	5/5/2018	16,396.68	62.07	10,080	625,647.2	443,603,984.1
2018-9	5/6/2018	5/12/2018	16,614.63	62.89	10,080	633,963.7	162,445,725.3
2018-10	5/13/2018	5/19/2018	13,806.98	52.27	10,080	526,832.4	1,437,0442,204
2018-11	6/10/2018	6/16/2018	15,298.26	57.91	10,080	583,735.0	3,965,740,249
2018-12	6/17/2018	6/23/2018	17,383.53	65.80	10,080	663,302.3	275,333,197.4
2018-13	6/24/2018	6/30/2018	17,047.49	64.53	10,080	650,480.2	14,220,644.08
2018-14	7/1/2018	7/7/2018	17,088.57	64.69	10,080	652,047.8	28,501,005.28
2018-15	7/8/2018	7/14/2018	18,187.14	68.85	10,080	693,965.6	2,233,175,172
2018-16	7/15/2018	7/21/2018	19,137.65	72.44	10,080	730,234.4	6,976,471,173
2018-17	7/22/2018	7/28/2018	19,624.64	74.29	10,080	748,816.5	10,425,916,968
2018-18	7/29/2018	8/4/2018	19,350.03	73.25	10,080	738,338.1	8,395,865,285
2018-19	8/5/2018	8/11/2018	19,499.80	73.81	10,080	744,053.1	9,475,842,646
2018-20	8/12/2018	8/18/2018	18,593.26	70.38	10,080	709,462.0	3,937,924,433
2018-21	8/19/2018	8/25/2018	18,085.95	68.46	10,080	690,104.9	1,883,188,015
2018-22	8/26/2018	9/1/2018	17,095.04	64.71	10,080	652,294.6	31,196,948.84
2018-23	9/2/2018	9/8/2018	17,223.03	65.20	10,080	657,178.3	109,603,267
2018-24	9/9/2018	9/15/2018	16,836.52	63.73	10,080	642,430.4	18,307,922.78
					Sum	**15,521,019.646114**	**80,780,499,509**

Note:
gpm: gallons per minute

Average weekly intake flow **(Q_i)** = 15,521,019.646114/24 = 646,709.151921417 ≈ **646,709.2 m^3/week**

Sample variance = 80,780,499,509/(24-1) = 3,512,195,630.84136

Sample standard deviation of average weekly intake flow = sqrt(3,512,195,630.84136) = 59,263.7800924086

Variance of average weekly intake flow = 3,512,195,630.84136/24 = 146,341,484.61839

Standard Error of average weekly intake flow = sqrt(146,341,484.61839) = 12,097.1684545761 m^3/week

Total Seasonal Entrainment = 7.623698 x 10^{-07}x 646,709.2 x 24 = 11.83276 ≈ **12 Chinook salmon fry per season**

Precision of Total Seasonal Entrainment

Precision of the estimated total entrainment for each season can be expressed as the limits of an asymmetric greater than 90% confidence interval. An asymmetric confidence interval for the statistic *TSE* takes into account that the total number of fish entrained cannot be less than 0. The variance, $var(TSE)$, standard error, SE_{TSE}, and coefficient of variation, CV_{TSE}, of total entrainment for each season are calculated using Equations 19 through 21 and the greater than 90% confidence interval, CI_{90+}, is applied by Equation 22. An approximate 95% confidence interval on TSE can be obtained by replacing 3 with 4 in Equation 22.

Equation 19[1]

$$var(TSE) = \left[var(ER_{adj})(\bar{Q})^2 + var(\bar{Q})(ER_{adj})^2 + var(ER_{adj})var(\bar{Q})\right] * (k)^2$$

Equation 20

$$SE_{TSE} = \sqrt{var(TSE)}$$

Equation 21

$$CV_{TSE} = \frac{SE_{TSE}}{TSE}$$

Equation 22[2]

$$CI_{90} = 0 \leq TSE \ \leq (\mathrm{TSE} + 3 * SE_{TSE})$$

1. In Equation 19, Q is treated as a random variable as specified in footnote 3 of the SAP.
2. In Equation 22, calculation of the 90%+ confidence interval has been adjusted based on statistical peer review of this report.

Variance = [(8.72 x 10^{-12}) x $(646709.2)^2$ + (1.46 x 10^8) x $(7.62 \times 10^{-07})^2$ + (8.72 x 10^{-12}) x (1.46 x 10^8)] x $(24)^2$ = 2101.179

Standard Error = sqrt(2101.179) ≈ 45.83

CV_{TSE}= 45.83 /11.83 = 3.873875 (387%)

CI_{90}= 0 to 11.83 + (3 * 45.83) ≈ **0 to 150 Chinook salmon fry per season**

Entrainment Impact on Hanford Reach Fall Chinook

The seasonal impact of entrainment on the total production of Hanford Reach Fall Chinook salmon is estimated by dividing the total seasonal entrainment estimate, *TSE*, by the modeled number of pre-smolts, provided by Washington Department of Fish and Wildlife.[3]

Equation 23

$$\% \text{ Entrainment} = \frac{TSE}{R} * 100$$

where:

TSE	=	total seasonal entrainment
R	=	modeled total number of pre-smolts given estimated egg escapement

R = 56,443,475 or 10,678,675 (based on two modeling methods by Washington Department of Fish and Wildlife)

Percent Entrainment (Method 1) = 100*(11.83/56,443,475) = 100*5.6 x 10^{-06} = **0.000021% of Hanford Reach pre-smolts entrained**

Percent Entrainment (Method 2) = 100*(11.83/10,678,675) = 100*1.1 x 10^{-06} = **0.00011% of Hanford Reach pre-smolts entrained**

A maximum percent entrainment can also be calculated using the upper confidence limit on TSE

Maximum Percent Entrainment (Method 1) = 100*(150.5/56,443,475) = 100*5.6 x 10^{-06} = **0.00027% of Hanford Reach pre-smolts entrained**

Percent Entrainment (Method 2) = 100*(150.5/10,678,675) = 100*1.1 x 10^{-06} = **0.0014% of Hanford Reach pre-smolts entrained**

[3] WDFW 2019. Email from Paul Hoffarth (Washington Department of Fish and Wildlife) to Kristi Geris (Anchor QEA) on November 9, 2019, regarding Hanford Reach Fry Estimates.

Appendix E
Historical Fish Occurrence and Risk Assessment of the Columbia Generating Station Intake Structure

February 2019
Columbia Generating Station Fish Entrainment Study

ANCHOR QEA

Historical Fish Occurrence and Risk Assessment of the Columbia Generating Station Intake Structure

Prepared for Energy Northwest

February 2019
Columbia Generating Station Fish Entrainment Study

Historical Fish Occurrence and Risk Assessment of the Columbia Generating Station Intake Structure

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Project Number: 171376-01.01

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ABBREVIATIONS

CFD	computational fluid dynamic
cfs	cubic feet per second
CGS	Columbia Generating Station
DPS	Distinct Population Segments
ESA	Endangered Species Act
ESU	Evolutionary Significant Unit
FL	fork length
fps	feet per second
gpm	gallons per minute
HRFCPPA	Hanford Reach Fall Chinook Protection Program Agreement
kcfs	thousand cubic feet per second
km	kilometer
m	meter
MASS1 and MASS2	Modular Aquatic Simulation System in One and Two Dimensions
mm	millimeter
mps	meters per second
MSL	mean sea level
NMFS	National Marine Fisheries Service
NPDES	National Pollutant Discharge Elimination System
Plan	*Draft Entrainment Characterization Study Plan for the Columbia Generating Station, Richland, Washington*
PRD	Priest Rapids Dam
rkm	river kilometer
RM	river mile
SD	standard deviation
TMU	Cooling Tower Make-Up pumphouse
VBSA	Vernita Bar Settlement Agreement
WDFW	Washington Department of Fish and Wildlife

Executive Summary

This Historical Fish Occurrence and Risk Assessment report provides a literature review on fish species present in the Hanford Reach, factors that determine fish entrainment, entrainment risk at the Columbia Generating Station (CGS), and a review of historical river elevations and discharges that may affect entrainment at the CGS intakes in the Hanford Reach of the Columbia River.

The two CGS intake structures are 9-meter (30-foot)-long, perforated cylindrical screens designed to distribute the intake water flow evenly along the outer surface of the structure. They are mounted above the riverbed and situated approximately mid-channel and approximately parallel to the river flow.

The CGS make-up water intake occurs downstream of Priest Rapids Dam in a section of free-flowing river known as the Hanford Reach, which supports the largest mainstem-spawning population of fall-run Chinook salmon (*Oncorhynchus tshawytscha)* in the Columbia River (Dauble and Watson 1997), as well as a smaller population of steelhead (*O. mykiss*; Nugent 2016). Additionally, the Hanford Reach is a migratory pathway for several species of anadromous fishes that reproduce and rear in upstream reaches, upper Columbia River spring Chinook salmon (Endangered), upper Columbia River steelhead (Threatened), Wenatchee and Okanogan sockeye salmon (*O. nerka*; not listed), and coho salmon (*O. kisutch*; coho salmon are unlisted, but currently a reintroduction effort exists to reverse historical extirpation from the middle and upper Columbia River Basin) and Pacific lamprey (*Entosphenus tridentatus*). A suite of resident native fishes can also be found that are typical of the riverine fish community in the Pacific Northwest.

A detailed review of biological factors that determine risk of entrainment included seasonal trends in species presence, fish life-histories and behavior, and habitat preferences. A subset of species was identified that is at risk of encountering the CGS intake due to seasonal presence, tendency to use mid-channel, and size that could become entrained through intake screen pores if in close proximity to the screen face. Further, the physical factors that determine fish entrainment for cylindrical screens such as those in use at CGS, including hydraulic bypass, behavioral avoidance by the fish, exclusion by screen pores, and sweep off were identified to be used in a review of entrainment risk for common species in the Hanford Reach. Risk of entrainment and impingement was considered in the context of the large seasonal variation in river discharge, depth, and velocity that occur at the site. The CGS intake was designed to bypass most fish, and recent hydraulic modeling shows that under most flow conditions at the site, the river velocity (sweeping velocity) would greatly exceed velocity perpendicular to the intake screens (approach velocity) causing most fish to be swept past the intake.

Taking a conservative approach that some risk exists for the subset of species identified, a review of biological factors determined that periods of higher risk of encountering the intake occur when the most vulnerable species are present in highest abundance from March through September. Though

hydraulic bypass of fish is facilitated by sweeping velocities that exceed approach velocity year-round, risk of encountering the intake may also increase late in the year when submergence depths are lower.

Concerns were raised by the National Marine Fisheries Service and Washington Department of Fish and Wildlife about risk of entrainment and impingement to Endangered Species Act-listed and non-listed salmonids. Typically, migratory smolts originating from the upper Columbia River Basin (upstream of Hanford Reach) are a size that would exclude them from becoming entrained through the CGS intake screens (greater than 75 millimeters). In addition, smolts from the upper Columbia River Basin tend to behave in ways that greatly minimize their risk of impingement: their peak emigration timing is in spring and summer, concurrent with peak sweeping velocities; they tend to migrate near the surface, placing them approximately 7 to 12 feet from the intake screens at this time of year; and they would have burst swimming capacities that greatly exceed through-hole velocities, allowing for behavioral avoidance of the intakes given a stimulus such as the sudden change in pressure that occurs as water moves around the intakes. Based on these biological factors, the risk of entrainment or impingement to migrating smolts from the upper Columbia River Basin was determined to be negligible for the CGS intake structures.

Salmon and steelhead that emerge and rear within the Hanford Reach have higher potential risk due to their small size and potential exposure to the intake during early development. Hanford Reach Fall Chinook salmon are the salmonid species at highest risk due to their proximity and abundance near the CGS intakes. The entrainment factors that create the most risk for fall Chinook salmon are their presence in proximity to the intake structure, their habitat preference that causes them to move away from nearshore areas as they grow, and their small size relative to the external screen pore size. These characteristics put fall Chinook salmon at relatively higher risk in April and May when large numbers of fry are both small in size and starting to move away from nearshore areas. However, fall Chinook salmon can also effectively avoid entrainment given their ability to sense rapid changes in acceleration and burst swimming capacity that also exceeds maximum approach velocity by a factor of 10.

Overall, the probability of fish that encounter the CGS intake becoming entrained or impinged is exceedingly low, due primarily to effective hydraulic bypass and secondarily by behavioral avoidance by most species. It is only the smallest and weakest fish and life-history stages that happen to occur in mid-channel that are at risk of entrainment or impingement.

1 Introduction

Energy Northwest's Columbia Generating Station (CGS) is a boiling-water nuclear power plant that began commercial operation in December 1984. A majority of the water used to cool the nuclear reactor recirculates between the reactor and cooling towers ("closed cycle cooling"). Some of this recirculating water is lost in the cooling towers by evaporation and drift of water droplets entrained in the air, leading to concentration of dissolved salts in the circulating water system. Water and dissolved salts are gradually replaced by release of a portion of the circulating water as "blowdown" water to the Columbia River. The combined losses from evaporation, drift, and blowdown are replenished by "make-up" water acquired from the Columbia River. The intake structure for this make-up water is the focus of ongoing studies to better characterize the risk of entrainment and impingement posed to fish or other aquatic life.

The CGS site is located in a unique section of the Columbia River known as the Hanford Reach, which is the only remaining free-flowing portion of the river in the United States. This section of the river hosts various life stages of native cold- and swift-water species that can no longer make use of impounded reaches, including a key population of fall Chinook salmon (*Oncorhynchus tshawytscha*) that has increased in abundance over the past 20 years.

The CGS intake structures are a cylindrical design oriented in the river channel to minimize fish entrainment. Initial testing carried out in 1981 showed no fish, fish eggs, or larvae were entrained, and SCUBA surveys in 1985 showed no fish impingement or screen blockage due to biofouling even though resident fish were observed near the intake.

On September 30, 2014, the Washington State Energy Facility Site Evaluation Council (EFSEC) published a reissuance of National Pollutant Discharge Elimination System (NPDES) Permit No. WA-002515-1 for Energy Northwest's CGS, which included consideration of the intake structure. The final permit, effective November 1, 2014, was the result of consultations between EFSEC and interested agencies, including the Washington Department of Ecology, Region 10 of the U.S. Environmental Protection Agency, and the National Marine Fisheries Service (NMFS). Concerns were raised by NMFS and Washington Department of Fish and Wildlife (WDFW) about risk of entrainment and impingement to Endangered Species Act (ESA)-listed and non-listed salmonids migrating from upstream spawning and nursery areas, given that the existing intake screens were installed using a design developed prior to the formal development of NMFS engineering design criteria (Suzumoto 2010; NMFS 2011a). The species called out by NMFS for consultation were the upper Columbia River spring Chinook salmon (Endangered), upper Columbia river steelhead (*O. mykiss*; Threatened), and coho salmon (*O. kisutch*; coho salmon are unlisted, but currently a reintroduction effort exists to reverse historical extirpation from the middle and upper Columbia River Basin).

To address NMFS' and WDFW's concerns regarding fish entrainment, NPDES Condition S12.B was included in the final permit that became effective on November 1, 2014, requiring CGS to prepare an entrainment characterization study design and submit it to EFSEC for approval by November 1, 2015. The *Draft Entrainment Characterization Study Plan for the Columbia Generating Station, Richland, Washington* (Plan; Coutant 2014; Appendix A) was submitted to EFSEC in October 2015. EFSEC approved the study plan in June 2016. The approved plan described the general methods for a 2-year fish entrainment monitoring study. The Plan reviewed existing literature to identify species at risk of entrainment or impingement and provided general methods for repeating field monitoring of entrainment rates in a manner similar to what was conducted when CGS first became operational. Direct field monitoring of entrainment is underway to enumerate and quantify the potential risk of entrainment of the current water intake screen design and location to listed and non-listed salmonids and other fish species that occupy Hanford Reach habitats. The monitoring is occurring over two field seasons with a final study report to be submitted to EFSEC by May 1, 2020.

An initial literature review of entrainment and impingement risk created by the type of cylindrical screens in use at CGS provided to Energy Northwest and stakeholders (Coutant 2014b) found that NMFS intake screen criteria were developed mainly for rotating drum screens, vertical screens, and inclined screens, but not cylindrical screens of the type and placement in the river channel as used at CGS. A review of controlled laboratory studies of cylindrical intake screens found that unlike other screen types, the assumption that pore size and approach velocity (velocity caused by flow through the screens) are important design criteria is not appropriate for cylindrical screens oriented parallel to flow in relatively high velocity water, where most fish are bypassed around the cylinder or swept off the face of the cylinder if they encounter the screen face.

In addition to describing the methodology used to conduct the 2-year fish entrainment study, the Plan also outlined the need for a more thorough review of existing literature to identify fish species and life stages at risk of entrainment or impingement. This Historical Fish Occurrence report builds upon the review of cylindrical screens in Coutant (2014b) by focusing on additional information from the literature on the various fish species present, their biological characteristics such as life histories, physiological capacity, and habitat preferences that make them vulnerable to entrainment. It provides a literature review of fish species that occur in the Hanford Reach of the Columbia River, evaluates entrainment and impingement risk posed by the CGS intake, and summarizes historical water elevations and river flow near the CGS intake structure that may influence that risk. The physical factors that affect entrainment by cylindrical screens are evaluated in the context of the biological characteristics of the fish species present and modeled hydraulic conditions near the water intake screens (Alden 2018; Perkins 2018), along with an assessment of potential risk to further inform the concerns raised by NMFS and WDFW.

1.1 Site Background

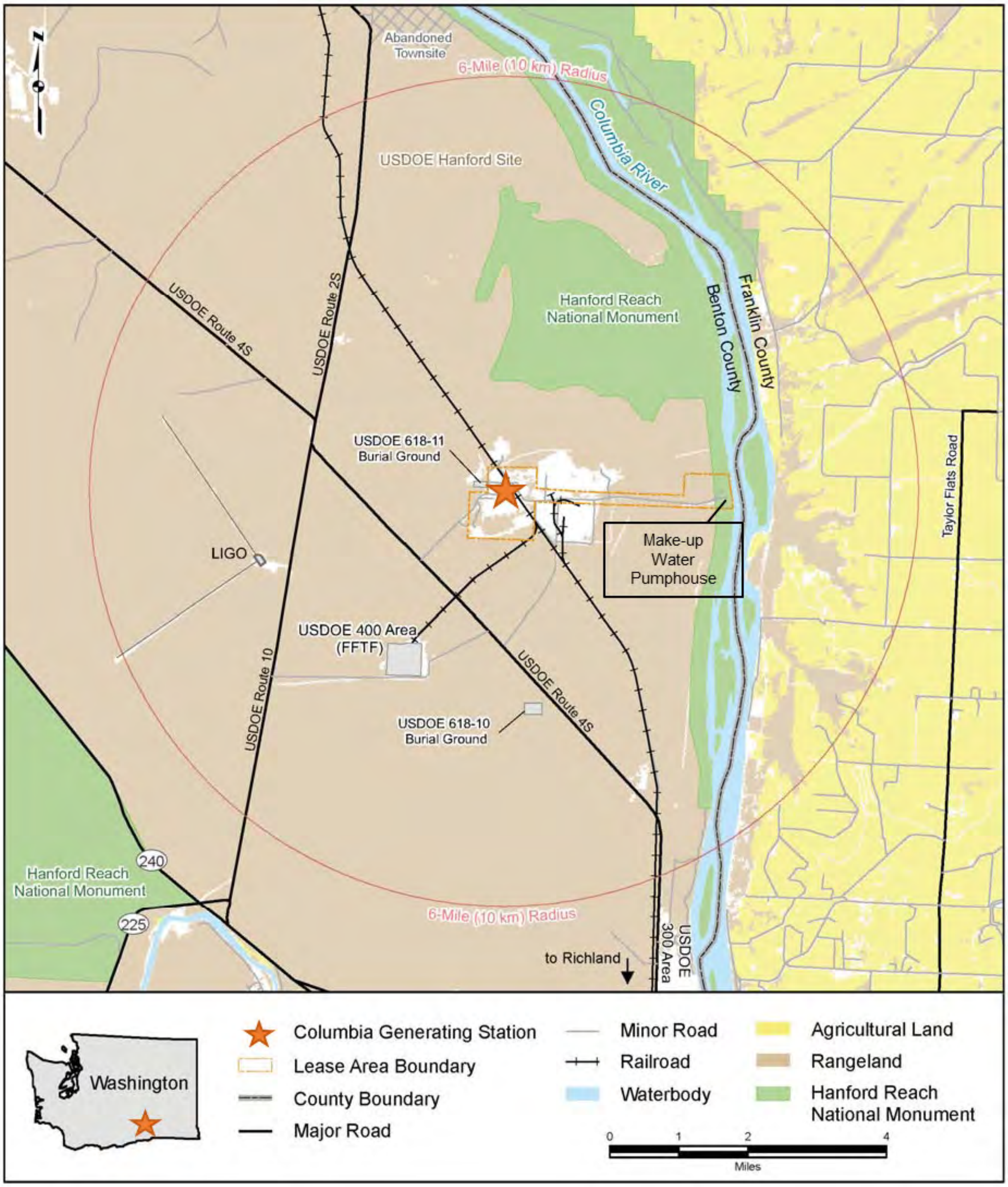
The CGS is located approximately five miles north of Richland, Washington, adjacent to the west bank of the Columbia River at river kilometer (rkm) 566 (river mile [rm] 352; Figures 1 and 2). The CGS is a single-unit, 1,170-megawatt boiling-water nuclear power plant that began commercial operation in 1984. The plant uses a closed-cycle cooling system that uses circulating water to cool and condense steam exiting the main turbine. A portion of the circulating water system water that is lost to evaporation, droplet drift, and blowdown is replenished by make-up water acquired from the Columbia River.

The CGS make-up water intake occurs downstream of Priest Rapids Dam (PRD) located at rkm 639 and upstream of the McNary Dam pool (Lake Wallula) in a section of free-flowing river known as the Hanford Reach. The Hanford Reach is a 90 kilometer (km; 56 mile) stretch of river that extends from PRD at its upstream end to the city of Richland at its downstream end where the river enters the head of Lake Wallula that is formed by McNary Dam. Three major tributaries enter Lake Wallula, the Yakima, Snake, and Walla Walla rivers, and converge with the Columbia River. The Hanford Reach is a significant habitat resource for native fish because it is the only remaining free-flowing section of the Columbia River within the United States that is accessible to anadromous fish and it retains much of its natural geomorphic features.

Figure 1
Site Location Map, 80-Kilometer (50-Mile) Radius

Source: EN 2010

Figure 2
Site Location Map, 10-Kilometer (6-Mile) Radius



Source: EN 2010

The Hanford Reach supports the largest mainstem-spawning population of fall-run Chinook salmon in the Columbia River (Dauble and Watson 1997), as well as a smaller population of steelhead (*Oncorhynchus mykiss*) (Nugent 2016). Additionally, the Hanford Reach is a migratory pathway for several species of anadromous fishes that reproduce and rear in upstream reaches, including spring-run Chinook salmon, summer-run steelhead, sockeye salmon, coho salmon, and Pacific lamprey (*Entosphenus tridentatus*). The CGS intake structure is being directly monitored as part of a 2-year fish entrainment study and a fish impingement study for its potential to impact fall-run Chinook salmon and steelhead fry that rear in the reach, migrating salmonid smolts originating from upriver, and other fishes that reside or migrate through the reach.

River flow, which is a variable affecting potential entrainment and impingement at the CGS intake, is regulated by interagency agreements. The term river discharge is used to describe the total volume of Columbia River water flowing past a given point, such as Priest Rapids Dam or the CGS intake structure site. River discharge in the Hanford Reach is determined by PRD located at rkm 72.4 (rm 45) upstream of CGS. To address impacts of fluctuating water levels on salmon survival and habitat downstream of PRD, the Vernita Bar Settlement Agreement (VBSA) was signed in 1979, implemented in 1984, and finalized in June of 1988. The VBSA limited salmon nest (redd) dewatering by setting minimum flow levels at 70,000 cubic feet per second (70 kcfs) leaving PRD and maintaining low elevation flow during the day to prevent redd building in areas that could become dewatered. The Hanford Reach Fall Chinook Protection Program Agreement (HRFCPPA), enacted in 1999 and finalized in 2004, superseded and replaced the VBSA. The HRFCPPA regulates flows leaving PRD during spawning, pre-hatch, post-hatch, emergence, and rearing periods. Under this agreement, a monitoring team conducts redd surveys every fall and sets a critical minimum flow based on the elevational distribution of the redds within the Hanford Reach, thus protecting them from dewatering. In addition to protecting redds, the HRFCPPA also minimizes the magnitude of flow fluctuations during the rearing period when juveniles are most at risk of being stranded due to flow fluctuations (Grant PUD 2004).

1.1.1 Columbia Generating Station Make-Up Water Intake Structure

The Cooling Tower Make-Up (TMU) water pumphouse is located 3 miles east of the CGS reactor complex, on the west bank of the Columbia River (Figure 2). The TMU pumphouse contains three make-up-water pumps situated in a pump well, with two pumps typically in use. Water is gravity-fed into the pump well via two 36-inch (91-centimeter)-diameter buried pipes that extend 900 feet (274 meters [m]) from the pumphouse to the river channel (Figures 3 and 4). Water is then pumped from the pump well by three 800-horsepower make-up-water pumps. (Figure 3). Each intake structure is designed to allow make-up-water withdrawal at a rate of 12,500 gallons per minute (gpm) for a maximum withdrawal capacity from the pump well of 25,000 gpm. However, the average daily make-up-water withdrawal for CGS is typically much lower. It was 15,438 gpm in 2018, and for

permitting purposes was estimated to draw approximately 17,000 gpm, or about 0.03% of the average mean annual river discharge of the Columbia River per day near the site. Withdrawal rates vary on an hourly, daily, and seasonal basis. Make-up-water pumps draw from the pump well and not directly from the river, therefore flow through the intake structures depends upon the hydraulic head differential between the river and the pumphouse, which is affected by drawdown for plant operations and by changing water levels in the Columbia River. The intake structures withdraw water from the river at a combined average rate of approximately 8,500 gpm (19 cfs).

Two intake structures are located in the river at the end of each of the buried pipes. The pipes make a 90-degree, upward bend and extend slightly above the surface of the riverbed (Figure 4). Attached to each of the pipes is a 30-foot (9 m)-long, cylindrical screen housing mounted above the riverbed and situated approximately mid-channel, approximately parallel to the river flow (Figure 4). Each cylinder is 6.5-feet (2 m)-long and mounted upstream and downstream of a central chamber attached to the buried pipe. Each cylinder is capped on both ends with conical caps. Each cylindrical screen consists of an outer and inner sleeve of perforated pipe designed to distribute the intake water flow evenly along the outer surface of the structure. The outer screen is 1.07 m (42 inches) in diameter with 9.5-millimeter (mm; 0.375-inch) holes comprising 40% of the surface area while the inner screen is 0.91 m (36 inches) in diameter with 19-mm (0.75-inch) holes comprising 7% of the surface area. For average intake conditions, the approach velocity of the bulk flow perpendicular to the screen surface is 0.07 fps, and the average normal through-pore velocity is 0.16 fps.

Hydrodynamic conditions around the two CGS intake structures were investigated in detail with a CFD model to describe the predicted pressure and velocity patterns around the intake at both broad and fine scales (Alden 2018). Scenarios were modeled for three river-discharge levels, four potential angles of river flow and whether the plant intake was operating or not, providing a wealth of data on flow patterns specific to the CGS intake structures. Special attention was paid to velocity and pressure changes that result from flow around the nose of the structures and fine scale examination of the approach velocities and sweeping velocities along the turbulent boundary layer of the perforated screens. Briefly, CFD model results confirmed that a rapid change in pressure, described as a bow wave, exists at the nose of the intakes resulting from the water intercepting the stationary intakes. The bow wave is implicated in hydraulically diverting fish (hydraulic bypass) and instigating evasive fish behavior (Coutant 2014; hypothesized effects on fish are discussed further in section 3.2). The bow wave had a relatively consistent form across the various river conditions modelled, growing only slightly when the river flow angle was more oblique to the intake screens, and was only slightly smaller when CGS intake pumps were off. At a finer scale, modeling characterized turbulence in a boundary layer along the screens, or the area within which the sweeping velocity is affected by friction with the intake screens. The boundary layer varied in thickness depending on modeled conditions, and areas of concentrated inflow were revealed downstream of the bow wave, approximately one-third of the way down the screen area. Importantly, at the fine scale within 20 and

200 mm of the screen surface, sweeping velocity and approach velocity varied with different river conditions and non-uniformity of flow along the cylindrical screens. Modeling of the pores indicated that the effective pore size due to hydraulic patterns was considerably smaller than the physical pore size. Notably, the risk of impingement or entrainment was effectively minimized by the hydraulics of water flow around the screens under most river and operating conditions, yet certain specific conditions were revealed that may increase risk of impingement or entrainment at certain parts of a screen based on present NMFS screening criteria. These conditions include scenarios of low river velocity or flow direction that was more oblique to the intake structure. A detailed summary of conditions that increase the risk to fish and the implications of these modeled flow patterns for fish impingement and entrainment and are explored further in Section 3.2.

Figure 3
Columbia Generating Station Make-Up Water Intake System Plan and Profile Views

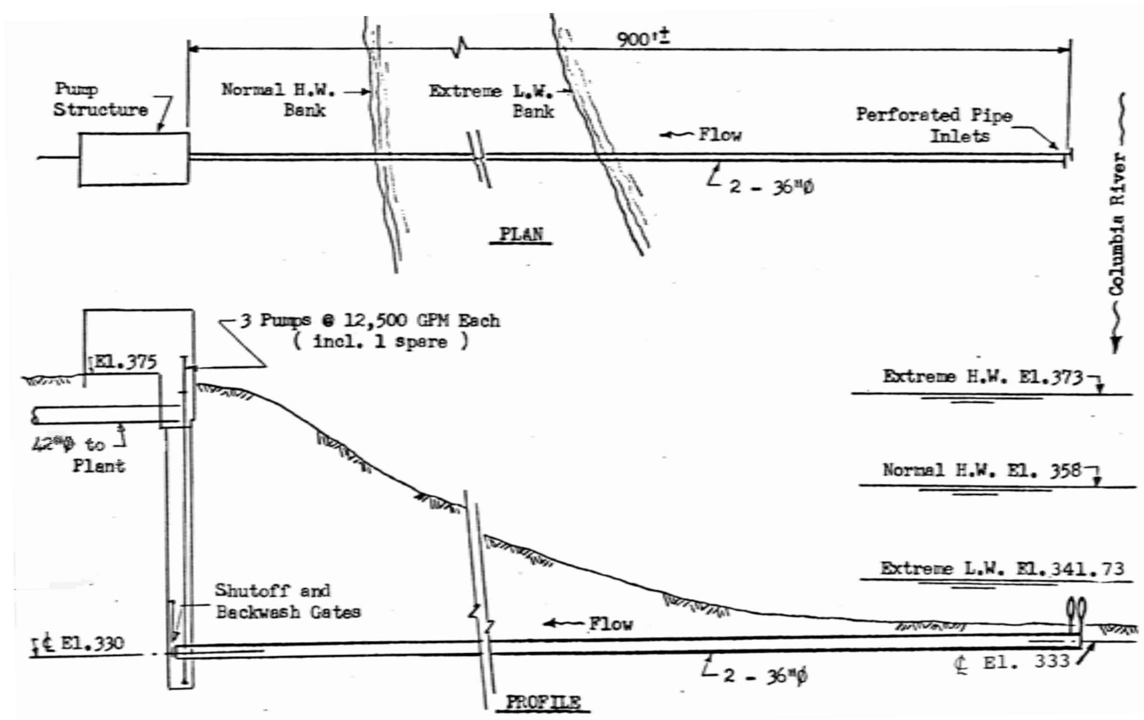
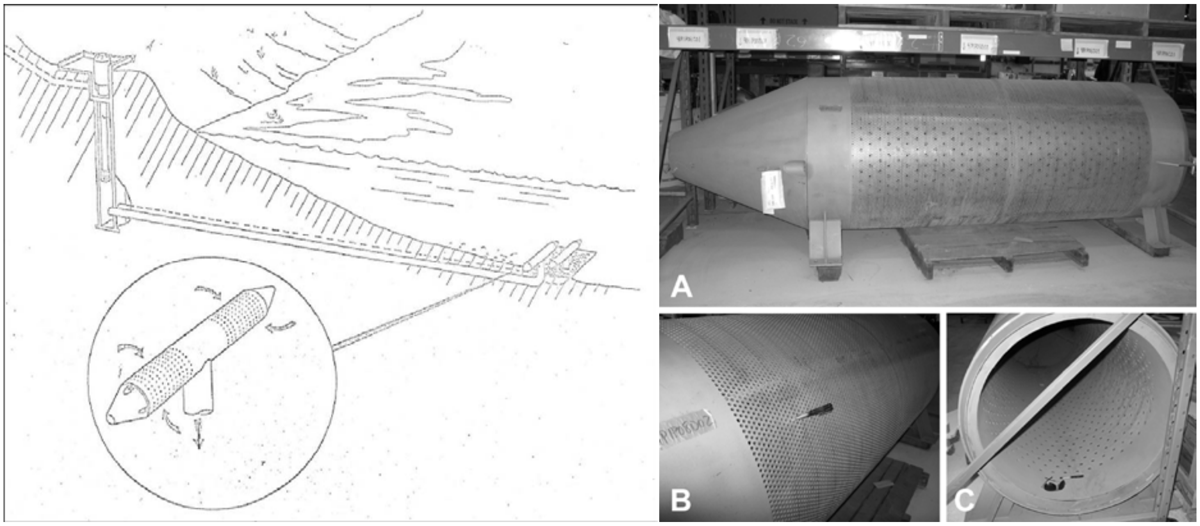


Figure 4
Artists' Rendering of the Columbia Generating Station Make-Up Water Intake System and Photographs of a Spare Intake Screen



Note: Left panel: artist's rendering; Right panel: photographs of a spare intake screen showing the side view (A) outer sleeve (B) and inner sleeve (C)

The river bed elevation at the intake structure is 101.50 m above mean sea level (MSL; 333.00 feet) and the two cylindrical intake structures are situated above the riverbed at the end of each buried intake pipe. Taking into account the intake structure mounting and cylinder diameter, the elevation of top of the cylinder is 104.02 m MSL (341.30 feet); shown in additional plan view figures in Appendix A. The intake structure was designed for river elevations that range at this location from approximately 104.16 m MSL (341.73 feet) during extreme low-water events to 113.69 m MSL (373.00 feet) during extreme high-water events, and where normal high-water elevation occurring at approximately 109.12 m (358.00 feet). These elevations translate to operating depths of water covering the cylindrical screens that range from 9.66 m (31.70 feet) to 0.13 m (0.43 feet) at extreme high- and low-water levels respectively, and normal high-water depth of 5.09 m (16.70 feet). Section 5 of this report provides a detailed analysis of the historical river elevation record that characterizes the observed ranges of extreme water levels and frequency of low water events.

1.1.2 Previous Entrainment Studies

Fish entrainment was a concern during design and construction of the CGS intake structure, and several studies were conducted in the 1970s through 1980s to assess the impacts of the intake on fish, particularly fall Chinook salmon. In a pre-operational study conducted from September 1974 through March 1980, the river environment near the intake structure was sampled using beach seines, hoop nets, gill nets, and electroshocking equipment. A total of 35,939 fish representing

37 species were observed with Chinook salmon representing 44% of the catch (WPPSS 1982). Initial entrainment and impingement studies were conducted between 1980 through 1985 and no fish nor debris were observed to be impinged on the intake screens; nor were any eggs, larvae, or fish captured in the pumphouse cages specially designed to intercept entrained organisms (EN 2010). A follow up study in 1985, targeting the juvenile salmon out migration, found no observable impingement or entrainment of fish, fish eggs, or larvae while the facility was operating at a minimum of a 75% power load (WPPSS 1985).

However, increases in fall Chinook salmon productivity in the Hanford Reach resulting from the HRFCPPA is a cause for renewed assessment of the potential of impingement and entrainment of fry. In the process of renewing the CGS operating license in 2011, the U.S. Nuclear Regulatory Commission conducted a biological assessment of essential fish habitat, and the potential effects of the CGS intake system on federally listed species. This assessment concluded that Endangered Species Act (ESA)-listed upper Columbia River spring Chinook salmon and upper Columbia River steelhead may be affected, but were not likely to be adversely affected (NRC 2011). Nonetheless, in correspondence addressing concerns regarding the renewal of the NPDES permit for the CGS (NMFS 2013a,b), the outer screen of the intake structure, with 9.5-mm (0.375-inch) openings, was identified as failing to meet current NMFS and WDFW screen criteria for water intake structures (NMFS 2011a). Fish smaller than 75 mm in body length were identified as being at risk of impingement or entrainment in the CGS intake structure (NMFS 2013a,b). Typically, migratory smolts are greater than 75 mm in size and are surface-oriented, supporting the U.S. Nuclear Regulatory Commission's conclusion that the intake structure presents a low risk to ESA-listed smolts migrating from reaches upstream; however, salmonid fry that emerge and rear near the CGS intake structure would be less than 75 mm in size and should be included in this category of potential elevated risk.

1.2 Literature Review Objectives

The objectives of this study are to characterize the fish present in the vicinity of the make-up-water intake structure located in the Columbia River, and to identify the potential for fish entrainment or impingement, with a focus on early life stages of Chinook salmon and steelhead. This report fulfills this objective in part, by providing:

- A description of the spatial and temporal characteristics of fish species and abundance in vicinity of the intake structure, through a literature review and synthesis using the following resources:
    - Fish community survey results summarized in Energy Northwest's licensing documents, both historical records from the 1970s and 1980s and related to the current license agreement (EN 2010)

    - Published academic literature and books describing fish communities and salmon population dynamics in the Hanford Reach (various authors cited, e.g. Dauble et al., Harnish et al., Wydoski and Whitney 2003)
    - Salmon and steelhead spawning survey reports for the Hanford Reach (e.g. Nugent and Cranna 2015)
- A description of how annual, seasonal, and diel variations in river discharge interact with the make-up-water intake structure to affect the degree of potential entrainment or impingement risk using the following resources:
    - Published academic literature on typical behavior and habitat preferences of key migratory fishes such as salmon and lamprey, and other resident species, where available (various authors cited)
    - Laboratory studies combining computational fluid dynamic (CFD) modeling, laboratory experimental data using scale models, and statistical analysis that describe fish entrainment and show the reactions of early life stages of several fish species to a cylindrical intake structure (NAI and ASA 2011).
    - Modular Aquatic Simulation System in One and Two Dimensions (MASS1 and MASS2) modelling developed by Battelle-Pacific Northwest National Laboratory scientists to simulate hydraulics across the Hanford Reach (Niehus et al. 2014), used to report predicted velocity and depth under varying river discharge levels at the CGS intake structures (Perkins et al. 2018)
    - Three-dimensional computational fluid dynamics (CFD) modeling of the physical flow patterns (i.e. velocity and pressure changes) around the CGS intake screens at various river discharge levels, angles of river flow, and plant operation conditions (Alden 2018)
    - Guidelines developed by NMFS to protect the most vulnerable life stages and species of fish from various types of intake screens (NMFS 2011)

2 Fish Species Present in the Hanford Reach

This section synthesizes historical literature describing the fish species present in the vicinity of the CGS intake. The fish species considered include those known to be present in the Hanford Reach of the Columbia River, bounded by the PRD upstream and McNary Dam downstream. Some riverine fish species may disperse upstream through normal movements, straying during migration, flood events, and angler introductions, therefore some species are included because of their occurrences in lower reaches of the Yakima River or Snake River, two major tributaries that converge with the Columbia River at the downstream end of the Hanford Reach. The following section is a narrative review of life stages, size classes, seasonal abundance, and general habitat preferences with a focus on describing life-history characteristics of the most commonly observed species groups and life stages in the Hanford Reach. The complete list of all species and life stages potentially present in Hanford Reach and at risk of entrainment or impingement is compiled in Appendix B, Table B-1 along with relevant biological information.

2.1.1 Salmonids

Salmon and trout generally require riverine conditions for spawning and embryo incubation with course gravels for building redds, and cold, low turbidity water flowing through the redds at relatively high velocities to oxygenate and sustain the incubating embryos. After emerging from gravels in the spring and early summer, salmonid fry typically rear in slower-velocity, micro-habitats that provide forage and cover by overhanging vegetation, wood, and river banks, often taking advantage of smaller side channels or off-channel habitat in the floodplain that may be seasonally wet.

Historically, salmon spawning and rearing occurred throughout the mainstem reaches of the middle and upper Columbia River. Presently, the majority of accessible habitat in the mainstem Columbia River has been converted to a series of deep, low-velocity pools impounded by hydroelectric dams with little habitat diversity. The Hanford Reach is the only unimpounded reach remaining, still maintaining the key habitat features that support salmonid spawning and rearing despite flow regulation by upstream dams. Thus, the Hanford Reach is currently the only significant spawning area for anadromous salmon and steelhead in the mainstem Columbia River.

The Hanford Reach supports a distinct reproducing population of fall Chinook salmon that represents the only significant population of fall-run Chinook salmon that spawn in the mainstem Columbia River, and the largest population of fall Chinook salmon in the Columbia Basin (Dauble and Watson 1997; WDFW 2018). As part of the upper Columbia River summer- and fall-run Chinook salmon Evolutionary Significant Unit (ESU), this population is a top priority for conservation because of its ecological, cultural, and economic significance as one of the few salmon stocks in the Pacific Northwest that are not listed under the ESA.

Summer steelhead are also present and known to spawn in the Hanford Reach, though in smaller relative abundance than fall Chinook salmon (WPPSS 1982; Nugent and Cranna 2015). The upper Columbia River Distinct Population Segments (DPS) of steelhead, listed as Threatened under the ESA (NMFS 2011b, 2014), are found in the Hanford Reach and in upstream tributary sub-basins.

Bull trout (*Salvelinus confluentus*) may have occupied the Hanford Reach historically, but are considered extirpated from the area, with only an occasional adult seen migrating through PRD or McNary Dam. Nonetheless, the Hanford Reach remains a U.S. Fish and Wildlife Service-designated critical habitat for middle and upper Columbia River bull trout, providing potential foraging, migrating, and overwintering habitat for juveniles and subadults that originate from colder tributaries and undertake a fluvial or adfluvial life histories (forms that undertake freshwater migrations within the Hanford Reach or among Columbia River reservoirs). The Columbia River bull trout DPS is listed as threated under ESA (USFWS 1999) and listed as a Washington State Candidate Species (WDFW 2008).

Mountain whitefish (*Prosopium williamsoni*) are also present in the Hanford Reach. In ecological monitoring studies conducted between 1974 and 1980, mountain whitefish were commonly observed and comprised up to 3.7% of species abundance near CGS (EN 2010). Relatively little information on juvenile mountain whitefish abundance and activity exists for the middle Columbia River, however all life stages are observed in the Hanford Reach. Small, age-0 fish less than 100 mm fork length (FL), are most likely present in Hanford Reach from March through the summer in shallow water, moving into deeper water as they grow (Wydoski and Whitney 2003; Dauble 2009). Juvenile mountain whitefish have been collected in nearshore surveys of the river (Becker et al. 1981; Dauble et al. 1989).

Anadromous salmonids from upstream Columbia River tributaries, including upper Columbia River spring and summer Chinook, sockeye, and coho salmon and upper Columbia River summer steelhead pass through the Hanford Reach on their seaward migration as juveniles and return spawning migrations by adults. Upper Columbia River spring Chinook salmon are listed as Endangered (NMFS 1999, 2005, 2014) and spring Chinook salmon are also listed by WDFW as a Washington State Candidate species (WDFW 2008). Juveniles of these stocks migrate downstream as relatively large yearling (age-1+) smolts and tend to pass through the free-flowing Hanford Reach quickly, traveling on average to 56 km per day (34 miles; Weitkamp and McEntee 1982). By virtue of large size and rapidity of passage through the high-velocity river, smolts would seem to be at negligible risk of entrainment or impingement. Spring Chinook, sockeye, and coho salmon smolts migrate through the Hanford Reach between April and July, with peak run timing depending on the species and stock.

In a cross-sectional study of juvenile salmonid occurrence in the water column in the Hanford Reach, the majority of migrating smolts were observed in the mid-channel of the mainstem (Dauble et al. 1989). Yearling (age-1+) spring Chinook salmon smolts were distributed throughout the water column up to 12.2 m (41 feet) deep, whereas steelhead were distributed at mid-depths or near the

bottom (nearly all collected greater than 4 m [13 feet] deep), and sockeye salmon smolts occurred at greater mean depths than other species (58% captured greater than 8 m [26 feet] deep). Mid-channel migration in high-velocity water is commonly observed in the mainstem Columbia River (Burley and Poe 1994; Chapman et al. 1995); however, the presence of smolts in deeper sections of the water column contrasts with studies of migration through lentic environments, such as impounded sections of the Columbia River, where smolts tend to migrate near the surface (upper 5 m [16 feet]) of the water column (e.g., Giorgi and Stevenson 1995; USACE 1995; Beeman and Maule 2006). Smolt migration through the unimpounded Hanford Reach may be influenced by microhabitat scale factors encountered in the riverine environment, such as site-specific hydraulic conditions. For instance, Dauble et al. (1989) found that more juvenile salmon were associated with the mid-channel or northeast shoreline rather than being equally distributed between the two shorelines, potentially as a result of fish orienting with areas of higher flow to initiate migration.

2.1.1.1 Hanford Reach Fall Chinook Salmon Life History

Salmonid populations that rear within the Hanford Reach are vulnerable to encountering the CGS intake, particularly the very early life stages of the locally-spawning fall Chinook salmon that are abundant in the Hanford Reach. The newly emerged fry are small in size and they rear in the Hanford Reach for weeks to months prior to migrating downstream. In addition, Hanford Reach fall Chinook salmon have been studied intensively over several decades in order to quantify the impacts of PRD upstream and contamination from the adjacent Hanford Reservation. A more detailed review of Hanford Reach fall Chinook salmon life history is warranted to support the fish entrainment monitoring efforts that are currently being undertaken to quantify the potential impact of fish entrainment at the population level.

Adult fall Chinook salmon enter freshwater at a fully mature state in late summer through fall, typically spawning in the Hanford Reach between mid-October through the third week of November (Dauble and Watson 1997; Nugent 2016). The majority of fall Chinook salmon redds occur consistently in major spawning areas located dozens of kilometers upstream of the CGS intakes; however, in recent years, hundreds of redds have been counted within 1 km of the CGS intake; discussed further below (Figure 2 and Table 1).

Fall Chinook salmon fry emerge from gravels from mid-March through mid-May, with peak emergence observed in mid- to late April depending on water temperatures (McMichael et al. 2005, 2015). Fry range in length between 37 and 44 mm FL at emergence, and are highly dependent on shallow, shoreline habitats for feeding and sanctuary (Tiffan et al. 2006; McMichael et al. 2015). Subyearlings (age-0) prefer shoreline habitats with warmer temperatures than the mainstem, low lateral bank slopes, and mean water velocities less than 1.5 feet per second (fps), as well as mid-sized substrates such as large gravel and cobble (Tiffan et al. 2006). Subyearling fall Chinook salmon feed and swim in the middle or upper portion of relatively shallow water (4 to 22 inches deep) during

daytime, while during nighttime they remain less active in the lower portion of the water column (Tiffan et al. 2006). As subyearlings increase in size, they begin to inhabit deeper water with greater velocities. Wild subyearlings that average 40 to 45 mm FL in size are observed in peak abundance between mid-April and late-May, whereas hatchery-reared subyearlings that range from 40 to 90 mm FL are abundant in June (Dauble et al. 1989). In the Hanford Reach, subyearling fall Chinook salmon are most abundant in nearshore areas occupying water depths of 4.9 to 19.4 feet, and preferring velocities between 0.6 to 2.6 fps; however, subyearlings can be found across the full width of the river and in the upper, middle, and lower portions of the water column (Dauble et al. 1989).

Swimming performance has been more thoroughly studied for salmon than any other family of species in the Pacific Northwest. Juvenile salmon have a well-developed lateral line neuron system for sensing near-field changes in water pressure, are highly mobile compared to other species, and are capable of varying their swimming speed depending on the activity. Burst swimming is a high activity swimming or sprint behavior that lasts for less than 15 seconds and used to avoid predation, forage, or pass through areas of high water velocity. Burst swimming would also be used by juvenile salmon when they encounter and escape areas of rapid acceleration, as has been observed at juvenile fish collection structures (Haro et al. 1998). Juvenile salmon are likely to react similarly to evade rapid changes in velocity they would encounter around the CGS intake structure. The swimming performance of Chinook salmon fry is similar to coho salmon, which has been studied in greater detail. Burst swimming capacity of coho salmon under 100 mm in size depends on fish size and water temperature, but is approximately 24 body lengths per second, or 3.5 fps for a newly emerged fry of 45 mm.

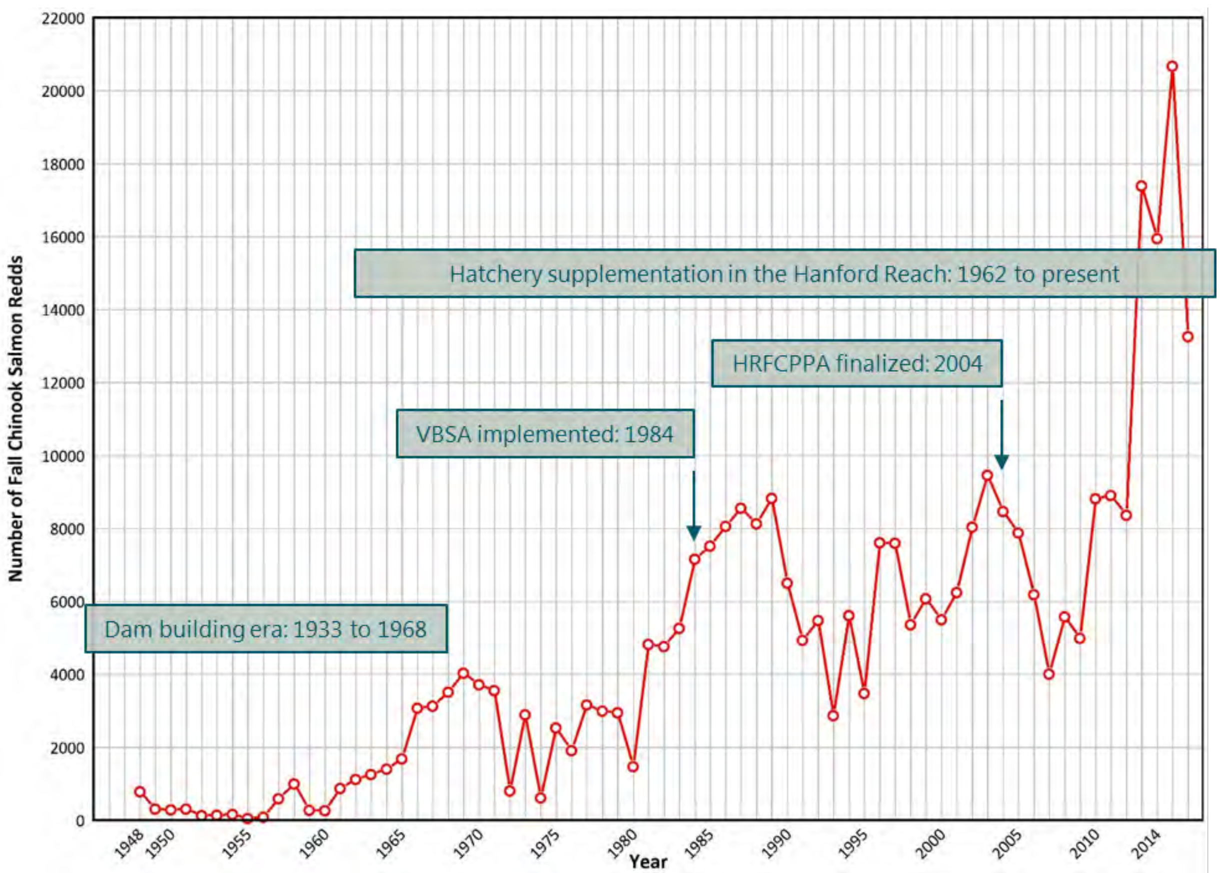
Once the wild Fall Chinook salmon smolt and initiate downstream migration in late spring (e.g., early June), they tend to travel rapidly through the free-flowing Hanford Reach. Smolts that are greater than 80 mm fork length were observed traveling a median rate of 30 km per day, but with high variability from less than 10 to greater than 80 km per day (Harnish et al. 2014a). Migration rate and travel patterns of smaller smolts are less well-studied as they are more difficult to tag and track through the mainstem Columbia River. Subyearling fall Chinook salmon tend to be observed in large numbers at McNary Dam from early June through mid-August at sizes averaging approximately 70 to 110 mm FL in early June, and 105 to 125 mm FL by mid-August, depending on the year (USACE Smolt Monitoring Program; summarized by McMichael et al. 2015). This suggests that subyearling fall Chinook salmon tend to emigrate from the Hanford Reach starting in late May and early June upon obtaining a body size larger than 70 mm.

Subsequent to the development of the Hanford Nuclear Reservation, aerial redd surveys have been carried out annually to quantify the number of spawning adults returning to the Hanford Reach. Redds have been enumerated in annual surveys since 1948 (Figure 5).

Several factors have influenced the number of salmon that use the Hanford Reach over time, primarily the loss of spawning habitat with the construction of dams and reservoirs in adjacent

reaches of the mainstem Columbia River, and later, variability in flows associated with PRD operations (Dauble and Watson 1990, 1997). Other factors contributing to changes in salmon numbers include hatchery production, juvenile and adult passage over hydroelectric dams, harvest management, and predation on juvenile fish during downstream migration to sea (Dauble and Watson 1990, 1997; Harnish et al. 2014a). In fact, a major survival bottleneck occurs just after smolts migrate from the Hanford Reach but prior to passing McNary Dam, with survival through the lower half of Hanford Reach estimated to be better than 80%, then declining to McNary Dam to just 30% to 40%, attributed to the abundance of piscivorous predators (including Northern pikeminnow [*Ptychocheilus oregonensis]* and smallmouth bass [*Micropterus dolomieu*]) in a potential predation hotspot in McNary Reservoir (Harnish et al. 2014a).

Figure 5
Visual Hanford Reach Fall Chinook Salmon Redd Counts, 1948 to 2016



Source: Adapted from Nugent 2016

Historically, fall Chinook salmon spawning was broadly distributed in the mainstem Columbia River from near the Dalles, Oregon (rkm 308) upstream to the Pend Oreille and Kootenay rivers in Idaho

(rkm 1200; Dauble and Watson 1990) and in the lower Snake River. In the early years of the Hanford Nuclear Reservation development, relatively few redds were found in the Hanford Reach (Poston et al. 2008). Between 1933 and 1968, several dams were constructed on the Columbia River upstream and downstream of the Hanford Reach, and the formation of reservoirs behind these dams eliminated most mainstem spawning habitat resulting in increased numbers of spawners observed using the reach (Figure 5; Dauble and Watson 1990). Completion of the Dalles Dam in 1957 may have actually increased access to the Hanford Reach by flooding Celilo Falls, an almost impassible barrier during low flows.

Hatchery supplementation of Hanford Reach fall Chinook salmon dates back to 1962, with variable numbers of juvenile fall Chinook salmon released each year including up to 11.8 million in the early 1980s and production goals of approximately 7.5 million released in recent years, contributing between 3,000 to 4,000 adults to the spawning grounds (WDFW 2018). Currently, 7.5 million age-0 Hanford Reach fall Chinook salmon smolts are released each year, with 3 million produced at the nearby Ringold Springs Hatchery (approximately 4 km upstream from CGS, located on the opposite river bank) and another 4.5 million released from the Priest Rapids Hatchery (located at PRD; WDFW 2018).

From the time of its completion in 1959 to finalizing the VBSA in 1984, PRD was operated to optimize power generation during peak demand (termed power-peaking or load-following), causing unnatural daily variability in river flow in the Hanford Reach. Large daily fluctuations in water elevation during spawning, incubation, and early rearing caused high mortality rates of incubating embryos and juveniles due to dewatering of redds and stranding of newly-emerged fry. The VBSA set minimum flow levels at 70 kcfs leaving PRD and constrained river discharge from PRD during the fall Chinook salmon spawning season to prevent spawning at higher elevations that could become dewatered, and to reverse the typical power generation pattern by providing low river discharge during the day when spawners are active and higher river discharge at night. The VBSA effectively protected incubating embryos, but did not regulate river discharge after the incubation period. The HRFCPPA (finalized in 2004) superseded and replaced the VBSA to set a critical minimum flow each year based on the elevational distribution of the salmon redds within the Hanford Reach and minimizes the magnitude of flow fluctuations during the rearing period to limit stranding and entrapment of juveniles during emergence and early rearing (Grant PUD 2004). These modern restrictions on operations at PRD have led to improvements in overwinter survival of incubating embryos and fry that have further increased fall Chinook salmon productivity in the reach (Harnish et al. 2014b). It is estimated that pre-smolt abundance increased from 14.3 million prior to the VBSA to 52 million after implementation of the HRFCPPA. Though pre-smolt production appears to be limited by density dependent factors (Harnish et al. 2014b), pre-smolt abundance was potentially even higher in recent years with record high escapement of the stock in 2014 to 2015 (WDFW 2018) and record numbers of redds observed in 2013 to 2016 (Figure 5).

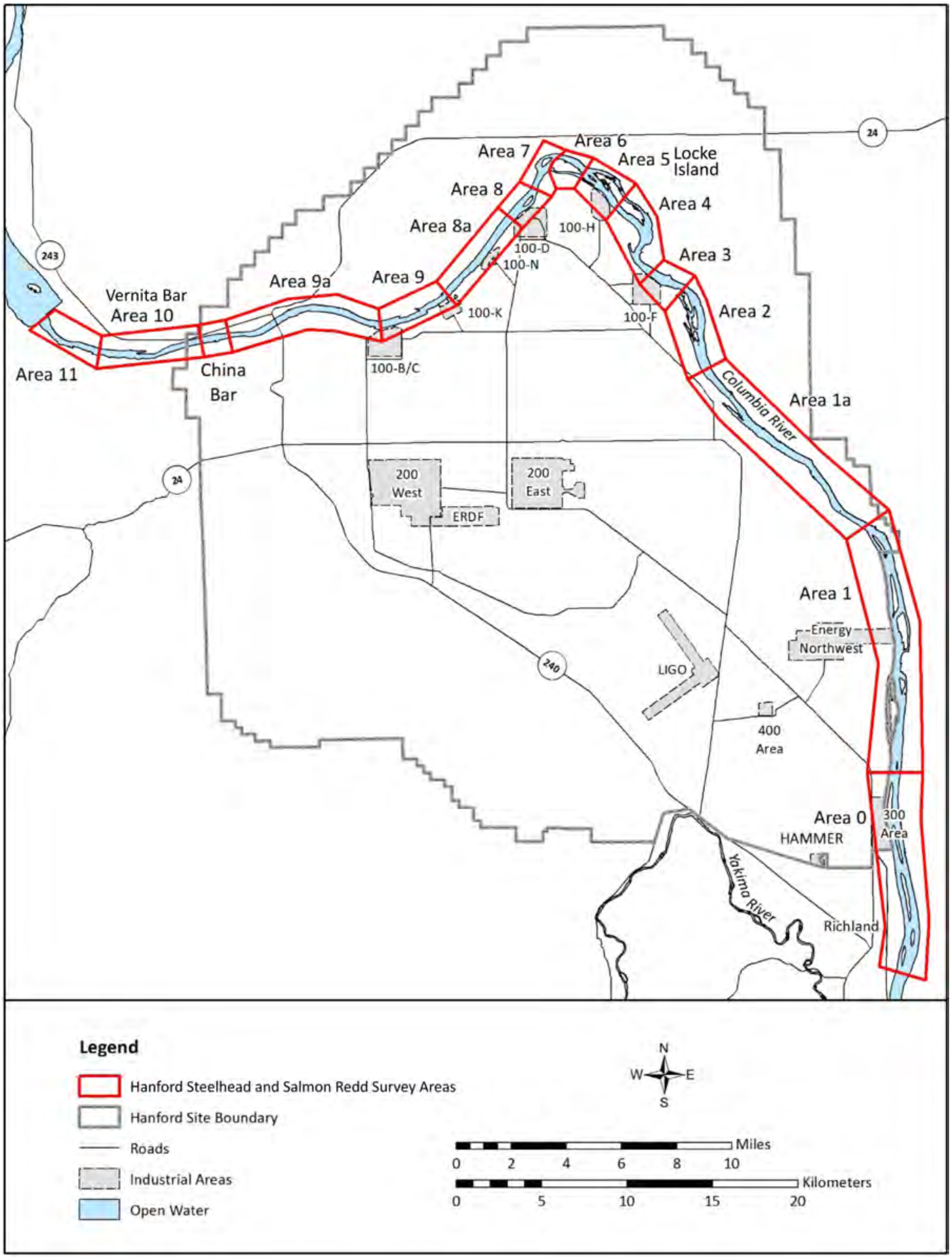
Major spawning areas have been identified throughout the reach with the majority of all spawning from 1948 through 1992 occurring in two areas: Vernita Bar (Figure 6; Area 10) and Upper Locke Island (Figure 6; Area 5; Dauble and Watson 1997). Preferential use of major spawning areas within the Hanford Reach has been consistent across many decades (Anglin et al. 2006; Poston et al. 2008) with spawning occurring in clusters in similar locations each year (Geist et al. 2006). Habitat features associated with preferred spawning locations include habitat complexity (such as around islands), consistent velocities greater than 3 fps, lateral slopes with less than 4% grade (Geist et al. 2000), and areas with higher gravel permeability, higher specific river discharge, and higher vertical hydraulic gradient. This suggests that areas with lower levels of fine sediment, higher flow permeating the substrate, and groundwater sources have remained consistent and preferred by spawners from year-to-year (Geist et al. 2006; Hatten et al. 2009). Recent redd counts are summarized for each survey area in Table 1.

Table 1
Fall Chinook Salmon Redd Counts by Survey Area in the Hanford Reach

Area	Description	2011	2012	2013	2014	2015	2016
0	Islands 17 to 21 (Richland)	3	0	0	0	0	0
1	Islands 11 to 16 (Ringold; CGS)	673	533	798	906	1,193	861
1a	Savage Island/Hanford Slough	ND	ND	0	0	0	0
2	Islands 8 to 10 (Area 100-F Islands)	814	807	2,200	1,565	3,145	1,735
3	Island 7	670	700	655	1,100	800	670
4	Island 6 (Locke Island; lower half)	1,181	1,375	3,340	2,530	2,315	1,807
5	Islands 4, 5, and upper 6	1,524	1,195	2,650	2,080	2,540	2,270
6	Island 3	525	475	1,000	1,000	1,100	600
7	Island 2	653	528	1,700	2,050	1,900	1,140
8	Island 1	295	340	900	500	1,000	340
8a	Upstream of Island 1 to Coyote Rapids	ND	ND	0	0	15	0
9	Coyote Rapids	44	29	520	500	750	235
9a	Upstream of Coyote Rapids to China Bar	ND	ND	0	0	230	20
China Bar	Midway/China Bar	67	68	100	60	1,500	80
10	Vernita Bar	2,463	2,315	3,505	3,650	4,175	3,500
11	Near PRD	3	3	30	10	15	10
	TOTAL	8,915	8,368	17,398	15,951	20,678	13,268

Notes:
ND indicates area not surveyed or no data due to poor visibility.
Source: Nugent 2016

Figure 6
Aerial Survey Areas for Salmon and Steelhead Redds



Source: Nugent 2016

The CGS intake structure is located in Area 1 where several hundred redds have been observed in recent years and a maximum of 1,193 redds were observed associated with a record returns in 2015 (Figure 6; Table 1). In contrast, for the period from 1948 to 1992 the number of redds observed in Area 1 each year averaged 57 redds and ranged from none or single digits in the late 1950s and early 1960s to 264 in 1988 (Dauble and Watson 1997). Redd counts suggest that the number of spawners using Area 1 has increased tenfold similar to trends observed across the entire Hanford Reach since river discharge from PRD has been regulated for fall Chinook salmon, which began with the Vernita Bar Agreement in 1984, the same year CGS became commercially operational.

The nearest spawning grounds are just over 300 m northeast and upstream of the intake structure, while larger spawning grounds are located approximately 1 km both north and south of the intake structure, taking advantage of optimal substrate and flow conditions at the margins of the mid-channel islands (EN 2010). Proximity to spawning areas suggests that recently-emerged fall Chinook salmon fry have the potential to occur near the CGS intake structure as they redistribute to shallow nearshore areas. Fall Chinook salmon fry may rear in the vicinity of the CGS intake for several weeks to months prior to emigrating as smolts in mid-late summer. Subyearling fall Chinook salmon that originate from upstream spawning areas within Hanford Reach are also likely to redistribute downstream toward the CGS intake over the spring and early summer as they forage and grow. In shallow areas near the CGS site, age-0 Chinook salmon were abundant and comprised approximately 44% of all fish (EN 2010).

2.1.1.2 Upper Columbia River Steelhead Life History

Similar to fall Chinook salmon, steelhead spawn and rear within the Hanford Reach and so are similarly vulnerable to encountering the CGS intake, particularly the very early life stages. The newly emerged fry are similarly small in size, but, in contrast, steelhead rear in the Hanford Reach for an entire year prior to migrating downstream. Population trends for steelhead in the Hanford Reach have not been intensively studied; however, their presence has been documented in redd surveys. A more detailed review of steelhead life history is warranted to characterize potential impact of fish entrainment to this ESA-listed species.

Adult steelhead typically move into the Hanford Reach from August to November with a peak in September; however, they may be present in the reach year-round as they hold for 6 to 8 months prior to spawning. Adults tend to migrate near shorelines in water depths of less than 3 m (Coutant 1973). Spawning has rarely been observed directly in the Hanford Reach, but is likely to occur between February and early June, with peak spawning in mid-May (Eldred 1970; Watson 1973).

Adult upper Columbia River steelhead typically use smaller tributary habitat and substrate to spawn in, compared to fall Chinook salmon, but steelhead will spawn in mainstem reaches of large rivers where suitable habitat exists. Habitat with suitable depths, velocity, substrate size, and substrate embeddedness

for steelhead spawning exists in several locations throughout the Hanford Reach at flows that typically occur during the spawning season (Stables and Tiller 2007 in Nugent and Cranna 2015).

Based on dam passage counts, it has been estimated that between the mid-1960s to mid-1990s an average of 9,000 to 10,000 potential spawners could have occurred in the Hanford Reach; however, these estimates did not account for what are now known to be thousands of "fallbacks"; straying adult steelhead of mainly Snake River origin that pass upstream over McNary Dam, then subsequently fall back through various dam passage routes prior to migrating up the Snake River to spawn.

Historical steelhead redd count surveys were undertaken sporadically in the Hanford Reach by boat or airplane resulting in redd counts ranging from 220 in 1968 to 95 in 1970 (Eldred 1970), and 75 in 1998 (Dauble 1998 in Nugent and Cranna 2015); however, recent observations suggest that an unknown number may have been fall Chinook salmon redds (Nugent and Cranna 2015). Historically, spawning likely occurred at Vernita Bar, Coyote Rapids, Locke Island, 100-F Islands, and Area 1 near Ringold; however, landslides from slumping bluffs have reduced spawning habitat near Locke Island.

Systematic aerial surveys for steelhead redds since 1998 show that steelhead spawning in the Hanford Reach is rare in comparison to fall Chinook salmon. No spawning has been observed in the several years surveyed. In certain years, limited spawning near the Ringold Hatchery (Island 15, rm 355) has been observed, suggesting spawners may have been of Ringold Hatchery origin. Single redds were observed in Area 0 in 2003, and near the upstream end of Locke Island in 2008.

Suitable spawning habitat exists approximately 1 km northeast and upstream of the CGS intake structure in the outflow area of the Ringold Hatchery intake. Four steelhead redds were first observed in the area in 2013. In 2015, a peak year for salmon and steelhead spawning in the Hanford Reach since the late 1990s, 15 steelhead redds were observed in the same area, with one additional redd approximately 1 km to the southeast and downstream of the CGS intake (Figure 7, Table 2; Nugent and Cranna 2015). Lower than normal flows in late April and early May of 2015 may have contributed to surveyors' ability to detect steelhead redds.

Steelhead fry emerge from the gravel 2 to 3 weeks after hatching, usually between mid-May through late-July. Fry are between 35 and 56 mm FL, and immediately move to shoreline environments with vegetation and submerged cover. As fry grow larger, they move away from nearshore environments, occupying shallow riffles and pools, yet remaining outside of the main channel, preferring low water velocities (0.67 fps). Juveniles rear year-round in freshwater, and smolts begin their outmigration after 1 to 3 years in the river environment, when they are between 165 and 241 mm FL.

Figure 7
Steelhead Redd Locations, 2015

Source: Nugent and Cranna 2015

Table 2
Steelhead Redd Counts by Survey Area in the Hanford Reach

Area	Description	2012	2013	2015
0	Islands 17 to 21 (Richland)	0	0	0
1	Islands 11 to 16 (Ringold, CGS)	0	4	15
1a	Savage Island/Hanford Slough			0
2	Islands 8 to 10 (Area 100-F Islands)	0	0	6
3	Island 7	0	0	0
4	Island 6 (Locke Island; lower half)	0	0	16
5	Islands 4, 5, and upper 6	0	0	6
6	Island 3	0	0	0
7	Island 2	0	0	0
8	Island 1	0	0	0
8a	Upstream of Island 1 to Coyote Rapids			0
9	Coyote Rapids	0	0	0
9a	Upstream of Coyote Rapids to China Bar			0
China Bar	Midway/China Bar	0	0	0
10	Vernita Bar	0	0	0
11	Near PRD	0	0	0
	TOTAL	0	4	43

Note:
Source: Nugent and Cranna 2015

If steelhead spawning were common in the Hanford Reach it would be expected that age-0 (young-of-the-year) fry would be regularly observed in juvenile fish surveys. Observations of age-0 steelhead fry are limited however; numerous studies have failed to collect age-0 steelhead despite methods directed at collecting salmonids in this life stage (Gray and Dauble 1976; Dauble et al. 1989, Wagner et al. 1997, Hoffarth et al. 1998, Nugent et al. 1999, 2000 in Wagner et al. 2012), confirming the rarity of steelhead spawning in the Hanford Reach. In June 2001, four wild steelhead fry were observed near Wooded Island just downstream of CGS (Area 1) during the fifth year of an ongoing fry-stranding study (Nugent 2002). Steelhead numbers may currently be low in the Hanford Reach but may increase with recovery efforts resulting from ESA-listing and protection of critical habitat.

2.1.2 Lamprey

Pacific lamprey and Western river lamprey (*Lampetra ayresii*) reportedly occupy the Hanford Reach (Wydoski and Whitney 2003); however, no Western river lamprey have been observed in the Columbia Basin since 1980, and the species may have been extirpated from the drainage (Lindsey et al. 2016). Recent studies have documented lamprey ammocoetes in the Hanford Reach several miles

upstream and downstream of CGS intake, however none were observed in the area surveyed nearest to the CGS intake structures (Bottom Wooded Island Bay, approximately 1 mile downstream of CGS; Lindsey et al. 2016). Both Pacific and Western river lamprey are listed by the U.S. Fish and Wildlife Service as Federal Species of Concern (USFWS 2010, 2018). Western river lamprey are listed as a State Candidate species (WDFW 2008).

Both Pacific lamprey and Western river lamprey are anadromous, with a relatively complex life history. After hatching, larvae (ammocoetes) drift downstream and burrow in soft substrate in areas of low water velocity (less than 1 fps) to filter feed and rear for up to 8 years (Torgerson et al. 2004; Moser et al. 2015). After metamorphosing, the macrophthalmia begin downstream migration, which usually occurs between late fall and spring. Lamprey mature into adults in the ocean, and spend several years in the marine environment. Adults migrate back to freshwater between February and June, and may spend up to a year in the freshwater habitat before spawning between March and July. Lamprey are largely nocturnal and generally migrate mid-channel in the lower part of the water column as they stop frequently to attach to substrate. Activity is usually restricted to darkness (Moser et al. 2015).

Lamprey are susceptible to entrainment as larvae and juveniles. Both life stages are small, with ammocoetes usually less than 40 mm in length and 2 mm in width as yearlings, but can get as large as 174 mm in length. Macrophthalmia range between 75 to 200 mm in length and 6 to 11 mm in width at the eye (Moser et al. 2015). Ammocoetes are relatively immobile in low-flow environments; however, they may be displaced during high water events, particularly in the springtime, when soft sediment burrows are scoured (Moser et al. 2015). Macrophthalmia outmigration is relatively lengthy compared to salmonids. Macrophthalmia have been observed in the Columbia River during every month of the year (Moser et al. 2015), with peak numbers collected in winter and early spring, usually coinciding with high river discharge events; however, substantial numbers are also observed from March through October. Additionally, lamprey are relatively poor swimmers, and intake approach velocities as low as 1.5 fps will cause impingement of macrophthalmia. However, reducing intake approach velocity to 1 fps allows most lamprey to escape (Moser et al. 2015). Because of their small size, benthic orientation, and poor swimming performance, juvenile stages of lamprey often become entrained or impinged at water diversion sites (USFWS 2010).

2.1.3 Minnows

An abundant resident fish population occurs in the Hanford Reach comprised of species that spend their entire life-cycle in the reach, in contrast to anadromous salmonids and lamprey that migrate long distances and only occur during portions of their life-cycle. Minnows make up the majority of the resident fish species present in the reach.

Peamouth (*Mylocheilus caurinus*), northern pikeminnow, and redside shiner (*Richardsonius balteatus*) are among the most abundant minnow species observed in the Hanford Reach (EN 2010; Gadomski

and Wagner 2009) with peamouth and northern pikeminnow more abundant in proximity to the CGS intake system and mid-river relative to other sites farther upstream or closer to shore (Gray and Dauble 2001). Adult chiselmouth (*Acrocheilus alutaceus*) are common; however, because chiselmouth are thought to spawn in tributary streams, few age-0 juveniles are observed (Gadomski and Wagner 2009). Longnose dace (*Rhinichthys cataractae*) have also been observed in proximity to the CGS intake, in lesser relative abundance. Gray and Dauble (2001) report collecting all three species of dace (longnose, leopard [*R. falcatus*], and speckled [*R. osculus*]) at a mid-river site upstream of CGS. Additionally, Umatilla dace (*R. umatilla*) are reportedly in the region (Gray and Dauble 1977), but direct observations of these dace species in the Hanford Reach have not been made in recent years. Leopard and Umatilla dace are listed by WDFW as State Candidate species (WDFW 2008).

Species in the minnow family occupy the Hanford Reach year-round. Juveniles demonstrate preference for nearshore and shoreline environments, occupying relatively shallow (1.5 to 15 feet) water with low velocities (0.36 to 3.3 fps). In the Hanford Reach, minnows are predominantly found in shallow water habitat that occurs in side channels that have flowing water during periods of high flow and become backwater sloughs at lower flows (Gray and Dauble 2001; Gadomski and Wagner 2009). Age-0 juveniles of the minnow family are abundant in dense schools of mixed minnow and sucker species in shoreline areas with less than 1 m (3.3 feet) of water from late June through September or October, following the spring and summer spawning season (Gray and Dauble 2001; Gadomski and Wagner 2009). Longnose dace are an exception that prefer to be near the surface in open water, until 4 months of age. Most adult minnows are also found in low velocity (less than 1.5 fps) environments, preferring shoreline environments during the warmer months, while retreating to deeper water from October through April. Again, adult longnose dace are an exception, preferring benthic habitat in swift flowing water (3 fps). Northern pikeminnow juveniles and adults are observed in depths up to 3 m (9.8 feet) from March through August. It is unclear whether the decline in numbers in shallow areas in fall and winter reflects movement offshore, migration downstream to the McNary Pool, or relative inactivity with low winter temperatures (Gray and Dauble 2001). Peamouth and chiselmouth are not typically observed in January through March.

Adult minnows spawn between mid-May and early-August, with larvae emerging days to weeks later, depending on the species. The size of age-0 minnows ranges from 36 to 123 mm FL, depending on the species. At the end of their first summer, Gadomski and Wagner (2009) observed sizes (mean standard lengths) of juvenile age-0 minnows that ranged from 17 to 23 mm FL for northern pikeminnow and redside shiner, 27 to 38 mm FL for suckers (*Catostomus* spp.) and 35 to 46 mm FL for peamouth. As adults, redside shiners are on the smaller end, ranging in size between 120 to 143 mm FL, while chiselmouth, peamouth, and northern pikeminnows range between 229 and 305 mm total length. Gray and Dauble (2001) estimated size at age for the most common minnow species observed in the Hanford Reach. Northern pikeminnow are relatively fast-growing and long-lived predatory minnows and may grow more than 50 mm per year through age-3 with slower growth in

subsequent years with individuals up to 15 years old observed in the Hanford Reach. Redside shiner were approximately 50 mm in size at age-1 and 87 mm at age-2, with growth slowing at approximately age-5 and when length is 154 mm. Peamouth growth rates are greatest during their first 3 years, from 51 to 63 mm per year, achieving an average size of 63 mm at age-1 and 114 mm at age-2. Similarly, chiselmouth grow rapidly in annual increments of 60 to 80 mm in the first 3 years. Common carp (*Cyprinus carpio*) were observed in low numbers that were 61 to 69 mm in size at age-1.

2.1.4 Sculpin

Prickly, mottled, and torrent sculpin (*Cottus aspar, C. bairdii, and C. rhotheus*, respectively) occupy the Hanford Reach (Gray and Dauble 1977; WPPSS 1982; Wydoski and Whitney 2003; Dauble 2009) and "miscellaneous species" have been documented in proximity to the CGS intake (WPPSS 1982), though in relatively low abundances to other fish species. Sculpin occupy the river environment year-round. Juveniles prefer shoreline, pelagic environments between March and July, while moving to the benthos after 30 to 35 days post-hatch (Wydoski and Whitney 2003). All three species prefer benthic environments as adults, with prickly sculpin preferring shoreline environments with sand or gravel substrates. Both mottled and torrent sculpin prefer moderate to swift currents (1.4 to 4 fps) in relatively shallow (0.5 to 3 feet) water. Adults range in size from 127 to 152 mm total length, while juveniles range between 6 and 35 mm total length. Due to their size and use of multiple habitats, juvenile sculpin could be at risk of impingement or entrainment.

2.1.5 Sturgeon

White sturgeon (*Acipenser transmontanus*) are the largest fish species in the Columbia River drainage, reaching up to 12 feet in length. White sturgeon are well documented in the Hanford Reach and specimens have been observed in proximity to the CGS intake system (EN 2010). During spawning, eggs are broadcast into the water column in relatively swift portions of the river and may be dispersed downstream before settling into river substrate. Larvae hatch approximately 1 week later and grow rapidly, reaching sizes greater than 100 mm total length by fall. However, spawning areas in the Hanford Reach are unknown at this time, and eggs and larvae may only be present in the vicinity if sturgeon regularly spawn immediately upstream of the CGS intake. All life stages prefer relatively deep water (39 to 72 feet), with young fish preferring water velocities between 1.3 and 2 fps (Wydoski and Whitney 2003). Eggs, larvae, and age-0 white sturgeon could be at risk for entrainment at the CGS intake due to their size, particularly between May and July (McCabe and Tracy 1994).

2.1.6 Suckers

Largescale suckers (*Catostomus macrocheilus*) are one of the most abundant species near the CGS intake system (WPPSS 1982), and juvenile suckers are some of the most abundant fish found in shallow shoreline areas of the Hanford Reach (Gadomski and Wagner 2009). Longnose, bridgelip, and mountain suckers (*C. catostomus, C. columbianus, and C. latyrhynchus*, respectively) are also

associated with the Hanford Reach, but relative abundance for these species is unknown. The mountain sucker is listed by WDFW as a State Candidate species (WDFW 2008). Species in the sucker family inhabit the river environment year-round. Adult suckers generally prefer deeper water habitats during the day, while moving to shoreline environments during the night. All species can tolerate relatively strong currents, with water velocity ranging from 1.3 to 3.6 fps, with bridgelip suckers often found at the ends of riffles in the main river channel. Adults range in size between 400 and 635 mm total length, and spawn between mid-April and July. Juveniles between 1.5 and 57 mm total length prefer shallower water, occupying pools, backwaters, and shoreline environments between 0.3 to 15 feet deep, between June and August (Gadomski and Wagner 2009). Sucker juveniles may be at risk for impingement in the summer months, given their habitat preferences for slower moving and shallow water.

2.1.7 Trout-Perches

The sand roller (*Percopsis transmontana*) is the only native species in the trout-perch family to occupy the Hanford Reach (Gray and Dauble 1989). However, this species has not been directly observed in proximity to the CGS intake system. Sand rollers are listed by WDFW as a State Monitored species (WDFW 2008). This species prefers backwater environments with cover, such as undercut banks or submerged debris, generally with slower moving currents and shallow water. However, specimens have been observed in depths up to 71 feet as well (Wydoski and Whitney 2003). Most adult fish are less than 127 mm FL, and spawn in between June and mid-July. If present near the CGS intake, this species may be susceptible to impingement due to its small size.

2.1.8 Non-Native Species

Several non-native species have been directly observed in proximity to the CGS intake in the Hanford Reach (EN 2010; Petersen et al. 2003), including American shad (*Alosa sapidissima*), common carp, yellow perch (*Perca flavescens*), bluegill (*Lepomis macrochirus*), black crappie (*Pomoxis nigromaculatus*), and smallmouth bass, with juveniles tending to occupy shallow nearshore areas. Walleye (*Sander vitreus*), pumpkinseed (*Lepomis gibbosus)*, and white crappie (*Pomoxis annularis*) are less commonly observed in the Hanford Reach (Dauble 2009).

Many of the non-native species that have invaded the Columbia River are more typically associated with lake habitats with aquatic vegetation and water with little to no current, with the exception of American shad. Larval and juvenile American shad (less than approximately 130 mm) have been observed in small numbers in backwaters and sloughs in the Hanford Reach. In the John Day Reservoir and below Bonneville Dam, American shad are one of the most abundant species (Petersen et al. 2003). Larval American shad are initially pelagic and can be found in plankton tows across the entire channel starting in late June, prior to recruiting to shallow shoreline areas in August. Age-0 juveniles are observed in nearshore areas from late July through September, before outmigrating to

the ocean in late fall (Wydoski and Whitney 2003; Dauble 2009). Age-0 Juvenile shad may be found in water between 3 and 20 feet deep and relatively slow velocities of 0.1 to 2.5 fps.

2.1.9 Uncommon Species

Gray and Dauble (1977) observed more than 45 species in the Hanford Reach in 1977. However, many of these species are not well documented or are uncommon in the Hanford Reach. Native species that are known to occur in adjacent reaches or tributaries to the Hanford Reach (such as the lower Yakima and lower Snake rivers) include Western river lamprey, burbot (*Lota lota*), Umatilla dace, Paiute sculpin (*Cottus beldingi*), reticulate sculpin (Cottus perplexus), threespine stickleback (*Gasterosteus aculeatus*), longnose sucker, and sand roller. Non-native species that may occur in the Hanford Reach include bullhead catfish species (*Ameiurus* spp.), channel catfish (*Ictalurus punctatus*), western mosquitofish (*Gambusia affinis*), tench (*Tinca tinca*), and largemouth bass (*Micropterus salmoides*). Details about the life histories and habitat preferences of these uncommon species can be found in Appendix B, Table B-1.

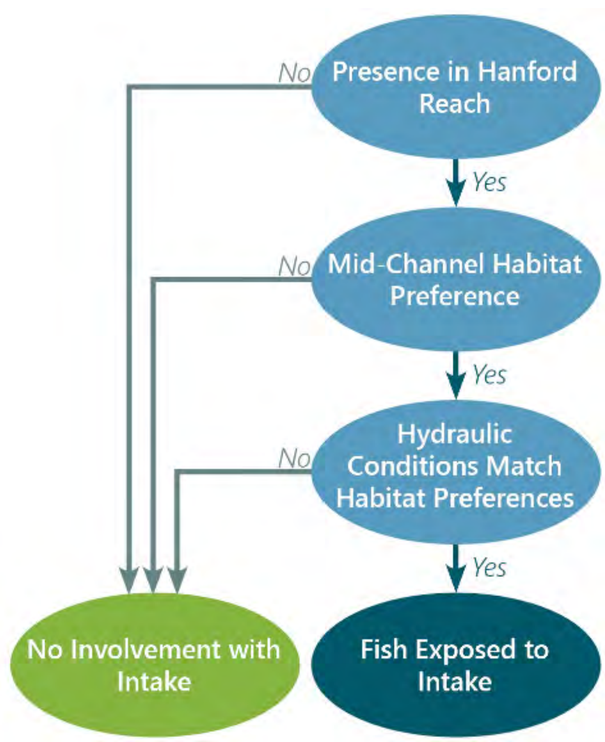
3 Factors that Determine Fish Entrainment

The overall risk of fish entrainment by the CGS intake structure can be broken down into a set of factors that contribute to, or lessen, the risk by determining whether fish encounter the intake and subsequently become entrained, excluded, or impinged. These factors are divided into biological factors that result from different fish life histories, and physical factors resulting from the interaction of the intake structure and the river environment. To evaluate risk of entrainment for fish in the Hanford Reach, each factor can be examined in a stepwise manner in order of its relative importance for each species or life stage.

3.1 Biological Factors of Fish Entrainment

The driving biological characteristic that creates a risk of encountering the intake structure is fish proximity to the intake. Whether a certain species tends to occur in proximity to the intake is a function of multiple factors, in this case the most obvious being a known presence in the Hanford Reach. Proximity to the intake is also a function of a species' seasonal occurrence (its presence in the Hanford Reach at specific times of the year) followed by species preference for the type of microhabitat where the CGS intake is located (see Figure 8).

Figure 8
Biological Determining Factors



The risk of entrainment is also a function of fish size. Fish size primarily affects swimming performance and the ability to respond behaviorally to the intake to avoid entrainment. Secondarily, fish size also determines whether a fish will be physically excluded from passing through intake screen pores.

1. **Presence in the Hanford Reach** – Refer to Section 2 for a detailed review of species known to be present in the Hanford Reach and seasonal trends in occurrence of their life stages.
2. **Habitat Type Preference** – Species and life stages that are more likely to encounter the CGS intake structure are those that tend to use the lower part of the water column in mid-channel habitat of riverine environments and those that are oriented to substrate or to shallow-water habitats.
3. **Hydraulic Conditions Preference** – Preferences for water velocities and depths will determine whether a given species or life stage tends to occur at the intake site. Habitat preference changes as fish pass through different life stages that are repeated on an annual cycle such as spawning, rearing, and migration seasons. Risk of entrainment changes across the year with the predictable seasonal changes in river discharge and differences in the preferences between life stages.
4. **Fish Size** – Generally, as larval and juvenile fish increase in size their swimming ability improves; however, swimming ability is also a species-specific trait that depends upon adaptations for different types of in-stream habitat. Species and life stages at elevated risk for entrainment by the CGS intake based on body size alone would be those with body widths less than the size of the intakes' outer screen pores, or 9.5 mm, which for salmonid fry and other species with similar fusiform, or "torpedo shaped" body types translates to a body length of approximately 75 mm or less (Bell 1990). Species groups with fusiform body types include the salmonids, shad, minnows and carps, suckers, sticklebacks, livebearers, perches, sand roller, and sturgeon. Lamprey ammocoetes and macrophthalmia have an elongated body type with body depths less than the size of the intake screen pore size and would not be excluded even at much longer body lengths. Conversely, fish that have body types that are compressed such as the sunfishes (laterally compressed) or depressed such as sculpin and catfishes (dorsal-ventrally depressed) may have body widths that exceed the intake screen pore size at shorter body lengths. A body of literature is building in response to the U.S. Environmental Protection Agency's Section 316(b) of the Clean Water Act, that requires cooling water intakes to estimate and minimize fish entrainment rates. In more recent studies of larval fish entrainment in marine and lake environments where larval fish are a large component of entrained zooplankton, the size of the larval head capsule has emerged as a determining metric for entrainment (e.g., Tenera 2013; Patrick et al. 2018). Body length and depth remains the metric most commonly used for predicting entrainment of inland fishes in the Pacific Northwest, including salmonids (NMFS 2011a).

The biological factors that determine fish exposure to the intake structure can be combined with the physical mechanisms of intake screen exclusion determined for cylindrical screens as a set of criteria

in a framework for evaluating entrainment and impingement risk for fish that are in proximity to the CGS intake structure.

3.2 Physical Factors of Fish Entrainment by Cylindrical Intake Screens

The CGS intake structure is a bullet-shaped cylindrical intake screen with nose cones that create unique hydraulic conditions around the structure, designed to minimize fish entrainment at the time of its installation. More recently, CFD modeling undertaken to evaluate hydraulics around the cylindrical screen revealed broad and fine-scale flow patterns that were evaluated against NMFS (2011) design criteria for intake screens to characterize the risk posed to fish in proximity of the intake (Alden 2018).

Direct experimentation with fish entrainment or impingement by the CGS intake structures is outside the scope of the current study, however a combination of computational fluid dynamic (CFD) modeling, laboratory experimental data, and statistical analysis were used to describe fish entrainment by similar cylindrical intakes using scale models with variable slot dimensions and variable water flow and approach velocities. The reactions of early life stages of several fish species with morphologically different larval body types from 0.3 to 2.3 mm in length were tested (NAI and ASA 2011). Compact body shapes were tested with larvae of Atlantic tomcod (*Microgadus tomcod*), Atlantic cod (*Gadus morhua*), and hybrid striped bass (*Morone saxatilis* striped bass males x *Morone chrysops* white bass females), and common carp. Elongate body shapes were represented by white sucker (*Catostomus commersonii*). Results of these studies can be used to characterize the mechanisms that lead to exclusion or entrainment of fish from similar intakes (Enercon 2010, as summarized in a memorandum to Energy Northwest by Coutant 2014b).

For fish that occur near a cylindrical intake, the following sequential events determined the proportion of fish that are ultimately entrained or impinged by the intake structure. These mechanisms of entrainment by a cylindrical intake apply broadly to egg, larval, early juvenile, and in some cases adult stages of small bodied species. Each event described below represents a mechanism by which fish may avoid entrainment by a cylindrical screen (NAI and ASA 2011):

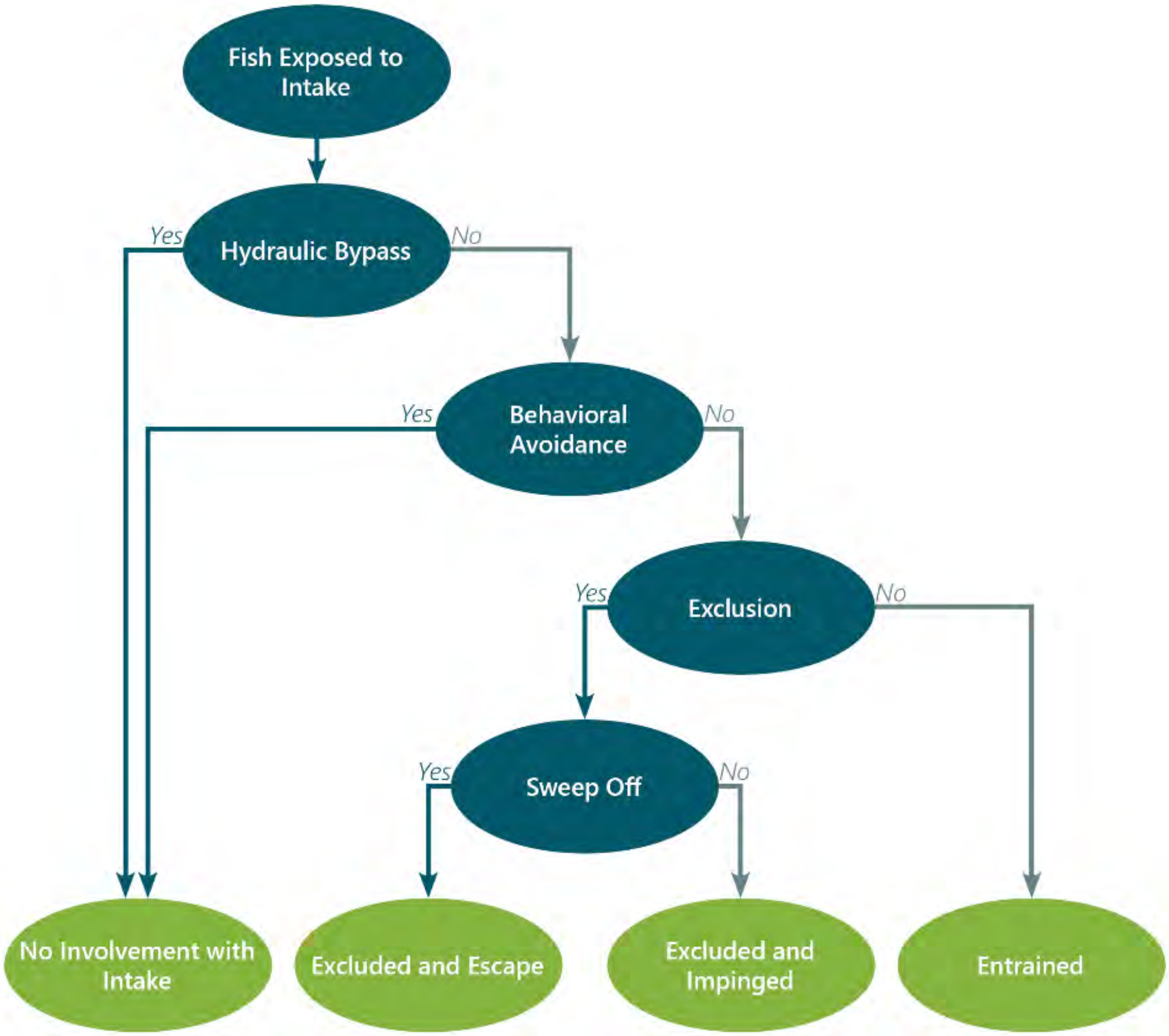
1. **Hydraulic Bypass** – Hydraulic bypass describes the portion of the water and particles (such as fish) that pass near to the intake structure but are not withdrawn from the river due to hydrodynamic and physical phenomena around the intake structure such as turbulence. For fish that encounter an intake screen, the probability of hydraulic bypass is related to river channel flow characteristics and screen characteristics. A combination of CFD modeling, laboratory experimental data, and statistical analysis found that the probability of hydraulic bypass for cylindrical wedge wire screens was primarily related to the physical bow wave at the nose cone, the sweeping velocity (the velocity parallel to the screen face) and to the screen characteristics of slot width and approach velocity (perpendicular to the screen face), but unrelated to screen

diameter or length (NAI and ASA 2011). The potential for hydraulic bypass at the actual CGS intakes can be evaluated using data from CFD modeling that quantified sweeping velocity and approach velocity under various river and operating conditions (Alden 2018).

2. **Behavioral Avoidance** – Fish have highly sensitive sensory systems that detect changes in fluid flows and often show an avoidance reaction to rapid changes in water velocity and pressure (Liao 2007; Stewart et al. 2014). In laboratory screen studies, the majority of larval fish that were not hydraulically bypassed avoided entrainment by actively swimming away from flow changes around the nose cone of a cylindrical screen (NAI and ASA 2011). The probability of behavioral avoidance was positively related to fish length and negatively related to sweeping velocity. In laboratory testing and CFD modeling, the diameter of the cylindrical screen as a function of the overall channel cross-section was not included in the probability calculation. Recent CFD modeling confirmed that the CGS intakes do create a stable bow wave extending several feet upstream of the nose of the intake that could provide the pressure change stimulus to fish that encounter the structures (Alden 2018). An assumption is that larval or juvenile fish encountering a cylindrical intake can sense the change in pressure or velocity associated with the bow wave well-before encountering the intake screens, and that they have the ability to respond to the sensory stimulus of the intake flow by actively swimming away from the intake. Fish must have the short burst swimming capacity to escape approach velocities. Particularly relevant is the startle response, in which the fish rapidly forms a C shape and snaps open thrusting the body away from the initial trajectory (Taylor and McPhail 1985; Stewart et al. 2014; Nair et al. 2015). This occurs in milliseconds. In order to exhibit successful behavioral avoidance fish must have an available escape route (NMFS 2011a), which for the CGS intakes is the sweeping flow around the intake unit. This is not the case for eggs, embryos, and some larval fish.
3. **Exclusion** – Exclusion is determined by fish size and screen pore diameter. If fish are not hydraulically bypassed and are unable to avoid the intake structure by startle response or swimming away, the geometry of the screen will mechanically exclude fish that are larger than the screen pore diameter. Effective pore size may also be affected by through-hole flow patterns at the "micro" scale
4. **Sweep-Off or Impingement** – For the fish that do come into contact with the screen, but are excluded by size, a portion of these will be swept-off by flows parallel to the screen face while any remaining fish will be impinged. The probability of sweep-off is determined by sweeping velocity, approach velocity, screen pore diameter, and fish size.

This results in four possible outcomes for fish (summarized in Figure 9) two of which are positive (no involvement with the intake structure or exclusion) and two of which are negative (impingement or entrainment).

Figure 9
Sequential Events that Determine Fish Entrainment or Impingement



Source: Adapted from NAI and ASA 2011

These controlled studies of fish interactions with the physical forces around a cylindrical intake structure provide a framework for evaluating the likelihood of entrainment by highlighting several metrics that determine how fish transition through the above sequence of events.

In an idealized experiment, the probabilities of the first three events (hydraulic bypass, behavioral avoidance, and exclusion) that determine the overall probability of entrainment for organisms that

encounter the intake screen could be tested using live fish at the CGS intake in its existing location to develop the following relationship:

$$\left(P_{Entrainment} = \left(1 - P_{Bypass}\right)\left(1 - P_{Avoidance}\right)\left(1 - P_{Exclusion}\right)\right)$$

Based on the following assumptions, if the probability of either bypass, avoidance, or exclusion is 100%, the probability of entrainment falls to zero. To approximate results of such an idealized experiment, one can rely on information about the intake and species characteristics from existing literature.

- The probability of bypass can be estimated based on studies of cylindrical intakes in controlled laboratory settings and compared to what is known about the dimensions and orientation of the CGS intake structure in the river. Hydraulics around the CGS intake, and therefore the probability of hydraulic bypass, may change over time with predictable seasonal changes in the river environment. CFD modeling of the CGS intakes under a variety of river conditions provides flow velocity and direction data at the nose cones and along the screen surfaces that can be used to evaluate the probability of bypass at this specific location.
- The probability of active avoidance depends on the abilities of species and life stages to sense rapid changes in pressure or velocity and have the startle response and adequate swimming strength to avoid the screen. Quantitative information is lacking for such abilities by all fish species in the CGS vicinity, but general assumptions can be made based on existing knowledge of similar species available in the literature.
- The probability of exclusion can be estimated based on fish sizes relative to the intake's outer screen pore size and the near-pore hydraulics identified by the CFD modeling.

To estimate the risk of entrainment to different fish species, the state of the knowledge related to these mechanisms of entrainment are reviewed in the following sections.

3.2.1 Specifications of the Columbia Generating Station Intake Structure Relative to NMFS Criteria

It is important to consider the geometry of cylindrical intake structures and orientation of the structure relative to the main flow of the river channel to accurately evaluate risk of entrainment and impingement.

The CGS intake structures are located approximately mid-channel of the main channel of the Columbia River, on the right of Homestead Island when looking downstream. The cylindrical screens are oriented parallel to the predominant flow through the reach. The structural and operational

specifications of the cylindrical screens in use at CGS that are relevant to evaluating risk of fish entrainment are summarized in Table 3. Potential sweeping velocities, approach velocities, and through-hole approach velocity across the intake screens have been derived using CFD modeling.

Table 3
Columbia Generating Station Cylindrical Screen Specifications

Specification	Measurement
Number of intake structures	2
Number of screens per intake structure	2; 1 outer and 1 inner
Outer screen diameter	1.07 m (42 inch)
Outer screen pore diameter	9.50 mm (0.375 inch)
Inner screen diameter	0.91 m (36 inch)
Inner screen pore diameter	19.05 mm (0.75 inch)
Screen length	1.98 m (6.50 feet)
Screen elevation (top)	104 m (341 feet) MSL
Average intake flow per 2-screen intake structure*	8,500 gpm or 19 cfs (0.54 cubic mps)
Average approach velocity for bulk flow*	0.07 fps
Average through-hole velocity*	0.16 fps
Hydrodynamically-effective pore diameter*	~3 mm

Note:
*Source: Alden 2018. Assumes screen is clear of debris

Specific criteria for cylindrical screens like those in use at CGS have not been included in NMFS criteria for fish screen and bypass facilities, and the CGS intake structures pre-date the initial development of intake criteria (NMFS 2011a). Nevertheless, certain elements of the criteria developed for end of pipe intake screens provide a starting point for evaluating the effect of intake screen geometry on potential approach velocities and risk to the size classes of fish that could become entrained, summarized in Table 4.

Table 4
NMFS Criteria for Preventing Fish Entrainment or Impingement by End of Pipe Screens

Criteria	Value
Near-field sweeping velocity	2.5 fps or greater
Approach velocity	0.2 fps or less
Outer screen pore diameter	2.4 mm
Submergence depth (at least 1 screen radius)	0.53 m (21 inch)

Note:
Source: NMFS 2011a

Comparing the CGS cylindrical intake to those used in controlled laboratory studies of fish entrainment is a useful starting point for evaluating this type of intake relative to NMFS criteria. However, caution should be taken in comparing the CGS intake structure to existing entrainment experiments with cylindrical intakes because most experiments have been conducted on screens using wedge wire rather than the perforated-pore screen used at CGS. Because of similar overall shapes of the screen structures, however, cylindrical intakes with perforated screens downstream of a nose cone likely have similar hydraulic bypass characteristics to cylindrical intakes with similarly placed wedge wire screens and fish are likely to have a similar behavioral response; however, the differences in pore shape and size may have different near-field hydraulic characteristics that cause different impingement and entrainment risk (Enercon 2010).

CFD modeling carried out by Alden Labs (2018) provides a wealth of data on the hydrodynamics around the CGS intake structures as they pertain to entrainment and impingement risk to fish. First, a broader scale "global" model was run for a range of conditions that could be observed at the CGS intakes: three different river velocities commonly observed over the year at the site (3, 6, and 9 fps), five river flow attack angles inferred by geomorphology of the channel (-24°, -12°, -6°, 0°, and 12°), and two make-up pump operating conditions (off/on). Key findings of the global model included the following:

- At the highest river velocity (9 fps) a low pressure bow wave extends from the nose of the intakes approximately 10 to 15 ft upstream whether pumps are operating or not, changing only slightly in size with changes in river velocity or obliqueness of flow
- A boundary layer of turbulent flow exists along the cylindrical screens that is much thinner when pump units are off. More oblique flows compress the boundary layer of the up-current face and expands the boundary on the leeward face, where a low pressure "back-eddy" develops and flow must move back toward the screen face.

Second, a near-field model was run to investigate the boundary layer and its interaction with screen perforations at a scale on the order of a few millimeters. The near-field model was run for a subset of global model flow conditions that encompassed the extremes in river velocity and attack angle and pump unit operation. Key findings of the near-field model included the following:

- Flow distribution across the screens exhibited some non-uniformity decreasing the effective screen area and causing regions of concentrated inflow.
- Sweeping velocity generally increases with river velocity and obliqueness of flow, but is remarkably similar whether pump units are operating or not. Sweeping velocity is above NMFS criteria of 2.5 fps for all simulations, with a single exception at very low river velocity (3 fps) and the most extreme attack angle (-24°) where sweeping velocity near the leeward face of the downstream screen drops to approximately 1.5 to 2 fps.
- The layer in which flow is oriented toward the screen face generally thins with increasing river velocity, ranging from approximately 400 mm at 3 fps to 200 mm at 9 fps. Approach velocity

varies within a few millimeters of the screen where flow rapidly accelerates through the screen pores. Oblique river flow acts to force water into the up-current face at velocities that exceed the NMFS criterion for approach velocity of 0.2 fps. Approach velocity increases slightly when pump units are operating and increases somewhat with river velocity, depending on obliqueness of flow and whether the screen faces up-current or leeward of the flow. Approach velocity is consistently less that the NMFS criteria of 0.2 fps at an arbitrary distance of 200 mm from the screen face when flow is axial to the intake structures. Approach velocity increases nearer to the screen face (20 mm from the screen face), exceeding (violating) NMFS criterion in some cases. When flows are oblique to the screen face, the NMFS criterion is violated for all cases modeled on the up-current, upstream face that bears the brunt of the river flow, regardless of whether the pump units are operating or not. On the leeward, downstream face, the NMFS criterion is generally met except at the leading edge of the screen where inflow is intensified.

The intake screen hole diameter at CGS is 9.5 mm, which is four times larger than the 2.4 mm pore diameter recommended by NMFS (NMFS 2011a, 2013a,b). The larger hole size increases the risk for entrainment compared to the 0.5 to 3 mm slot widths used in most cylindrical wedge wire laboratory and field testing (EPRI 2007; NAI and ASA 2011). Flow conditions through screen pores at the "micro" scale is affected by river flow and operating conditions; CFD modeling at CGS demonstrated that the effective pore size would be approximately 1/3 of the actual pore diameter due to a counter-rotating "micro-eddy" that could impede entrainment through the pores.

Perforated screen intakes are known to have surface profiles that are prone to clogging or snagging, resulting in greater head loss and poor velocity distribution across the screen face, and are now considered obsolete for most new developments (Enercon 2010). The intakes at CGS are passive screens and do not have an automated cleaning system for removing debris (NMFS 2011a, 2013a,b), putting the CGS intakes at greater risk for debris build up compared to a screen with automated cleaning systems. There is a risk that such fouling could create localized areas of higher approach velocity as the total area of screen intake is reduced (Enercon 2010; Reclamation 2009). The CGS intake's orientation parallel with the river channel and sweeping flows minimizes the potential for debris to become impinged on the intake structure. A 1985 study at CGS found no evidence that fouling by algae, insects, sponges, or plastic debris impeded proper operation of the intakes (WPPSS 1985) and debris impingement has not been identified as an operating problem over the 30 years of past operations at CGS. CGS periodically inspects and cleans intake structure screens as needed to reduce biofouling.

According to NMFS criteria (NMFS 2011a), end of pipe screens should be submerged to a depth of at least one screen radius below the minimum water surface to protect fish from entrainment; for the CGS intake structures this would amount to 21 inches of submergence between the top of the screen and river surface. Seasonally-fluctuating flows in the Hanford Reach create conditions of relatively

shallow water over the CGS intake structure in late summer to early fall that may increase risk of fish entrainment (seasonal trends in flow and velocity at CGS are explored further in Sections 4 and 5). It should be noted, however, that NMFS does not provide submergence criteria for cylindrical screens oriented parallel to the stream channel as is the case at CGS, and that shallower conditions may in fact increase the sweeping velocity at the top of the screen, increasing the likelihood of hydraulic bypass and reducing risk of entrainment (Coutant 2014b).

In summary, given the size of the intakes, the pumping rate, and NMFS' recommendation that the entire screen face area be used in calculation of the approach velocity, the CGS intakes generally meet NMFS requirement that approach velocity be less than or equal to 0.2 fps (0.06 meters per second [mps]) for salmonid fry when both intakes are running and are clear of debris (NMFS 2011a, 2013a,b). Exceptions are identified by CFD modeling that shows local scale turbulence and areas of higher approach velocity, especially with oblique flows. Fish vulnerability to entrainment or impingement may increase as pores become clogged with debris and biofouling, or total submergence is less than recommended (NMFS 2011a), such as occurs at CGS during extreme low flow conditions, (Enercon 2010; NMFS 2011a, 2013b).

3.2.2 Hanford Reach Morphology, River Discharge, and Effects on Sweeping Velocity and Depth

Hydraulic conditions around the intake depend upon interactions between river morphology and river discharge. A complete understanding of the effects of river discharge on river elevation and velocity is necessary to more thoroughly evaluate the resulting hydraulic conditions at the CGS intake as they affect vulnerability of fish to entrainment or impingement. River velocity at the site will be a major factor determining the probability of hydraulic bypass and sweep-off for species typically observed near the CGS intake. Seasonal differences in river elevation and velocity will also influence the tendency for certain fish species and life stages to occur near the CGS intake structure, given that different species and life stages tend to occur at certain times of year and prefer specific hydraulic conditions.

Despite upstream flow regulation, the unimpounded Hanford Reach maintains its historical variability in channel morphology and bathymetry compared to impounded reaches. Numerous side channels and islands create small-scale variations in velocity throughout the reach. The CGS intake is in the river right channel where the Columbia splits into two channels separated by Homestead Island and the river right channel is the wider of the two. While the intake is positioned near mid-channel by design, the depth of the water covering the intake structures and water velocity fluctuates with the natural hydrograph and with daily regulation of flow from PRD. PRD is a run-of-river type dam, so the magnitude of seasonal fluctuations in river discharge greatly exceed the storage capacity, allowing for major changes in flow in the Hanford Reach across seasons and across years, depending on regional climatic conditions.

Laboratory studies on cylindrical intake studies provide a good baseline of screen performance; however, changes in river flow and stage will affect flow angle and sweeping velocities, and therefore performance in the field. To address this data gap, the U.S. Bureau of Reclamation recommends that field evaluations be conducted for a wide variety of flow conditions to fully evaluate screen performance (Reclamation 2009). Energy Northwest directly measured velocities at various depths near the intake structures during high flows on June 23, 2017, when the annual maximum discharge reached approximately 310,000 cfs at Priest Rapids Dam (Table 5). Near-surface velocity was estimated to be approximately 7.6 fps based on boat drift speed, and depth was approximately 16 to 19 feet in the vicinity of the structures. More precise velocity measurements taken at 1 and 3 feet below the boat (corrected for boat drift) range from approximately 6 to 9 fps, with higher values occurring at shallower depths.

Table 5
Velocity Observations on June 23, 2017, as Reported by Energy Northwest

Location	Velocity (fps)	
	1-foot depth	~ 3-foot depth
At intake structures	8.8	5.6
	8.9	5.5
50 feet south of intake structures	7.7	7.7
	8.7	7.3
	8.5	
50 feet north of intake structures	7.4	6.2
	7.2	6.2

Additional direct field measurement of a broader range of flow conditions at the CGS intake is outside the scope of the current report; however due to its unique hydraulic conditions compared to impounded reaches and its importance for salmon habitat, the Hanford Reach has been the focus of intensive study since the 1970s.

To better characterize relationships between river discharge and hydrodynamic conditions, the Modular Aquatic Simulation System in One and Two Dimensions (MASS1 and MASS2) model has been used by Battelle-Pacific Northwest National Laboratory scientists to simulate hydraulics throughout the reach and across time based on mapped bathymetry (Coleman et al. 2010) and river discharge observed from 1917 through 2011. The MASS1 model produces averaged predictions for river discharge, velocity, water elevation, and temperature per individual cross sections. The MASS 2 model can predict the same metrics, but does so in a plan view, thus producing averages per cell. This provides spatially distributed estimates across the river channel in the resolution of the available bathymetric data. The most comprehensive modeling of the Hanford Reach to date was conducted in

2014; the entire reach was modeled using both MASS1 and MASS2 to a resolution of 5 m (Niehus et al. 2014). These modeled hydraulic data are used here to estimate the range of river conditions that can occur at the CGS intake.

Estimated velocity, water depth, and water surface elevation at the specific location of the CGS intake structure was modelled using the MASS2 model at river discharges representing times of particular biological significance (Table 6). A range of river discharge levels were modeled to correspond to conditions that could be observed during extreme low flow conditions (40 kcfs), mean conditions during minimum flows typically observed in October (70 kcfs), mean conditions in March when fall Chinook salmon fry begin to emerge (100 kcfs), mean conditions in June when peak flows and peak smolt migration typically occurs (190 kcfs), and extreme high flow conditions (350 kcfs).

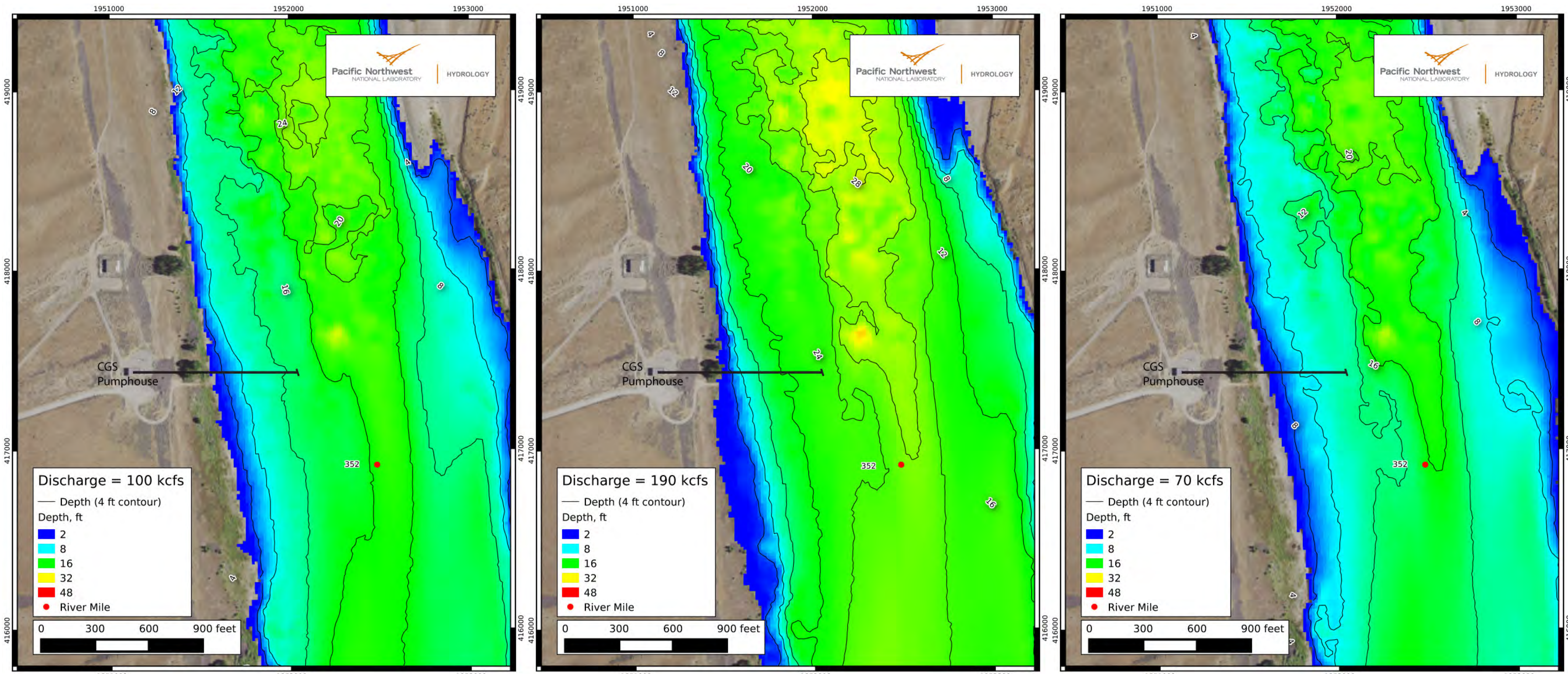
Typical depths and velocities in given months of the year, shown in Figures 10 and 11, respectively, illustrate that depth and velocity are not evenly distributed across the channel, and localized variation exists within this reach. Depths and velocities resulting from the minimum and maximum river discharges observed across the period of record (1917 through 2011) are depicted in Figures 12 and 13. During these months the average river discharge ranges from 100 to 190 kcfs with corresponding water depths of 0 to 28 feet and velocities ranging from 0 to 6 fps within the reach upstream and downstream of the intake structure. Additional visualization of the hydrodynamic conditions near the CGS intake structure are included in Appendix C, Hydrodynamic Model Description and Data, Perkins et al. 2018.

Table 6
Modeled Hydraulic Conditions at the Columbia Generating Station Intake Structure at Different River Discharge Levels

Flow Threshold	Biological Relevance	River Discharge (kcfs)	Depth (feet)	Velocity (fps)	Water Surface Elevation (cubic feet)
Average March Flow[1]	Fall Chinook salmon emergence begins	100	16	5	347.8
Average June Flow[1]	Seasonal high flows	190	20	6	353.4
Average October Flow	Seasonal low flows	70	12	4	345.6
Minimum Flow (Daily Mean)	Historical extreme low flows	40	8	3	343.2
Maximum Flow (Daily Mean)	Historical extreme high flows	350	24	7	360.6

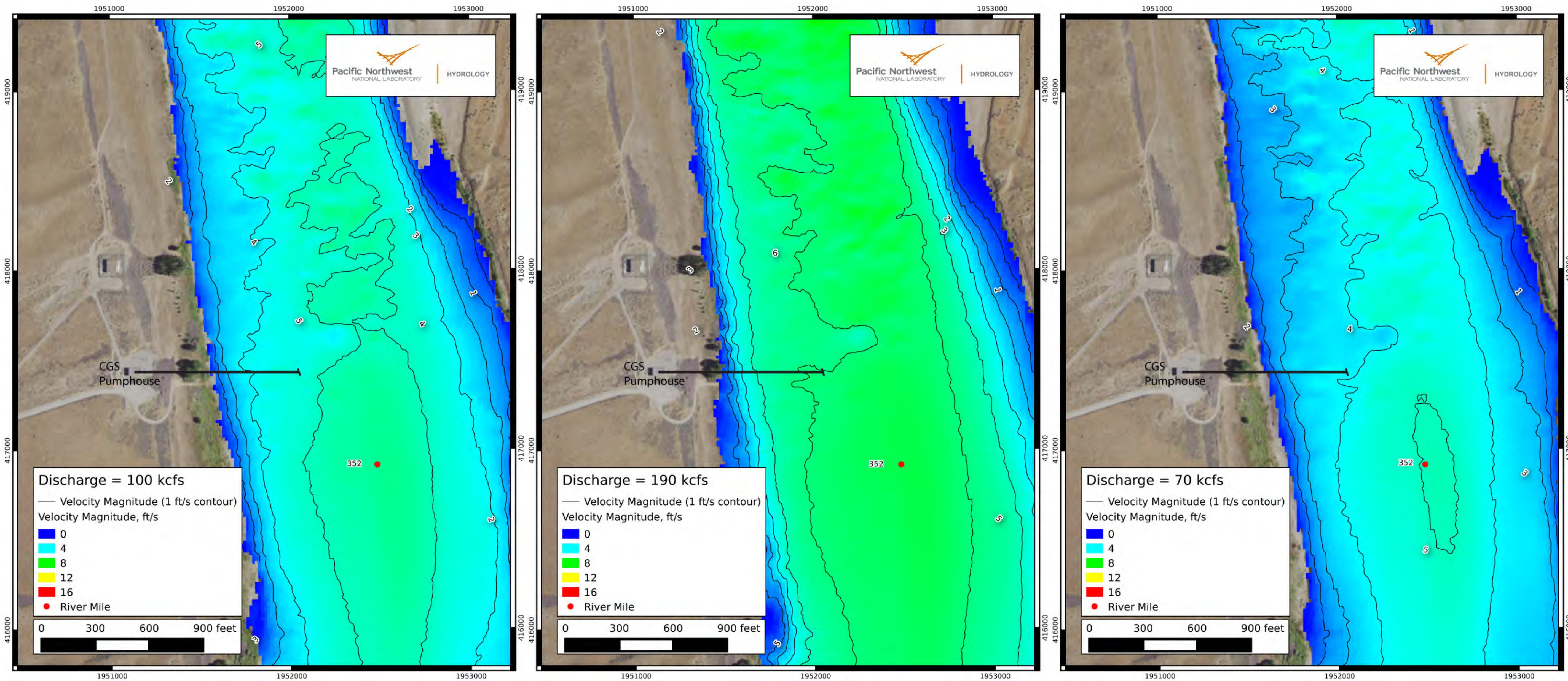
Notes:
1. Hanford Reach Chinook salmon fry occur from March through June.
Source: Perkins et al. 2018

Figure 10
Mean Monthly Water Depths in March (Left Panel), June (Middle Panel), and October (Right Panel)



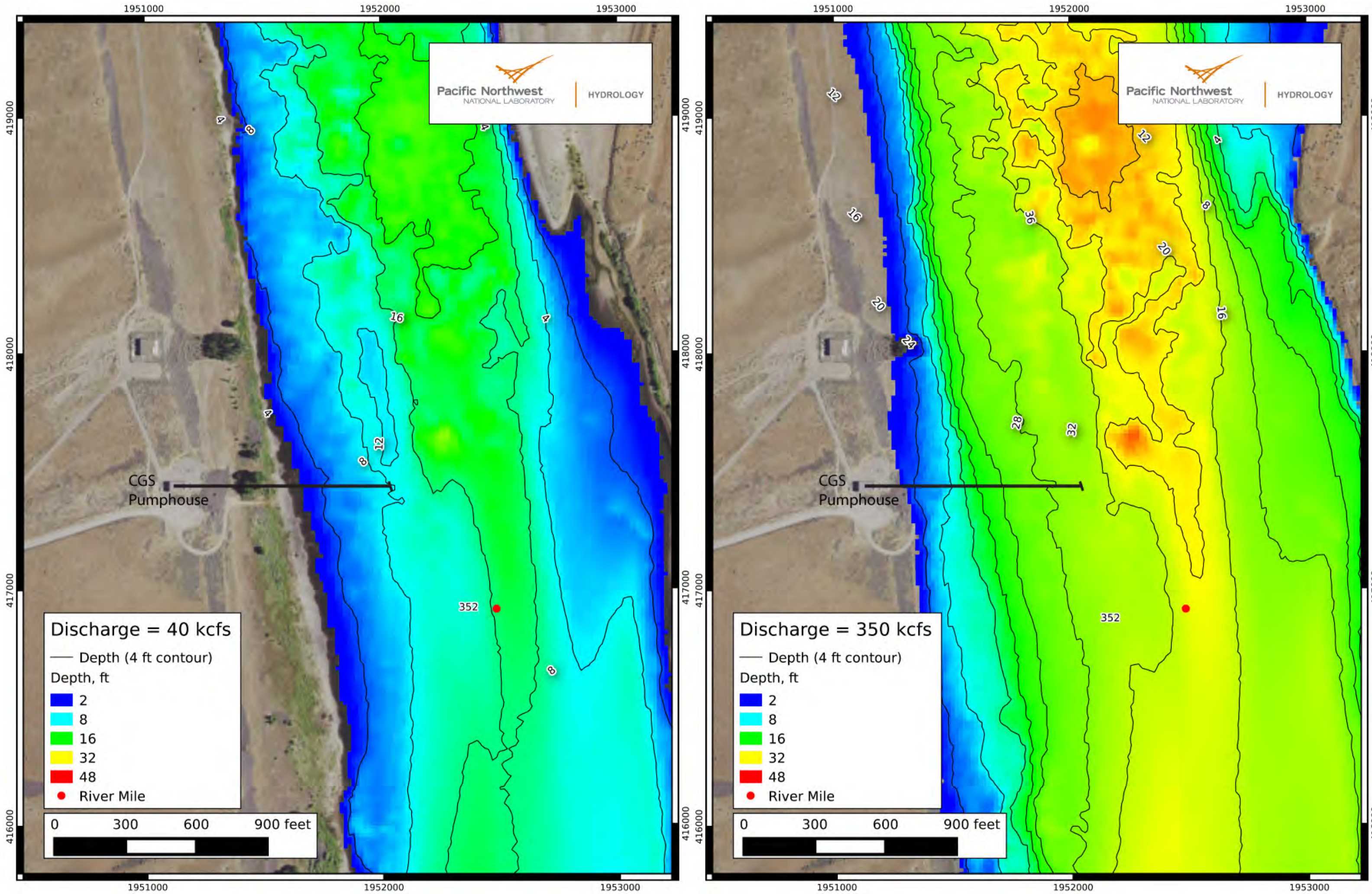
Note: Monthly means are based on river discharge observed from 1917 through 2011. The location of the CGS intake structure and buried intake pipes are shown in black.

Figure 11
Mean Monthly Water Velocities in March (100 kcfs; Left Panel), June (190 kcfs; Middle Panel), and October (70 kcfs; Right Panel)



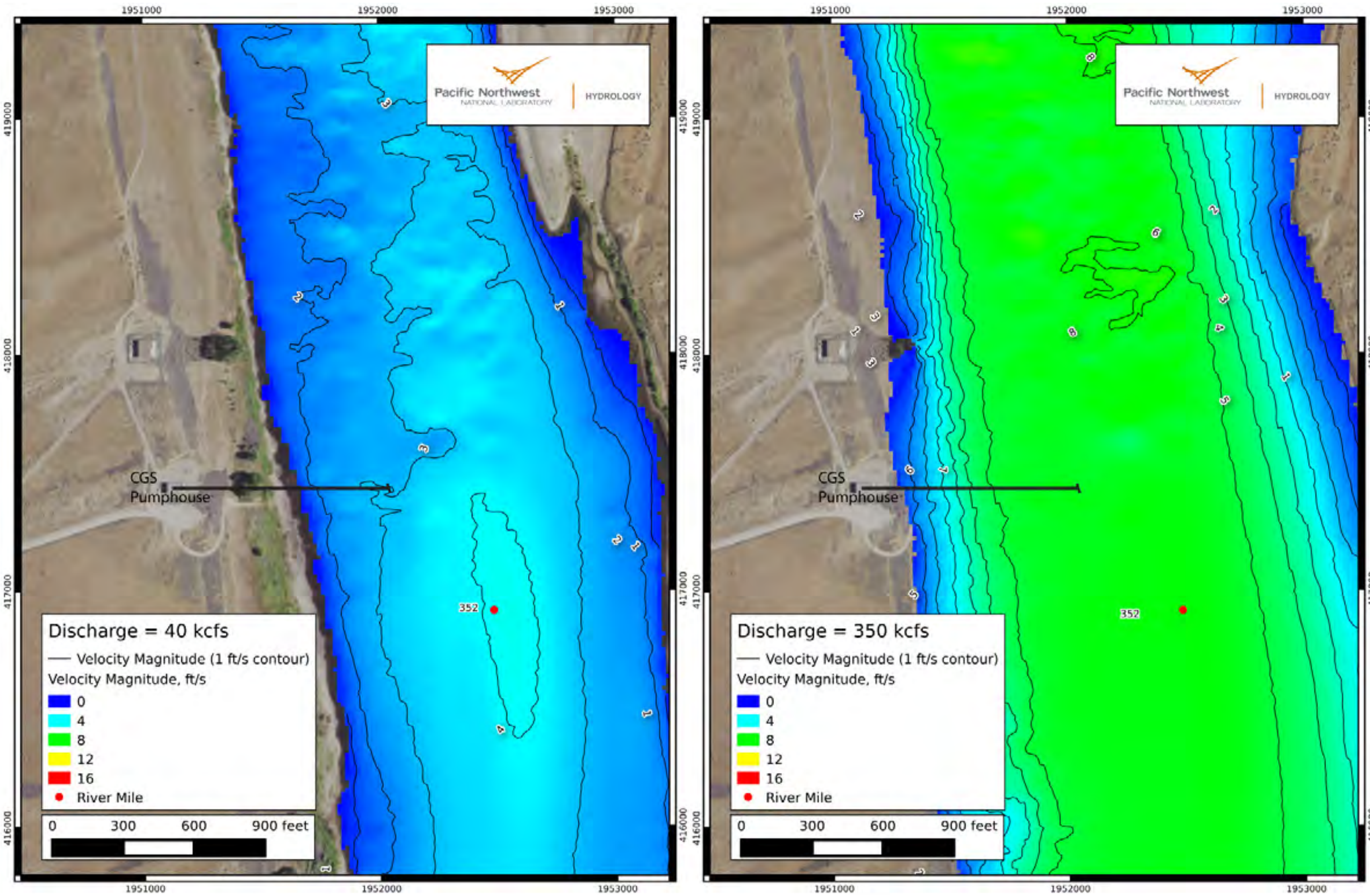
Note: Monthly means are based on river discharge observed during the period of record from 1917 through 2011. The location of the CGS intake structure and buried intake pipes are shown in black.

Figure 12
Minimum (Left Panel) and Maximum (Right Panel) Water Depths



Note: Data are based on monthly mean river discharge levels for the maximum and minimum on record since 1917. The location of the CGS intake structure and buried intake pipes are shown in black.

Figure 13
Minimum (Left Panel) and Maximum (Right Panel) Water Velocities at the Columbia Generating Station Intake Structures



Note: Data are based on monthly mean river discharge levels for the maximum and minimum on record since 1917. The location of the CGS intake structure and buried intake pipes are shown in black.

3.2.3 Historical Spring River Elevations and River Discharges

Broad seasonal fluctuations in water level occur in the Hanford Reach and are driven primarily by the natural hydrograph, and secondarily by flow regulation from upstream dams. Prior to the implementation of the VBSA (signed in 1979, implemented in 1984, and finalized in June of 1988), rapid changes in river discharge from PRD caused dewatering of redds in the fall and stranded large numbers of juvenile salmon in the spring. The VBSA set minimum flow levels at 70 kcfs leaving PRD (Grant PUD 2004). The HRFCPPA (enacted in 1999 and finalized in 2004) superseded and replaced the VBSA to set a critical minimum flow each year based on the elevational distribution of the salmon redds within the Hanford Reach and minimize the magnitude of flow fluctuations during the rearing period (Grant PUD 2004). This change in dam operation regimes over time presents a unique case to be able to observe changes in the frequency of extreme water level conditions that can affect entrainment.

River elevation at the CGS intake site was modeled for river discharges from March of 1976 to January of 2016 (Niehus et al. 2014; Perkins et al. 2018), thus encompassing periods prior to implementation of the VBSA in 1984, after implementation of the VBSA, and after initial application of the HRFCPPA agreement in 1999. Table 7 and Figure 14 display the number of low water events, mean event duration in hours, mean river flow, and mean river discharge during the events for each period. Standard deviation (SD) is reported to illustrate the spread in the data, reported as one SD around the mean, which represents the majority (68.2%) of the data points, assuming the data are normally distributed. The top elevation of the CGS screen is 104.02 m (341.30 feet) above MSL, and the minimum amount of submergence to protect fish from entrainment if considered an end of pipe screen would be one screen radius, 21 inches, or approximately 1.75 feet (NMFS 2011a); therefore, for this analysis, a low water event as it relates to elevated risk of fish entrainment is classified as the river elevation falling below 104.56 m (343.05 feet) MSL.

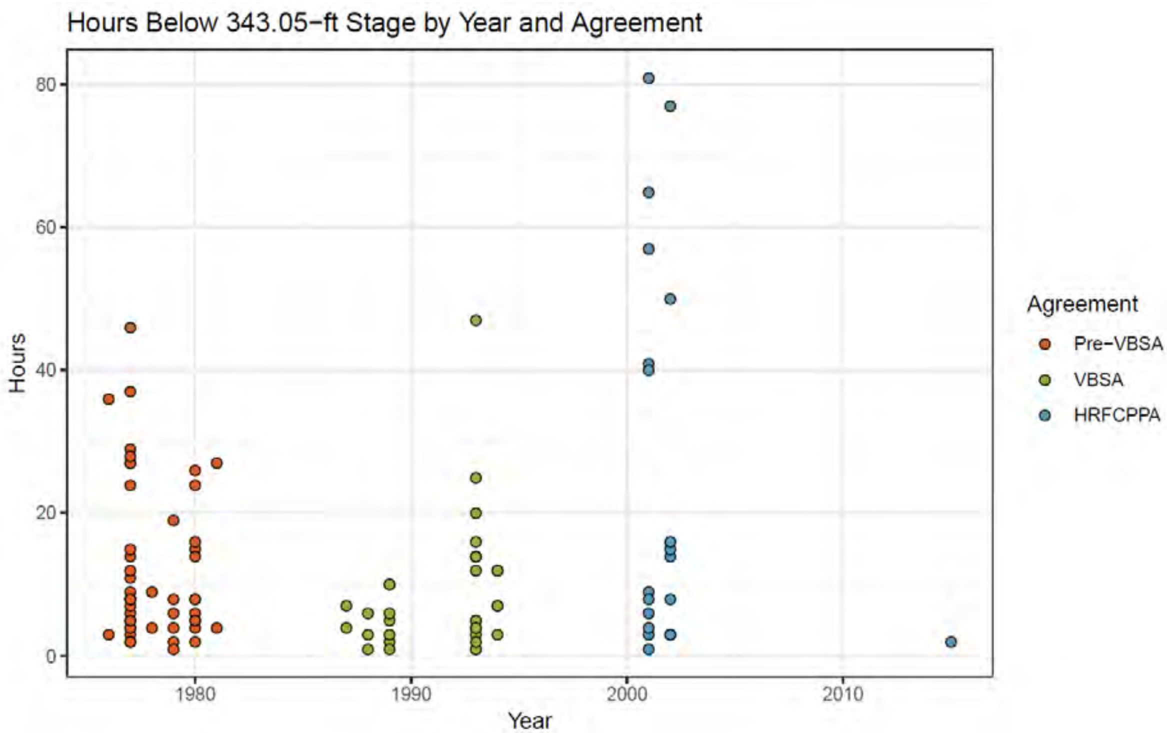
Extreme low water elevations occurred more frequently prior to the VBSA (52 events in 9 years compared to 54 events in 32 years). However, despite the greater number of events in the pre-VBSA years, the mean duration of such events is actually the highest in the post HRFCPPA period. During the 1999 to 2015 period, low flow events lasted on average 24.1 hours. In 2001 and 2002, five events exceeding 40 hours, with one event lasting longer than 80 hours. During the VBSA period, the majority of low flow events were short in duration. This can be compared to the events of the HRFCPPA period, when fewer low flow events have occurred, but the mean duration of low flow events has been longer. Note that the HRFCPPA was not finalized until 2004, and since then there has only been one 2-hour extreme low-flow event in 2015.

Table 7
Summary of Extreme Low Water Events at the Columbia Generating Station Intake during the Juvenile Chinook Salmon Emergence and Migration Period

Agreement	Period	Years	Number of Events	Mean Duration of Low Flow Events ± SD (hours)	Mean River Flow ± SD (cfs)	Mean River Stage ± SD (feet)
Pre-VBSA	1975 through 1983	9	52	11.9 ± 10.7	49,170 ± 5,098	342.5 ± 0.5
VBSA	1984 through 1998	15	33	8.7 ± 9.1	55,140 ± 2,888	342.9 ± 0.2
HRFCPPA	1999 through 2015	17	21	24.1 ± 27.0	49,794 ± 5,707	342.6 ± 0.5

Note:
The juvenile Chinook salmon emergence and migration period is defined as March 1 through June 30. Data are modeled to estimated river flow and stage at the CGS intake. One SD around the mean is given to show the spread of the data, representing the majority of the data (68%) assuming the data are normally distributed.

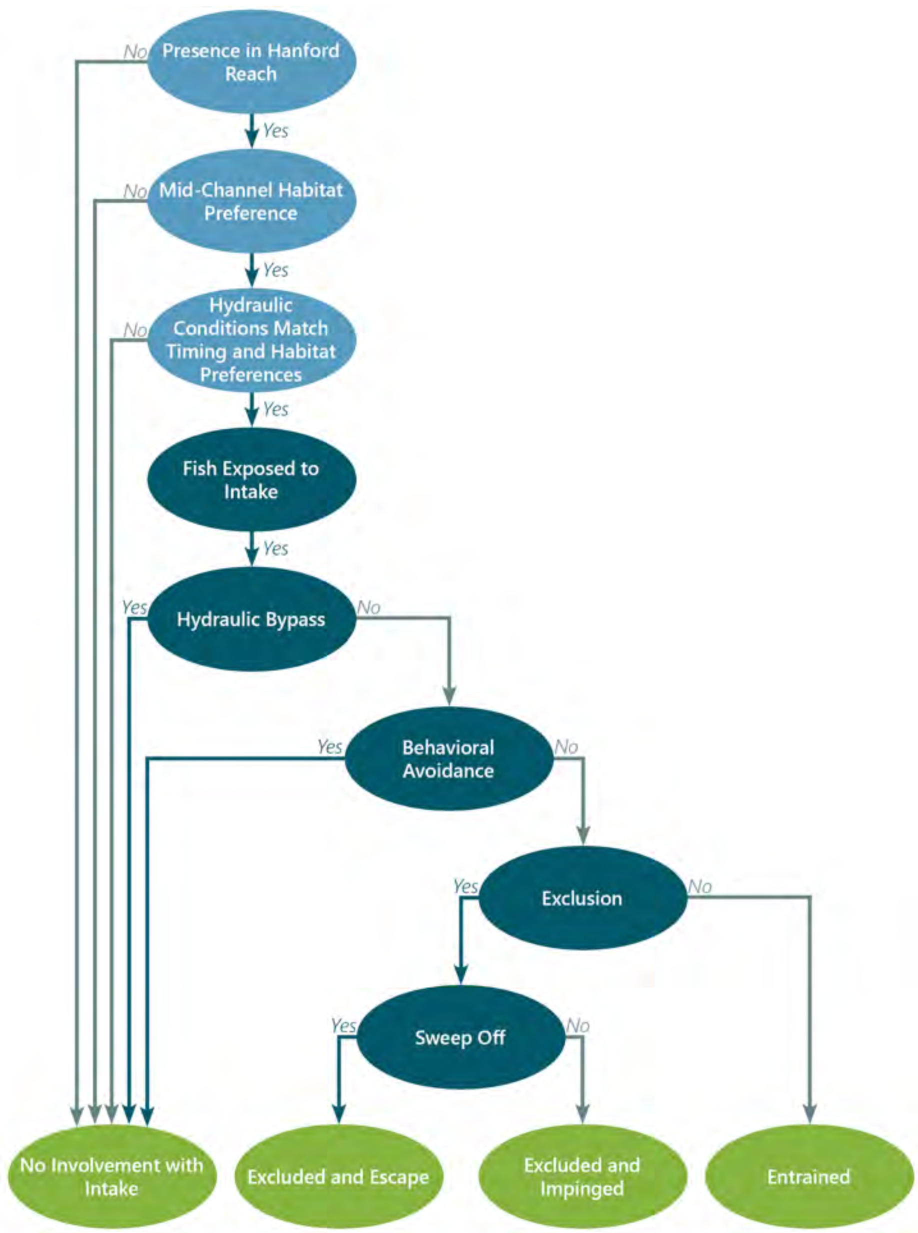
Figure 14
Number of Hours River Elevation Fell Below 343.05 Feet at the Columbia Generating Station Intake by Year and Agreement



4 Entrainment Risk at the Columbia Generating Station

The biological and physical factors that determine encounters, exclusion, entrainment, or impingement with intake structures can be combined and used to determine whether individual species that are present in the Hanford Reach are at higher or lower risk, due to their habitat preferences, size, and life history characteristics (Figure 15).

Figure 15
Determining Factors of Encounter, Exclusion, Entrainment, or Impingement of a Species or Life Stage at the Columbia Generating Station Intake Structure



4.1 Fish Presence in Hanford Reach

Of all species and life stages that are known to occur in the Hanford Reach, a subset can be identified that are at elevated risk of entrainment or impingement because their habitat preferences increase their potential to occur in proximity to the CGS intake. The species listed in Table 8 are: 1) abundant in the Hanford Reach; 2) prefer mid-channel or benthic habitat; and 3) inhabit waters where conditions exceed the minimum depth and velocity observed at the CGS intake site of 8 feet and 3 cubic feet per second (cfs), respectively. The subset of species and life stages listed are also those that can be small in body size, increasing their risk of impingement or entrainment due to poor swimming ability or ability to pass through screen pores. The complete list of species that occur in the Hanford Reach are the focus of Section 3 and are listed in Table B-1 in Appendix B.

Of the 14 species listed in Table 8 and shown in Figure 16, nearly all overlap in proximity to CGS in September through October, with the exception of migratory salmonids. This exception includes Hanford Reach subyearling fall Chinook salmon, which typically have emigrated from the reach by September. March through June is when fall Chinook salmon fry emerge in the Hanford Reach and therefore are most at risk of entrainment. March through June is also when smolts from upstream tributaries are typically migrating through the Hanford Reach. Low flows in late summer through winter largely affect resident fish species and those with extended residency before outmigration (steelhead, lamprey). River discharge is typically lowest in October, resulting in lowest average monthly river depths and lowest sweeping velocities past the CGS intake. In Figure 16, the presence of a given species in the Hanford Reach over time is indicated by gray bars. The species that occur in the Hanford Reach during periods of highest fish abundance and lowest flows are indicated by yellow and orange, respectively.

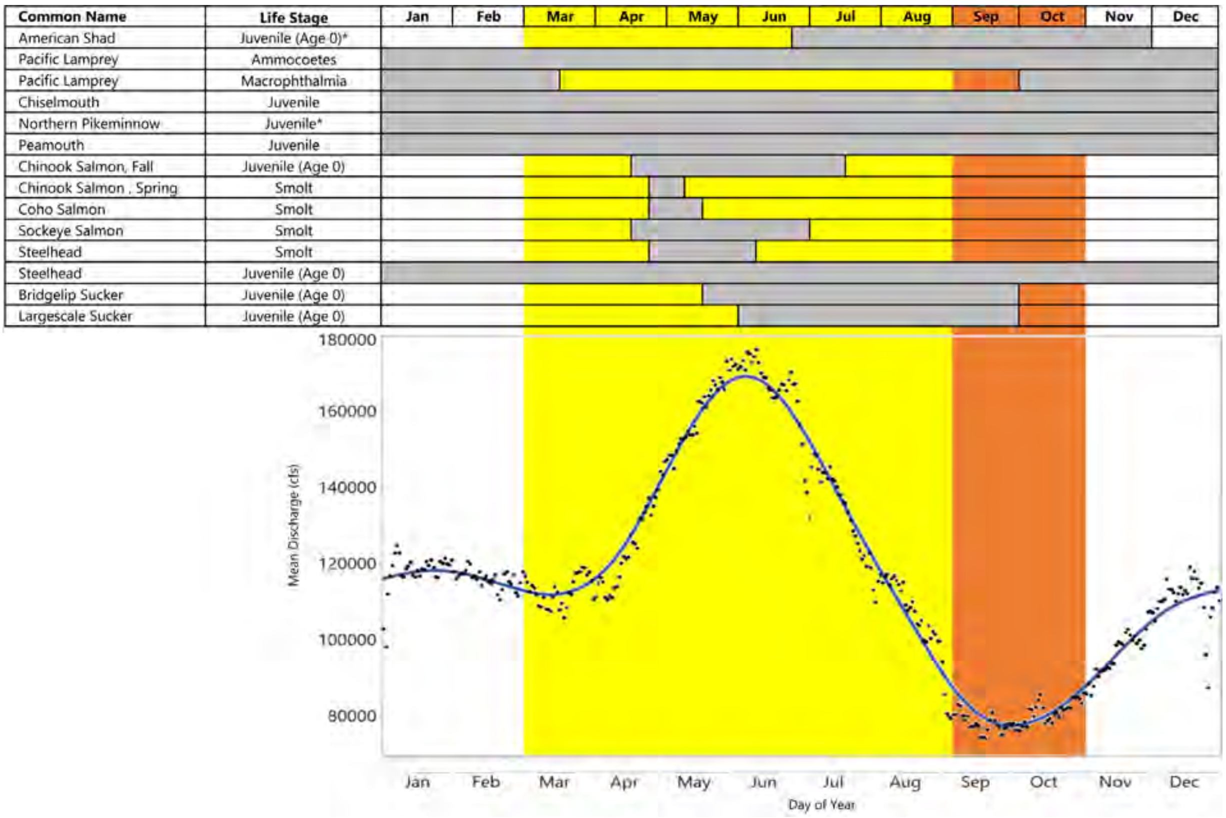
Table 8
Species and Life Stages at Risk of Exposure to the Columbia Generating Station Intake Structure

Common Name	Scientific Name	Life Stage	Preferred Habitat Type	Preferred Depth (feet)	Preferred Velocity (fps)	Size (length in mm)
Herring						
American Shad	*Alosa sapidissima*	Juvenile (Age-0)*	Mid-channel, Sloughs	3 to 20	0.1 to 2.5	75 to 125
Lamprey						
Pacific Lamprey	*Lampetra tridentata*	Macrophthalmia	Mid-channel/ Benthic	3 to 40	High; individuals drift with flow	125 to 200
		Ammocoetes*	Mid-channel/ Benthic	2 to 3	Less than 0.8 (prefer less than 0.3)	Less than 125
Minnows and Carps						
Chiselmouth	*Acrocheilus alutaceus*	Juvenile	Nearshore, pools, then mid-channel later in summer	Shallow to deep	Low to Moderate	30 to 250
Northern Pikeminnow	*Ptychocheilus oregonensis*	Juvenile*	Nearshore, pools, then mid-channel later in summer	Greater than 15	Greater than 3	9 to 75
Peamouth	*Mylocheilus caurinus*	Juvenile	Nearshore, then mid-channel later in summer	Shallow to deep	Low to Moderate	9 to 75
Salmonids						
Chinook Salmon, Fall	*Oncorhynchus tshawytscha*	Juvenile (Age-0)	Nearshore, then mid-channel later in summer	5 to 20	< 2.6	45 to 80
Chinook Salmon, Spring	*O. tshawytscha*	Smolt	Mid-channel	6.5 to 40	3 to 4.5	100 to 225
Coho Salmon	*O. kisutch*	Smolt	Mid-channel	5 to 40	3 to 4.5	90 to 130
Sockeye Salmon	*O. nerka*	Smolt	Mid-channel	6.5 to 40	3 to 4.5	74 to 100
Steelhead	*O. mykiss*	Juvenile (Age-0)	Nearshore, then mid-channel later in summer	Less than 10	Less than 1.5	35 to 155
Steelhead	*O. mykiss*	Smolt	Mid-channel	13 to 40	4 to 4.5	165 to 240

Common Name	Scientific Name	Life Stage	Preferred Habitat Type	Preferred Depth (feet)	Preferred Velocity (fps)	Size (length in mm)
Suckers						
Bridgelip Sucker	*Catostomus columbianus*	Juvenile (Age-0)	Mid-channel	2 to 8	Low	Less than 80
Largescale Sucker	*C. macrocheilus*	Juvenile (Age-0)	Nearshore/ Benthic, Pools	0.3 to 15	Low	8 to 55

Note:
*Larvae have a pelagic stage

Figure 16
Seasonal Occurrence of Fish Species at Risk of Entrainment in Relation to Average Daily River Discharge



Notes:
Fish presence is indicated by gray bars. Months with highest abundance of juvenile fish are highlighted in yellow. Months with lowest sweeping velocity and water depth are highlighted in orange. Mean Daily River Discharge shows the daily mean river discharge below PRD with each day represented by a black dot and the overall seasonal trend represented by the blue line. Data were collected from January 1975 through January 2016.
* Eggs may drift, or larvae have a drifting pelagic phase vulnerable to entrainment by the CGS intake.

4.2 Habitat Preference

Of this subset of fish species and life stages that could occur near the CGS intake, most are more likely to inhabit shallow nearshore areas with low velocities during very early larval and juvenile development phases. Risk of becoming exposed to the intake structure may increase as age-0 fry grow throughout the summer and begin to move offshore into the mid-channel habitat. American shad larvae may also be vulnerable to entrainment during their very early pelagic stage, prior to recruiting to shallow nearshore habitats; however, in the Hanford Reach, American shad larvae are mainly observed in backwater slough habitats in contrast to impounded reaches where they are observed across the entire channel (e.g., John Day Reservoir; Petersen et al. 2003).

Declining river discharge in September through November to annual minimums may pose additional risk to fish along with a corresponding reduction in submergence depth of the intake screens (less than 12 feet total river depth and less than 8.5 feet depth over the top of the cylindrical screens; Figure 10) and sweeping velocity (less than 4 fps). The reduction in flow may increase the likelihood for juveniles or small-bodied adults such as minnows to encounter the intake structures at shallower depths and slower velocities; however, risk to these species is still relatively low in the fall due to their tendency to prefer areas with overhanging cover or aquatic vegetation and velocities less than 4 fps.

The assumptions about fish risk of entrainment based on depth and habitat preferences are only estimates based on review of the literature; a conservative analysis should assume that fish may behave outside the norm. For instance, Dauble et al. (1989) found subyearling Chinook salmon in the Hanford Reach throughout the water column and across the entire river channel up to mean river depths of 40 feet and velocities of 5 fps, although the common assumption is that their habitat preferences would isolate them to shallow, slow velocity, nearshore areas. In addition, more fish may encounter the intake structure at times of the year when fish densities are highest, such as in March through May for Hanford Reach fall Chinook salmon or June through September for spring-spawning minnows and suckers.

4.3 Fish Size

Nearly all other species that are prone to entrainment as age-0 juveniles may experience fast growth in their first summer and may be too large to become entrained by September. Other fishes that reside in the Hanford Reach are poor swimmers and small enough to become entrained through the intake screens; however, their depth and velocity preferences make it unlikely that they would occur in close proximity to the intake structure. These include the dace species, redside shiner, and sculpin species, that prefer very shallow water less than 3 feet deep, and age-0 juvenile sturgeon, mountain whitefish, walleye, crappie, and lamprey ammocoetes that prefer low velocities less than 1.5 fps. Risk of entraining these species is low, but not zero, as they may become exposed to the intake as they drift downstream from upstream habitats or spawning areas.

4.4 Hydraulic Bypass

Hydraulic bypass is the phenomenon that some fish in the water directly approaching the intake system would likely pass by the screen (bypass) without coming close enough to it to be vulnerable to entrainment or impingement. Three mechanisms can lead to hydraulic bypass, that is, passing the screen before becoming involved with the approach velocity and through-pore velocities that cause fish to become entrained through the screen. First, hydraulic bypass at the CGS intakes is first determined by the "bow wave," i.e., the pressure and velocity changes at the nose cone that create flow vectors away from the screen at the sides of the cone. Second, the bow wave can also induce a startle response and active avoidance behavior by the fish stimulated by the hydraulic patterns

around the intake. Third, the sweeping flow can move fish along the screen before they can be affected by the approach velocity (sweeping velocity greater than approach velocities). Early studies lumped all fish bypassing the structure as "hydraulic bypass" without distinguishing between the mechanisms, other than theoretically. More recent lab experiments have distinguished between the physical and behavioral factors that can cause fish to be bypassed.

Physical factors that cause hydraulic bypass are a function of the interactions between approach velocity at the face of the intake screen and sweeping velocity past the intake screen. Generally, at the CGS intake structure, approach velocity of the bulk flow is 0.07 fps (0.02 mps) for average operating conditions and 0.16 fps (0.05 mps) through-pore velocity. Both are much less than the sweeping velocity of the free-flowing Columbia River.

The two cylindrical intake screens at CGS are oriented parallel to the stream channel; therefore, the modelled river surface velocity oriented in the same direction can be used as a surrogate measure of the sweeping velocity. Average river velocity at the CGS site ranged from 3 fps at the lowest river discharge levels to 7 fps at the highest river discharge levels observed over the period of record from 1917 to 2011. At very high flows observed on June 23, 2017, direct measurements of surface velocity reached 8.9 fps at just 1 ft below the surface and 5.6 fps at 3 ft below the surface. Modeled mean velocities range from lows of 4 fps in October to highs of 6 fps in June. Even at the lowest river discharge levels, river velocity at the CGS intake structure exceeds the maximum approach velocity created by intake suction more than fiftyfold. Therefore, at the river scale, sweeping velocity overcomes approach velocity of the CGS intake structure throughout the year. Given the much greater sweeping velocities relative to approach velocities observed at the CGS intake structure, and assuming approach velocity is not greatly amplified by reduction in intake area due to clogged screen pores, it is likely that most fish bypass the intake structure without becoming entrained or impinged. Extrapolating from cylindrical wedge wire laboratory test data to sweeping velocities of 3 fps or greater, the probability of bypass is expected to be 0.8 or greater (NAI and ASA 2011).

Finer-scale investigation of the hydrodynamics around the intake structure a by CFD modeling revealed localized variation in sweeping and approach velocity as water moves around and through the intake screens. The ratio of sweeping velocity to approach velocity is a concise indicator of entrainment or impingement risk derived from the near-field CFD modeling, where higher values indicate lower risk (Alden 2018). Using NMFS criteria of minimum threshold for sweeping velocity of 2.5 fps and maximum threshold for approach velocity of 0.2 fps, a minimum threshold for the ratio could be inferred to be 12.5. This threshold is generally exceeded (NMFS criterion met) when flow is axial to the intake screens with marginal exceptions occurring locally very near the upstream edge of the downstream screen only. When flow is oblique to the screens the ratio is consistently less than 12.5 (in violation) at a distance of 200 mm from the up-current, upstream screen face, but increases

in value closer to the screen face (within 20 mm) as stream flow is forced to turn to become more tangential to the screen face.

4.5 Behavioral Avoidance for Bypass

The pressure bow wave that exists at the nose of the intakes is relatively large in size (reaching 10-15 ft upstream) relative to the size of juvenile and small-bodied fish at highest risk of entrainment or impingement. This bow wave is the first stimulus a downstream-migrating fish would encounter around the intake structure and may provide a strong signal for fish to swim away from the structure before coming within several feet of the screens, if not cause hydraulic bypass of fishes that are pushed out of the way of the structure by the bow wave. Of the fish that are not protected by hydraulic bypass and come closer to CGS intake structure, many would have the ability to respond behaviorally to sudden changes in flow (pressure or velocity) with an avoidance responses. As demonstrated in laboratory experiments, the avoidance can have two phases, a rapid and largely involuntary startle response that breaks the drifting trajectory (milliseconds) followed by active burst swimming. Assuming a submergence depth of at least one screen radius as required by NMFS guidelines (NMFS 2011a), at a river velocity of 2 fps, a fish approximately 20 mm in length would be expected to avoid the screen 95% of the time (NAI and ASA 2011). As bulk river velocity increases, the ability of fish to avoid the CGS intakes will decrease, but the probability of hydraulic bypass will also increase (NAI and ASA 2011).

NMFS screen criteria (2011a) are intentionally conservative to protect the weakest fish, in this case, those fish that are poor swimmers that may encounter the CGS intake by chance if not prevented by hydraulic conditions. The smallest and weakest life stages that may become entrained are young of the year juveniles and larvae of species listed in Table 8, including post-emergence fall Chinook salmon fry. Other species present in the Hanford Reach would have the ability to evade the typical bulk approach velocities of the CGS intake structure of 0.07 fps and through-pore velocities of 0.16 fps with escape or burst swimming even without high sweeping velocity, with the possible exception of drifting larval stages of American shad, Pacific lamprey, Northern pikeminnow, walleye, and white sturgeon.

4.6 Exclusion

For fish that are not bypassed and are unable to swim away from the approach velocity, some will be physically excluded if they are larger than the CGS screen pore diameter of 9.5 mm (0.375 inch). In addition, "micro-eddies" created within screen pores have been identified with CFD modeling, which reduce the effective pore size to as small as 3 mm in diameter for entrainment of passive particles. This effective pore size still exceeds the NMFS criterion of 2.4 mm, however. Fish size is typically discussed in terms of length; however, body depth or the size of the incompressible head may be the dimension most likely to determine the ability of some species to pass through small openings. Body

depth is likely the determining factor for larval lamprey with an elongated cylindrical and flexible body shape, but in ammocoete entrainment studies probability of entrainment is tightly correlated with length (Rose and Mesa 2011). Head size may be the most important body dimension as in the case of resident fish like sculpin, that have a dorsal-ventrally flattened body shape.

The ratio of body length to depth has been used to predict juvenile salmonid entrainment or impingement (NMFS 2013a,b; Bell 1990); however, for many species and life stages, body depths are unavailable in reviewed literature. Using criteria presented by Bell (1990), fish with a body length of 75 mm are at risk for entrainment at the CGS intake. Salmonids with body lengths of 75 mm typically would have a body depth of 12 mm (Bell 1990); however, this varies by species and developmental and nutritional state.

4.7 Sweep-Off or Impingement

Sweeping velocity also contributes to sweep-off, or the movement of eggs, larvae, or juvenile fish along the screen after initially becoming impinged. Sweep-off accounts for a minor component of fish that escape entrainment but become impinged on the surface of the intake screens. Boundary-layer hydrodynamics that may affect sweep-off are similar to those that affect hydraulic bypass. Fish that are larger in size than the screen pores but cannot avoid approach velocities may become impinged on the intake screens. Impingement is more likely to occur when sweeping velocity is lowest, such as in the fall, and on certain areas of a screen when oblique flow occurs.

4.8 Species at Risk

An examination of the framework of biological and physical factors that determine fish interactions with the CGS intake reveals some species, life history stages, and seasons at potentially elevated risk. However overall, the physical design of the intake effectively minimizes that risk. Characterizing risk for a given species is complicated by changes in species presence across seasons and river habitat that changes seasonally with flow. A species or life stage is at risk if an overlap exists between its seasonal presence and its preferred hydraulic conditions. For instance, many age-0 fish would be vulnerable when they occur at the smallest sizes in spring and early summer, but river discharge is highest during this time of the year, resulting in a smaller percentage of the flow encountering the intake structures than when river discharge is low. The high river flow also causes fry to tend to stay isolated in nearshore and backwater environments, away from the CGS intake structure located in deep, swift water in the mid-channel. Of the species and life stages that are at higher risk of encountering the intake structure, some species are present year-round and remain small in body size for at least their first year, whereas other species are only present for short periods of the summer or grow quickly in their first year so that they exceed a vulnerable size threshold by the end of the summer.

Figure 16 shows the seasonal presence of the species identified to be at highest risk of encountering the CGS intake based on overlapping habitat preference for mid-channel or benthic habitat with river conditions and fish size. A conservative assumption is that some risk exists for these species even though the CGS intake was designed to bypass most fish. That potential risk is a result of localized areas of concentrated inflow or minimal sweeping velocity around the intake screens revealed by the CFD models. In addition, flows that are oblique to the intake structures increase risk to fish by forcing flow directly through the intake screen on the up-current side of the upstream screen. It is possible that river discharge levels and river elevations cause more oblique flows to occur at specific times of the year and not others, however such direct measurements of hydraulic conditions around the CGS intake have not been performed. Therefore, the most conservative assumption is that periods of higher risk of encountering the intake occur when the most vulnerable species are present in highest abundance from March through September, highlighted in yellow in Figure 16.

Though hydraulic bypass of fish is facilitated by sweeping velocities that exceed approach velocity under most river discharge and river flow angles examined (Alden 2018), risk of encountering the intake may also increase late in the year when river velocity is lowest and submergence depths may fail to meet NMFS criteria of greater than one screen radius, or 1.75 feet, highlighted in orange in Figure 16.

4.8.1 Risk to Upper Columbia River Salmon and Steelhead Smolts

Concerns have been raised about risk of entrainment and impingement to salmon and steelhead migrating from upstream spawning and nursery areas (upstream of Hanford Reach), including the upper Columbia River spring Chinook salmon (ESA-listed as Endangered), upper Columbia River steelhead (Threatened), Wenatchee and Okanogan sockeye salmon (not listed), and coho salmon (coho salmon are unlisted, but currently a reintroduction effort exists to reverse historical extirpation from the middle and upper Columbia River Basin).

Typically, smolts originating from the upper Columbia River Basin follow a “stream-type” life-history strategy, spending an entire year rearing in headwater tributaries prior to navigating the mainstem Columbia River downstream to the ocean. These yearling smolts are relatively large, typically around 100 mm at the time of migration (see Table 8 and Appendix B for species specific sizes at emigration), and are a size that would prevent them from becoming entrained through the CGS intake screens (greater than 75 mm).

Once initiating their downstream migration, smolts tend move downstream rapidly by orienting with the main flow of the river, passing through the Hanford Reach in 1 to 2 days on average which reduces their exposure to the CGS intakes compared to species that rear in the reach for extended periods of time. In addition, smolts from the upper Columbia River Basin tend to behave in ways that greatly minimize their risk of impingement: their peak emigration timing is in spring and summer,

concurrent with peak sweeping velocities (shown in Figure 16); they tend to migrate near the surface, placing them approximately 7 to 12 feet from the intake screens at this time of year.

Finally, yearling smolts are robust swimmers, with burst swimming capacities greater than 2.5 fps (Taylor and McPhail 1985) and sustained swimming speeds greater than 1.0 fps, which greatly exceed the bulk flow approach velocities of 0.07 fps through the CGS intakes.

Taken together, smolts from upper Columbia River tributaries are at small risk of encountering the CGS intakes due to their typical life-histories and migration behavior. If these smolts were to encounter the intake, there is a high likelihood they could become bypassed by hydraulics around the screens, or by burst-swimming as part of the startle response upon encountering the bow wave or approach velocities near screen pores. Finally, they are too large to become entrained, and while they could become impinged, their tendency to occur in the Hanford Reach during the periods of highest sweeping velocities in spring and early summer supports the hypothesis that they are likely to become swept of the face of the intake screens. Based on this combination of biological and physical factors, the risk of entrainment or impingement to migrating smolts from the upper Columbia River Basin is negligible for the CGS intake structures.

4.8.2 Risk to Hanford Reach Fall Chinook Salmon

As previously discussed in Section 2.1.1.1, fall Chinook salmon that originate from the Hanford Reach, although not ESA listed, have unique significance and are a key Columbia River Chinook salmon population, warranting a more detailed evaluation of entrainment risk. Fall Chinook salmon fry and age-0 juveniles are abundant in shallow nearshore areas near the CGS intake (EN 2010). To examine the risk posed by the CGS intake to fall Chinook salmon in detail, the framework of biological and physical factors that determine fish interactions with the CGS intake described in Section 3 can be examined relative to known biological characteristics of Hanford Reach fall Chinook salmon.

The large body of published literature on Hanford Reach fall Chinook salmon, and Chinook salmon in general, can be used to evaluate risk level and change in risk over the season. The determining factors of entrainment are evaluated individually in Table 9 relative to the biological characteristics of Hanford Reach fall Chinook salmon (discussed in detail in Section 2.1.1.1) to characterize the level of risk created by each individual factor. Each entrainment factor and relevant biological characteristics are briefly summarized on the left-hand side of Table 9, and the level of risk created by the entrainment factors and biological characteristics are shown on the right side of the table by month as red, yellow, and green, representing the range from high, to moderate, to low risk.

Table 9 shows that the entrainment factors that create the most risk for fall Chinook salmon are their presence in proximity to the intake structure, their habitat preference that causes them to move away from nearshore areas as they grow, and their small size relative to the external screen pore size.

These characteristics put fall Chinook salmon at relatively higher risk in April and May when large numbers of fry are both small in size and starting to move away from nearshore areas.

Entrainment factors that effectively minimize the risk to fall Chinook salmon are facilitated by orientation of the intake in a relatively high-velocity, near-mid-channel location, mostly parallel to flow which creates sweeping velocities that exceed typical approach velocity of the bulk flow by at least a factor of 50. It can also be assumed that fall Chinook salmon can effectively avoid entrainment given their ability to sense rapid changes in acceleration and burst swimming capacity, that also exceeds maximum approach velocity by a factor of 50.

It is the combination of the listed entrainment factors that determine the overall probability of entrainment for fish. In an idealized scenario, if fish to do not come into proximity of the intake, or if the probability of either bypass, avoidance, or exclusion is 100%, the probability of entrainment falls to zero. In reality, a conservative assumption is that some risk may always exist, but for many cases the risk is exceedingly low. Even so, if the risk is low for one of the factors identified in Figure 15 in a given month, subsequent entrainment factors, however potentially hazardous on their own, could not pose added risks. For instance, the combined entrainment risk to fall Chinook salmon fry in March is low because they tend to inhabit nearshore and backwater areas just after emergence, so that even though they are small enough to pass through the intake screen pores at this time of year they are not in proximity of the intake structures. Though risk created by some entrainment factors is higher in some months, when all the biological and physical factors of entrainment are considered in combination, the risk of entrainment is low across the entire year.

Table 9
Risk to Fall Chinook Salmon Created by the Columbia Generating Station Intake Structure by Entrainment Factor and by Month

Entrainment Factor	Review of Literature Summary	Risk Level Created by Each Determining Factor of Entrainment by Month						
		Mar	Apr	May	Jun	Jul	Aug	Sep
Presence in Hanford Reach	Fry emerge from mid-March through mid-May, redistribute to shallow nearshore areas through early summer, and migrate downstream from early June through mid-August.	*M*	*H*	*H*	*H*	*H*	*M*	*L*
Habitat Preference	Emergent fry use shallow, shoreline habitats with mean water velocities less than 1.5 fps. Older subyearlings are found in water depths of 4.9 to 19.4 feet, and velocities between 0.6 to 2.6 fps, mainly in nearshore areas but can be found across the entire river channel and water column.	*L*	*L*	*H*	*H*	*H*	*H*	*H*
Fish Size	37 to 44 mm at emergence, 70 to 110 mm by early June, and 105 to 125 mm by mid-August	*H*	*H*	*H*	*M*	*M*	*L*	*L*
Hydraulic Bypass	Mean sweeping velocity ranges from 4 to 5 fps during the months that emerging fry and subyearlings are present and exceeds the typical bulk flow approach velocity of 0.07 fps by at least a factor of 50.	*L*	*L*	*L*	*L*	*L*	*L*	*L*
Behavioral Avoidance	Burst swimming capacity of 3.5 fps exceeds the typical approach velocity of 0.07 fps by a factor of 50.	*L*	*L*	*L*	*L*	*L*	*L*	*L*
Exclusion	Salmon larger than approximately 75 mm excluded from outer screen pores that are 9.5 mm in diameter. Most subyearlings reach 75 mm by June.	*H*	*H*	*H*	*M*	*L*	*L*	*L*
Sweep-Off or Impingement	Sweeping velocities that exceed approach velocities contribute to sweep-off. Blocked screen pores may contribute to higher and uneven approach velocities and increase the potential for impingement; river debris is likely to be swept off; however, biofouling of screen pores may increase across the summer.	*L*	*L*	*L*	*L*	*M*	*M*	*M*
Combination of All Entrainment Factors	**Low risk for one factor negates the risk posed by subsequent factors**	***L***	***L***	***L***	***L***	***L***	***L***	***L***

Note:
Each entrainment risk factor and relevant biological characteristics are briefly summarized on the left-hand side of the table and the relative level of risk is shown on the right side of the table, by month, as red, yellow, and green, representing the range from high (H), to moderate (M), to low (L) risk. The overall risk created by the combination of entrainment factors is depicted in the bottom row, representing the outcome of the sequence of entrainment factors shown in Figure 15.

5 Conclusions

A broad diversity of species exists in the Hanford Reach, representing native species that are well-adapted to free-flowing, cold river habitat, and expansion of non-native species from impounded areas. Many of the most vulnerable species and life stages, those that are small in size and poor swimmers such as subyearling (age-0) salmon and minnows, prefer slow water and shallow nearshore habitat, excluding them from occurring in proximity of the intake in large numbers. With the possible exception of American shad, the non-native species present in Hanford Reach also tend to prefer slow, backwater sloughs. Therefore, of all species found in the Hanford Reach only a small subset are likely to occur in the mid-channel habitat near the CGS intake structure during a limited period of late spring or summer as they grow and move offshore. Other species that have passively drifting larval stages may be entrained as larvae are swept past the CGS intake structure; however, larval lamprey (macropthalmia) are the only species known to drift in benthic, main channel habitat.

Upon detailed examination of the biological characteristics of all fish and life stages known to occur in the Hanford Reach, most are excluded from risk of entrainment because of their habitat preferences, and few are at risk of entrainment, including Hanford Reach fall Chinook salmon and upper Columbia River steelhead.

Salmonids are the focus of regulatory concern in the Columbia River, with particular interest in evaluating whether the CGS intake poses risks to threatened or endangered species, in this case, upper Columbia River spring-run Chinook salmon and steelhead. These and other salmonid species that originate from reaches upstream of the Hanford Reach (sockeye salmon, coho salmon) typically pass through the Hanford Reach rapidly during their downstream migration to sea, minimizing their exposure to the CGS intake. In addition, their tendency to smolt at a relatively large size as yearlings excludes them from entrainment, and their burst swimming capability at this age and size allows them to avoid impingement. Risk of entrainment or impingement posed by the CGS intake is, therefore, found to be negligible for smolts that originate from tributaries to the upper Columbia River.

Two factors that largely determine fish habitat preferences are river depth and velocity; however, without direct and constant monitoring the magnitude of change in depth and velocity over time can be challenging to estimate in a large river. Using LiDAR-mapped bathymetry and river discharge levels gauged at PRD, MASS models were applied to determine range of depth and velocity at the CGS intake structure (Coleman et al. 2010; Niehus et al. 2014; Appendix C). Modelling verified that the CGS structure is oriented parallel to the river flow velocity vectors and demonstrated that river velocity is greater than 3 fps at the site, even during minimum flows. These physical interactions between the intake structure and river conditions confirm that fish encounters with the intake screens would be effectively minimized by hydraulic bypass around the structure created by the hydraulic bow wave at the cone and sweeping velocity along the screen as well as likely behavioral

avoidance of changes in pressure and velocity near the screens. Year-round, that sweeping velocity exceeds typical bulk approach velocity by a factor of at least 50, such that entrainment or impingement are unlikely even if fish come into close proximity with the intake screens. Modeled hydrodynamic conditions around the cylindrical CGS intake structures provide data on conditions that mostly prevent entrainment, but also highlight exceptions that may increase risk of entrainment or impingement, including localized turbulence causing concentration of inflow and higher-than-optimal approach velocity when flows are more oblique to the structures. A conservative approach must assume that some risk may always exist. Risk exists for fish that encounter areas of the intake where approach velocity is highest (e.g. the up-current side of the upstream screen with oblique flows at the highest velocity of the year) and where sweeping velocity is lowest (e.g. the leeward side of the downstream screen where back eddies direct flow toward the screen with oblique flows). Risk may be elevated when fish are most abundant, when screen submergence depth is lowest in the fall, or if screen pores become clogged due to biofouling causing uneven increases in approach velocity across the screen face.

Overall, the probability of fish becoming entrained or impinged by the CGS intake exists for small-bodied fish in the Hanford Reach, including fall Chinook salmon and steelhead fry that rear in the Hanford Reach. However, the risk is exceedingly low, with only the smallest and weakest fish that happen to occur in mid-channel at risk of entrainment or impingement.

6 References

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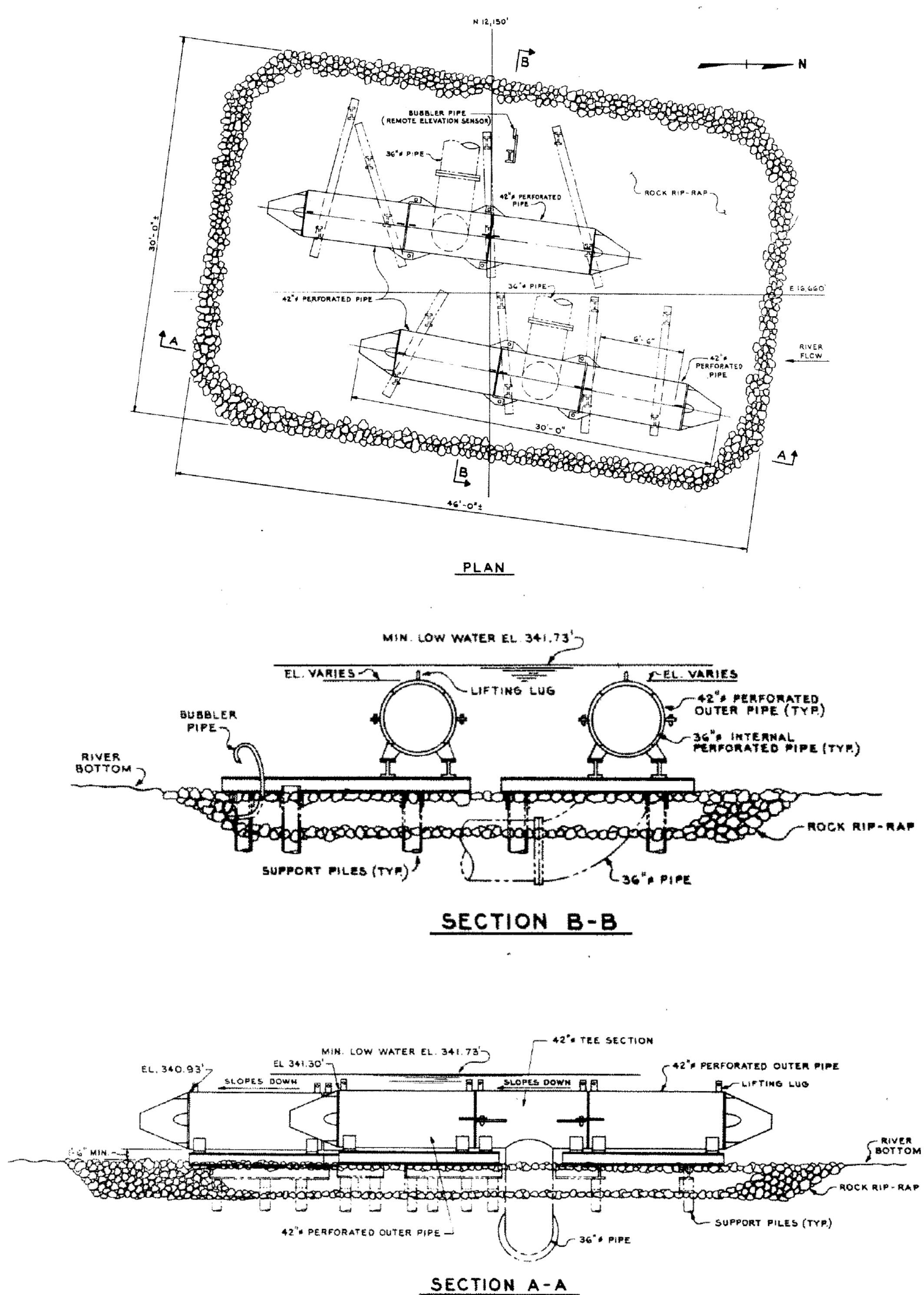
Appendix A
Intake Structure Engineering Drawings

Figure A-1
Plan and Section Views of the Columbia Generating Station Cylindrical Intake Structure Screens



Appendix B
Master Species Table of Fishes Occurring in the Hanford Reach

Table B-1
Master Species Table

Family	Common Name[a]	Scientific Name[a]	Life Stage	Relative Abundance Near CGS[1]	Approximate Size (mm)	Seasonal Occurence	Habitat Uses	Preferred Habitat	Preferred Depth (ft)	Preferred Velocity (ft/sec)	State	Federal	Origin	Source
Bullhead Catfishes	Black Bullhead	*Ameiurus melas*	Juvenile	Uncommon	<170	Year-Round	Rearing	Nearshore, Backwaters	Shallow to moderate	Low	--	--	Non-native	b, c, d
Bullhead Catfishes	Brown Bullhead	*Ameiurus nebulosus*	Juvenile	Uncommon	<190	Year-Round	Rearing	Nearshore, Backwaters	Shallow to moderate	Low	--	--	Non-native	b, c, d
Bullhead Catfishes	Yellow Bullhead	*Ameiurus natalis*	Juvenile	Uncommon	<110	Year-Round	Rearing	Nearshore, Backwaters	Shallow to moderate	Low	--	--	Non-native	b, c, d
Bullhead Catfishes	Channel Catfish	*Ictalurus punctatus*	Juvenile	Uncommon	<250	Year-Round	Rearing	Nearshore, Backwaters, Pools	Shallow	Moderate to High	--	--	Non-native	b, c, d
Herrings	American Shad	*Alosa sapidissima*	Juvenile*	Abundant	75-125	Late Jun- late fall	Rearing	Nearshore	3-20	0.1-2.5	--	--	Non-native	b,c,d, f
Lamprey	Pacific Lamprey	*Lampetra tridentata*	Ammocoetes*	Common	< 125	Year-Round	Rearing	Mid-channel/Benthic	2 to 2.5	< 0.8 (pref <0.3)	--	Species of Concern	Native	c, d, e,
Lamprey	Pacific Lamprey	*Lampetra tridentata*	Macrophthalmia	Common	125-200	October - early spring	Migratory	Mid-channel/Benthic	3 to 40	High; individuals drift with flow	--	Species of Concern	Native	c, d, e,
Lamprey	River Lamprey	*Lampetra ayresii*	Ammocoetes*	Uncommon	< 175	Year-Round	Rearing	Mid-channel/Benthic	Shallow to moderate	<0.5 - 0.1	Candidate	Species of Concern	Native	c, d, e,
Lamprey	River Lamprey	*Lampetra ayresii*	Macrophthalmia	Uncommon	> 175	Early Apr - mid-June	Migratory	Mid-channel/Benthic	Deep	High; individuals drift with flow	Candidate	Species of Concern	Native	c, d, e,
Livebearers	Western Mosquitofish	*Gambusia affinis*	Adult	Uncommon	> 40	Year-Round	Resident	Nearshore, Backwaters, Pools	Shallow	Low	--	--	Non-native	b, c, d
Livebearers	Western Mosquitofish	*Gambusia affinis*	Juvenile	Uncommon	< 40	Year-Round	Rearing	Nearshore, Backwaters, Pools	Shallow	Low	--	--	Non-native	b, c, d
Minnows and Carps	Longnose Dace	*Rhinichthys cataractae*	Subadult/Adult	Common	100-125	Year-Round	Resident	Benthic	3	3	--	--	Native	a, b, c, d
Minnows and Carps	Longnose Dace	*Rhinichthys cataractae*	Juvenile*	Common	7-100	Mid May - Mid July	Rearing	Mid-channel	1.5	3	--	--	Native	a, b, c, d
Minnows and Carps	Northern Pikeminnow	*Ptychocheilus oregonensis*	Subadult/Adult	Abundant	75 - 440	Year-Round	Resident	Mid-channel, Nearshore	>15	>3	--	--	Native	a, b, c, d, g
Minnows and Carps	Peamouth	*Mylocheilus caurinus*	Subadult/Adult	Abundant	75 - 290	Year-Round	Resident	Mid-channel, Nearshore	Shallow to deep	Low to Moderate	--	--	Native	a, b, c, d, g
Minnows and Carps	Chiselmouth	*Acrocheilus alutaceus*	Subadult/Adult	Common	65-290	Year-Round	Rearing	Mid-channel, Nearshore, Pools	Shallow to deep	Low to Moderate	--	--	Native	a, b, c, d, g
Minnows and Carps	Redside Shiner	*Richardsonius balteatus*	Subadult/Adult	Abundant	120-140	Year-Round	Resident	Nearshore	Shallow	Low to Moderate	--	--	Native	a, b, c, d, g
Minnows and Carps	Northern Pikeminnow	*Ptychocheilus oregonensis*	Juvenile (Age 0)	Abundant	9-75	Year-Round	Rearing	Nearshore	<15	<3	--	--	Native	a, b, c, d, g
Minnows and Carps	Peamouth	*Mylocheilus caurinus*	Juvenile (Age 0)	Abundant	9-75	Year-Round	Rearing	Nearshore	Shallow	Low	--	--	Native	a, b, c, d, g
Minnows and Carps	Common Carp	*Cyprinus carpio*	Juvenile	Present	6-305	spring-summer	Resident	Nearshore	<4	Low	--	--	Non-native	a, b, c, d, g
Minnows and Carps	Umatilla Dace	*Rhinichthys umatilla*	Subadult/Adult	Uncommon	50 -100	Year-Round	Resident	Nearshore	< 3.3	< 1.5	Candidate	--	Native	c, d
Minnows and Carps	Umatilla Dace	*Rhinichthys umatilla*	Juvenile	Uncommon	< 50	Year-Round	Rearing	Nearshore	< 3.3	Low to Moderate	Candidate	--	Native	c, d
Minnows and Carps	Tench	*Tinca tinca*	Juvenile (Age 0)	Uncommon	< 75	Year-Round	Rearing	Nearshore, Backwaters, Pools	Shallow	Low	--	--	Non-native	b, c, d
Minnows and Carps	Redside Shiner	*Richardsonius balteatus*	Juvenile	Abundant	<50 - 120	Jul-Sep	Rearing	Nearshore, Pools	Shallow	Low to Moderate	--	--	Native	a, b, c, d,
Minnows and Carps	Speckled Dace	*Rhinichthys osculus*	Subadult/Adult	Present	50 -100	Year-Round	Resident	Nearshore, Benthic/Pools, Runs, Riffles	<3	Low to High	--	--	Native	b, c, d
Minnows and Carps	Speckled Dace	*Rhinichthys osculus*	Juvenile	Present	< 50	Year-Round	Rearing	Nearshore, Benthic/Pools, Runs, Riffles	<3	Low	--	--	Native	b, c, d
Minnows and Carps	Leopard Dace	*Rhinichthys falcatus*	Juvenile*	Present	7-70	Mid May - Early Aug	Rearing	Nearshore/Benthic	1.5	1.5	Candidate	--	Native	c, d
Minnows and Carps	Leopard Dace	*Rhinichthys falcatus*	Subadult/Adult	Present	70-120	Year-Round	Resident	Nearshore/Benthic, Pools, Riffles	3	1.5	Candidate	--	Native	c, d
Minnows and Carps	Chiselmouth	*Acrocheilus alutaceus*	Juvenile (Age 0)	Uncommon	<65	Year-Round	Rearing	Tributary streams	1.5	0.4	--	--	Native	a, b, c, d,
Perches	Yellow Perch	*Perca flavenscens*	Juvenile	Present	<10 - 130	Year-Round	Rearing	Nearshore	Shallow	Low	--	--	Non-native	b, c, d
Perches	Walleye	*Sander vitreus*	Juvenile*	Present	13-225	Year-Round	Rearing	Nearshore/Benthic	1	Low	--	--	Non-native	a, b, c, d,
Salmonids	Mountain Whitefish	*Prosopium williamsoni*	Juvenile (Age 0)	Common	15-100	Year-Round	Rearing	Benthic	< 1	0.9	--	--	Native	a, b, c, d,
Salmonids	Chinook Salmon, Spring	*Oncorhynchus tshawytscha*	Smolt	Common	100-225	Late Apr	Migratory	Mid-channel	6.5-40	3.2-4.7	Candidate	Endangered	Native	b, c, d
Salmonids	Coho Salmon	*Oncorhynchus kisutch*	Smolt	Common	90-130	Late Apr - Mid May	Migratory	Mid-channel	5-40	3.2-4.7	--	--	Native	b, c, d
Salmonids	Sockeye Salmon	*Oncorhynchus nerka*	Smolt	Common	74-100	Mid Apr - Late June	Migratory	Mid-channel	6.5-40	3.2-4.7	--	--	Native	b, c, d
Salmonids	Steelhead	*Oncorhynchus mykiss*	Smolt	Present	165-240	Late Apr - Early Jun	Migratory	Mid-channel	13-40	4.2-4.7	Candidate	Threatened	Native	a, b, c, d,
Salmonids	Chinook Salmon, Fall	*Oncorhynchus tshawytscha*	Juvenile (Age 0)	Abundant	45-80	Mid Mar - Mid June	Rearing	Mid-channel, Nearshore	5-20	0.6-2.6	--	--	Native	a, b, c, d,
Salmonids	Steelhead	*Oncorhynchus mykiss*	Juvenile (Age 0)	Present	35 - 155	Year-Round	Rearing	Mid-channel, Nearshore	< 10	<1.5	Candidate	Threatened	Native	b, c, d
Sculpins	Mottled Sculpin	*Cottus bairdii*	Adult	Present	25-125	Year-Round	Resident	Mid-channel/Benthic, Nearshore	0.5-3	1-3	--	--	Native	b, c, d

Table B-1
Master Species Table

Family	Common Name[a]	Scientific Name[a]	Life Stage	Relative Abundance Near CGS[1]	Approximate Size (mm)	Seasonal Occurence	Habitat Uses	Preferred Habitat	Preferred Depth (ft)	Preferred Velocity (ft/sec)	State	Federal	Origin	Source
Sculpins	Mottled Sculpin	*Cottus bairdii*	Juvenile (Age 0)	Present	6-25	Mar-Jul	Rearing	Mid-channel/Benthic, Nearshore	0.5-3	1-3	--	--	Native	b, c, d
Sculpins	Torrent Sculpin	*Cottus rhotheus*	Adult	Present	25 - 152	Year-Round	Resident	Mid-channel/Benthic, Nearshore	Shallow	1.4-4	--	--	Native	b, c, d
Sculpins	Torrent Sculpin	*Cottus rhotheus*	Juvenile (Age 0)	Present	< 25	May-Late Jul	Rearing	Mid-channel/Benthic, Nearshore	Shallow	1.4-4	--	--	Native	b, c, d
Sculpins	Paiute Sculpin	*Cottus beldingi*	Adult	Uncommon	35-125	Year-Round	Resident	Mid-channel/Benthic, Nearshore	Shallow	1.4-4	--	--	Native	b, c, d
Sculpins	Paiute Sculpin	*Cottus beldingi*	Juvenile (Age 0)	Uncommon	< 35	May-Late Jul	Rearing	Mid-channel/Benthic, Nearshore	Shallow	1.4-4	--	--	Native	b, c, d
Sculpins	Prickley Sculpin	*Cottus asper*	Adult	Present	13-150	Year-Round	Resident	Nearshore/Benthic	0.5-3	Low	--	--	Native	b, c, d
Sculpins	Prickley Sculpin	*Cottus asper*	Juvenile (Age 0)*	Present	13-35	May-Late Jul	Rearing	Nearshore/Benthic	0.5-3	Low	--	--	Native	b, c, d
Sculpins	Reticulate Sculpin	*Cottus perplexus*	Adult	Uncommon	40-100	Year-Round	Resident	Nearshore/Pools, Riffles	Shallow	0-4	--	--	Native	b, c, d
Sculpins	Reticulate Sculpin	*Cottus perplexus*	Juvenile	Uncommon	< 43	Year-Round	Rearing	Nearshore/Pools, Riffles	Shallow	0-4	--	--	Native	b, c, d
Sticklebacks	Threespine Stickleback	*Gasterosteus aculeatus*	Adult	Uncommon	55-75	Year-Round	Resident	Mid-channel/Benthic, Nearshore	Shallow to moderate	Low	--	--	Native	b, c, d
Sticklebacks	Threespine Stickleback	*Gasterosteus aculeatus*	Juvenile	Uncommon	< 55	Year-Round	Rearing	Mid-channel/Benthic, Nearshore	Shallow to moderate	Low	--	--	Native	b, c, d
Sturgeons	White Sturgeon	*Acipenser transmontanus*	Juvenile (Age 0)*	Present	< 280	Mid May - Late July	Rearing	Mid-channel/Benthic, Nearshore	40-90	1.3	--	--	Native	a, b, c, d,
Suckers	Bridgelip Sucker	*Catostomus columbianus*	Juvenile	Common	< 200	Year-Round	Rearing	Mid-channel	2-8	Low	--	--	Native	a, b, c, d,
Suckers	Mountain Sucker	*Catostomus platyrhynchus*	Juvenile	Present	40-125	Year-Round	Rearing	Mid-channel	3.3-5	1.5	Candidate	--	Native	b, c, d
Suckers	Mountain Sucker	*Catostomus platyrhynchus*	Juvenile (Age 0)	Present	25-40	July-Sep	Rearing	Nearshore	0.5-1.3	Low to Moderate	Candidate	--	Native	b, c, d
Suckers	Longnose Sucker	*Catostomus catostomus*	Juvenile	Uncommon	< 200	Year-Round	Rearing	Pools	Shallow	Low	--	--	Native	c, d
Suckers	Longnose Sucker	*Catostomus catostomus*	Juvenile (Age 0)	Uncommon	< 75	June - Sep	Rearing	Pools	< 11	Low	--	--	Native	c, d
Suckers	Bridgelip Sucker	*Catostomus columbianus*	Juvenile (Age 0)	Common	< 80	Mid May - Sep	Rearing	Pools, Nearshore	0.03-2	Low	--	--	Native	a, b, c, d,
Suckers	Largescale Sucker	*Catostomus macrocheilus*	Juvenile (Age 0)*	Common	8-55	Jun-Aug	Rearing	Pools, Nearshore	0.32 -15	Low	--	--	Native	a, b, c, d,
Sunfishes	Bluegill	*Lepomis macrochirus*	Juvenile	Present	< 90	Year-Round	Rearing	Backwaters	Shallow	Low	--	--	Non-native	a, b, c, d,
Sunfishes	Pumpkinseed	*Lepomis gibbosus*	Juvenile	Present	< 90	Year-Round	Rearing	Backwaters	Shallow	Low	--	--	Non-native	b, c, d
Sunfishes	Largemouth Bass	*Micropterus salmoides*	Juvenile (Age 0)	Uncommon	6-190	Year-Round	Rearing	Backwaters	< 20	Low	--	--	Non-native	b, c, d
Sunfishes	Burbot	*Lota lota*	Juvenile (Age 0)	Uncommon	< 205	Year-Round	Rearing	Deep nearshore, Deep pools	Shallow to moderate	Low	--	--	Native	b, c, d
Sunfishes	Black Crappie	*Pomoxis nigromaculatus*	Juvenile (Age 0)	Present	< 105	Year-Round	Rearing	Mid-channel, Nearshore	< 10	Low	--	--	Non-native	a, b, c, d,
Sunfishes	White Crappie	*Pomoxis annularis*	Juvenile (Age 0)	Present	< 125	Year-Round	Rearing	Mid-channel, Nearshore	< 10	Low	--	--	Non-native	b, c, d
Sunfishes	Smallmouth Bass	*Micropterus dolomieui*	Juvenile (Age 0)	Present	< 80	July-Winter	Rearing	Nearshore	< 25	Low	--	--	Non-native	a, b, c, d,
Trout-perches	Sand Roller	*Percopsis transmontana*	Adult	Uncommon	75-105	Year-Round	Resident	Mid-channel, Nearshore	3-70	Low	Monitor	--	Native	b, c, d
Trout-perches	Sand Roller	*Percopsis transmontana*	Juvenile	Uncommon	< 75	Year-Round	Rearing	Nearshore	3-70	Low	Monitor	--	Native	b, c, d

Notes:
* Eggs may drift or larvae have a pelagic phase
1. Relative Abundances: Abundant = >10%, Common = > 1%, Present = < 1% (as reported in WPPSS 1982). Some species are noted as abundant or present in other literature but not directly observed in CGS studies. Uncommon = suspected presence but rarely observed
Sources:
a. WPPSS 1982, cited in EN 2010
b. Gray and Dauble 1977
c. Wydoski and Whitney 2003
d. Dauble 2009
e. Lindsey et al. 2016
f. ASMFC 2009
g. Gadomski and Wagner 2009

Appendix C
Modeled Velocity and Depth at CGS Intakes with Various River Flows

Hydrodynamic Model Data Near Energy Northwest Plant Intake (Columbia River Mile – 352.13)

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Marshall Richmond – marshall.richmond@pnnl.gov

Sara Niehus - sara.niehus@pnnl.gov

Hydrology Group – Pacific Northwest National Laboratory

February 9, 2018

PNNL-SA-132236

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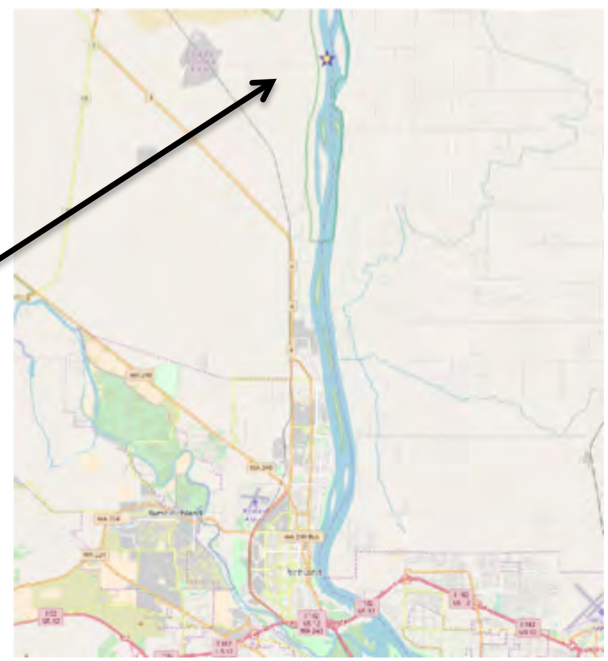
Background

- Larissa Rohrbach of Anchor QEA requested Hanford Reach model outputs to support a study of fish entrainment in the intake for Energy NW nuclear power plant.
  - PNNL will provide 2-D MASS2 model outputs (maps) and an excel file of 1-D MASS1 model output (water elevation and discharge)
  - Contact info: lrohrbach@anchorqea.com; (509) 293 8737
- Results are from the updated PNNL models (MASS1 and MASS2) documented in report to Grant County PUD
  - Niehus, et al (2014).

Site location: right bank of the Columbia, near RM 352.13



PNNL Model Overview

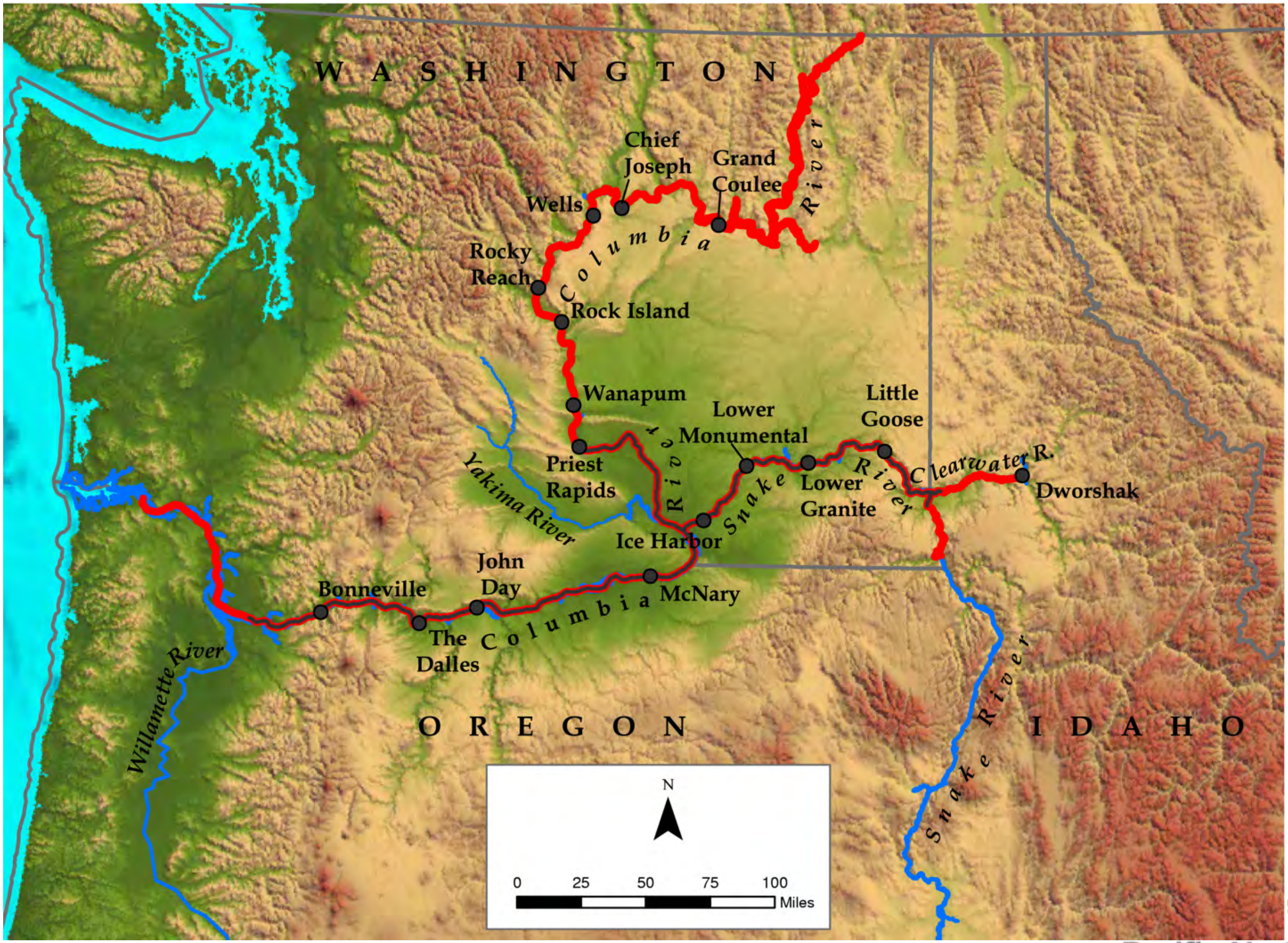
- Unsteady flow simulation (1-D and 2-D)
  - Physics-based models for hydrodynamics
  - Mass and momentum conservation
  - Time-varying prediction of river discharge, velocity, water surface elevation
- Water quality simulation (1-D and 2-D)
  - Temperature
  - Total dissolved gas, Dissolved tracers
  - Sediment (MASS2 only)
- References

  - Niehus, S. E., W. A. Perkins, and M. C. Richmond. 2014. “Simulation of Columbia River Hydrodynamics and Water Temperature from 1917 through 2011 in the Hanford Reach.” Final Report PNWD-3278. Richland, Washington 99352: Battelle-Pacific Northwest Division. doi:10.13140/RG.2.1.5146.8409.
  - Richmond MC, and WA Perkins. 2009. "Efficient Calculation of Dewatered and Entrapped Areas Using Hydrodynamic Modeling and GIS." Environmental Modelling & Software 24(12):1447-1456. doi:10.1016/j.envsoft.2009.06.001
  - Perkins WA, and MC Richmond. 2007. MASS2, Modular Aquatic Simulation System in Two Dimensions, Theory and Numerical Methods . PNNL-14820-1, Pacific Northwest National Laboratory, Richland, WA.
  - Perkins WA, MC Richmond, and GA McMichael. 2004. "Two-Dimensional Modeling of Time-Varying Hydrodynamics and Juvenile Chinook Salmon Habitat in the Hanford Reach of the Columbia River." ASCE World Water and Environmental Resources Congress 2004, June 27 – July 1, 2004, Salt Lake City, Utah.
  - Waichler, S. R., J. A. Serkowski, W .A. Perkins, and M. C Richmond. 2017. “Simulation of Columbia River Floods in the Hanford Reach.” PNNL-26204. Richland, WA: Pacific Northwest National Laboratory. doi:10.13140/RG.2.2.16036.17282.

PNNL Model Overview

- Two representations of the river hydraulics are used
  - **MASS1** – one-dimensional, cross-sectional averaged
    - Predicts one discharge, velocity, water elevation, temperature per individual river cross-section
    - Represents an average across the river cross section
    - Unsteady
  - **MASS2** – two-dimensional, depth-averaged
    - Predicts discharge, velocity, water elevation, temperature in plan view
    - Represents an average over the water depth in each cell
    - Provides spatially distributed estimates across the river
    - Unsteady
  - **Elevation datum for both models is NGVD29**

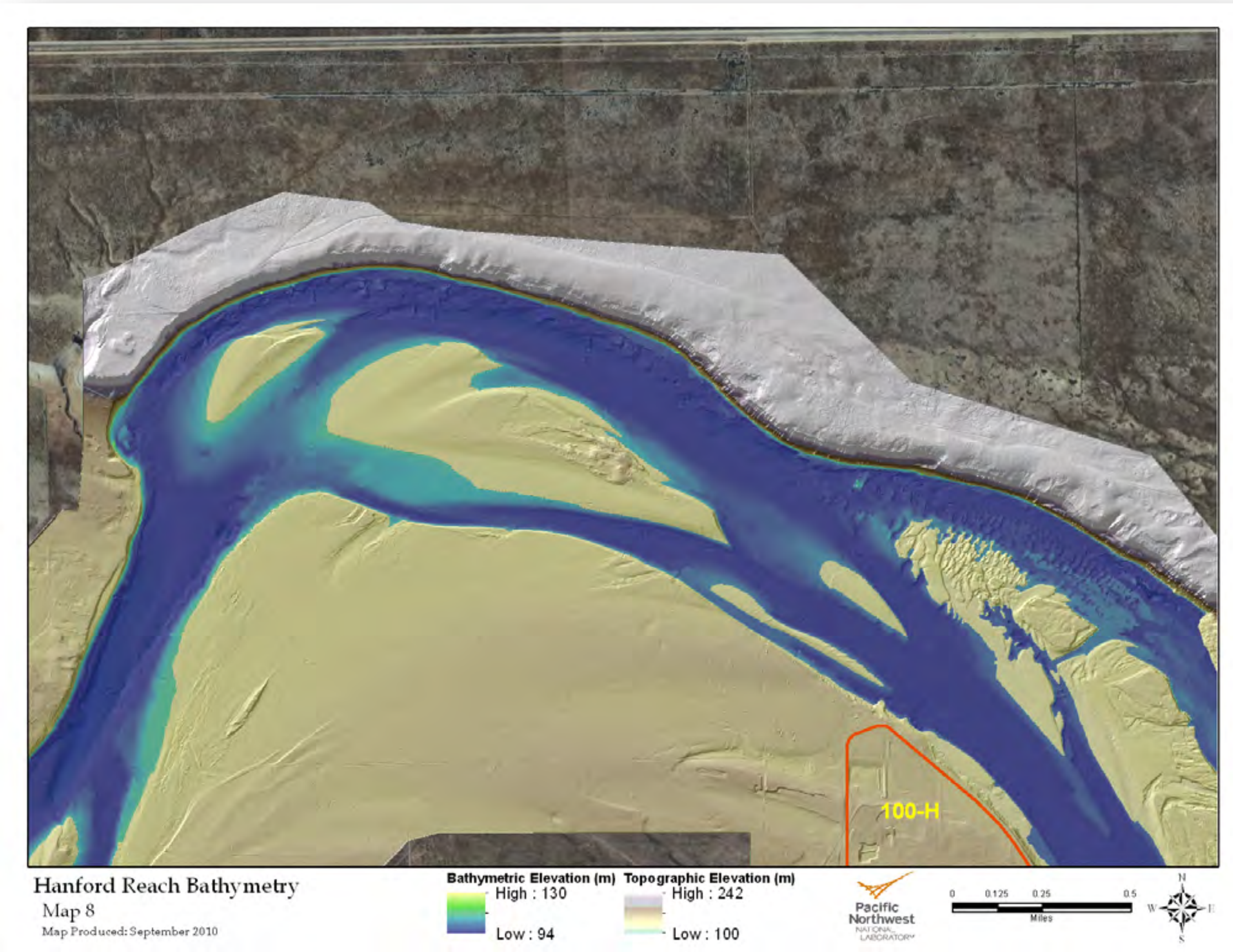
PNNL Regional Scale 1D/2D Modeling
Hanford Reach Models are a Subset

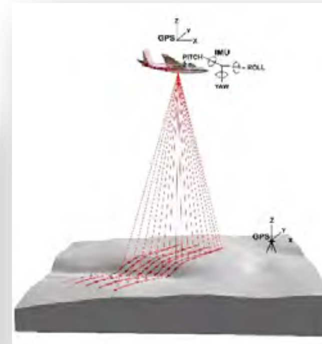


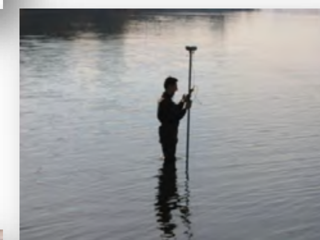
1D **MASS1** model zone – red line
2D **MASS2** model zone – black inset line

High-Resolution Bathymetry Development for the Hanford Reach

Used in the MASS1 and MASS2 models







Reference: Coleman AM, DL Ward, KB Larson, and JW Lettrick. 2010. Development of a high-resolution bathymetry dataset for the Columbia River through the Hanford Reach . PNNL-19878, Pacific Northwest National Laboratory, Richland, WA.

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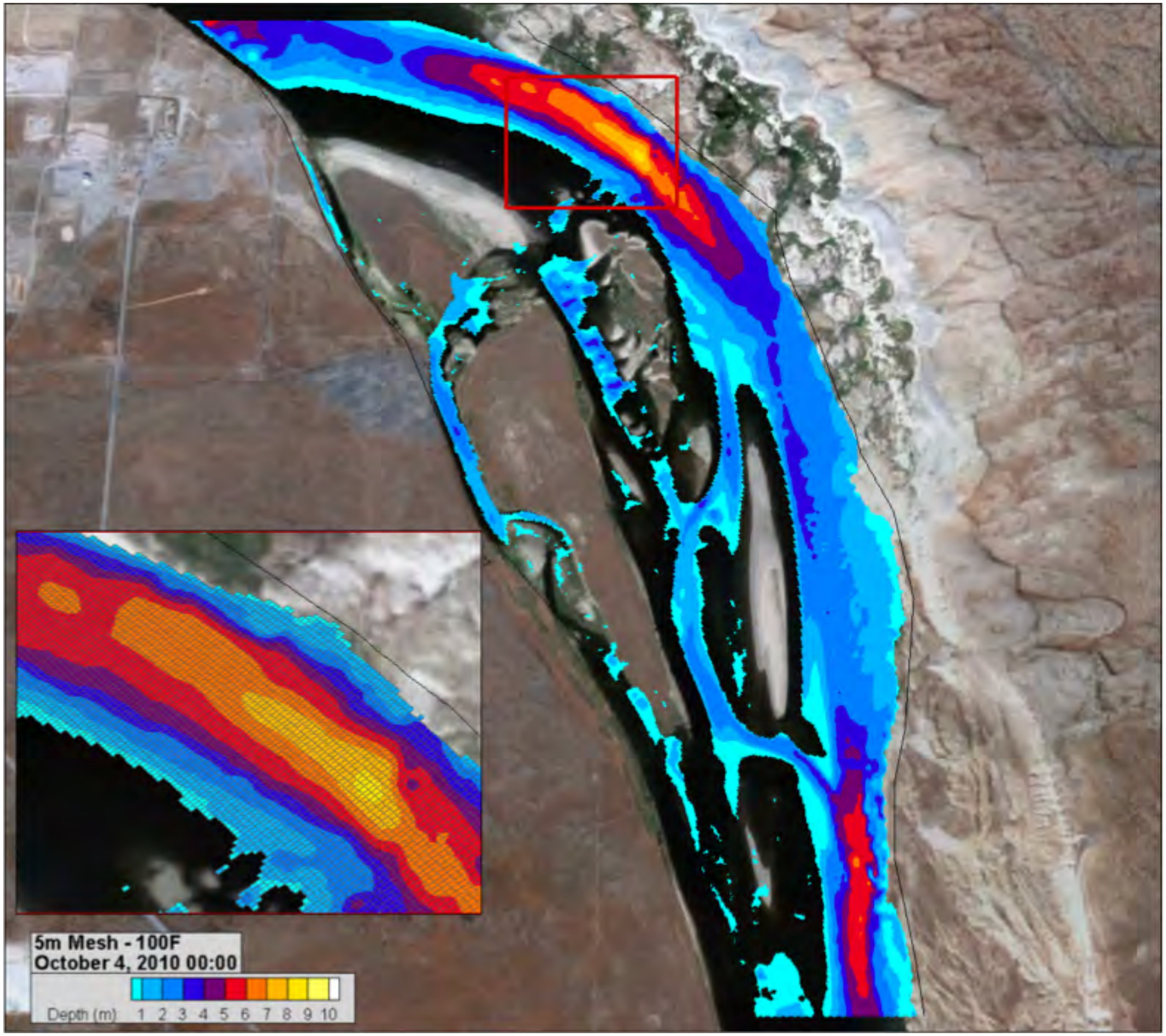
Spatial Resolution for MASS2

Snapshot of simulation on October 4, 2010 at 0:00 hours

Variables (velocity, water elevation, temperature) are simulated on the 5-meter mesh. Detail shown at right.



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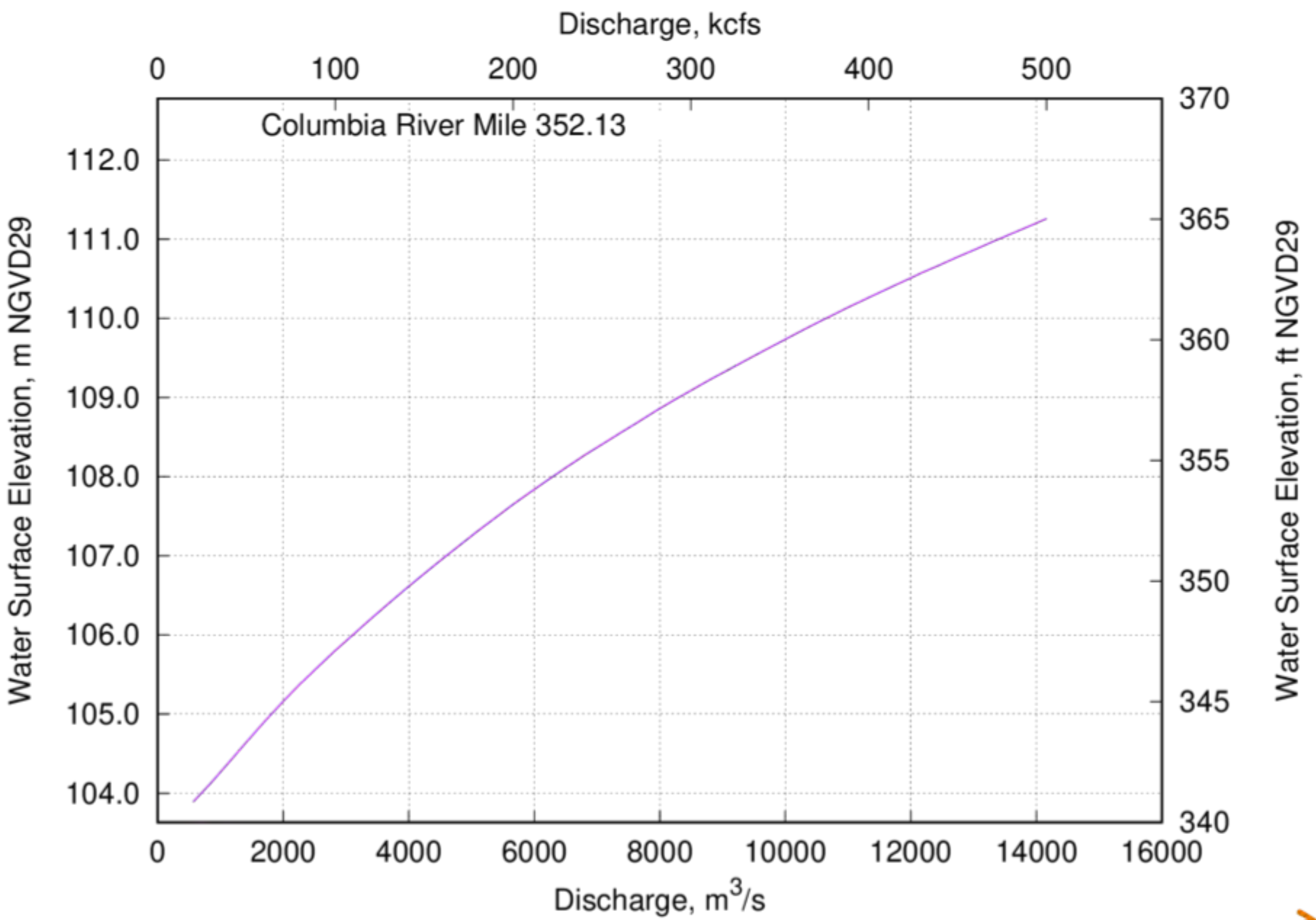
Stage/Discharge Curve



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MASS2 Simulation Maps

- MASS2 with 5-m mesh (Niehus, et al, 2014)
- Steady Priest Rapids Dam discharge
- McNary forebay stage constant at 340 feet
- Map horizontal coordinates are WA South State Plane, NAD83, feet
- Vertical datum is NGVD29

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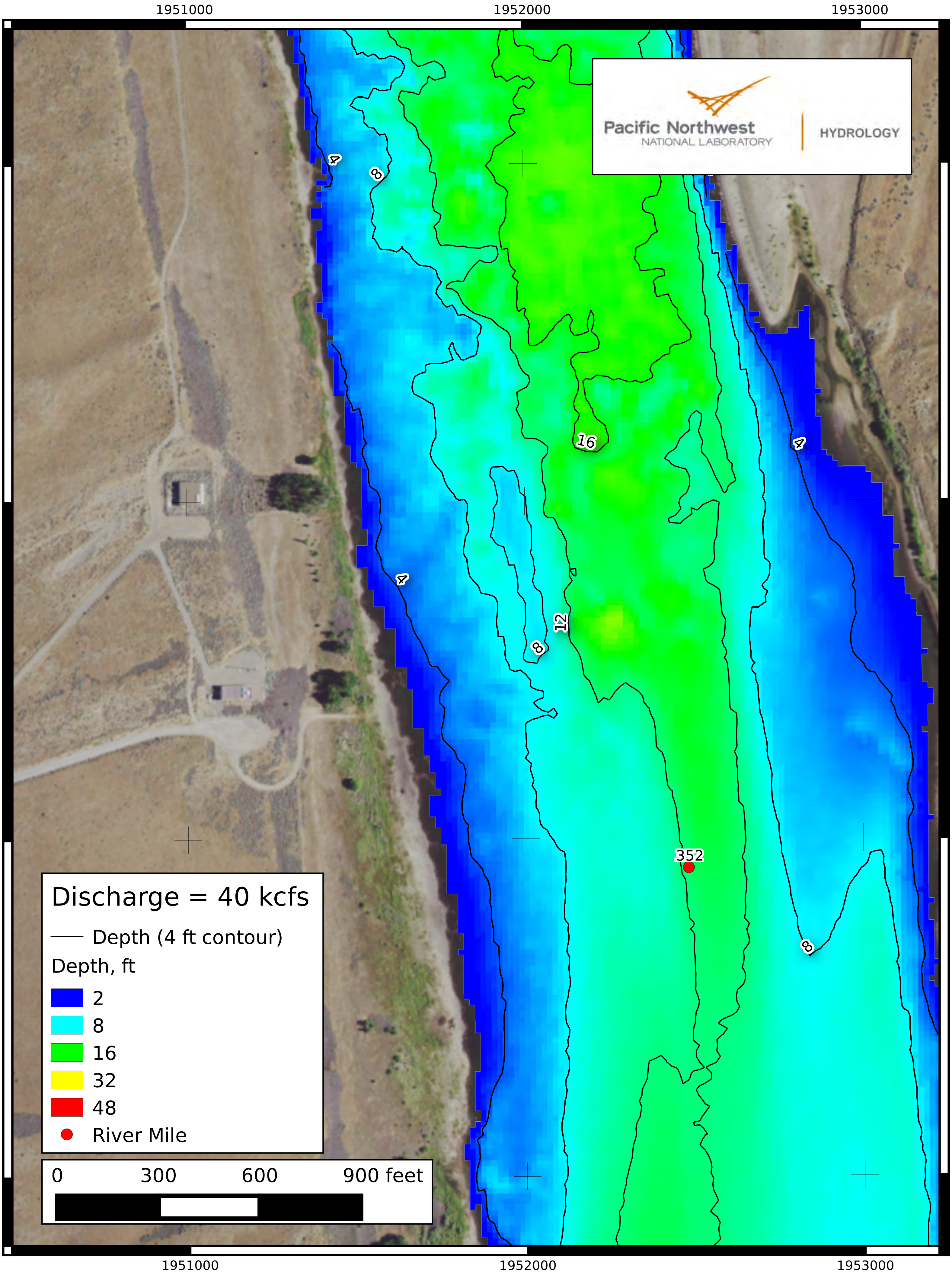
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Discharge = 40 kcfs
Depth (4 ft contour)
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River Mile
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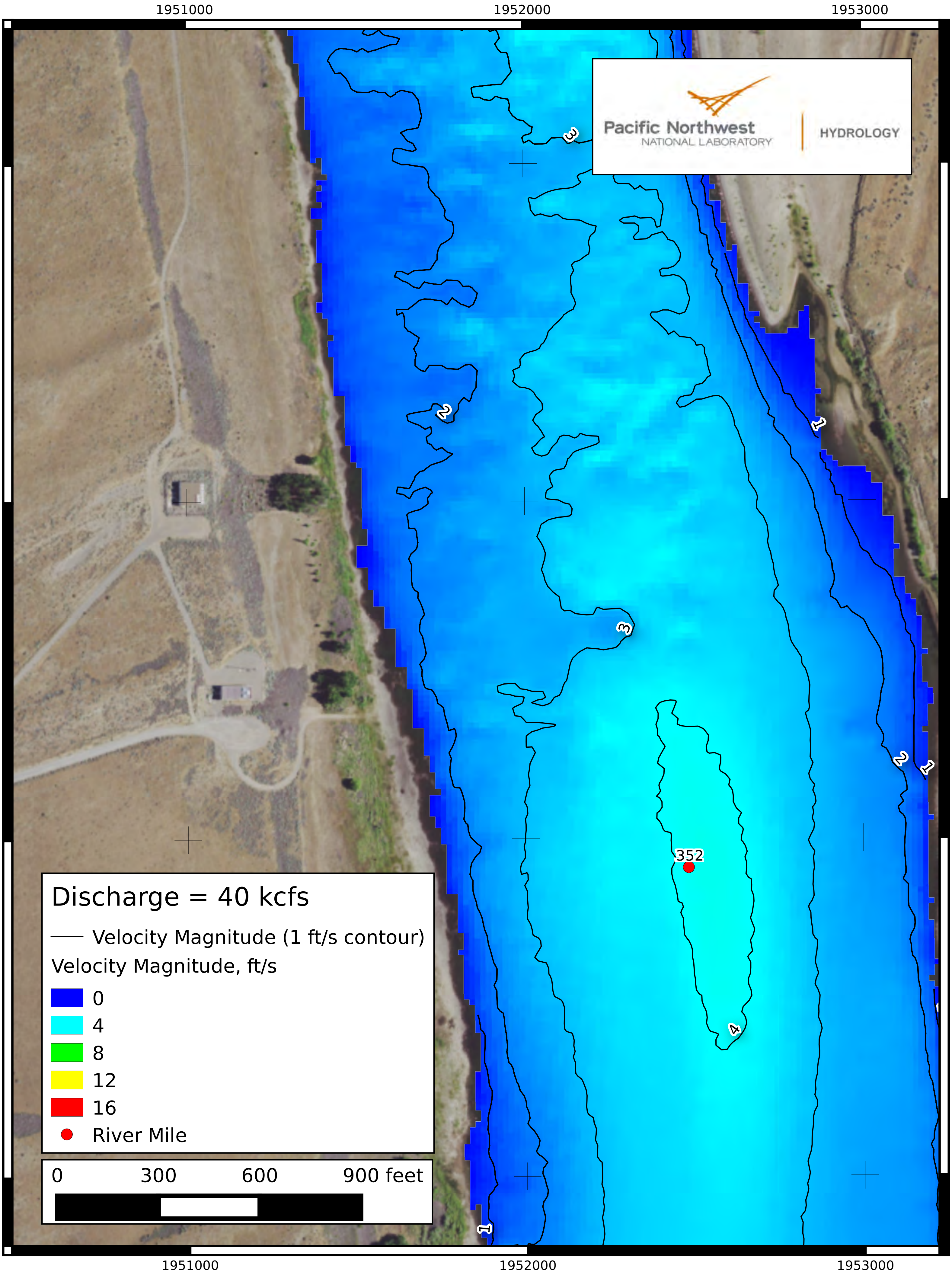

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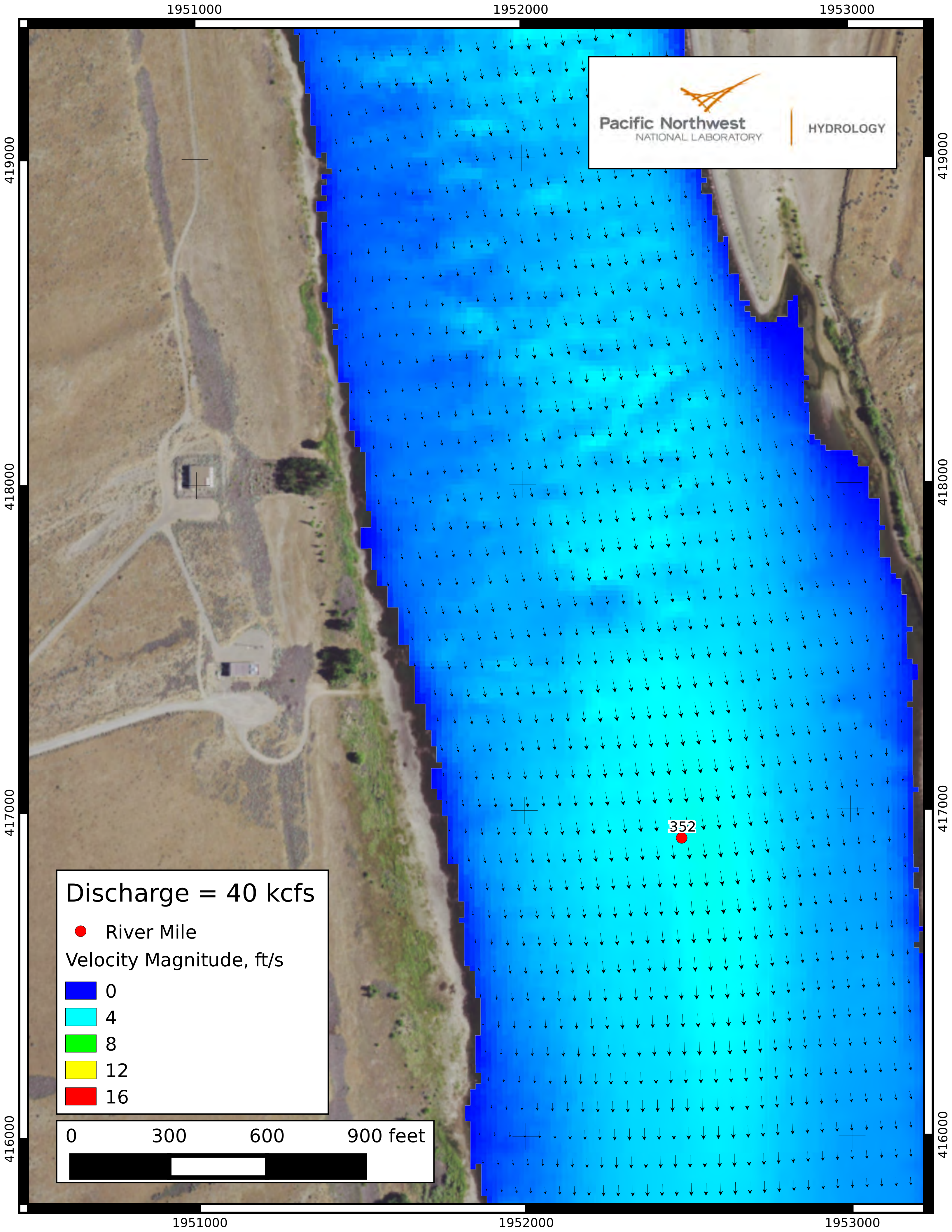
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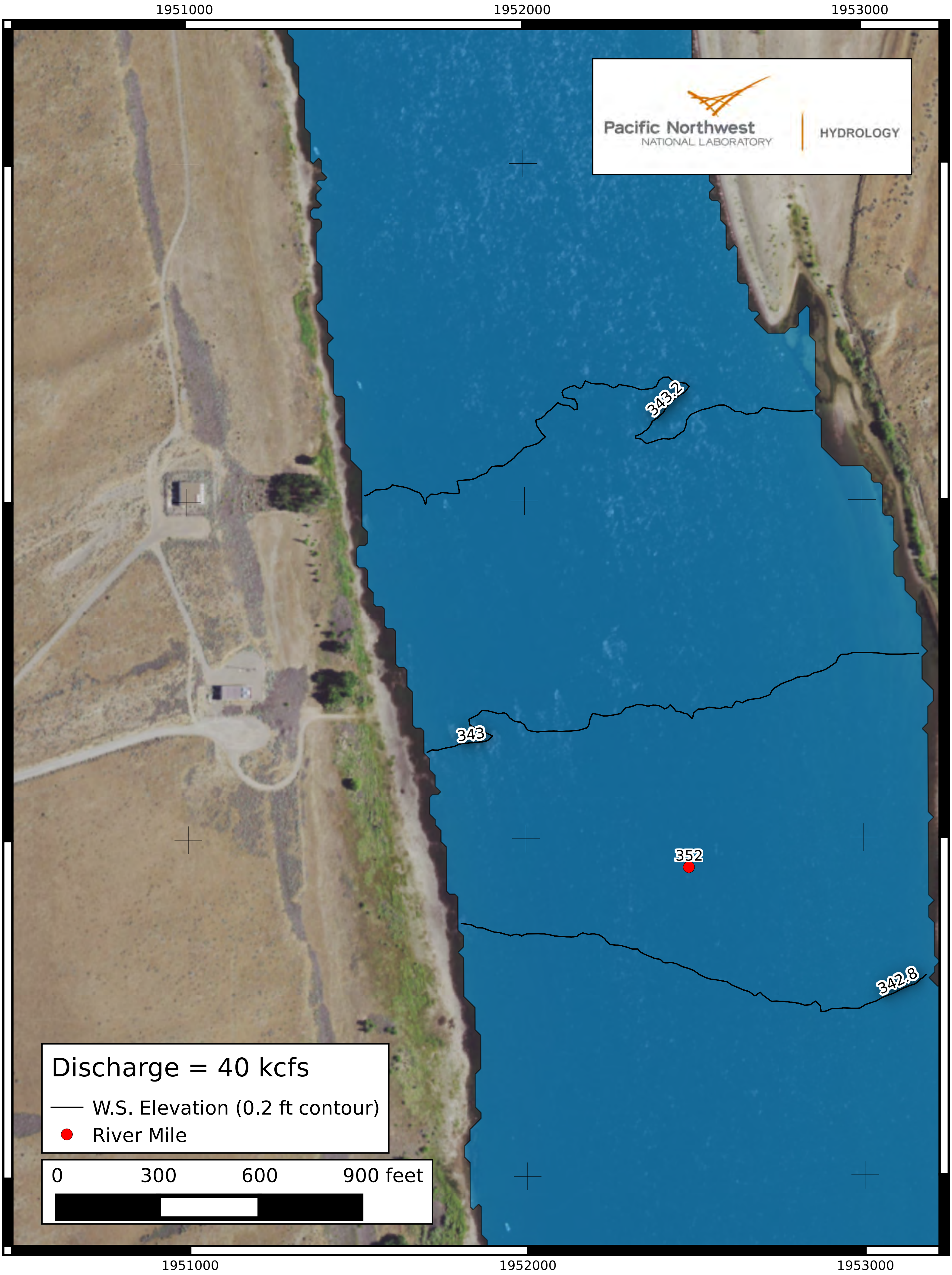
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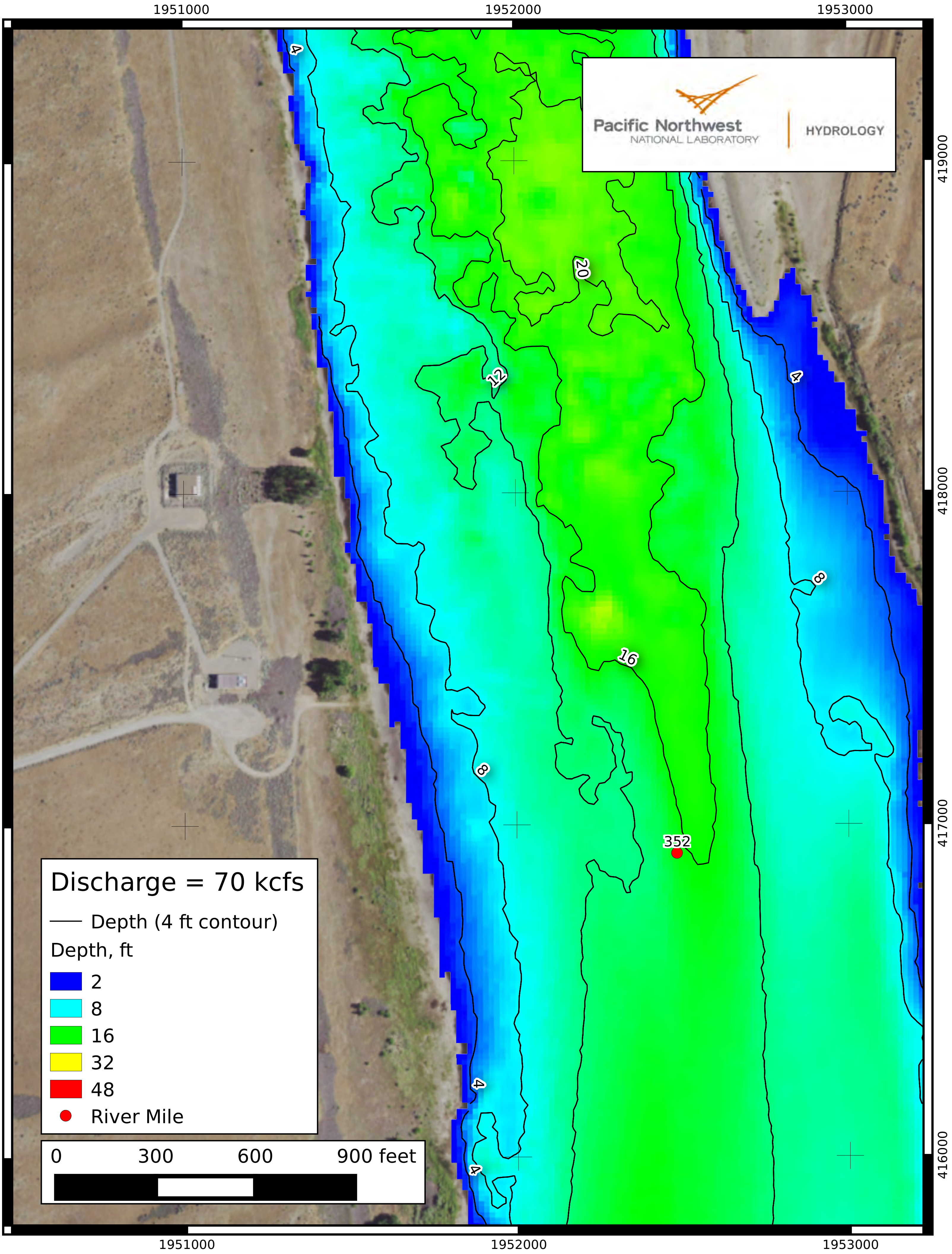

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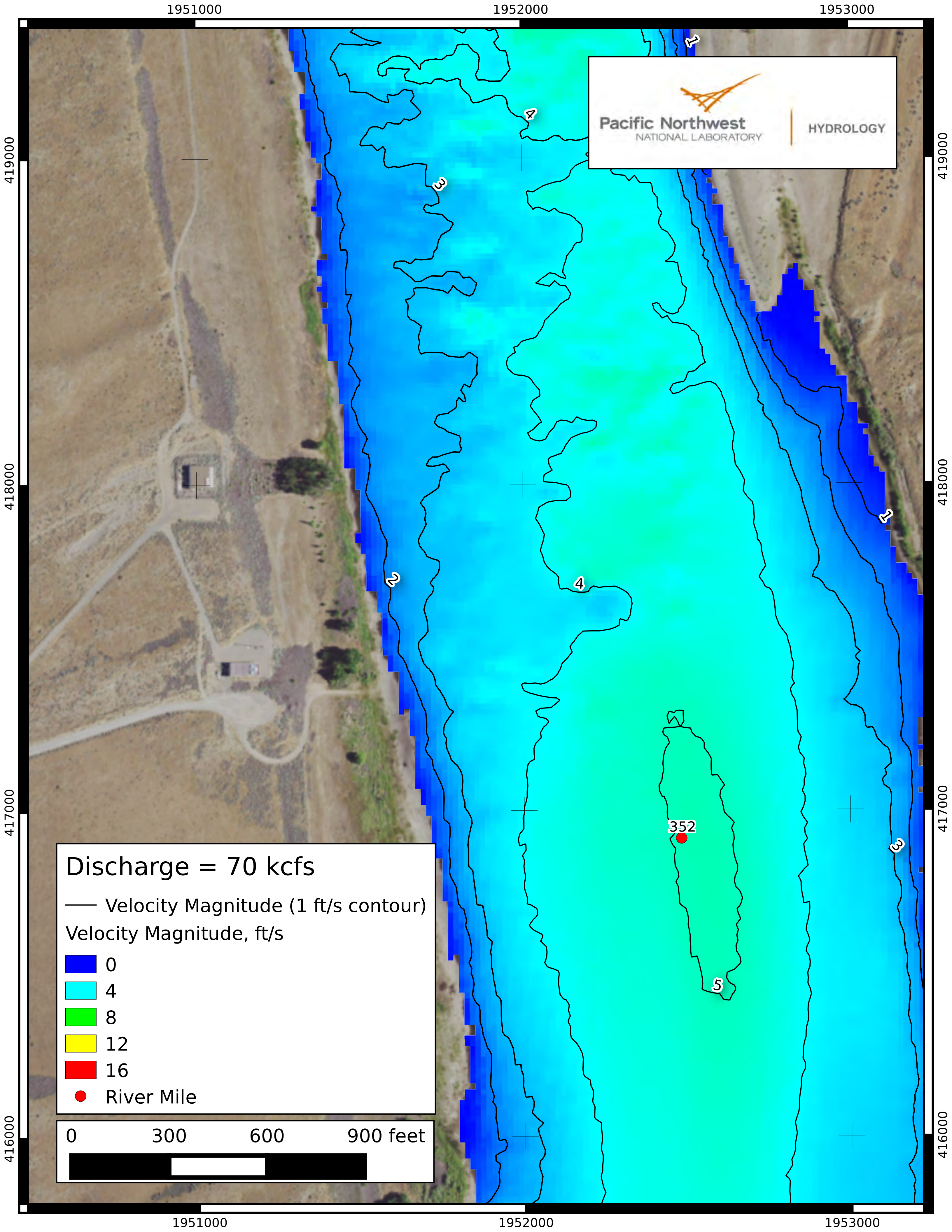

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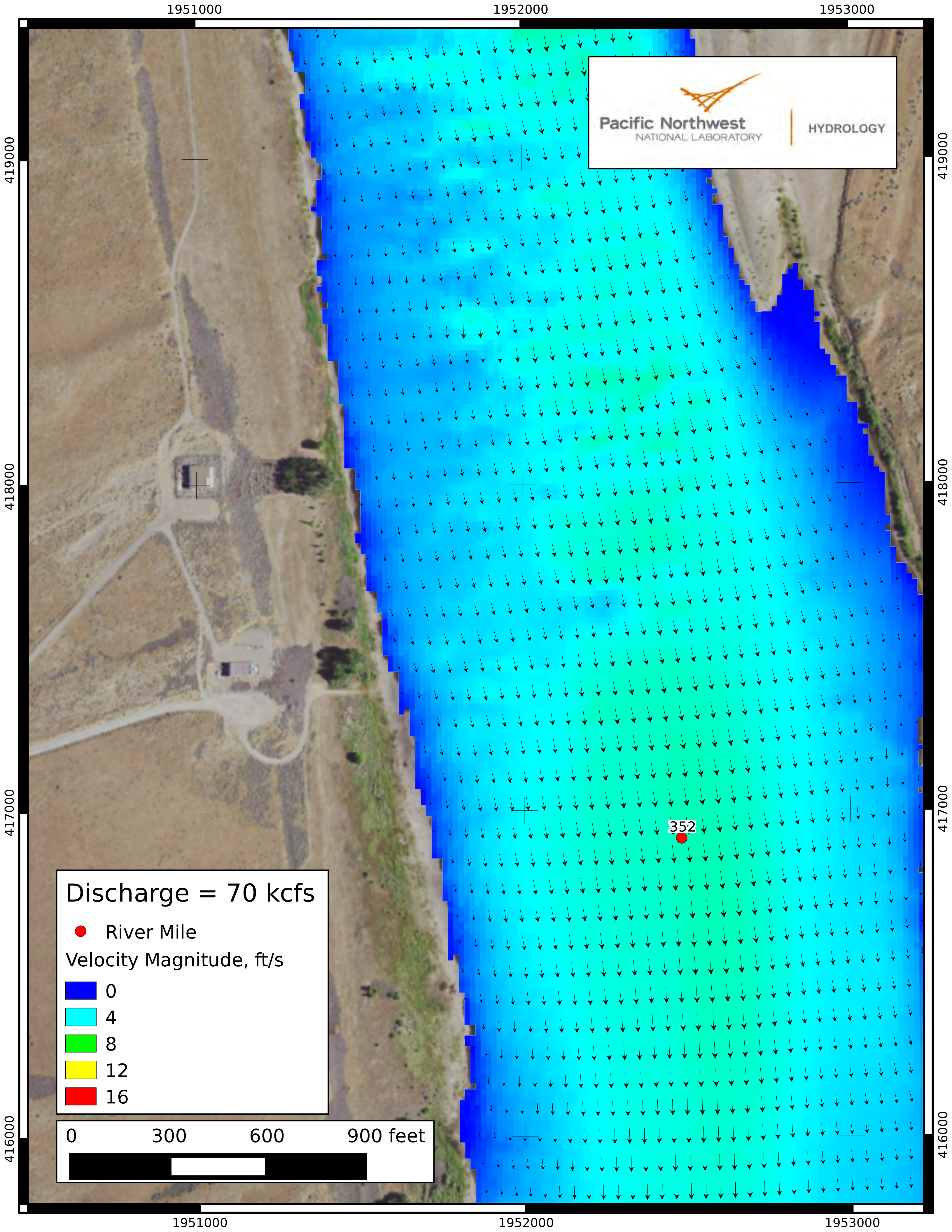
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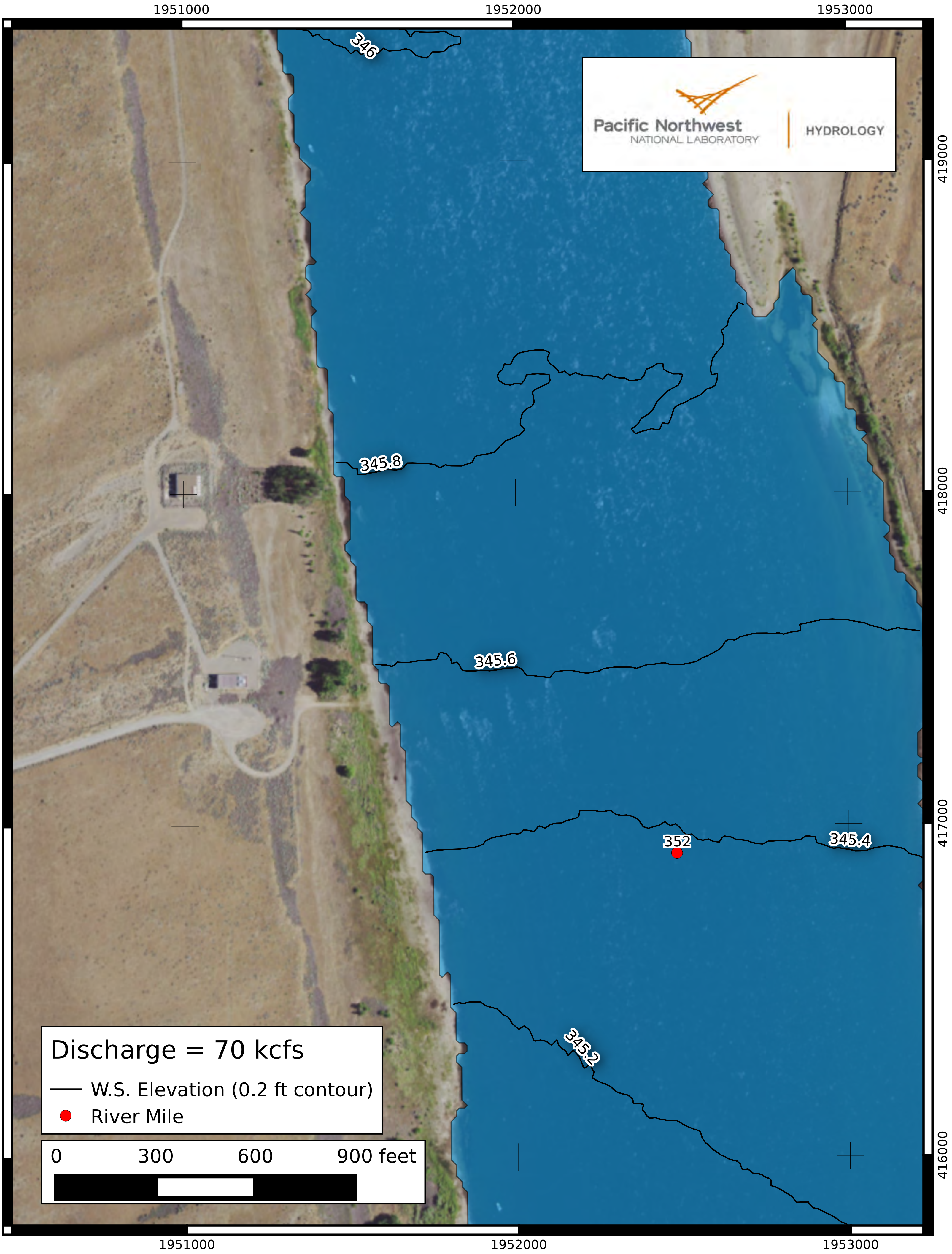
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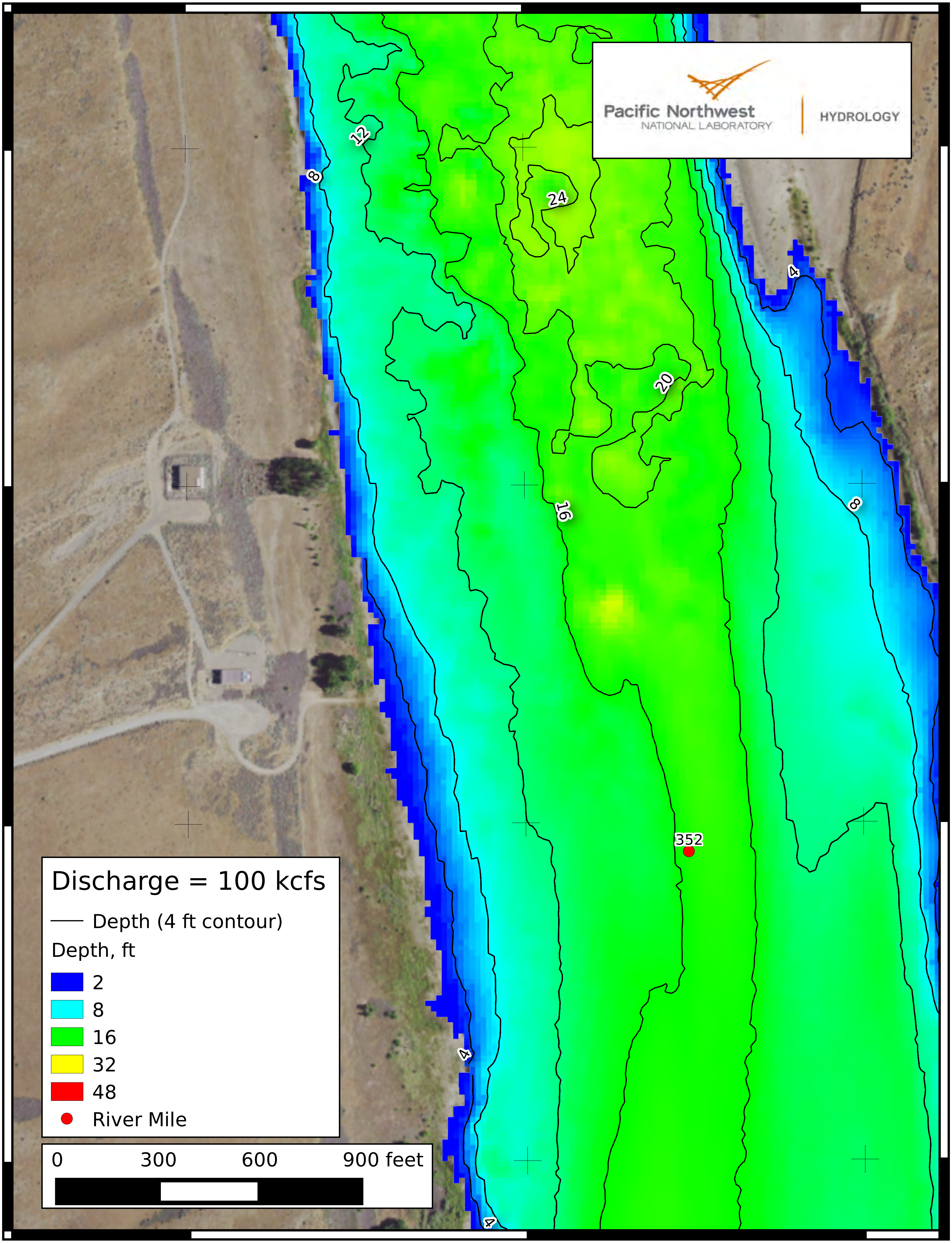

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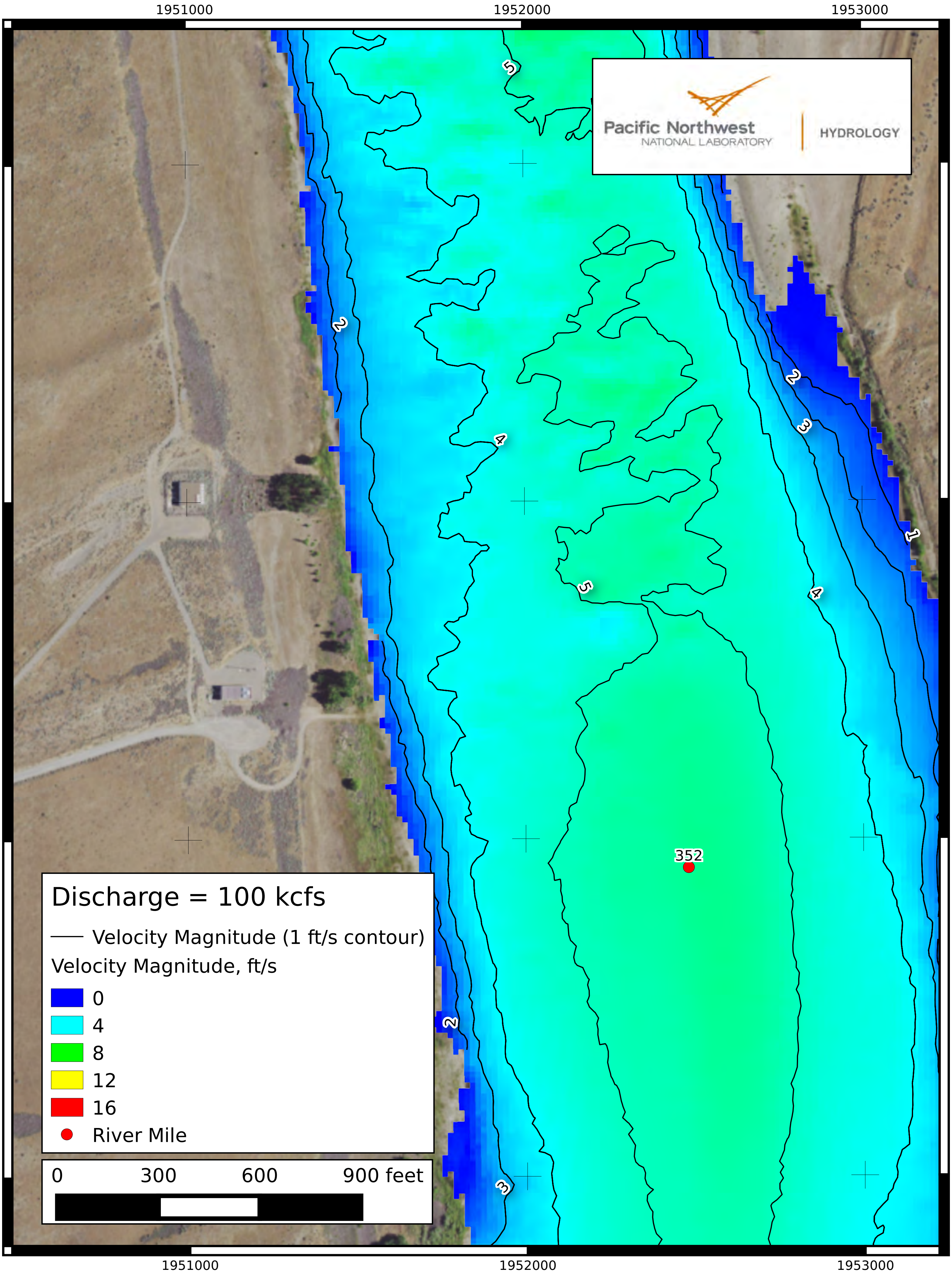

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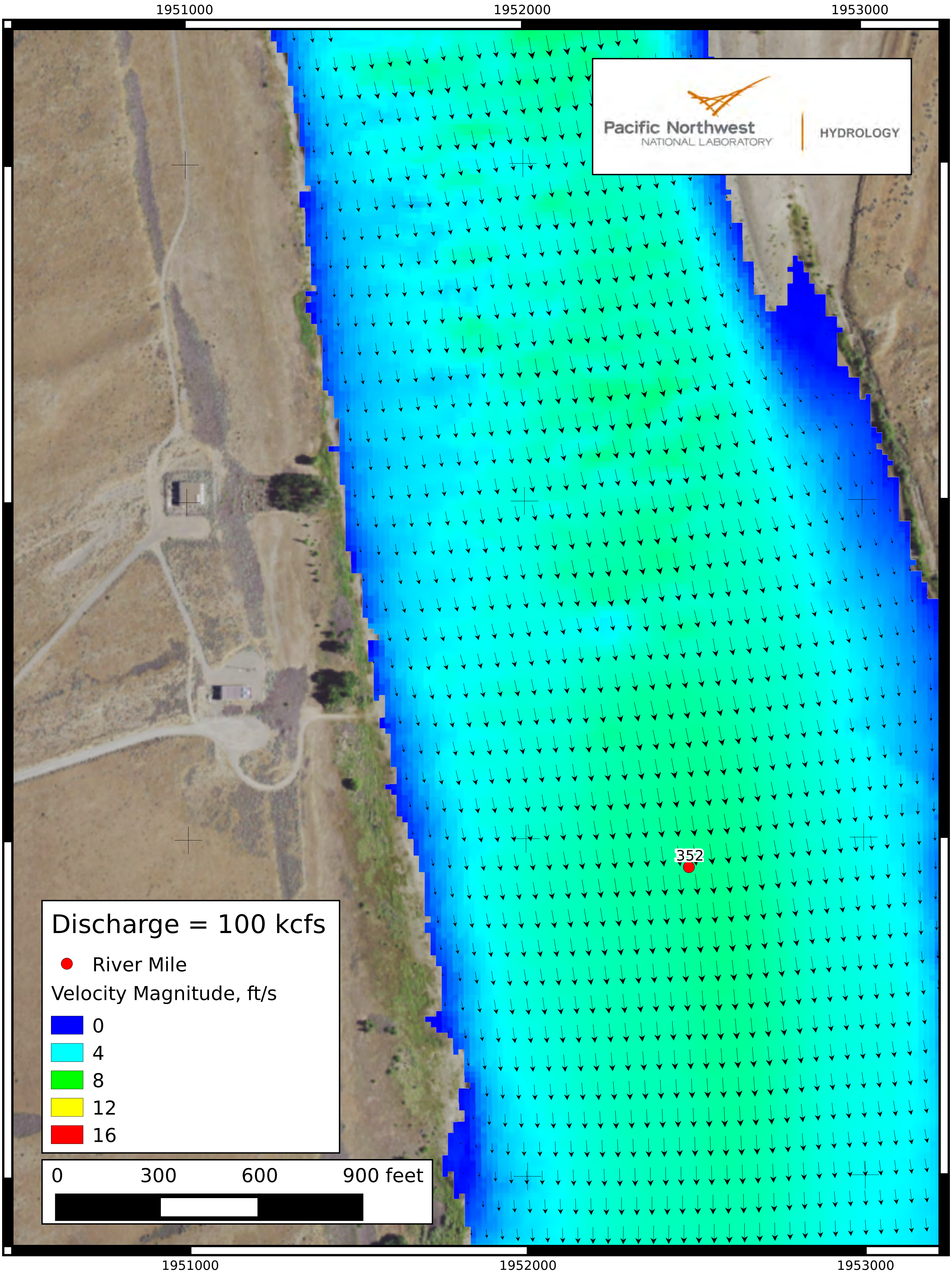

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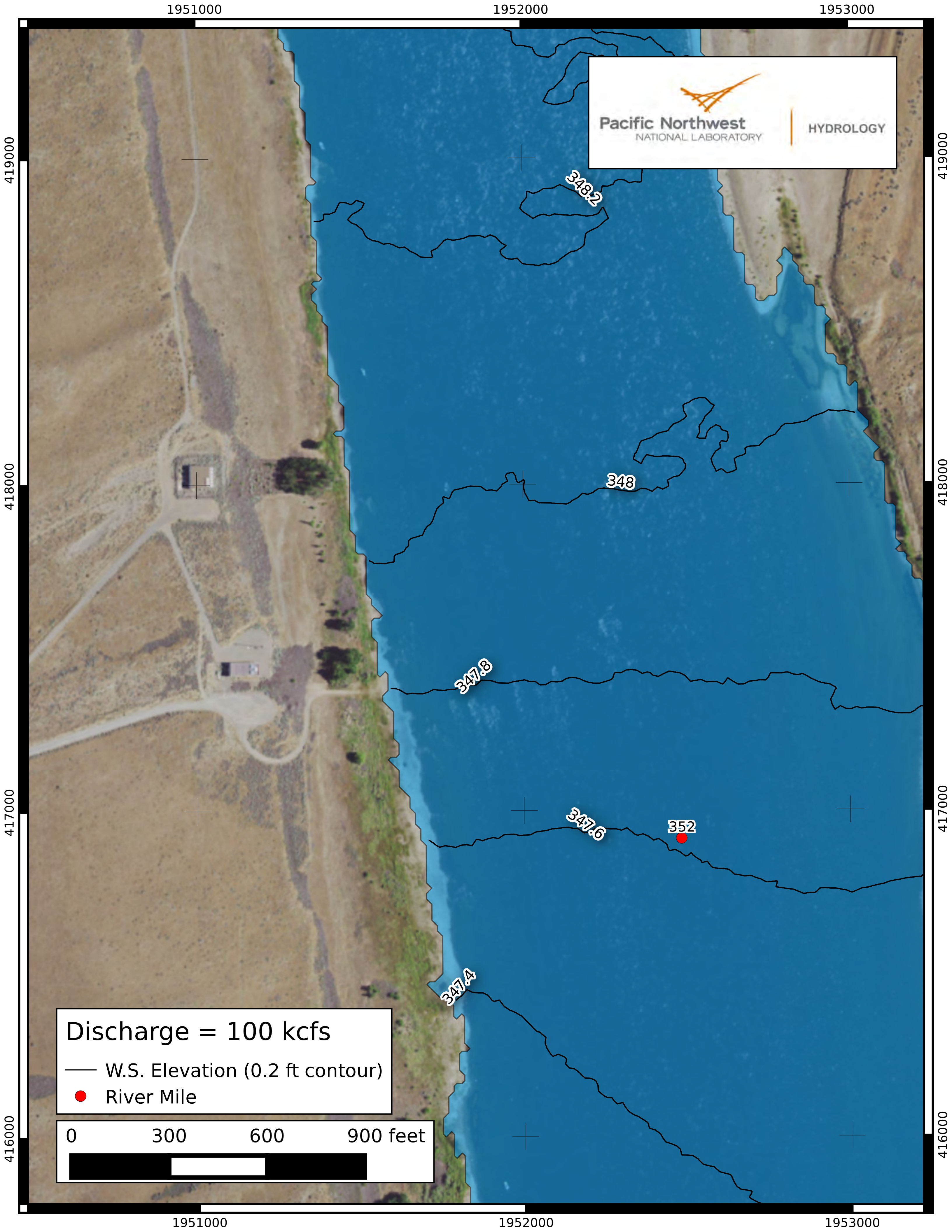

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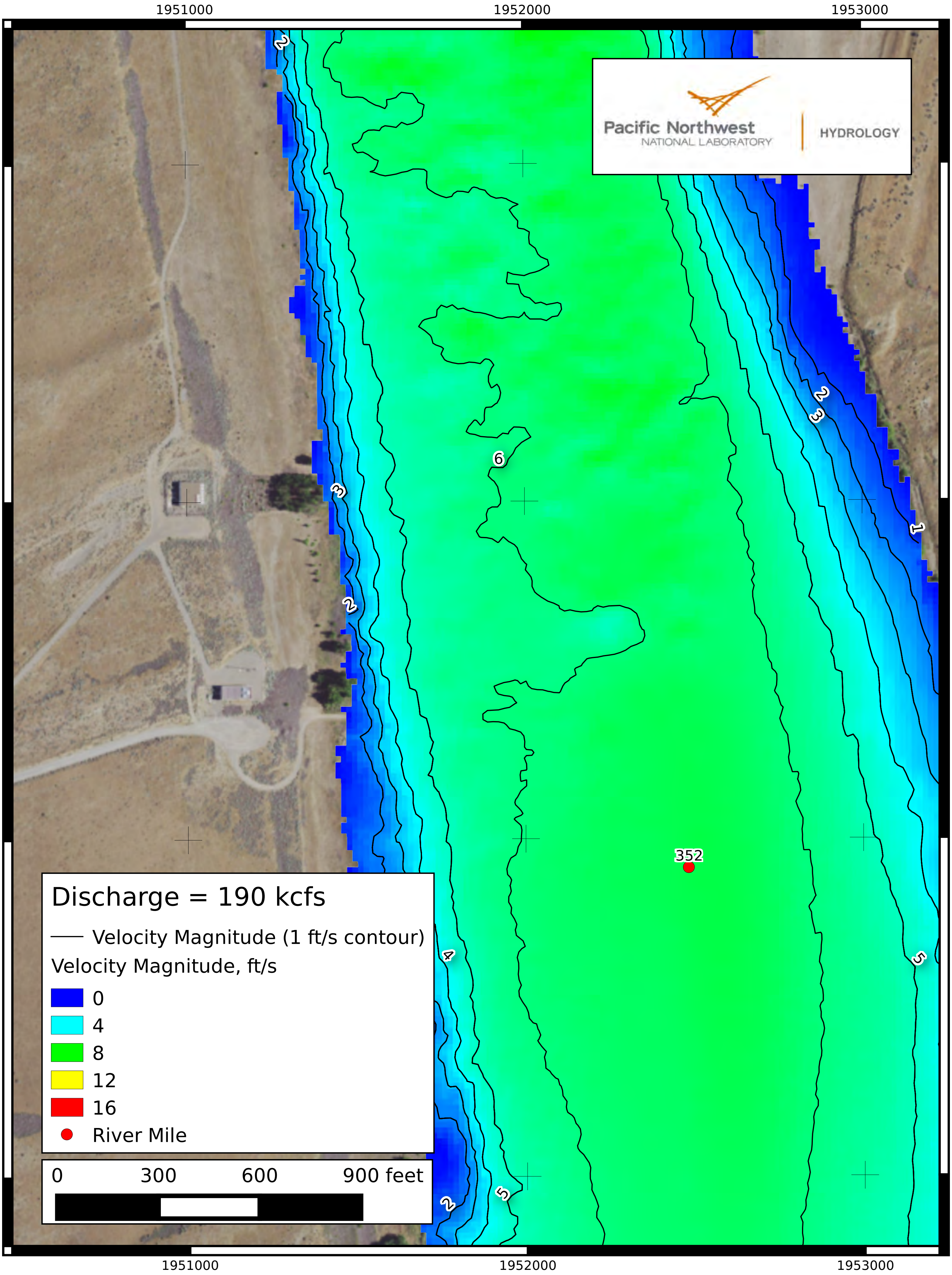

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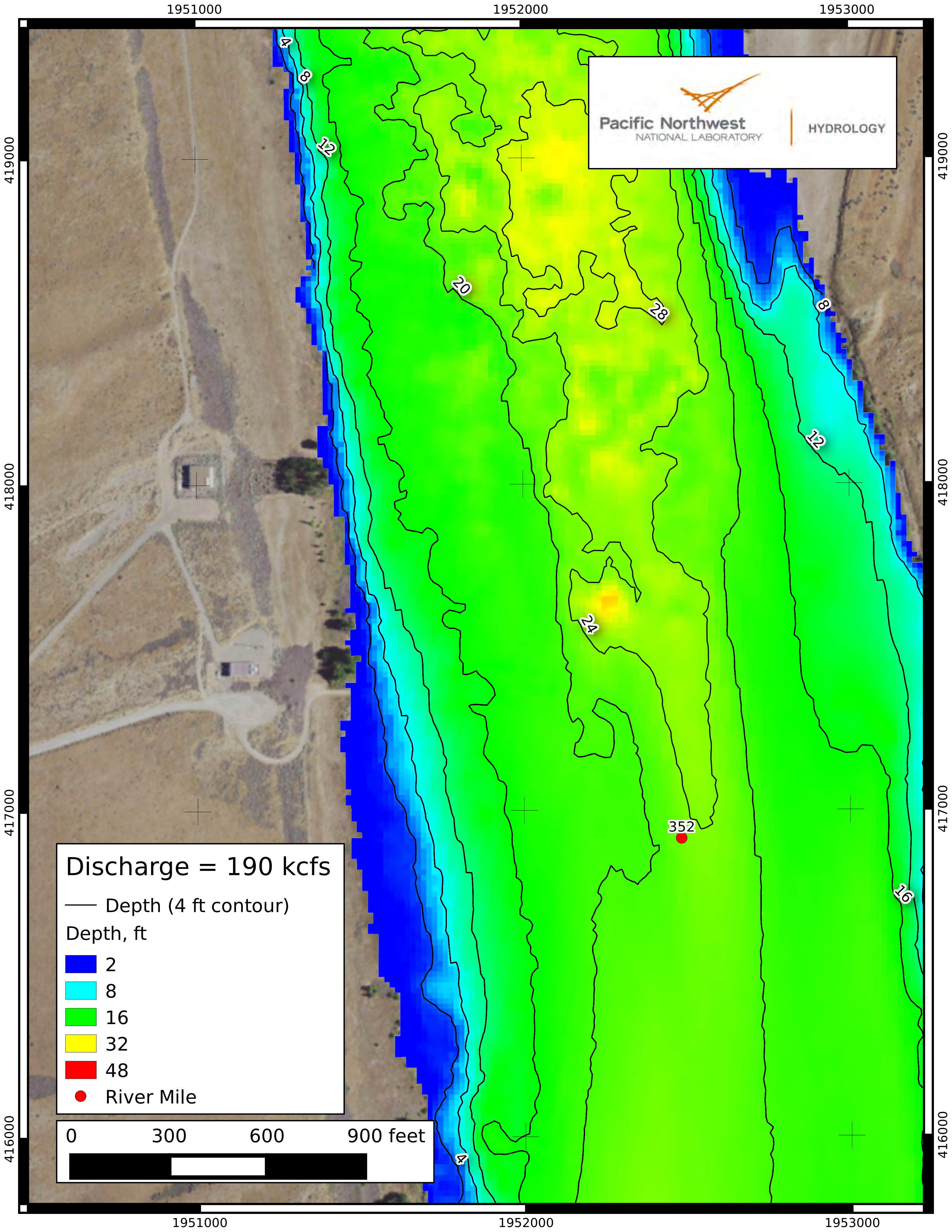

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River Mile
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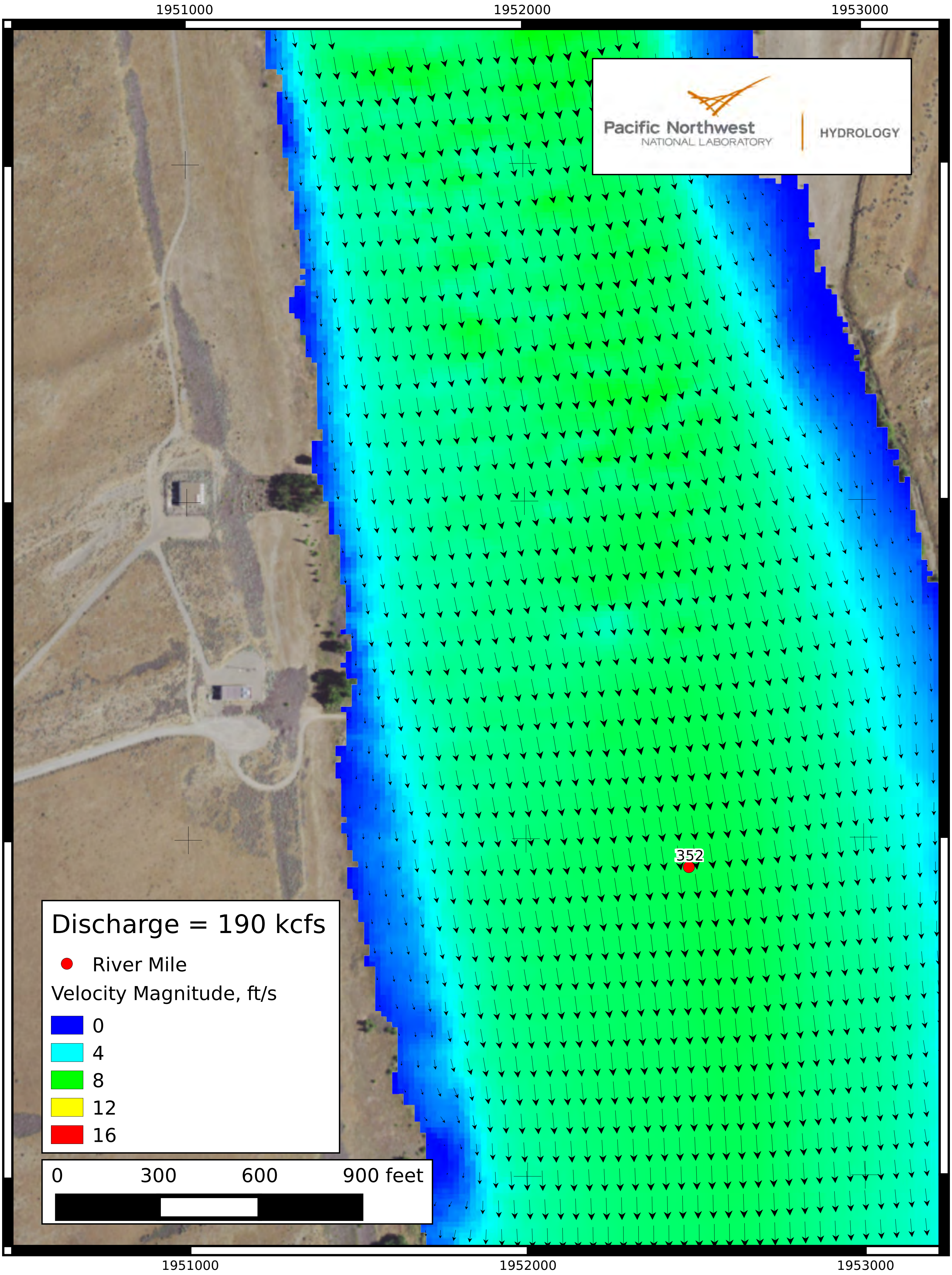

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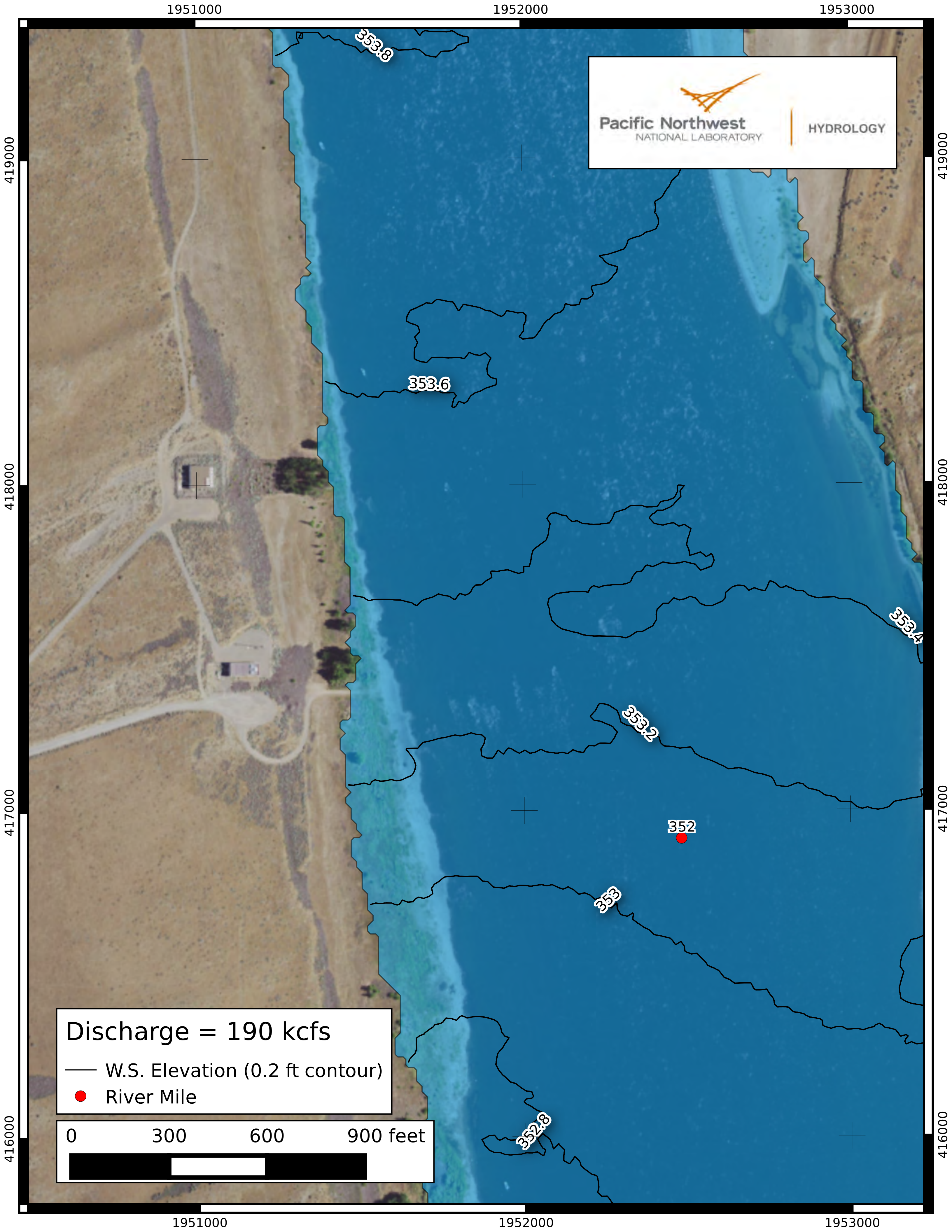

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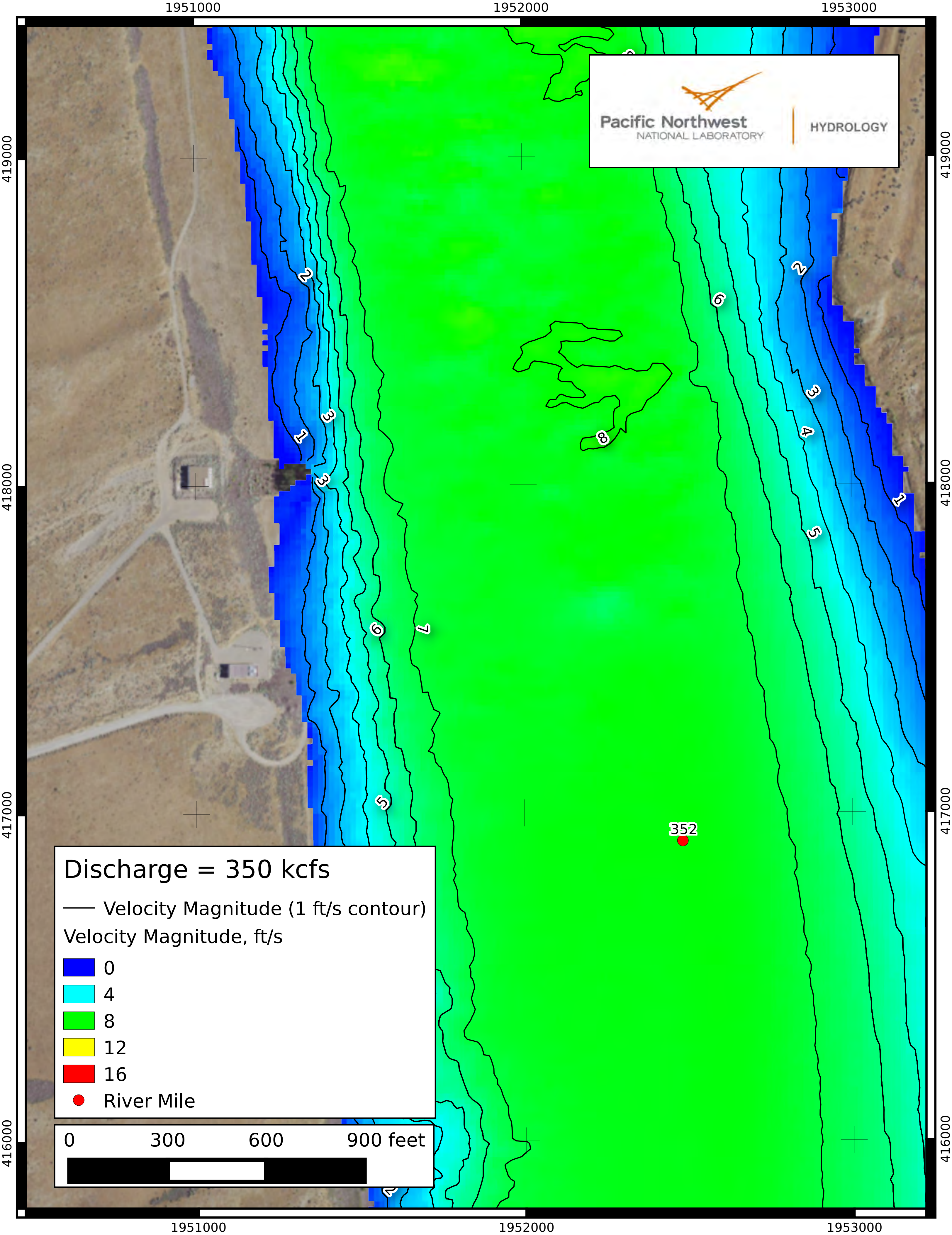

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River Mile
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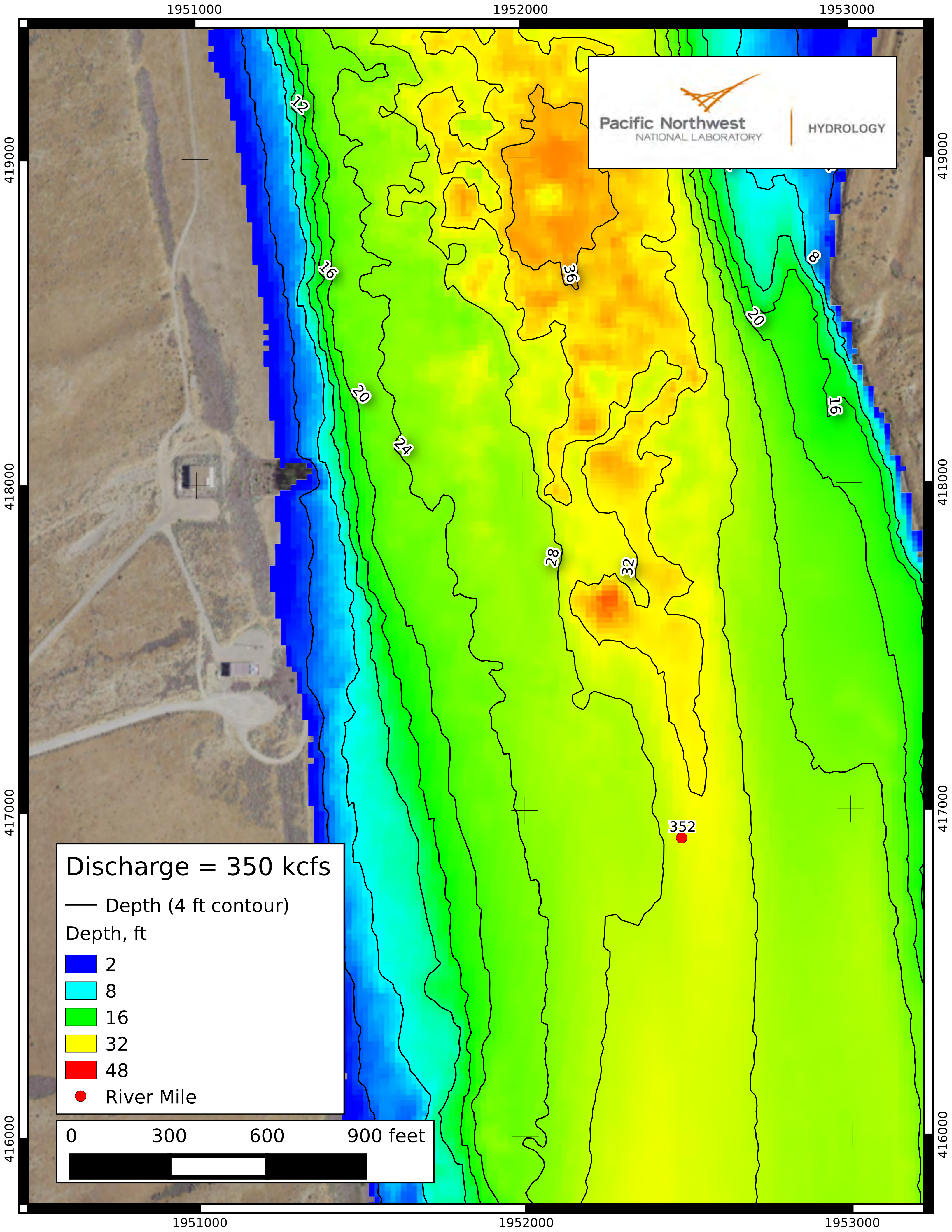

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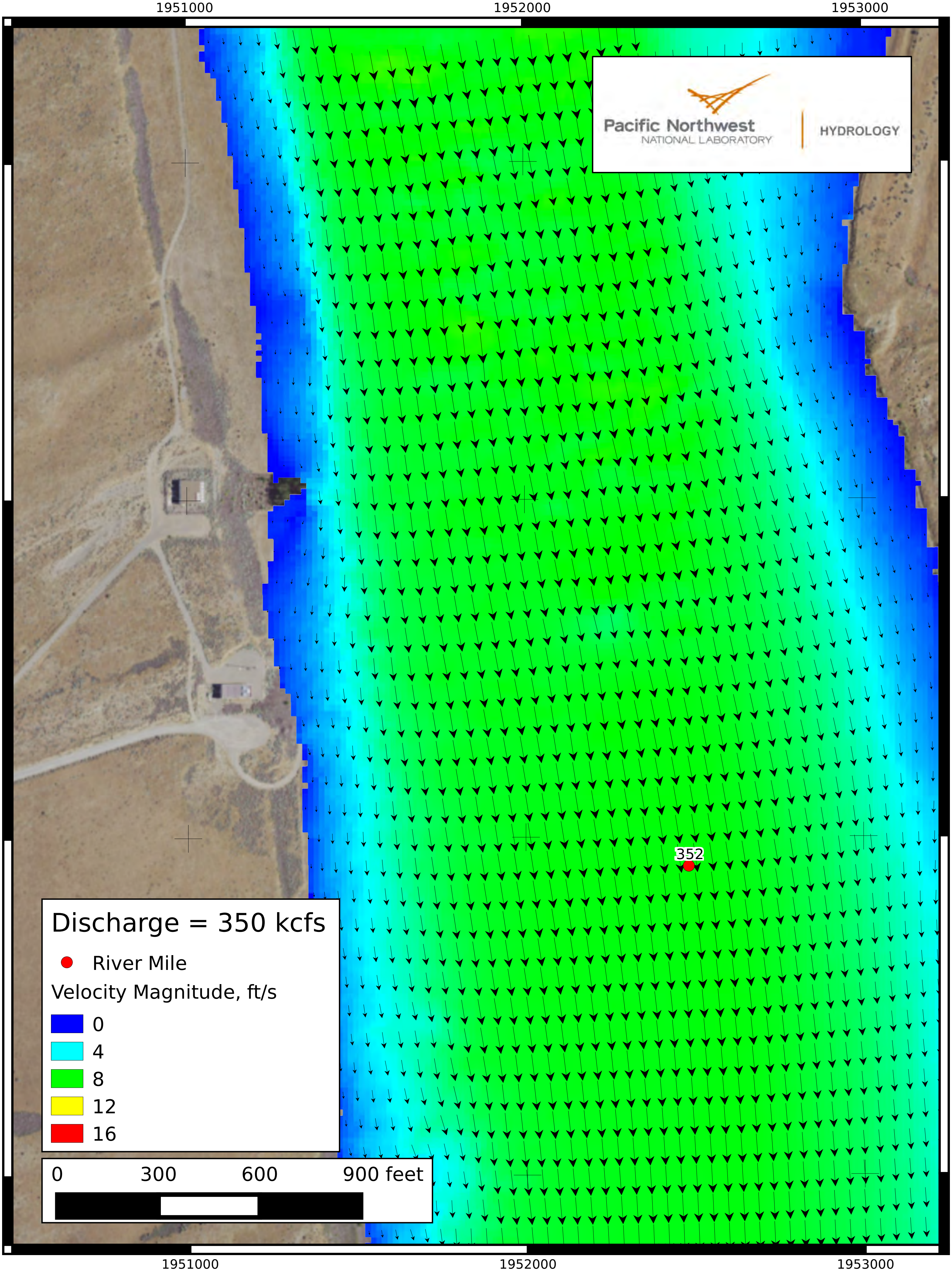
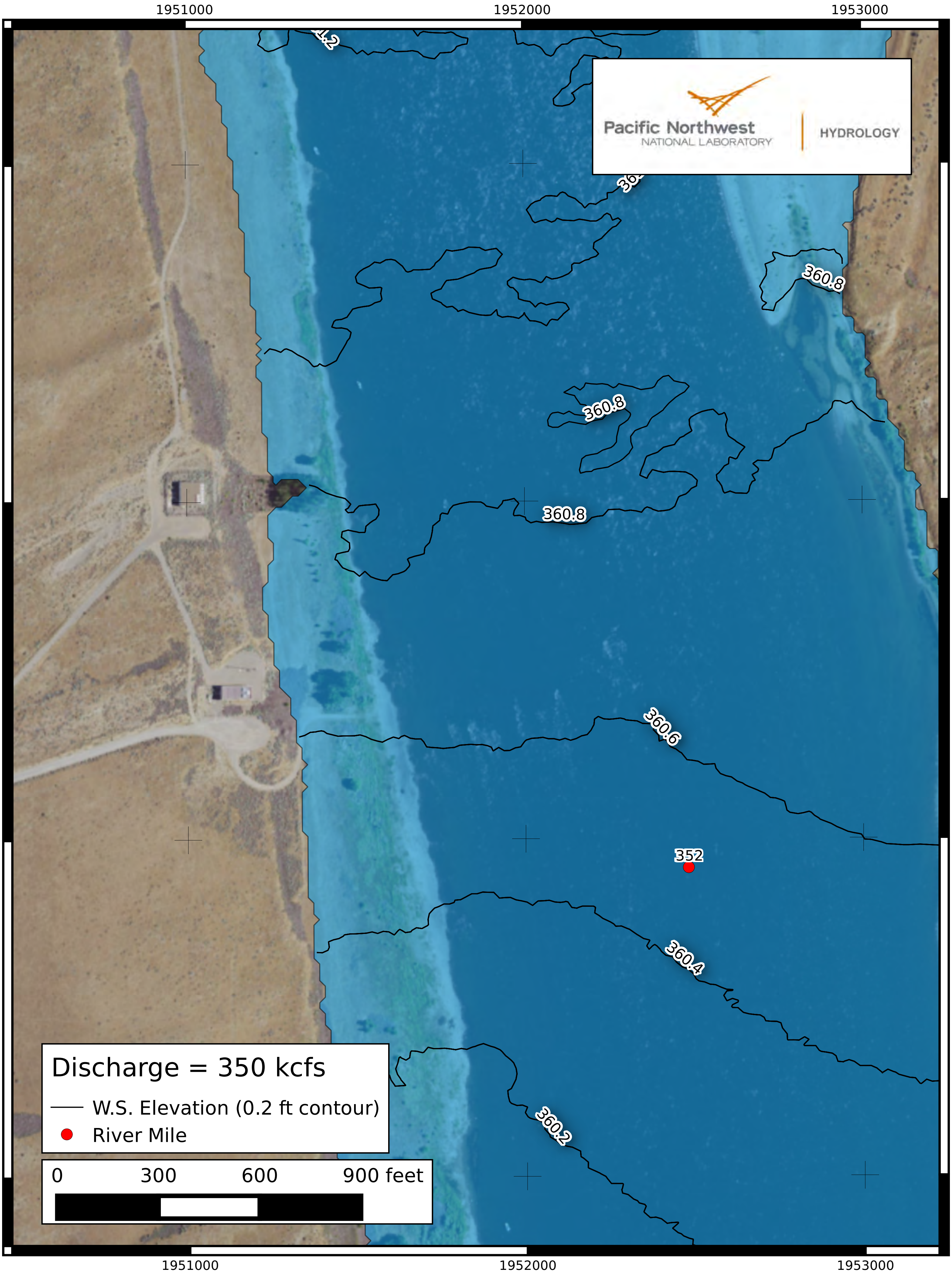
Pacific Northwest
NATIONAL LABORATORY
HYDROLOGY
12
16
20
24
36
28
32
8
352
Discharge = 350 kcfs
Depth (4 ft contour)
Depth, ft
2
8
16
32
48
River Mile
0
300
600
900 feet



1951000
1952000
1953000
419000
418000
417000
416000
Pacific Northwest
NATIONAL LABORATORY
HYDROLOGY
352
Discharge = 350 kcfs
River Mile
Velocity Magnitude, ft/s
0
4
8
12
16
0
300
600
900 feet


1951000
1952000
1953000
419000
418000
417000
416000
Pacific Northwest
NATIONAL LABORATORY
HYDROLOGY
360.8
360.8
360.8
360.6
352
360.4
360.2
Discharge = 350 kcfs
W.S. Elevation (0.2 ft contour)
River Mile
0
300
600
900 feet

Appendix F
Washington Department of Fish and Wildlife Fish Transport Application/Permit

PERMIT #: 7675-01-05-18

WASHINGTON DEPARTMENT OF FISH AND WILDLIFE
600 CAPITOL WAY NORTH
OLYMPIA, WASHINGTON 98501-1091

FISH TRANSPORT APPLICATION/PERMIT

To Import, Export or Transfer, Live Fin Fish, Viable Eggs or Gametes
(Please print or type items 1-5 and return to address above)

1. Type of application: ☐ Import ☐ Export ☒ Transfer
2. Name of Applicant Larissa Rohrbach/Anchor QEA on behalf of Energy Northwest Phone number (509) 293-8737

   Mailing address 23 South Wenatchee Avenue City Wenatchee State WA Zip 98801

   WDFW Aquatic Farm Registration # (for commercial aquaculture facilities only) ______
3. Species Rainbow trout, Steelhead, or Chinook Salmon Number (fish or eggs) up to 1000
4. Destination (name of facility/receiving waters) Energy Northwest Columbia Generating Station

   County Benton Sec.______ Twnshp.______ Rng.______
5. Source of fish/eggs: Facility name Ringold/Meseberg Hatchery Phone number (509) 264-4448

   Physical Location 1871 Ringold River Road City Mesa State WA Zip 99343

   Mailing Address 1871 Ringold River Road City Mesa State WA Zip 99343

   WDFW Aquatic Farm Registration # (for commercial sources in Washington) ______
6. Applicant's Signature Larissa Rohrbach Date 1/5/2018

INSTRUCTIONS: Return this applicatio to the address at the top of the form.

NOTE: It is unlawful to transport or stock fish without a permit issued by the Director or his/her designee. Failure to comply with any provisions of this permit or to perform any act not included in this permit shall be grounds for revocation of this permit and may constitute a gross misdemeanor.

INFORMATION BELOW TO BE COMPLETED BY WDFW PERSONNEL

Provisions For an entrainment study. No fish will be released to the river.

Expiration date 4/30/18

☐ Additional provisions attached

Approved ☒ Not Approved ☐ Fish Health Manager [signature] Date 1/11/18

Approved ☐ Not Approved ☐ Aquaculture Coordinator ______ Date ______

PERMIT #: 7972-01-31-19

WASHINGTON DEPARTMENT OF FISH AND WILDLIFE
600 CAPITOL WAY NORTH
OLYMPIA, WASHINGTON 98501-1091

FISH TRANSPORT APPLICATION/PERMIT

To Import, Export or Transfer, Live Fin Fish, Viable Eggs or Gametes
(Please print or type items 1-5 and return to address above)

1. Type of application: ☐ Import ☐ Export ☐ Transfer
2. Name of Applicant Larissa Rohrbach/Anchor QEA on behalf of Energy Northwest Phone number(509) 293-8737

   Mailing address 23 South Wenatchee Avenue City Wenatchee State WA Zip 98801

   WDFW Aquatic Farm Registration # (for commercial aquaculture facilities only) ________
3. Species Rainbow trout or Steelhead Number (fish or eggs) up to 1000
4. Destination (name of facility/receiving waters) Energy Northwest Columbia Generating Station

   County Benton Sec.____ Twnshp.____ Rng.____
5. Source of fish/eggs: Facility name Ringold/Meseberg Hatchery Phone number (509) 264-4448

   Physical Location 1871 Ringold River Road City Mesa State WA Zip 99343

   Mailing Address 1871 Ringold River Road City Mesa State WA Zip 99343

   WDFW Aquatic Farm Registration # (for commercial sources in Washington) ________
6. Applicant's Signature [signature] Date 1/31/19 TK

INSTRUCTIONS: Return this applicatio to the address at the top of the form.

NOTE: It is unlawful to transport or stock fish without a permit issued by the Director or his/her designee. Failure to comply with any provisions of this permit or to perform any act not included in this permit shall be grounds for revocation of this permit and may constitute a gross misdemeanor.

INFORMATION BELOW TO BE COMPLETED BY WDFW PERSONNEL

Provisions FOR AN ENTRAINMENT STUDY. NO FISH WILL BE RELEASED TO THE RIVER

Expiration date 7/31/19

☐ Additional provisions attached

Approved ☒ Not Approved ☐ Fish Health Manager [signature] Date 2/14/19

Approved ☐ Not Approved ☐ Aquaculture Coordinator ________ Date ________

Appendix G
Energy Northwest's Request Letter to EFSEC for Updated Fish Entrainment Schedule and EFSEC Schedule Approval Letter

Shannon E. Khounnala
Columbia Generating Station
P.O. Box 968, MD PE03
Richland, WA 99352-0968
Ph. 509-377-8639
sekhounnala@energy-northwest.com

January 17, 2018
GO2-18-013
DIC 409.3

Jim LaSpina
Energy Facility Siting Specialist
Energy Facility Site Evaluation Council
P.O. Box 43172
Olympia, WA 98504-3172

ELECTRONIC SUBMITTAL ONLY

Dear Mr. LaSpina:

Subject: NPDES PERMIT FISH ENTRAINMENT STUDY UPDATED SCHEDULE

References:
1) GO2-15-151, dated October 21, 2015, electronic submittal of “Columbia Generating Station Draft Fish Entrainment Characterization Study Plan” via State of Washington Department of Ecology’s Online Reporting System.
2) Letter, GI2-16-060, dated June 22, 2016, from S. Posner (EFSEC) to RA Dutton (Energy Northwest) “NPDES Permit No. WA-002515-1 Condition S12.B.1: EFSEC Approval of Entrainment Characterization Study Plan.”
3) NPDES Permit No. WA002515-1 Condition S12.B.

The Energy Facility Site Evaluation Council (EFSEC) reissued National Pollution Discharge Elimination System (NPDES) Permit No. WA-002515-1 to Energy Northwest (EN) for the Columbia Generating Station (CGS) on September 30, 2014. Permit Condition S12.B.1 required EN to prepare documentation of the proposed fish entrainment characterization study design and submit the study plan to EFSEC for approval by November 1, 2015. On October 15, 2015, EN submitted the draft entrainment characterization study plan to EFSEC and outlined a 2-year monitoring study in which samples of entrained fish would be taken weekly mid-March through mid-June (the risk window for early juvenile Chinook salmon) and biweekly from July through September. On June 22, 2016, EFSEC approved the entrainment characterization study plan. NPDES Permit Condition S12.B.2.b requires CGS to submit the characterization study’s final report to EFSEC by May 1, 2019.

As previously discussed with you, EN began the characterization study in the spring of 2017 but ran into mechanical issues associated with the operation of the fish cages, which caused the study team to question the efficacy of the cages for capturing and retaining fish (capture efficiency). To address this issue, EN personnel spent a number of months over the course of 2017 studying the operation of fish cages, engineered cage retrofits, and conducted

successful trials to ensure that fish capture and retention efficiency is adequate for both cages.

<u>Entrainment Study Updated Schedule</u>
Because of the delay in the start of the 2-year entrainment characterization study, EN is proposing the following schedule for EFSEC's approval:

- EN will begin the first year of the study in the spring of 2018 and finish the first year fieldwork in the fall of 2018.
- At the end of the first year, EN will submit an interim report to EFSEC by May 1, 2019.
- EN will begin the second year of the study in the spring of 2019 and finish the study's fieldwork in the fall of 2019.
- EN will submit the final entrainment characterization study report to EFSEC by May 1, 2020.

Energy Northwest would also like to request that EFSEC provide guidance on the sequence of events that are required for CGS to maintain compliance with the entrainment characterization study NPDES permit requirements.

I certify under penalty of law, that this document and all attachments were prepared under my direction or supervision in accordance with a system designed to assure that qualified personnel properly gather and evaluate the information submitted. Based on my inquiry of the person or persons who manage the system or those persons directly responsible for gathering information, the information submitted is, to the best of my knowledge and belief, true, accurate and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for knowing violations.

If you require any additional information regarding this request, please contact WK Whitehead at (509) 377-8794.

Sincerely,

17/01/18 11:30:14 -08:00

X 

Khounnala, Shannon E. , Environme...

Shannon E. Khounnala
Environmental and Regulatory Programs Manager

SEK/nb

Cc: Eleanor Key, WDOE
Jeff Ayres, WDOE
Katie Hall, WDOE

INTERNAL DISTRIBUTION:		FILE COPY
SEK/lb		Columbia Files 964Y
		Docket File PE20

STATE OF WASHINGTON
ENERGY FACILITY SITE EVALUATION COUNCIL
PO Box 47250 • Olympia, Washington 98504-7250

November 19, 2018

Shannon Khounnala
Energy Northwest Environmental and Regulatory Programs Manager
P.O. Box 968, Mail Drop PE03
Richland, WA 99352-0968

Subject: Columbia Generating Station, Energy Northwest (EN)
Fish Entrainment Study Updated Schedule
National Pollutant Discharge Elimination System (NPDES) Permit No. WA-002515-1

Dear Ms. Khounnala:

The Energy Facility Site Evaluation Council (EFSEC) received your letter regarding the NPDES Permit, No. WA-002515-1 (Permit), Fish Entrainment Study Updated Schedule on January 17, 2018. In your letter, EN explained that the fish entrainment characterization study is delayed one year due to mechanical problems with the fish cages. Therefore, the submittal of the final fish entrainment characterization study will also be delayed by one year to May 1, 2020.

To satisfy the conditions of the NPDES Permit, EN must submit an interim report to EFSEC by May 1, 2019 that details the fish entrainment characterization study status, delay, and anticipated schedule. The final fish entrainment characterization study report is due to EFSEC on May 1, 2020. If you have any questions, please contact Amy Moon at (360) 664-1362.

Sincerely,

Sonia E. Bumpus
Energy Facility Siting and Compliance Manager

cc: Amy Moon, EFSEC, Siting Specialist
Mary Ramos, Energy Northwest
Katie Hall, Ecology, Nuclear Waste Program
Ellie Ott, Ecology, Water Quality Program
Rich Domingue, NMFS
Justin Allegro, WDFW

Karen Burgess, EPA

Appendix H
Report Peer Review Letters

ENVIRONMENTAL & STATISTICAL CONSULTANTS
1610 East Reynolds Street, Laramie, WY 82072
Phone: 307-721-3172 ◆ www.west-inc.com ◆ Fax: 307-721-3815

DATE: 12 February 2020

TO: Wayde (Kip) Whitehead, Energy Northwest

FROM: Dr. Jared Studyvin and Dr. Lyman McDonald, WEST Inc.

We have reviewed the Columbia Generating Station Fish Entrainment Study Final Report. We have provided comments and suggestions to Anchor QEA and have seen that those comments have been addressed.

The main comment is the calculation of the confidence interval which relies on an assumption of normality. Per our suggestion the multiplier for the confidence interval was changed to 3, providing a confidence interval that is most likely at least 90% but the exact confidence level is unknown.

Practically, with so few fish entrained any statistical analysis is superfluous. We believe with the large estimated population size compared to so few fish entrained, that any analysis done with these data will arrive at the same conclusions presented in the report.

We believe the statistical analysis presented is appropriate given the magnitudes of the numbers of fish entrained and the estimated population sizes.

Charles C. Coutant, Ph. D.
Aquatic Ecologist

120 Miramar Circle
Oak Ridge, TN 37830-8220
865-483-5976
e-mail: ccoutant3@comcast.net

January 16, 2020

Kip Whitehead via email: wkwhitehead@energy-northwest.com
Environmental and Regulatory Programs
Energy Northwest
P. O. Box 989
Richland, WA 99352

Dear Kip:

As requested in your email of January 9, 2020, I have reviewed the draft "Fish Entrainment Characterization Report" prepared for Energy Northwest by Anchor QEA dated January 2020. This is the final report of the Columbia Generating Station Fish Entrainment Study. My focus was on the text and figures although I skimmed Appendix D on entrainment calculations (I understand that WEST, Inc. has been retained to do a detailed computational and statistical review).

The report judiciously follows the approved Study Plan and provides appropriate descriptions of goals, methods, facilities, and schedule, as well as environmental and plant-operating data that might correlate with entrainment and impingement. It documents only four fish collected in the two-years of sampling. It is very comprehensive in evaluating risk factors for entrainment and impingement, and is well organized and well written.

Most of my comments and suggested edits are editorial in nature for purposes of clarity or consistency. Pending reviews by others, I believe the report successfully demonstrates that the Columbia Generating Station's cooling-water intake system is not significantly entraining or impinging salmon smolts migrating from upstream reaches of the Columbia River or early life stages of fall Chinook salmon from the local Hanford Reach. The two salmon captured in the study represent a trivial percentage of the fall Chinook salmon production of the Reach.

I have uploaded my review copy of the main text with comments and suggested edits to the Energy Northwest share file.

If you have questions, let me know.

Sincerely,

Charles C. Coutant, Ph.D.