CHELAN RIVER USE ATTAINABILITY ANALYSIS AND SITE-SPECIFIC CRITERIA DEVELOPMENT

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CHELAN RIVER USE ATTAINABILITY ANALYSIS
AND SITE-SPECIFIC CRITERIA DEVELOPMENT

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<th>Definition</th>
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<td>Clean Water Act Section 401 Certification</td>
</tr>
<tr>
<td>7-DADMax</td>
<td>7-day average of the daily maximum</td>
</tr>
<tr>
<td>B-IBI</td>
<td>benthic index of biological integrity</td>
</tr>
<tr>
<td>BOSR</td>
<td>biological objectives status report</td>
</tr>
<tr>
<td>CFR</td>
<td>Code of Federal Regulations</td>
</tr>
<tr>
<td>cfs</td>
<td>cubic feet per second</td>
</tr>
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<td>Chelan PUD</td>
<td>Public Utility District No. 1 of Chelan County</td>
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<td>Washington Department of Ecology</td>
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<td>FERC</td>
<td>Federal Energy Regulatory Commission</td>
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<tr>
<td>Lake</td>
<td>Lake Chelan</td>
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<tr>
<td>LLO</td>
<td>low-level outlet</td>
</tr>
<tr>
<td>mg/L</td>
<td>milligram per liter</td>
</tr>
<tr>
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<td>Megawatt</td>
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<td>NSWG</td>
<td>Natural Science Working Group</td>
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<tr>
<td>NTU</td>
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<td>Revised Code of Washington</td>
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<td>Settlement Agreement</td>
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<td>total phosphorous</td>
</tr>
<tr>
<td>UAA</td>
<td>Use Attainability Analysis</td>
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<td>USC</td>
<td>United States Code</td>
</tr>
<tr>
<td>USEPA</td>
<td>U.S. Environmental Protection Agency</td>
</tr>
<tr>
<td>WAC</td>
<td>Washington Administrative Code</td>
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EXECUTIVE SUMMARY

Introduction
Washington State water quality standards currently designate an aquatic life use of salmonid spawning, rearing, and migration for the Chelan River (River). The designation was assigned by default\(^1\) without an evaluation of whether this use was an existing or attainable use in the River. This Chelan River Use Attainability Analysis and Site-Specific Criteria Development report (Report) describes the process and information used to assess the highest aquatic life use that is attainable in the River, and proposes a revision of the default aquatic life use to the highest attainable use and site-specific temperature and dissolved oxygen (DO) criteria to protect the highest attainable aquatic life use.

Project and Regulatory History
The River originates at the Lake Chelan Dam (Dam), which is part of the Lake Chelan Hydroelectric Project (Project). The Project is operated by Public Utility District No. 1 of Chelan County (Chelan PUD) under a Federal Energy Regulatory Commission (FERC) license (FERC, 2006). For almost 80 years prior to the current license, flows from the River were diverted into a penstock for power generation. With the exception of periods with spill flows from the Dam, surface flow was absent in the River for most of the year. As a result, attainable aquatic life uses in the River were unknown.

In order to determine the highest attainable aquatic life use, the Clean Water Act Section 401 Certification (401 Certification) that was issued by the Washington State Department of Ecology (Ecology), and incorporated into the current FERC license, included minimum instream flows and identified specific biological objectives for the River. The 401 Certification required that Chelan PUD implement reasonable and feasible measures to achieve the biological objectives and to undertake a 10-year monitoring, evaluation, and adaptive management program to evaluate whether the biological objectives could be achieved.

Paragraph IV.H. of the 401 Certification further provides that, if Ecology determines at the completion of the 10-year monitoring and evaluation program that some of the biological objectives have not been met, but that all known, reasonable, and feasible measures have been implemented to achieve them, then “Ecology intends to initiate a process to modify the applicable water quality standards to the extent necessary” to reflect the objectives achieved.

The development of this Report follows the implementation of all known, reasonable, and feasible measures and the completion of the 10-year monitoring, evaluation, and adaptive management program in accordance with the 401 Certification (Chelan PUD, 2011-2019, 2019b). Findings from this program were used to assess the highest attainable aquatic life uses for the River. Specifically, the history, data, and regulatory considerations for proposed changes to existing aquatic life use designations were systematically evaluated in the Use Attainability Analysis (UAA) presented herein. These data were also used to develop site-specific temperature and DO criteria that protect the highest attainable aquatic life uses, which reflect the unique conditions of the lake and river system.

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\(^1\) Washington Administrative Code 173-201A-600(1): “All surface waters of the state not named in Table 602 are to be protected for the designated uses of: Salmonid spawning, rearing, and migration;(...)”
Reasonable and Feasible Measures Implemented

The lack of historical flows and associated baseline habitat use data created uncertainty for predicting the attainability of future uses by native fishes including Westslope Cutthroat Trout (Cutthroat Trout), Summer Chinook Salmon (Chinook Salmon), and steelhead. As a component of the FERC licensing process for the Project, Chelan PUD worked collaboratively with state and federal fishery managers, Tribes, and stakeholders in the Natural Science Working Group (NSWG) to develop plans to restore ecosystem functions in the River (Figure E-1).

The NSWG compiled and evaluated a broad range of flow and habitat enhancement measures to evaluate the highest attainable aquatic life use within the River. The NSWG recognized that even with restored flows in the River, the natural physical conditions of the River, low productivity, and high water temperatures originating from Lake Chelan (Lake) during the summer could limit the suitability of downstream habitat in the River. Given this uncertainty, the NSWG planning efforts included evaluating native fish responses to different flow regimes and other habitat variables to determine which habitat enhancements would provide the largest benefit.

The Chelan River Biological Evaluation and Implementation Plan (CRBEIP) identified the biological objectives for evaluating the attainable aquatic life uses; reasonable and feasible instream flows and habitat enhancement measures; and an adaptive management plan to actively determine progress and make refinements to these measures. The CRBEIP was part of the 2003 Lake Chelan Settlement Agreement (Chelan PUD, 2003), and was subsequently incorporated into the 401 Certification and the Project’s FERC license (Figure E-1).

The following alternatives, developed by the NSWG, were determined to be reasonable and feasible measures, selected for inclusion in the Lake Chelan Settlement Agreement, and incorporated into the FERC license (Chelan PUD, 2006):

- Study of water temperature at the forebay of the Dam to determine the best design and location for a flow release structure to maximize the potential for cold water withdrawal at the base of the Dam
- Construction of the flow release structure (low-level outlet [LLO]) at the Dam to convey the coldest available water from the forebay to the natural riverbed
- Establishment of minimum instream flows
- Construction of a pumping station in Reach 4 (Figure E-2) to provide spawning flows for anadromous Chinook Salmon and steelhead rather than supplying this flow from Lake storage
- Achievement of flow criteria to meet spawning objectives, protect redds, and reduce the risk of stranding juvenile fish
- Construction of river channel and riparian habitat improvements in the lowermost reach of the River, Reach 4 (Figure E-2)
- Conducting a 10-year adaptive management plan supported by comprehensive monitoring and evaluation

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Figure E-1. Framework of Restoration, Monitoring, and Adaptive Management Actions Implemented in the Chelan River
In addition, the following alternatives developed by the NSWG were excluded from further consideration because they were determined to be neither reasonable nor feasible:

- Increasing flow to maintain River water temperatures within 0.3°C of natural temperatures when water temperature exceeds 18°C (Chelan PUD, 2003). The higher flow option was eliminated because it would not contribute significantly to meeting biological objectives and high flows would have reduced habitat area available for native fish species.
- Building a pipeline to transport cool water several miles from deeper regions of the Lake to provide flows for a minimum-flow release structure. This option was eliminated because of limited ability to provide cooler water and excessively high costs.
- Pumping groundwater into the upper River (Reach 1). This option was eliminated due to the low probability that enough groundwater would be available to create thermal refugia.
- Pumping surface water from the Columbia River into the lower River (Reach 4). This option was eliminated due to expectation of warmer water temperatures in the Columbia River during Chinook Salmon spawning and the adverse ecological consequences of mixing these waters.

**Monitoring and Evaluation Results**

The monitoring and evaluation activities associated with the CRBEIP were conducted with oversight from the Chelan River Fishery Forum (CRFF), which comprises local, state, federal, and tribal entities with fisheries management expertise and authority. In 2019, the CRFF completed the final review of the monitoring and evaluation data collected to support the evaluation of biological objectives for
Chinook Salmon, steelhead, and Cutthroat Trout and documented the results in the final Biological Objectives Status Report (BOSR; Chelan PUD, 2019b). Table E-1 summarizes the final achievement designations for each species as summarized in the BOSR. Ecology reviewed the final BOSR and provided a letter of determination that concurred with these achievement designations. Ecology also confirmed that all reasonable and feasible measures were implemented towards achieving the biological objectives that were not achieved.

Table E-1. Summary of Final Biological Objectives Achievement Designations for Chinook Salmon, Steelhead, and Cutthroat Trout

<table>
<thead>
<tr>
<th>Overarching Biological Objective</th>
<th>Biological Objective Component</th>
<th>Achievement Designation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chinook Salmon</td>
<td>Spawning Habitat for Chinook Salmon Meets Design Characteristics</td>
<td>Achieved</td>
</tr>
<tr>
<td></td>
<td>Chinook Salmon Use of Spawning Habitat Throughout Constructed Habitat</td>
<td>Achieved</td>
</tr>
<tr>
<td></td>
<td>Chinook Salmon Tailrace Intragravel DO ≥ 6.0 mg/L</td>
<td>Achieved</td>
</tr>
<tr>
<td></td>
<td>Egg to Emergence Success Equal to ≥ 80% of Methow River Average or 70% Survival, whichever is Less</td>
<td>Achieved</td>
</tr>
<tr>
<td></td>
<td>Use of Available Rearing Habitat from Emergence–June</td>
<td>Achieved</td>
</tr>
<tr>
<td></td>
<td>Evidence of Adult Production from Chinook Salmon Produced in the River</td>
<td>Achieved</td>
</tr>
<tr>
<td>Steelhead</td>
<td>Spawning Habitat for Steelhead Meets Design Characteristics</td>
<td>Achieved</td>
</tr>
<tr>
<td></td>
<td>Steelhead Use of Spawning Habitat Throughout Constructed Habitat</td>
<td>Achieved</td>
</tr>
<tr>
<td></td>
<td>Steelhead Tailrace/Reach 4 Intragravel DO ≥ 6.0 mg/L</td>
<td>Achieved</td>
</tr>
<tr>
<td></td>
<td>Egg to Emergence Success Equal to ≥ 80% of Methow River Average or 70% Survival, whichever is Larger</td>
<td>Achieved</td>
</tr>
<tr>
<td></td>
<td>Use of Available Rearing Habitat Until Entering Columbia River</td>
<td>Achieved</td>
</tr>
<tr>
<td></td>
<td>Evidence of Adult Production from Steelhead Produced in the River</td>
<td>Achieved</td>
</tr>
<tr>
<td>Cutthroat Trout</td>
<td>Year-Round Presence of at Least 200 Cutthroat Trout in Reaches 1 through 3</td>
<td>Not Achieved</td>
</tr>
<tr>
<td></td>
<td>Create Habitat to Support a Viable Population of Cutthroat Trout in Reaches 1 through 3</td>
<td>Not Achieved</td>
</tr>
<tr>
<td></td>
<td>Colonization of Reaches 1 through 3 by Native Fishes</td>
<td>Not Achieved</td>
</tr>
</tbody>
</table>

Figure E-3 summarizes the habitat attributes and habitat use by native fish in the River. Overall, both Chinook Salmon and steelhead used the available habitat in Reach 4 for spawning, rearing, and successful egg-to-fry development in multiple years of the study. Rearing in summer months did appear to be limited by high water temperatures. There was also indirect evidence that adult production may be occurring from adult Chinook Salmon and steelhead spawning in the River. All the biological objectives for Chinook Salmon and steelhead were achieved.
Figure E-3. Illustration of Flow Routing and Habitat Conditions in the Chelan River
For Cutthroat Trout in Reaches 1 through 3, there was no evidence that a viable population had been established or that the abundance of Cutthroat Trout was increasing over time. Instead, the abundance of Cutthroat Trout appeared to be driven by stocking efforts. Additionally, no young-of-the-year or juvenile Cutthroat Trout were ever observed in Reaches 1 through 3, which indicates spawning and rearing did not occur. For these reasons, the biological objectives for Cutthroat Trout were not achieved. These results were consistent with the predictions made during the FERC relicensing process that high summer water temperatures, low productivity, and other habitat limitations would create challenging conditions for the establishment of a viable Cutthroat Trout population (Chelan PUD, 2003).

**Role of Natural Conditions**

Historical data and monitoring and evaluation results showed that the habitat conditions observed in the River are heavily influenced by the Lake, which is the source water for the River. Year-round, the Lake is extremely unproductive and, from mid-spring through mid-fall, water temperatures routinely exceed the temperature criteria of 17.5°C for salmonid spawning, rearing, and migration. The shallow Lake outlet contributes to heating the water. Figure E-4 depicts the representative water temperatures in the Lake outlet and downstream solar heating in the River during the warmest months of a typical year. Prior to dam construction, temperatures in the Lake outlet may have been warmer because the unimpounded lower Wapato Basin would have been even shallower.

When the already warm water from the Lake enters the River through the LLO, the lack of riparian vegetation along the River channel precludes significant shading and thus allows further heating to occur as the water travels downstream (Figure E-4). In all years of the CRBEIP, summer temperatures exceeded 20°C at the LLO, which draws water from the coolest depths of the forebay before conveying the water into Reach 1 of the River. Additional solar heating between the top of Reach 1 and end of Reach 3 resulted in temperature increases of up to 3.5°C (on a 7-day average of the daily maximum [7-DADMax] basis). Downstream in Reach 4, the constructed habitat channel is also subject to high summer water temperatures from Reaches 1 through 3, limiting the quality of the habitat for salmonids during this period.

The opportunity to limit solar heating with riparian shade was evaluated as a component of the CRBEIP, but the results demonstrated that the site potential for future riparian vegetation was very low in Reaches 1 through 3 and would subsequently limit the establishment of riparian shade. Mechanistic modeling demonstrated that at the anticipated extent of future riparian shading the reduction in the solar heating within the River would not be significant.

Independent of temperature, the suitability of Reaches 1 through 3 for Cutthroat Trout is also limited by other natural conditions, including lack of spawning gravels, low productivity, and limited prey resources. The natural barriers above Reach 4 (Figure E-3) not only prevent anadromous fish from colonizing Reaches 1 through 3, but they also preclude the deposition of marine derived nutrients from spawned out carcasses that would otherwise increase productivity in these reaches.
1. During summer months, water temperatures may exceed salmonid tolerance limits in all habitats less than 25 ft deep in the outlet of Lake Chelan. Longitudinally, mid-summer lake surface temperatures in excess of 20°C were observed at distances of 5-10 miles from the dam in all recent years (2016-2018).

2. During July, August and September, Lake Chelan Outlet water temperatures frequently exceed salmonid thermal tolerance limits prior to entering the LLO and generation intake/penstock.

3. Tailrace flows from generation are not subject to solar heating because they are conveyed through an underground penstock. Therefore, generation tailrace water temperatures remain more similar to Lake Chelan outlet temperatures as compared to the flows in the Chelan River.

4. During the warmest summer months, pump-back flow offers little thermal benefit to salmonids because the “coolest” source water in the tailrace originates from Lake Chelan and already exceeds salmonid thermal tolerance limits.

5. As the Chelan River flows downstream, surface water temperatures increase because of solar heating. This heating can account for water temperature increases of >3°C (7-DADMx difference between LLO and end of Reach 3).

Figure E-4. Illustration of Site-Specific Conditions that Result in High Mid-Summer Temperatures
Proposed Revisions to Water Quality Standards

The monitoring and evaluation data clearly indicate that salmonids (specifically the native Cutthroat Trout) make very limited use of Reaches 1 through 3 and do not rear or spawn in the available habitat. In Reach 4, Chinook Salmon and steelhead do make extensive use of the available habitat for spawning, rearing, and migration; however, warm summer temperatures coincide with decreased use. The default designated aquatic life use is substantially constrained in all River reaches by naturally occurring high temperatures that originate in the Lake and, in Reaches 1 through 3, by low productivity and other natural physical conditions. Exceedances of the existing 17.5°C temperature criterion occurred every year of CRBEIP implementation, and there are no reasonable or feasible measures that can reduce the water temperature below this criterion within the River from mid-spring through mid-fall. For these reasons, Chelan PUD is proposing: (1) revisions to the aquatic life use designation to reflect the highest attainable uses in the River; and, (2) site-specific temperature and DO\(^3\) criteria that protect the proposed aquatic life use designations, which reflect the unique nature of the lake and river system.

Proposed Designated Aquatic Life Uses in the Chelan River

The proposed revisions to the aquatic life use designation are illustrated in Figure E-5. The systematic studies completed over the last 10 years following the adoption of the CRBEIP are the technical foundation for the proposed use changes. The specific regulatory justifications for these changes are as follows:

Reaches 1 through 3:

- 40 Code of Federal Regulations (CFR) 131.10 (g)(5) – Physical conditions related to the natural features of the water body that are unrelated to water quality preclude the attainment of the use—in this case, a natural upstream passage barrier, lack of riparian cover, and substrate all contribute to limiting the highest attainable use.
- 40 CFR 131.10 (g)(1) – Naturally occurring pollutant concentrations prevent attainment of the use—in this case, high water temperatures originating from the Lake from mid-spring through mid-fall due to natural solar heating and the Lake’s unique morphometry, which has existed since before the Project’s construction.

Reach 4:

- 40 CFR 131.10 (g)(1) – Naturally occurring pollutant concentrations prevent attainment of the use—in this case, high water temperatures originating from the Lake from mid-spring through mid-fall that continue to warm within Reaches 1 through 3 of the River before reaching Reach 4.

\(^3\) The proposed revisions to the dissolved oxygen criteria are necessitated by the high water temperatures, which preclude attainment of the existing dissolved oxygen criteria even at saturation concentrations.
Proposed Temperature Criteria

Site-specific water quality criteria development is centered on temperature because it is the primary water quality parameter that does not meet the existing temperature criteria and also poses a limitation on aquatic habitat suitability.

The following framework is proposed for consideration as site-specific temperature criteria:

- **Reaches 1 through 3** – limit the extent of warming within the River to a numeric value that is expressed as the 7-DADMax temperature measured at the end of Reach 3 minus the 7-DADMax background temperature measured at the LLO.
- **Reach 4** – limit the extent of warming within the River to a numeric value that is expressed as the 7-DADMax temperature measured at the end of each segment in Reach 4 minus the 7-DADMax background temperature measured at the end of Reach 3 for the habitat channel and the high-flow channel and at the powerhouse for the tailrace.
- For both criteria, an exceedance is two or more non-overlapping 7-DADMax temperature increases above the corresponding numeric values in any calendar year.
- Limit the cumulative effects of any new anthropogenic sources of heating within both Reaches 1 through 3 and Reach 4, including the tailrace, to a 7-DADMax increase of 0.3°C in addition to the corresponding numeric criteria above.
- The numeric criteria may not be exceeded at a frequency of more than once in every 10 years.
Based on a statistical evaluation of observed temperature increases within the River, and after considering the effects of climate change on air temperature increases and its associated impacts on water temperature increases within the River, the following year-round, 7-DADMMax temperature increases are recommended as the magnitude of the numeric criteria in the framework above: 3.6°C within Reaches 1 through 3 and 1.0°C in Reach 4. These criteria will be protective of salmonid spawning, rearing, and migration in Reach 4 when it does occur from mid-fall through mid-spring because the Lake itself is cooler over this period, and provides a cooler water source. Conditions within the River do not result in temperatures above 17.5°C during this period (i.e., conditions within the River do not reach levels that may be harmful for salmonids). From mid-spring through mid-fall when conditions in the Lake and solar heating within the River result in temperature levels that may be harmful to salmonids that are moving downstream, the criteria above will maintain the highest attainable condition within the River by limiting the cumulative impact of any new anthropogenic sources of heat to 0.3°C or less.

A minor revision to the daily minimum DO aquatic life use criterion of 8 milligrams per liter (mg/L) is proposed to account for the effects of temperature. Whenever the daily minimum DO falls below 8.0 mg/L as a result of temperature and barometric pressure, the daily minimum DO criterion is proposed to be at or greater than 90% of saturation.
1. INTRODUCTION

1.1 Purpose and Scope
This report was developed at the request of Public Utility District No. 1 of Chelan County (Chelan PUD) to evaluate potential changes to the water quality standards for the Chelan River (River), as contemplated by paragraph IV.H. of the Clean Water Act Section 401 Certification (401 Certification) issued by the Washington Department of Ecology (Ecology) to Chelan PUD for the Lake Chelan Hydroelectric Project (Project). The River is a short tributary of the Columbia River (Figure 1-1) that flows approximately 4 miles from its headwaters at Lake Chelan Dam (Dam) to its confluence with the Columbia River. Specifically, this report presents a Use Attainability Analysis (UAA) that assesses the attainability of the current default designated aquatic life uses in the River and, based on that assessment, proposes a change to the aquatic life use designations for the River to the highest attainable uses. This report also proposes site-specific criteria for temperature and dissolved oxygen (DO) that protect the proposed highest attainable aquatic life use designations.

1.2 Authority for Rule Change
In Washington State, Ecology has the authority to adopt and revise water quality standards pursuant to Clean Water Act (CWA) subsection 303(c), 33 United States Code (USC) 1313(c), and Revised Code of Washington (RCW) 90.48.035 and 90.48.260(1)(a). Water quality standards must be consistent with these statutes and with U.S. Environmental Protection Agency (USEPA) regulations at 40 Code of Federal Regulations (CFR) part 131, including 40 CFR 131.10 regarding use designations and 40 CFR 131.11 regarding water quality criteria for the protection of designated uses. In particular, a revised aquatic life designated use that requires less stringent water quality criteria must be based on a UAA (40 CFR 131.10(g), (j)). Ecology has also adopted rules for the adoption of revised use designations (Washington Administrative Code [WAC] 173-201A-440) and site-specific water quality criteria (WAC 173-201A-430).

Any revision to state water quality standards, including changes in use designations and water quality criteria, must be reviewed and approved by USEPA pursuant to 33 USC 1313(c) in order to be effective under the CWA per 40 CFR 131.21. Ecology must adopt revised standards as rules, RCW 90.48.035, which are codified in WAC chapter 173-201A.

1.3 Organization of this Document
This UAA document is organized into six sections. Section 2 provides background on the River and Lake Chelan (Lake) and the licensing history of hydropower operations associated with the River. Section 3 discusses findings of a systematic 10-year monitoring and evaluation program that was designed to assess the attainable aquatic life uses in the River. Section 4 discusses proposed changes to the designated uses in the River. Section 5 provides the technical details for the proposed water quality criteria for the new designated uses. Section 6 provides the conclusions of the UAA.
Introduction

Figure 1-1. Lake Chelan and Chelan River
2. BACKGROUND

2.1 Chelan River and Lake Chelan Background

2.1.1 Chelan River

The River is located entirely in Chelan County, Washington (Figure 1-1). The climate in the lower Lake/River watershed is semi-arid with an annual average precipitation of 11 inches (WEST Consultants, 2014). The majority of precipitation occurs from November to February. Summers are warm (during the warmest months, average air temperature is greater than 85°F or 29.4°C) and dry, and winters are cold (during the coldest months, daytime maximum air temperatures remain near freezing 32°F or 0°C).

The River originates at the Dam and travels approximately 4 miles to its confluence with the Columbia River (Figure 2-1). The watershed area upstream of the Dam is 924 square miles. Dam operations control the flows in the River. Historically, the River remained dry through most of the year except under high flow (12,000–15,000 cubic feet per second [cfs]) conditions, when water was spilled from the Dam. Since 2009, however, year-round flows have been provided per the requirement in the current Federal Energy Regulatory Commission (FERC) license (Section 2.1.2).

The River has four distinct reaches (Figure 2-1).
Reach 1 – This reach extends from the Dam through the first 2.29 miles, and has a gradient of about 1%. This reach is characterized by large cobbles and small boulders and is scarce in riparian vegetation. Upper sections of this reach are approximately 100 to 140 feet wide, with middle and lower sections narrowing down considerably. There is a braided section towards the lower end of the reach, which has the most significant riparian vegetation (Herrera, 2015).

Reach 2 – This reach is 0.75 miles long with a similar gradient and a narrower channel relative to Reach 1. The substrate is coarser than Reach 1.

Reach 3 – This reach is 0.38 miles long and is referred to as the “gorge” because of the steep, confined bedrock. The reach is characterized by a steep gradient of approximately 9%. This reach has several waterfalls with heights ranging from 5 to 20 feet, numerous cascades, bedrock chutes, and large deep pools. The steep gradient and waterfalls in this reach create a natural upstream passage barrier to anadromous salmonids and trout (R2 and IA, 2000). A review of the historical fish assemblages in the River and Lake concluded that the natural passage barrier in Reach 3 has effectively prevented anadromous salmonids from using habitats in Reaches 1 through 3 or the Lake (BioAnalysts, 2000).

Reach 4 – This reach is 0.50 miles long and extends to the confluence of the Columbia River. This reach has a high flow channel that is characterized by large cobbles and boulders, and an engineered habitat channel that became operational in 2009 and where year-round flows are presently maintained (see inset in Figure 2-1). A pump station was constructed to withdraw water from the tailrace and provide additional flows to the habitat channel through the pump flow channel to meet incubation and spawning objectives (see inset in Figure 2-1). During spill conditions, higher flows that move down the River largely bypass the habitat channel and flow through the original high flow channel. The original channel is thought to have been braided prior to 1995, based on older photographs (Stillwater Sciences, 2001). The lower end of the reach merges with the powerhouse tailrace before the confluence with the Columbia River. The tailrace extends from the powerhouse to the Columbia River and is approximately 0.32 miles long. The lower portion of the tailrace is nearly flat. Water depths in the tailrace range from 10 to 30 feet.

The River has been shaped by unique natural habitat processes that have resulted in distinct geomorphological characteristics, including a large proportion of coarse bed materials and general lack of fine sediments. Stillwater Sciences (2001) described these processes and the resulting geomorphology as part of a study that was conducted prior to the FERC relicensing process:

The Chelan River is anomalous relative to other rivers because it has the flow regime of a 924-m² (2393-km²) basin, but only derives sediment from the lower 6.4 kilometers of the river. The interception of sediment has been occurring in Lake Chelan since the Pleistocene epoch, whereas in most dammed rivers, sediment interception has been occurring over a much shorter time scale. This has a profound effect on the sediment dynamics and geomorphology of the Chelan River. Because there is no sediment supplied from upstream, sediment is delivered to the channel via local mass wasting events or erosion of the bed and banks. Fine sediments are typically transported through the system upon delivery (Chelan PUD 2000b). The substrate is very coarse and sediment

4 The pump station is used to provide supplemental incubation flows during Chinook Salmon and steelhead spawning periods in mid-fall and mid-spring, respectively (Section 2.3.3.3).
from the channel bed is transported only during very high flow events. This differs from many other rivers where the majority of sediment is transported during bankfull flood events that occur about every 1.5–2 years.

As discussed in greater detail in Section 2.1.3, the River’s productivity and temperature are heavily influenced by the Lake.

2.1.2 Lake Chelan Hydroelectric Project

The Lake Chelan Hydroelectric Project (Project) is presently owned and operated by Chelan PUD. Prior to construction of the Project, other dams were built to facilitate water supply and navigation for the City of Chelan (from 1892-1894), which were all washed out under flood conditions. In 1899, the first hydropower dam was constructed by the Chelan Water Power Company and became operational in 1903. Following a series of ownership transitions, the Washington Water Power Company subsequently obtained ownership in 1925 and received a 50-year federal license. The Project dam and powerhouse as it exists today were built in 1926 (Figure 2-2).

Figure 2-2. Lake Chelan Hydroelectric Project: Lake Chelan Dam (top panel); Hydroelectric Powerhouse (bottom panel)
Project operations commenced in 1927 following the construction of the Dam. The Dam is 40 feet high and approximately 500 feet long. The Project’s powerhouse is located near the Columbia River. Water is conveyed to the powerhouse from the Dam forebay through a 14-foot diameter, 2.2-mile-long power tunnel. The powerhouse was originally built with two turbines for a combined capacity of 48 megawatts (MW). In 2009, the older turbines were replaced with higher capacity turbines for a combined power generation capacity of 59 MW. Water from the powerhouse is discharged into the tailrace approximately 1,700 feet from the Columbia River.

Dam operations control the elevation of the Lake as well as flows in the River. From 1929-2008 most of the annual flow out of the Lake was diverted to the power tunnel, except during high flows when the Lake was full, leaving the River dry under non-spill conditions until year-round flows were provided in 2009.

2.1.2.1 Licensing History

The Project is operated under a license from FERC. The current Project license is the third license in its operational history. The previous two licenses from FERC and the first 401 Certification issued by Ecology did not require Chelan PUD to provide flows in the River as part of Project operations.

Chelan PUD filed for relicensing in 2002. During this process a number of resource agencies and stakeholders filed as intervenors with FERC. Subsequently, a Settlement Group comprised of the intervenors was formed to obtain a long-term settlement agreement for the Project.

The Lake Chelan Hydroelectric Project Comprehensive Settlement Agreement (Settlement Agreement; Chelan PUD, 2003), was signed in 2003 and represents the consensus reached by the Settlement Group regarding the relicensing of the Project. As part of the Settlement Agreement, Chelan PUD committed to providing year-round flows in the River and implementing the Chelan River Biological Evaluation and Implementation Plan (CRBEIP). The CRBEIP provided a series of adaptive monitoring, evaluation, and management actions to be completed over a 10-year period to assess the biological uses in the River. The CRBEIP is discussed in greater detail in Section 2.3. The Settlement Agreement, including the CRBEIP, is incorporated in the current FERC license. Ecology issued a 401 Certification in April 2003 as part of the relicensing process, which specifically included the CRBEIP.

2.1.3 Influence of Lake Chelan on the Chelan River

The Lake is a 55-mile long, narrow, and deep lake that was formed from two glaciers, the Chelan Glacier from the north and the Okanogan-Columbia Valley lobe of the Cordilleran Ice Sheet that extended from the south (Whetten, 1967). The Lake is characterized by two basins that are separated by a sill at Wapato Point, also termed “the narrows” (Figure 2-3). The upper basin of the Lake is the Lucerne Basin, which is a deep, fjord-like basin that extends approximately 40 miles north up to the mouth of the Stehekin River, which is the largest tributary of the Lake. The Wapato Basin is shallower, extends south to the City of Chelan, and forms the headwaters of the Chelan River (Figure 2-3). Construction of the Dam raised the Lake level by 21 feet at the maximum storage elevation of 1,100 feet above sea level.
Background

The depth profile (Figure 2-3) and general morphometry of the Lake (Table 2-1) have been described in detail by Kendra and Singleton (1987). Figure 2-4 provides an overview of the bathymetry of the southern-most region of the Lake including a portion of the Lucerne Basin and all of the Wapato Basin. The Wapato Basin is the shallower of the two basins with depths ranging from over 300 feet to less than 30 feet near the Lake outlet and Dam (see inset in Figure 2-4). The outlet portion of the Wapato Basin is shallower due to a thick deposit of sediments that is thought to have been left behind by the retreating Okanogan-Columbia Valley lobe (Whetten, 1967). In contrast, the Lucerne Basin is very deep and narrow compared to the Wapato Basin. There is a large section that is consistently deeper than 1,400 feet. Because it is significantly wider than Lucerne Basin, the Wapato Basin surface area is approximately a quarter of the Lake’s total surface area even though it holds less than 8% of the Lake’s volume (Table 2-1). These unique morphometric characteristics of the Wapato Basin have a profound effect on the conditions in the River, which are discussed below.

Table 2-1. Lake Chelan Morphometric Summary

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Wapato Basin</th>
<th>Lucerne Basin</th>
<th>Lake Chelan</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max. Length (miles)</td>
<td>12</td>
<td>38.4</td>
<td>50.4</td>
</tr>
<tr>
<td>Max. Effective Length (miles)</td>
<td>9.6</td>
<td>15.4</td>
<td>15.4</td>
</tr>
<tr>
<td>Maximum Width (miles)</td>
<td>1.8</td>
<td>1.4</td>
<td>1.8</td>
</tr>
<tr>
<td>Mean Width (miles)</td>
<td>1.1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Maximum Depth (feet)</td>
<td>400</td>
<td>1,486</td>
<td>1,486</td>
</tr>
<tr>
<td>Mean Depth (feet)</td>
<td>140</td>
<td>590</td>
<td>474</td>
</tr>
<tr>
<td>Shoreline Length (miles)</td>
<td>27.6</td>
<td>82.3</td>
<td>109.2</td>
</tr>
<tr>
<td>Shoreline Development</td>
<td>2.1</td>
<td>3.7</td>
<td>4.3</td>
</tr>
<tr>
<td>Surface Area (square miles)</td>
<td>13.5</td>
<td>38.6</td>
<td>52.1</td>
</tr>
<tr>
<td>Percent of Lake Surface Area</td>
<td>26</td>
<td>74</td>
<td>100</td>
</tr>
<tr>
<td>Volume (billion cubic yards)</td>
<td>1.95</td>
<td>23.5</td>
<td>25.5</td>
</tr>
<tr>
<td>Percent of Lake Volume</td>
<td>7.6</td>
<td>92.4</td>
<td>100</td>
</tr>
</tbody>
</table>

Source: Kendra and Singleton (1987)
Note: Bathymetry contours were adapted from Kendra and Singleton (1987)

**Figure 2-4. Lake Chelan Bathymetry**
2.1.3.1 Lake Chelan Temperature
Temperature data from the Lucerne and Wapato basins (Figure 2-4), collected during 2016 through 2018, were analyzed to characterize the temperature and seasonal stratification patterns within the Lake. Chelan PUD classifies each year as wet, dry, or average based on the inflow into the Lake during the runoff period (April through July) for maintaining its operational commitments towards the FERC license for the Lake Chelan Hydroelectric Project (Chelan PUD, 2007). Accordingly, 2016 and 2018 are classified as average years, and 2017 is classified as a wet year.

Based on these data, summer stratification and high surface water temperatures occur annually in both basins. Figure 2-5, Figure 2-6, and Figure 2-7 show depth profiles of temperature at the lower end of the Lucerne Basin (Station LC-8), and the upper (Station LC-4) and lower (Station LC-2) ends of the Wapato Basin, respectively.

Note: See Figure 2-4 for location of LC-8

Figure 2-5. Temperature Depth Profiles at the Lower End of Lucerne Basin: Station LC-8

5 Data were collected by the Chelan County Department of Natural Resources. Other sources of historical water temperature data are limited.
While surface temperatures in the Lucerne Basin were typically lower than those observed in the Wapato Basin, peak temperatures in the top 20 feet of the Lucerne Basin exceeded 18°C in all years, and reached 21°C in August in two of the three years sampled (Figure 2-5). Epilimnetic temperatures in the Wapato Basin exceeded 20°C in July and August in all three years, and, in 2016, reached this level as early as June (Figure 2-6 and Figure 2-7).

\[\text{Note: See Figure 2-4 for location of LC-4}\]

\textit{Figure 2-6. Temperature Depth Profiles at the Upper Portion of Wapato Basin: Station LC-4}
Background

The extent of epilimnetic warming is also evident from the consistency of high temperatures from data collected at multiple longitudinal sampling sites (Figure 2-8). During the warmest month of the year, August, temperatures in the surficial layer of the Lake (approximately the top foot) were near or above 20°C at all sampling locations within 15 miles of the sampling location that was most proximal to the Dam (Figure 2-8; see Figure 2-4 for monitoring locations). These patterns are comparable to the historical maximum surface temperatures in the Wapato Basin in August, which were reported to be consistently above 21°C in August of 1987, 1995, and 1996 (Ecology, 1997). Figure 2-8 also shows that temperature at the low-level outlet (LLO) may be slightly lower than the lower Wapato Basin surface temperature to the extent there is thermal stratification within the forebay. Typically, such stratification is minor but nonetheless represents the colder water source to the River (Section 2.3.3.1).

Figure 2-7. Temperature Depth Profiles at the Lower Portion of Wapato Basin: Station LC-2

Note: See Figure 2-4 for location of LC-2
Note: See Figure 2-4 for locations of temperature monitoring stations in Lake Chelan

Figure 2-8. Longitudinal Temperature Profile in the Wapato and lower Lucerne Basins of Lake Chelan

The higher water temperatures observed in the Wapato Basin are driven in part by its depth and width. Specifically, the Wapato Basin is shallower and wider than the Lucerne Basin. As a result, a given volume of water in the Wapato Basin is subject to greater solar heating compared to the same volume in the Lucerne Basin (Figure 2-5 and Figure 2-6).

Although water temperature data are not available from the pre-dam period, the increase in water depth resulting from Dam operations may also have affected water temperatures in the Wapato Basin. Under pre-dam conditions, the water depth in the lower Wapato Basin would have been even shallower than present (by approximately 21 feet; Kendra and Singleton, 1987). Therefore, for the equivalent climatic conditions, the Wapato Basin would likely have reached higher daily maximum temperatures compared to the present during the low flow periods when the air temperatures are warmer than the Lake.

Given the fact that the River originates from the Wapato Basin, the natural warming that occurs in the Wapato Basin during summer months is translated directly to the River and drives the
downstream thermal regime. As illustrated in Section 2.1.3.1, River temperatures are closely aligned to water temperatures from the outlet of the Lake. Specifically, the River is sourced by a massive layer of warm water that forms miles upstream of the Dam and this water increases in temperature as it moves through the progressively shallower Wapato Basin and approaches the River.

Under current operations, the impact of high Lake temperatures on River temperatures is minimized by the use of the LLO, which draws water from the deepest, coolest portion of the water column in the Dam forebay to produce surface flows in the River. The use of the LLO avoids releasing the warmest surficial water into the River as would have occurred during the pre-dam period. The increase in the elevation of the Lake associated with current operations may also reduce some solar heating that would have been translated to the River during the pre-dam period.

**2.1.3.2 Lake Chelan Productivity**

Because the Lake is the sole source water for the River, it is also the primary nutrient source for the River. Therefore, historical studies were reviewed to characterize Lake productivity in an effort to better describe subsidiary River productivity. Overall, the Lake is extremely nutrient-poor and unproductive (ultraoligotrophic) because of the limited supplies of nutrients to the Lake (Pelletier et al., 1989). Approximately 75% to 90% of the Lake’s phosphorus loads are from natural sources within the basin, with the remaining phosphorus loads coming from agricultural (4% to 12%) and stormwater (1% to 12%) runoff and septic systems (1% to 5%; Pelletier et al., 1989). The anthropogenic sources typically provide inputs for periphyton accumulations in nearshore environments (Pelletier et al., 1989). The total phosphorous (TP) concentration was highest in the epilimnion of the Wapato Basin at 3.9 micrograms per liter but remained below the 4.5 micrograms per liter threshold for ultraoligotrophic waters (Ecology, 1997). In addition to TP, other indicators of trophic status, including chlorophyll a, algal biovolume, Carbon-14 productivity, and phytoplankton species assemblage, confirm the nutrient poor and unproductive status of the Lake (Pelletier et al., 1989; Ecology, 1997). Overall, the concentration of available nutrients for algal growth appears to be lower in the outlet region during the summer because of algal uptake occurring in the Wapato Basin above the outlet (Pelletier et al., 1989).

Beyond the nearshore environments that may receive anthropogenic nutrient sources, periphyton biomass in the Lake is limited (Jacoby et al., 1991). Pelletier et al. (1989) documented very low periphyton levels in the Lake outlet channel (4-10 milligrams chlorophyll-a per square meter), which is consistent with the apparent depletion of nutrients occurring in the outlet.

**2.1.3.3 Lake Chelan Zooplankton and Fish Species Assemblage**

The dominant zooplankton species in the Lake are cladocerans (*Daphnia spp.* and *B. longirostris*) and copepods (*L. ashlandi* and *Diacyclops thomasi*). *Mysis diluviana* is also present but its distribution in the Wapato Basin is limited and precluded in the summer by the presence of (1) a relatively deep thermocline and warm epilimnetic waters that extend to the sill that partitions the Wapato and Lucerne basins, and (2) a 14°C thermal tolerance threshold for *M. diluviana* (Schoen et al., 2015).

Cladocerans and copepods are two of the dominant drift invertebrate taxa found in the lower River, which suggests that zooplankton production in the Wapato Basin contributes significantly to the observed invertebrate biomass in the River (Van den Broek et al., 2018).
The current fish assemblage in the Lake includes both native and non-native species (Table 2-2). The native fish assemblage includes Westslope Cutthroat Trout (Cutthroat Trout), Mountain Whitefish, Burbot, Largescale Sucker, Longnose Sucker, Northern Pikeminnow, Peamouth, Redside Shiner, and other non-salmonid species. Common non-native species include kokanee, Rainbow Trout, Lake Trout, and Smallmouth Bass. As a result of the low productivity and high summer temperatures in the epilimnion, cold water fish species such as kokanee and Cutthroat Trout are likely precluded from foraging in the surface waters of the Lake during the warmest months (Pelletier et al., 1989).

A series of natural upstream passage barriers near the end of Reach 3 precludes anadromous fish from accessing habitats in Reaches 1 through 3 (BioAnalysts, 2000). Therefore, the fish assemblage in the Lake is the only potential source of colonizers for habitats in Reaches 1 through 3 whereas Reach 4 is also accessible by anadromous colonizers originating from the Columbia River.

**Table 2-2. Lake Chelan Fish Assemblage**

<table>
<thead>
<tr>
<th>Species</th>
<th>Scientific Name</th>
<th>Native?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Westslope Cutthroat Trout</td>
<td>Oncorhynchus clarki lewisi</td>
<td>Yes</td>
</tr>
<tr>
<td>Mountain Whitefish</td>
<td>Prosopium williamsoni</td>
<td>Yes</td>
</tr>
<tr>
<td>Pygmy Whitefish</td>
<td>P. coulterii</td>
<td>Yes</td>
</tr>
<tr>
<td>Burbot</td>
<td>Lota lota</td>
<td>Yes</td>
</tr>
<tr>
<td>Largescale Sucker</td>
<td>Catostomus macrocheilus</td>
<td>Yes</td>
</tr>
<tr>
<td>Longnose Sucker</td>
<td>C. catostomus</td>
<td>Yes</td>
</tr>
<tr>
<td>Bridgelip Sucker</td>
<td>C. columbianus</td>
<td>Yes</td>
</tr>
<tr>
<td>Northern Pikeminnow</td>
<td>Ptychocheilus oregonensis</td>
<td>Yes</td>
</tr>
<tr>
<td>Peamouth</td>
<td>Mylocheilus caurinus</td>
<td>Yes</td>
</tr>
<tr>
<td>Threespine Stickleback</td>
<td>Gasterosteus aculeatus</td>
<td>Yes</td>
</tr>
<tr>
<td>Chiselmouth</td>
<td>Acrocheilus alutaceus</td>
<td>Yes</td>
</tr>
<tr>
<td>Mottled Sculpin</td>
<td>Cottus bairdi</td>
<td>Yes</td>
</tr>
<tr>
<td>Slimy Sculpin</td>
<td>C. cognatus</td>
<td>Yes</td>
</tr>
<tr>
<td>Prickly Sculpin</td>
<td>C. asper</td>
<td>Yes</td>
</tr>
<tr>
<td>Redside Shiner</td>
<td>Richardsonius balteatus</td>
<td>Yes</td>
</tr>
<tr>
<td>Rainbow Trout</td>
<td>O. mykiss</td>
<td>No</td>
</tr>
<tr>
<td>Kokanee</td>
<td>O. nerka</td>
<td>No</td>
</tr>
<tr>
<td>Landlocked Chinook Salmon</td>
<td>O. tshawytscha</td>
<td>No</td>
</tr>
<tr>
<td>Lake Trout</td>
<td>S. namaycush</td>
<td>No</td>
</tr>
<tr>
<td>Smallmouth Bass</td>
<td>Micropterus dolomieu</td>
<td>No</td>
</tr>
<tr>
<td>Largemouth Bass</td>
<td>M. salmoides</td>
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</tr>
<tr>
<td>Eastern Brook Trout</td>
<td>S. fontinalis</td>
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</tr>
<tr>
<td>Pumpkinseed</td>
<td>Lepomis gibbosus</td>
<td>No</td>
</tr>
<tr>
<td>Bluegill</td>
<td>L. macrochirus</td>
<td>No</td>
</tr>
<tr>
<td>Tench</td>
<td>Tinca tinca</td>
<td>No</td>
</tr>
</tbody>
</table>

Notes:
Data Sources: BioAnalysts, 2000; TWC, 2011; BioAnalysts, 2019
Blue shading highlights non-native species
2.1.3.4 Lake Chelan Water Levels

The FERC license includes minimum Lake levels that vary based upon seasonal objectives. While inflows to the Lake are dependent on weather and snowpack in the Lake’s watershed, Project operations serve as an important regulator of Lake levels for various benefits including minimum flows in the River, reducing high flows in the River, flood control, recreation, reducing shoreline erosion, preventing fish passage blockages in Lake Chelan tributaries, and minimizing the effect of refill on the attainment of flow objectives for salmon in the mainstem of the Columbia River. To achieve these objectives, the Settlement Agreement (Chapter 8 – Lake Level Management; Chelan PUD, 2003) commits Chelan PUD to maintaining Lake levels at different times of the year with monthly minimum elevation targets fluctuating between 1,087.6 to 1,099 feet.

Primary contact recreation is a designated and existing use in Lake Chelan. There are numerous private and public recreational sites including campsites, hiking trails, beaches, boat launches, and resorts. Lake level affects access to and use of these sites. The Settlement Agreement includes an objective to provide usable lake levels for recreation at or near “full” pool (1,098 feet or higher). The summertime minimum elevation targets from July 1 through September 7 aim to meet this objective as the lake level targets are 1,098.0 and 1,098.7 feet respectively.

2.2 Designated and Existing Uses in the Chelan River

Washington State standards define designated uses as those uses specified in WAC 173-201A for each water body or segment, regardless of whether or not the uses are currently attained. For waterbodies such as the River that are not listed explicitly under WAC 173-201A-602, the state standards assign the following default designations in WAC 173-201A-600 (1): All surface waters of the state not named in Table 602 are to be protected for the designated uses of: Salmonid spawning, rearing, and migration; primary contact recreation; domestic, industrial, and agricultural water supply; stock watering; wildlife habitat; harvesting; commerce and navigation; boating; and aesthetic values. The applicable water quality standards for the River under the default designations above are shown in Table 2-3.

Existing uses are defined in the WAC and USEPA’s regulations as those uses attained on or after November 28, 1975, whether or not they are designated uses. Furthermore, the WAC notes that, “Introduced species that are not native to Washington, and put-and-take fisheries comprised of non-self-replicating introduced native species, do not need to receive full support as an existing use.” As discussed in Section 2.1.2, the River was historically dry for most of the year until the introduction of year-round flows in 2009. As a result, the extent to which default designated uses were attainable, either seasonally or year-round, was unknown. The recent studies completed in the CRBEIP are aimed at determining what uses are attainable in the River after the provision of year-round flows.
Table 2-3. Applicable Water Quality Standards for the Chelan River for Default Designated Uses

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>1. 7-day average of the daily maximum (7-DADMax) ≤ 17.5°C</td>
</tr>
<tr>
<td></td>
<td>2. Human-caused change ≤ 0.3°C when 7-DADMax &gt; 17.2°C</td>
</tr>
<tr>
<td></td>
<td>3. Human-caused change when background 7-DADMax &lt; 17.5°C:</td>
</tr>
<tr>
<td></td>
<td>a. For individual point sources &lt; 28/(T+7)</td>
</tr>
<tr>
<td></td>
<td>b. Cumulative change for all non-point sources &lt; 2.8°C</td>
</tr>
<tr>
<td>DO</td>
<td>1. Daily minimum DO ≥ 8.0 mg/L</td>
</tr>
<tr>
<td></td>
<td>2. Human-caused change ≤ 0.2 mg/L when Minimum DO &lt; 8.0 mg/L</td>
</tr>
<tr>
<td>Turbidity</td>
<td>1. Change ≤ 5 NTU, when background ≤ 50 NTU</td>
</tr>
<tr>
<td></td>
<td>2. Change ≤ 10% of background, when background &gt; 50 NTU</td>
</tr>
<tr>
<td>pH</td>
<td>1. pH shall be within the range of 6.5 to 8.5</td>
</tr>
<tr>
<td></td>
<td>2. Human-caused variation within the range above &lt; 0.5 units</td>
</tr>
<tr>
<td>Total Dissolved Gas</td>
<td>≤ 110% saturation</td>
</tr>
<tr>
<td>General Criteria</td>
<td>1. Toxic substances shall not be introduced above natural background levels at levels that adversely affect designated uses as specified in WAC 173-201A-240 and 40 CFR 131.45</td>
</tr>
<tr>
<td></td>
<td>2. Free of deleterious concentrations of radioactive materials as defined in WAC 173-201A-250</td>
</tr>
<tr>
<td></td>
<td>3. Aesthetic values must not be impaired by the presence of materials or their effects excluding those of natural origin, which offend the senses of sight, smell, touch, or taste</td>
</tr>
</tbody>
</table>

2.3 Chelan River Biological Evaluation and Implementation Plan

2.3.1 Scope
Prior to and during the FERC relicensing process, knowledge of habitat use by fish within the River was limited to historical accounts, and pre-Project habitat conditions within the river were largely unknown. In short, the absence of year-round instream flow, from 1927 through 2009, precluded the establishment of baseline data to delineate attainable uses within the dewatered portion of the River (i.e., Reaches 1 through 3). The CRBEIP, which was developed during the relicensing process and subsequently incorporated into the Project’s FERC license, provided opportunities to establish year-round instream flows, construct habitat enhancements, and establish a baseline of habitat use by fish and other aquatic species. Even though the CRBEIP was not specifically designed for the purpose of a UAA, it nonetheless provided the essential baseline data to determine attainable uses.

The CRBEIP originated from work performed by the Natural Science Working Group (NSWG), which included Chelan PUD and state, federal, and tribal fishery managers. The NSWG was established to develop biological objectives and identify and prioritize reasonable and feasible flow restoration and habitat enhancement measures that would be implemented as part of the new FERC license. In addition, the NSWG helped develop the adaptive management process by which baseline data would be established to inform decision-making and guide on-the-ground activities. Importantly, the CRBEIP was guided by the broad range of fishery management expertise within the NSWG and the final version was included in the Settlement Agreement and FERC license (Chelan PUD, 2003).

Once the FERC license was issued, Chelan PUD began implementation of the reasonable and feasible measures identified within the CRBEIP, including the following (Sections 2.3.3 and 2.3.4):

- Construct a flow release structure on the Dam to convey Lake water to the natural riverbed
- Establish year-round instream flows
- Construct a river channel and riparian habitat improvements in Reach 4
- Construct a pumping station in Reach 4 to provide spawning flows for anadromous Chinook Salmon and steelhead
- Conduct Project operations to meet flow criteria for spawning objectives and redd protection and to reduce stranding risks to juvenile salmonids
- Perform a comprehensive 10-year monitoring and evaluation program to inform the adaptive management of the CRBEIP
- Provide periodic reporting including a final 10-year report

The chronological process of implementing the CRBEIP from relicensing to the final 10-year report is summarized in Figure 2-9. This simplified figure highlights key stages in the progression of the CRBEIP including (1) identifying reasonable and feasible measures and biological objectives during relicensing; (2) constructing habitat improvement projects and providing instream flow; and (3) implementing the 10-year adaptive management plan and completing the final compliance reporting.

The CWA Section 401 Certification Order No. 1233, II.E. (Ecology, 2004) provides a process for Ecology to modify the applicable water quality standards for the River at the end of the 10-year adaptive management period, as incorporated into Ecology’s CWA Section 401 Certification for the Project, under the following conditions:

- Biological objectives are achieved but one or more water quality standards are not met
- Some or all of the biological objectives have not been met and Chelan PUD has undertaken all known, reasonable, and feasible measures to achieve those objectives

The remainder of this section describes the biological objectives; the restoration, monitoring, evaluation, and adaptive management actions that were implemented; and the role of a technical forum of experts and stakeholders that oversaw the implementation of these actions.
Relicensing: Identifying Reasonable and Feasible Measures and Biological Objectives 1998-2006


License Implementation: CRBEIP/Adaptive Management 2009-Present

Adaptive Management Process

Figure 2-9. Framework of Restoration, Monitoring, and Adaptive Management Actions Implemented in the Chelan River
2.3.2 Biological Objectives
The CRBEIP identifies species-based biological objectives that are intended to contribute to the overall goal of creating a “functional aquatic ecosystem” (Chelan PUD, 2003). The species-based biological objectives focus on Chinook Salmon, steelhead, and Cutthroat Trout. Within the CRBEIP, each species has a broad biological objective (Table 7.9 from Chelan PUD, 2003) and additional detailed biological objectives (Table 7.10 from Chelan PUD, 2003), which include the following (the broad objective appears next to the species name and detailed objectives are bulleted below):

Chinook Salmon: Adult production from fish produced in Reach 4 of the Chelan River
- Areas developed to support spawning meet design habitat characteristics (depth, velocity, and substrate) at the design flow (as-built functionality).
- Distribution of spawning use should reflect distribution of constructed spawning habitat.
- Intragravel DO greater than 6.0 milligram per liter (mg/L).
- Egg-to-emergence success greater than or equal to 80% of Methow River average or 70% survival, whichever is less.
- Fry presence and use of available habitat.

Steelhead: Adult production from fish produced in Reach 4 of the Chelan River—net benefit to the Evolutionarily Significant Unit
- Areas developed to support spawning meet design habitat characteristics (depth, velocity, and substrate) at the design flow (as-built functionality).
- Distribution of spawning use should reflect distribution of constructed spawning habitat.
- Intragravel DO greater than 6.0 mg/L.
- Egg-to-emergence success greater than or equal to 80% of Methow River average or 70% survival, whichever is larger.
- Fry presence and use of available habitat.

Cutthroat Trout: Establish a viable population of Cutthroat Trout in Reaches 1 through 3 of the Chelan River
- A viable population that is not limited by Project operations. Viable is defined in the CRBEIP as “naturally produced (not stocked) fish, viable (population has representatives of several age classes), healthy (fish condition better than starvation), and of reasonable density (200 fish of various ages) consistent with the habitat conditions.”
- Presence of 200 fish including various age classes.
- Habitat improvements for Cutthroat Trout, as related to water temperature, may include:
  - New, naturally evolved stream channel
  - Riparian shade
  - Thermal refugia/pumping studies
  - Increased flows

2.3.3 Habitat Protection and Enhancement Actions
The habitat protection and enhancement actions identified in the Settlement Agreement (Chelan PUD, 2003) included major construction projects that subsequently provided the flows, flow
modulation capability, and other habitat attributes necessary to attempt to achieve the biological objectives identified in the CRBEIP.

2.3.3.1 Low-Level Outlet

The LLO was constructed to provide minimum instream flows year-round and allow for flow modulation to meet specific biological objectives. The LLO is integrated into the Dam infrastructure at the outlet of the Lake (Figure 2-10) and derives water from an existing unused penstock intake located in the bottom of the forebay.

The LLO releases the coldest water available in the forebay to the River. The key steps and chronology of the LLO construction included the following:

- June 6, 2005 – water temperature profile study results for pre-design published (Chelan PUD, 2005)
- November 30, 2007 – 90% design documents submitted to FERC (Yow, 2007)
- December 5, 2008 – LLO construction began (Chelan PUD, 2010b)
- September 21, 2009 – construction completed and LLO commissioned (Chelan PUD, 2010b)
- October 2009 – perennial surface water flows established in the River (Figure 2-11)
2.3.3.2 Reach 4/Tailrace Habitat Enhancement

The habitat improvements in Reach 4 included creating a river channel and planting riparian vegetation to enhance the quantity and function of habitat available to salmonids. The design and construction process included multiple steps. Several of the key milestones are summarized below:

- January 2008 – 100% design report published (Anchor Environmental, 2008)
- July 1, 2008 – lower tailrace habitat construction work began (Chelan PUD, 2010b)
- September 5, 2008 – tailrace habitat construction completed (Chelan PUD, 2010b)
- October 14, 2009 – Reach 4/tailrace habitat channel commissioned and Chinook Salmon spawning flow initiated (Chelan PUD, 2010b)

Figures 2-12 through 2-16 highlight the scale and nature of habitat improvements that were made in Reach 4. Figure 2-12 illustrates the large alluvial deposition area downstream of the dry historical riverbed and the general lack of a defined channel through the alluvial sediments. The construction and operation of the new habitat channel are shown in Figure 2-13 and Figure 2-14. The maturation of riparian vegetation in the Reach 4 area is ongoing and the progression from construction to 2018 is captured in Figure 2-14, Figure 2-15, and Figure 2-16.
Figure 2-12. Reach 4 Vicinity Prior to Habitat Enhancement Projects

Figure 2-13. Reach 4 Vicinity Following Habitat Channel Construction and Immediately Before Operations in 2009
Figure 2-14. Reach 4 Vicinity and Constructed Habitat Channel During Initial Operations in 2009

Figure 2-15. Reach 4 Vicinity and Constructed Habitat Channel Illustrating the Presence of Riparian Vegetation in 2017
2.3.3.3 **Tailrace Pump Station**

A pump station was designed to convey water from the powerhouse tailrace to the newly constructed habitat channel to supplement the flows in the habitat channel (Figure 2-17). As discussed in the Section 2.3.3.4, supplemental flows for spawning and egg incubation may be provided through any combination of spill, LLO, and pumping water from the tailrace (Chelan PUD, 2003). Any supplemental pump-back flows from the tailrace that are provided from mid-spring through mid-fall may provide an additional cooling benefit to the habitat channel because the tailrace is cooler than the flows entering the habitat channel from Reaches 1 through 3 over this period even though this is not the intent of the supplemental pump-back flows. Additionally, the pumping station provides an alternate method to supplement flows to Reach 4 from lake storage (Chelan PUD, 2003). The key project milestones included the following:

- April 2007 – pump station findings report (CH2MILL, 2007a) and pump procurement technical specifications published (CH2MILL, 2007b)
- November 30, 2007 – 90% design documents submitted to FERC (Yow, 2007).
- September 14, 2009 – construction completed and commissioning of the pump station began (Chelan PUD, 2010b)

Figure 2-18 shows adult Chinook Salmon using the spawning flows.
2.3.3.4 Establishment of Year-Round Instream Flow
After completion of the major habitat construction projects in 2009, perennial flow was established in the River channel and Chelan PUD was able to begin managing those flows to meet specified flow targets and associated biological objectives. The flow targets were chosen to optimize the quantity
of usable habitat available to native fish species based on instream flow incremental methodology results (Chelan PUD, 2003). Ramping rates\(^7\) were also specified to protect vulnerable salmonid embryos and juveniles: “The project shall not exceed the following ramping rate for the purpose of preventing stranding of fish in the Chelan River, of two inches per hour, to be modified in consultation with the CRFF, as described in Section 3.2, Table 7-6 of the CRBEIP” (Ecology, 2004).

The CRBEIP adaptive management process has led to updates to the flow and ramping rate requirements to maintain suitable habitat conditions. Table 2-4 summarizes current instream flow and ramping rate requirements.

### Table 2-4. Minimum Instream Flow Requirements and Ramping Schedule by Year Type

<table>
<thead>
<tr>
<th>Reach</th>
<th>Minimum Instream Flow Requirements for the Chelan River(^1)</th>
<th>Average Year</th>
<th>Wet Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>1, 2, and 3(^2)</td>
<td>80 cfs all months</td>
<td>80 cfs July 16–May 14</td>
<td>80 cfs July 16–May 14</td>
</tr>
<tr>
<td></td>
<td>May 14 ramp up to 200 cfs</td>
<td>May 14 ramp up to 320 cfs</td>
<td></td>
</tr>
<tr>
<td></td>
<td>200 cfs May 15–July 15</td>
<td>320 cfs May 15–July 15</td>
<td></td>
</tr>
<tr>
<td></td>
<td>July 16–ramp down to 80 cfs</td>
<td>July 16–ramp down to 80 cfs</td>
<td></td>
</tr>
<tr>
<td>4(^3) Spawning flow</td>
<td>80 + 180 cfs pumped March 15 to May 15 and Oct. 15 to Nov. 30 Incubation flow, as needed</td>
<td>260 cfs by combination of spill and pumping March 15 to May 15 and October 15 to November 30 Incubation flow, as needed</td>
<td>260 cfs by combination of spill and pumping March 15 to May 15 and Oct. 15 to Nov. 30 Incubation flow, as needed</td>
</tr>
</tbody>
</table>

Notes:
1. Table source: 162 FERC ¶ 62,052 (2018)
2. Flows measured at the Dam by ultrasonic flow meter.
3. Flows measured at the Dam and at the pump station by ultrasonic flow meter.

#### 2.3.3.5 Summary of Actions Determined to be Infeasible

The CRBEIP also eliminated options deemed “infeasible or inordinately costly for low or uncertain biological benefit” (Chelan PUD, 2003). These included the following measures:

- Increasing flow to maintain River water temperatures “within 0.3°C of natural temperatures when water temperature exceeds 18°C” (Chelan PUD, 2003). The higher flow option was eliminated for the following reasons: “it is not expected to contribute significantly to meeting the biological objectives, it diminishes the usable habitat area in the Chelan River, and it has a significant negative impact to other existing beneficial uses . . .” (Chelan PUD, 2003). This conclusion was based on an evaluation of the rearing habitat that would be available under flows ranging from 40 cfs to 650 cfs for various fish species present in the River: Smallmouth bass, suckers, Rainbow and Cutthroat trout in Reaches 1 through 3; and juvenile Chinook Salmon and steelhead, in addition to those evaluated in Reaches 1 through 3, in Reach 4 (also see discussion Section 3.2.2). In addition to the negative impacts on the useable habitat area, the CRBEIP also considered other negative impacts from higher flows. These included the negative effects of lower flows on fish that spawn in the tailrace and the net thermal load to the Columbia River. When higher flows are released to Reaches 1 through 3 to limit

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\(^7\) When flows are ramped up (when spill is commenced) or down (when spill ceases) water levels in the River can change rapidly. This can lead to stranding of salmonids in sections that may become isolated or dewatered under low flows. A gradual change in flow will provide salmonids with sufficient time to return to areas with flows.
temperature increases to 0.3°C, a greater volume of water would be subject to thermal heating within the River than under the scenario where this flow is conveyed through the underground penstock to the powerhouse. Therefore, the higher flow scenario would result in greater thermal loading to the Columbia River, particularly during summer months when this concern is the greatest (Chelan PUD, 2003).

- Building a pipeline to transport cool water several miles from deeper regions of the Lake to provide flows for a minimum-flow release structure. This option was eliminated because of the significant negative environmental consequences, excessive cost, and uncertain biological benefits for the River.
- Pumping groundwater into Reach 1. This option was eliminated due to the low probability that enough groundwater would be available to create thermal refugia.
- Pumping surface water from the Columbia River into Reach 4. This option was eliminated due to the warmer water temperatures in the Columbia River during the period when Chinook Salmon would be spawning in Reach 4.

2.3.4 Monitoring, Evaluation, and Adaptive Management Actions

The monitoring, evaluation, and adaptive management portions of the CRBEIP began in October 2009 following the completion of the flow and habitat improvements. Year 1 was defined as October 15, 2009, to December 31, 2010 (132 FERC ¶ 62,147).

The Settlement Agreement established the Chelan River Fishery Forum (CRFF), which was tasked with overseeing the implementation of the monitoring and evaluation activities and adaptive management actions proposed in the CRBEIP. The CRFF is comprised of federal, state, and tribal representatives that were parties to the Settlement Agreement. The CRBEIP lays out the role of the CRFF as follows (Chelan PUD, 2003):

*Chelan PUD will evaluate the success of the CRBEIP in meeting the biological objectives and will report results to the Chelan River Fishery Forum (CRFF). Chelan PUD will make recommendations for implementation of optional components of the CRBEIP or other actions, if necessary, to support achieving the biological objectives. Chelan PUD will provide the CRFF with a draft of such reports and will consult with CRFF members prior to issuing final reports. The intent is for Chelan PUD and the CRFF to reach consensus regarding the evaluation and recommendations. If a CRFF member is not in agreement with the draft report or recommendations and has an alternative evaluation or recommendation, Chelan PUD shall include a discussion of that alternative evaluation or recommendation in the final report.*

The CRBEIP also contemplated several broad categories of management decisions that would be used within the adaptive management framework. These included:

- Additional actions to address high temperatures
- Flow security options for the tailrace
- Temperature management for summer rearing
- Habitat use – modify habitat types
Chelan PUD has developed several reports to meet the reporting requirements in the CRBEIP and FERC license article 401. The key reports include the following:

- **Annual Flow and Temperature Monitoring Reports** (Chelan PUD, 2008-2010, 2011-2019) – These reports provided an annual summary of the flow, temperature, and in some years, water quality conditions.

- **Biological Objective Status Reports** (BOSRs; Chelan PUD, 2013b, 2015b, 2017b, and 2019b) – These reports documented the adaptive management actions taken and the progress towards achievement of the biological objectives. The final BOSR (Chelan PUD, 2019b) provides a comprehensive review of all actions completed over the 10-year adaptive management period and provides Ecology with the information necessary to make a determination on the degree of attainment of the biological objectives. Ecology concurred with the determinations in the final BOSR that the biological objectives for Chinook Salmon and steelhead had been achieved but that the biological objectives for Cutthroat Trout had not.8 With respect to the Cutthroat Trout biological objective, Ecology further determined that all known, reasonable, and feasible measures to achieve the objective had been undertaken and that Project operations did not limit achievement of the objective.

Water quality monitoring activities were conducted in accordance with an Ecology and FERC-approved Quality Assurance Project Plan (Appendix A in Chelan PUD, 2007; Chelan PUD, 2015c). Other reports that were developed to document the studies conducted in support of the CRBEIP include the following:

- **Chelan River Riparian Revegetation Feasibility Assessment** (Herrera, 2015)
- **Chelan River Temperature Model** (WEST Consultants, 2014, 2016)
- **Snorkel Surveys** (BioAnalysts, 2016; 2019)
- **Macroinvertebrate Investigation** (Van den Broek et al., 2018)

Findings from the monitoring and evaluation activities described in the studies above are summarized in Section 3.

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8 Letter from Breean Zimmerman, Central Region Hydropower Projects Manager, Washington Department of Ecology to Jeffrey Osborn, Senior License Compliance Specialist, Chelan PUD, dated August 2, 2019.
3. MONITORING AND EVALUATION PROGRAM FINDINGS

Monitoring and evaluation activities began in October 2009 following the completion of the habitat channel construction. Findings from these studies are discussed for 2010-2018, a 9-year period after year-round flows were restored in the River. Not all surveys were required in all years. For example, water quality data collection was required for only 2 years. Therefore, in some cases the discussions are limited to periods when data were collected.

3.1 Flow

Flows in the tailrace, from spill, and the combined total flow for the period with year-round flows are shown in Figure 3-1. Data from 2009 are not shown because year-round flows did not begin until October 2009 to allow for construction of the habitat channel. The figure illustrates several key requirements in the CRBEIP:

- During the non-spill period, the minimum required instream flow is 80 cfs or greater from July through May of the following year.
- In Reach 4 supplemental spawning and incubation flow (see Table 2-4) can be a combination of flows from Reaches 1 through 3 and the pumped flow from the tailrace. Pumping is not required under the CRBEIP, but was included to provide more options for maintaining the required flows in the habitat channel during spawning conditions or for dry years (for example, 2015). In Figure 3-1, periods when steelhead and Chinook Salmon spawning occurred are shown shaded in gray. Periods with pumped flows are shown with a cross-hatch. Figure 3-1 shows that in some years it was possible to provide spawning flows through higher flows from the LLO (for example, 2016).
- Spill conditions occur predominantly in late spring, after steelhead spawning, through mid-summer, which is well before Chinook Salmon spawning begins in early fall. Thus, high flows that can affect useable habitat and egg incubation are controlled through spill timing.
Figure 3-1. Chelan River Flows
3.1.1 Comparison of Chelan River Flows to Adjacent Watersheds

It is useful to understand flows in the River relative to the inflows to the Lake, and flows in the adjacent watershed that have a comparable hydrological cycle. For the purpose of this comparison, long-term daily average flows were obtained from U.S. Geological Survey gaging stations on the Wenatchee, Methow, and Stehekin rivers. The Wenatchee and Methow watersheds are undammed (except for a small dam at Tumwater Canyon on the Wenatchee River, which is a run of the river dam and does not appreciably affect timing of river flows). Stehekin River is the largest tributary of the Lake and represents the timing of the inflows to the Lake.

Figure 3-2 shows the median and range of the long-term flow record shown by the day of the year. For the River, the total outflows from the Lake (flows to powerhouse + LLO + spill) are shown. This figure illustrates that all four rivers’ peak flows are driven by snowmelt and occur from late spring through early summer. The higher flows for the River in fall and spring are a reflection of tailrace flows and, as such, do not affect the habitat channel where the flows are lower in fall through spring (Figure 3-1). Because historical (pre-dam) flows in the River are unknown, the actual flows that would have been present historically in the River cannot be illustrated. However, Stehekin River flows are a good representation of the River hydrograph under a pre-dam condition, albeit River flows would have been higher since it includes flows from other tributaries to the Lake. Thus, a comparison to the Stehekin River flows shows that under a pre-dam condition, when all the flow in the River would have been through Reaches 1 through 3, the magnitude of flows would have been substantially greater year-round. As discussed in Section 2.3.3.5, at these higher flows the useable habitat area would be lower (Chelan PUD, 2003), presumably precluding any spawning and incubation of salmonids historically in the Reach 4 high flow channel (Figure 2-1).
Figure 3-2. Comparison of Chelan River Flows to Upstream Flow and Flows in Adjacent Watersheds

3.2 Temperature

Temperature data were analyzed from several high-frequency temperature sensors deployed along the River. Figures 3-3 through 3-6 show the 7-day average of the daily maximum (7-DADMax) temperatures calculated from the hourly temperatures at the end of Reach 1, end of Reach 3, end of Reach 4 habitat channel (hereafter referred as End of Reach 4; also see Figure 2-1 for definition of reach breaks), and powerhouse tailrace, respectively. In all four figures, the 7-DADMax temperature at the LLO and the temperature criterion for salmonid spawning, rearing, and migration are also shown for reference. Temperature data were not collected in Reach 2 because of access limitations.

These figures show that temperatures in the River are driven by the LLO, which in turn is a reflection of the conditions in the Wapato Basin (Section 2.1.3.1). The temperatures in all reaches, and in the LLO, exceed the temperature criterion from mid- to late-spring through early fall in all years. The greatest warming within the River occurs in Reach 1, where the increase in the 7-DADMax temperatures can be 3°C or higher during the summer conditions (Figure 3-3). Further warming is minimal (less than 1°C in most cases) as evidenced by the temperatures at the end of Reach 3 (Figure 3-4) and at the end of Reach 4 (Figure 3-5). The observed solar heating within the River is discussed in greater detail in Section 3.2.1. Conditions in the tailrace are largely similar to the LLO (Figure 3-6). This is a consequence of the underground intake tunnel that eliminates any solar exposure during the transfer to the powerhouse. Warming within the tailrace is minimal because flows are high within the tailrace resulting in short hydraulic residence times.

Figure 3-7 shows the diurnal temperature ranges for spring and mid- and late-summer during average, wet, and dry years. The greatest diurnal temperature fluctuations occur in summer as shown in Section 2.1.3.1 (middle panels for July). The diurnal changes in mid-spring and late-summer are comparable and lower than the range in mid-summer, with some periods showing no diurnal variation at all (for example, see May 2018 and September 2018 panels). These periods reflect high flow conditions in the River. Under these conditions, the temperature in the River is not appreciably different from those of the LLO or the tailrace.
Figure 3-3. Chelan River Temperatures at the End of Reach 1

- **End of Reach 1 (7DADMax)**
- **Temperature Criterion**
- **Low Level Outlet (7DADMax)**

Chelan River Use Attainability Analysis and Site-Specific Criteria Development

December 2019
Figure 3-4. Chelan River Temperatures at the End of Reach 3
Figure 3-5. Chelan River Temperatures at the End of Reach 4
Figure 3-6. Chelan River Temperatures at the Powerhouse Tailrace
Figure 3-7. Hourly Temperatures in the Chelan River Illustrating Diurnal Temperature Variations
3.2.1 Observed Temperature Changes

To assess the extent of solar heating within the River, the change in the 7-DADMax temperature within Reaches 1 through 3 and within the Reach 4 habitat channel were calculated (Figure 3-8). The temperature change was calculated as the difference in the 7-DADMax temperature calculated at the upper and lower ends of each segment from the 2009 to 2018 hourly temperature data. The temperature change is shown as the mean, range, and 90th percentile for each day over the 10-year record. Table 3-1 shows the same data for each month for Reaches 1 through 3 and Reach 4.

Figure 3-8 and Table 3-1 illustrate that the highest temperature changes occur in late April and early May and then again in mid- to late summer. The change in 7-DADMax temperature is generally within 1°C to 2°C from spring to summer on average, but can get as high as 3.5°C immediately before the high flows from snowmelt. As illustrated in Figures 3-3 through 3-6, the river water temperature is approximately 18°C in mid-spring. Thus, the greatest solar heating within the River does not occur in mid-summer when the River 7-DADMax temperatures consistently exceed 21°C and can get as high as 23°C (see Figures 3-3 through 3-5). As discussed in Section 2.1.3.1, the high mid-summer temperatures in the River originate from Lake Chelan when the LLO exceeds 21°C.

The Reach 4 habitat channel shows a similar pattern; however, the extent of temperature change is much smaller compared to Reaches 1 through 3 (change is within 0.5°C most of the time). Between late May and early July (when 7-DADMax temperature ranges from 18°C to 20°C), there is lower solar heating within the River because of higher flows from snowmelt and associated spill to Reaches 1 through 3 (see Figure 3-1 and Figure 3-2 for flows in River). In mid- through early winter, the temperature changes are negative on average in both sections of the River because the Lake water is generally warmer over this period, and the River loses heat to the ambient air.

Note: A positive temperature difference indicates warming within the reach

![Figure 3-8. Temperature Changes in the Chelan River Determined from CRBEIP Data](image-url)
### Table 3-1. Summary of Observed Temperature Changes by Month

<table>
<thead>
<tr>
<th>Month</th>
<th>Reaches 1 Through 3 (°C)</th>
<th>Reach 4 Habitat Channel (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>Median</td>
</tr>
<tr>
<td>January</td>
<td>0.11</td>
<td>0.21</td>
</tr>
<tr>
<td>February</td>
<td>0.92</td>
<td>0.98</td>
</tr>
<tr>
<td>March</td>
<td>1.57</td>
<td>1.62</td>
</tr>
<tr>
<td>April</td>
<td>1.83</td>
<td>1.85</td>
</tr>
<tr>
<td>May</td>
<td>1.34</td>
<td>1.14</td>
</tr>
<tr>
<td>June</td>
<td>0.84</td>
<td>0.59</td>
</tr>
<tr>
<td>July</td>
<td>1.12</td>
<td>1.07</td>
</tr>
<tr>
<td>August</td>
<td>1.30</td>
<td>1.35</td>
</tr>
<tr>
<td>September</td>
<td>0.82</td>
<td>0.91</td>
</tr>
<tr>
<td>October</td>
<td>0.30</td>
<td>0.30</td>
</tr>
<tr>
<td>November</td>
<td>-0.33</td>
<td>-0.29</td>
</tr>
<tr>
<td>December</td>
<td>-0.43</td>
<td>-0.43</td>
</tr>
</tbody>
</table>

**Notes:**
1. Temperature differences are based on 7-DADMax temperature determined from hourly data collected from 2009 to 2018.
2. Temperature change was calculated as end of Reach 3 to top of Reach 1.
3. Temperature change was calculated as end of Reach 4 habitat channel to top of Reach 4 habitat channel.
4. A positive temperature difference indicates warming within the reach.

### 3.2.2 Effect of Flow Changes

The CRBEIP evaluated a range of high flow releases that would limit the warming in Reach 1 (Section 2.3.3.5). The high flows were eliminated from further consideration for the following reasons:

- It reduced the amount of useable habitat area within the River, producing greater scour under higher flows and thereby limiting the activity of periphyton and other primary producers even further.
- The higher flows absorbed and transported more heat to the Columbia River on a cumulative basis, even though the temperature increase within the River was lower than the temperature increases under lower flows (Chelan PUD, 2003). The Columbia River is listed on Washington State’s CWA Section 303(d) list of impaired waterbodies for temperature exceedances. Therefore, it is undesirable to further increase the thermal loading on the Columbia River.

A QUAL-2K model of the River was developed to evaluate the efficacy of additional management options proposed in the CRBEIP including optimization of flow releases from the LLO (WEST Consultants, 2014, 2016). The model was applied to assess flow releases of 80 to 500 cfs for July 2014 meteorological conditions. The study found that the average increase in daily maximum temperature was 0.5°C lower at 200 cfs and 1.5°C lower at 500 cfs. However, under these flows, the model also predicted a concomitant increase in night-time temperatures because water in the Lake and the forebay cool slower than water in the River. Therefore, any thermal refugia that could exist in the River may be affected. These results showed that the net benefit of the flow increases over the entire day were minimal. Furthermore, recognizing that the LLO itself is 20°C or greater through the
summer and early fall period (temperatures much above the current salmonid spawning, rearing, and migration criterion of 17.5°C), these flow increases will not produce a reduction in the river temperature to levels that are optimal for salmonids. When viewed in light of the fact that the higher flows in the River can eliminate any thermal refugia that could exist and limit the useable habitat within the River, these flow increases are unlikely to result in protective conditions for salmonids while also increasing the thermal loading to the Columbia River.

### 3.2.3 Effect of Riparian Shading

The CRBEIP required an evaluation of the potential reductions in the extent of warming within the River that could result from an increased vegetative cover, especially in Reach 1. To address this requirement, a riparian revegetation feasibility study was completed (Herrera, 2015). The predicted long-term improvements in the riparian cover were then simulated in the QUAL-2K model to assess the extent to which warming within the River can be reduced (WEST Consultants, 2016). Modeling results showed that even with the fully mature riparian vegetation estimated in the riparian feasibility study, the reduction in the daytime maximum temperatures relative to the current conditions would be less than 0.2°C within Reaches 1 through 3. These results showed the limited potential for temperature improvements within the River even under a planned and well-managed riparian revegetation program.

### 3.2.4 Effect of Changes to Geomorphic Factors

The CRBEIP required an evaluation of geomorphic factors such as channel depth-to-width ratio and migration of the river thalweg towards the southern and western banks to better use topographic shading. The QUAL-2K model was applied to evaluate these scenarios (Mugunthan and Koontz, 2019). For a scenario with a 50% increase in the depth-to-width ratio (deeper, narrower channel) the model predicted a temperature reduction of up to 0.67°C in the daytime maximum temperature. For a scenario where the river thalweg was shifted 50% closer to the southern/western bank, the model predicted that the reductions in afternoon daytime maximum were offset by the increases in mid-morning temperatures, with a negligible net-benefit. Producing these depth-to-width ratio changes or shifting the channel thalweg can require extensive re-engineering of the channel if an active approach is adopted, or can take a long time (possibly decades) if a passive approach such as strategic placement of boulders or other such structures is used. Site-specific constraints such as slope stability can also limit the extent to which these geomorphic changes can be achieved.

The various temperature reduction scenarios discussed above all show marginal benefits in terms of limiting the daytime maximum temperatures, sometimes with undesirable effects (such as the potential for elimination of thermal refugia in the high flow scenario and/or an increase in mid-morning temperatures under the shifted thalweg scenario). As temperatures exceed 20°C, Cutthroat Trout become lethargic and cease feeding, leading to mortality with prolonged exposure; above 24°C Cutthroat Trout mortality can occur within 7 days (Bear et al., 2007). Recognizing that the LLO temperature exceeded 20°C through most of the summer in nearly all years, and exceeded 24°C for extended periods in many years, the actions above would do little to bring temperatures within the River below the temperature in the LLO.
It is important to put these findings in the context of the biological objective for which these options are being considered and ultimately the highest attainable use in Reaches 1 through 3. If the primary biological objective of improvement of habitat conditions to support a viable, self-sustaining population of Cutthroat Trout were achievable, then it would demonstrate that the salmonid spawning and rearing habitat is an attainable use, which in turn would indicate that other cold water life that are included under that aquatic life use designation could also be supported. As discussed in Section 2.1.3, conditions in the Lake are a major driver of the conditions in the River. While effecting geomorphic changes within the River can marginally limit the extent of further warming, it will not reduce water temperatures below the LLO, and certainly not to levels that would be considered suitable for year-round rearing of Cutthroat Trout (i.e., below 17.5°C criterion for salmonid spawning, rearing, and migration). In Section 3.5.1, in addition to the effects of temperature, the influence of other attributes such as River productivity and spawning substrate that limit the habitat conditions for Cutthroat Trout and other salmonid species are discussed.

### 3.2.5 Temperature Changes Under Future Conditions

Climate change can affect a number of factors that contribute to water temperature increases both in the Lake and in the River. Average air temperatures in the Northwest United States have increased at approximately 0.25°C per decade over the 4 decades from 1976-2015 (Isaak et al., 2018). The air temperature changes and associated flow changes due to earlier snowmelt can be important factors in altering stream temperature regimes and, hence, the aquatic habitat conditions (Isaak et al., 2011; Mantua et al., 2010).

In order to assess the effects of climate change on the River, the QUAL-2K model that was developed to assess the flow, riparian shading, and geomorphic changes (WEST Consultants, 2016; Mugunthan and Koontz, 2019) was adapted to simulate the air temperature changes associated with climate change. For the purpose of this simulation, air temperature increases of 1°C and 2°C were simulated over a 7-day period, which represent approximately 4 and 8 decades of warming respectively at the historically observed rate in the Northwest United States (Isaak et al., 2018). The QUAL-2K model simulations were set up by adding the projected air temperatures to May 2013, September 2013, and July 2014 conditions. These periods were also used for the flow, riparian shading, and geomorphic scenarios, and were therefore adopted here for comparability to keep these simulations consistent with past work.

The predicted maximum temperature changes in the River under current conditions and the associated additional temperature changes resulting from the projected air temperature increases are summarized in Table 3-2. Figure 3-9 shows the predicted temperatures under current and future conditions with the projected air temperature increases. Figure 3-9 and Table 3-2 show that simulated water temperature increases associated with projected air temperature increases are generally small. The greatest changes occur within Reaches 1 through 3, which is expected given the length of Reach 1. Note that the results in Table 3-2 are based on the maximum change in the simulation period. Changes based on the 7-DADmax were similar in magnitude, but are not shown here because each simulation period is only 7 days long. Therefore, the 7-DADmax would essentially have a single result for each simulation. The overall maximum likely provides the worst-case condition for the 7-day period for each simulation and was therefore preferred over the 7-DADmax.
Table 3-2. Predicted Temperature Changes in Response to Projected Air Temperature Increases Due to Climate Change

<table>
<thead>
<tr>
<th>Simulation</th>
<th>Maximum Predicted Temperature Change Within Reach under Current Conditions (°C)</th>
<th>Predicted Additional Temperature Increase in Response to Air Temperature Increase Relative to Base Case (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Reaches 1-3</td>
<td>Reach 4</td>
</tr>
<tr>
<td>May 2013</td>
<td>2.87</td>
<td>0.08</td>
</tr>
<tr>
<td>July 2014</td>
<td>3.57</td>
<td>0.28</td>
</tr>
<tr>
<td>Sep 2013</td>
<td>2.53</td>
<td>0.19</td>
</tr>
</tbody>
</table>

Figure 3-9. Predicted Temperature Changes in the Chelan River from Projected Air Temperature Increases from Climate Change
3.3 Water Quality
The CRBEIP required DO, pH, and turbidity measurements in Reach 4 for a 2-year period that covers the most biologically productive months of July through September (Chelan PUD, 2003). Total dissolved gas (TDG) measurements were required in Reach 1 below the spillway when spill was occurring. Water quality data were collected in accordance with a Quality Assurance Project Plan (Appendix A in Chelan PUD, 2007; Chelan PUD, 2015c). DO and pH data were collected at different periods over the 10 years, and met the CRBEIP requirement of collection over July through September in 2015 and 2018 (Chelan PUD, 2016, 2019). Turbidity monitoring over the growing season was not completed until 2018 because of a change in the monitoring protocols for establishing background turbidity in Reach 4 (Chelan PUD, 2019).

The daily minimum DO levels observed in the Reach 4 habitat channel are shown in Figure 3-10. The daily minimum DO met the 8.0 mg/L criterion for most dates. Occasionally DO levels drifted below the criterion during peak summer conditions, particularly at the top of Reach 4, presumably as a result of higher temperatures (for example, see years 2015 and 2018 in Figure 3-10 and Figure 3-5). A larger decline in DO in November 2015 and declines in spring of 2016 at the top of Reach 4 were attributed to a malfunctioning sensor (Chelan PUD, 2016, 2017).

Figure 3-11 shows the DO saturation in the habitat channel calculated from paired temperature measurements and for an atmospheric pressure of 29 inches of Hg (corrected for powerhouse tailrace elevation of approximately 710 feet above sea level). The figure shows that the majority of the observed DO levels are at or near saturation, except for the periods noted above when there were sensor anomalies or higher temperatures.

Hourly pH measurements in Reach 4 are shown in Figure 3-12. pH remained generally within the applicable pH range criteria. In 2016 and 2018, pH values exceeded the 8.5 criterion for some periods. These exceedances were attributed to possible periphyton activity in 2018 and drifts indicated in the pH sensors for both years during the post-calibration check (Chelan PUD, 2017, 2019).
Figure 3-10. Daily Minimum Dissolved Oxygen in the Chelan River
Figure 3-11. Percent Saturation of Daily Minimum Dissolved Oxygen in the Chelan River Habitat Channel
Figure 3-12. pH in the Chelan River
Figure 3-13 shows turbidity data collected in Reach 4. For evaluating whether the turbidity standard was met, data from the top of Reach 4 was used as the background relative to the end of Reach 4. Of the 1,895 paired hourly measurements between the top and end of Reach 4, less than 1% of the measurements at the end of Reach 4 did not meet the standard (Chelan PUD, 2019). This indicates that an overwhelming majority of the turbidity data meet the turbidity standard.

TDG measurements were conducted in 2016 under spill conditions, with spill flows reaching up to 9,000 cfs. The highest observed TDG saturation was reported as 106.5%, well below the 110% TDG criterion (Chelan PUD, 2017).

3.4 Macroinvertebrates

Based on monitoring and evaluation surveys, the macroinvertebrate community within the River has a low benthic index of biological integrity (B-IBI) and the community is generally reflective of the low productivity conditions within the Lake (Van den Broek et al., 2018). In addition, the species assemblage has limited quantities of the macroinvertebrates that are typically preyed on by stream-dwelling salmonids and the assemblage comprises macroinvertebrate species tolerant of, or that prefer, high temperatures (Van den Broek et al., 2018). The 2018 survey and previous years of macroinvertebrate surveys were summarized by Van den Broek et al. (2018):
The benthic macroinvertebrate species diversity was low in Reach 1, and B-IBI scores were poor to very poor (B-IBI ranged from 15 to 24). The River had lower B-IBI scores than reference streams:

*The mean Chelan River B-IBI metric scores were lower than all comparison streams.*

*Streams from the reference sites, high temperature sites, and lake-fed sites had higher B-IBI scores than the Chelan River.*

Large macroinvertebrates that typically occur in trout rearing habitats and prefer lower temperature ranges were rare in the River (i.e., EPT taxa: Ephemeroptera, Plecoptera, and Trichoptera).

Many of the benthic macroinvertebrate species found in the River prefer or only occur in habitats with higher temperatures:

*The comparison does tend to support a hypothesis that water temperature is a key limiting factor in establishing a high-quality benthic community in the Chelan River, as evidenced by higher temperature preference and occurrence values for all reported taxa found in the Chelan River than for any of the EPT species reported.*

### 3.5 Fish

The 2019 Biological Objectives Status Report (hereafter “2019 BOSR”) was the primary source of information used to characterize fish habitat use in the River. The 2019 BOSR summarized the results of monitoring and evaluation activities conducted during the implementation of the CRBEIP. Additionally, peer-reviewed literature and other reports related to the River and Lake were used to augment the focused monitoring and evaluation activities reported in the 2019 BOSR.

The focal species in the CRBEIP and 2019 BOSR included Westslope Cutthroat Trout (used interchangeably with “Cutthroat Trout” in this report), Chinook Salmon, and steelhead. These species were evaluated in reach-specific contexts (Section 2.1.1) that reflected habitat accessible to each species and proximity to potential source populations capable of colonizing the habitats. More specifically, non-anadromous Cutthroat colonization and habitat use were evaluated in Reaches 1 through 3 because (1) Cutthroat are native to the Lake and River watershed (Table 2-2), and (2) Reaches 1 through 3 were accessible from the Lake both historically and after flows were reestablished as part of the CRBEIP. Anadromous Chinook Salmon and steelhead colonization and habitat use were evaluated in Reach 4 because (1) both species are native to the lower River (i.e., downstream of Reaches 1 through 3), and (2) Reach 4 is accessible from the Columbia River as a route of colonization.

The delineation of anadromous habitat (i.e., Reach 4) and non-anadromous habitat (Reaches 1 through 3) is based on natural barriers to passage in Reach 3 that currently and historically precluded anadromous fish from accessing the Lake or the upper reaches of the River. (BioAnalysts, 2000) conducted a comprehensive review of historical fish assemblage data and literature and determined that (1) anadromous fish did not use the Lake prior to or after Dam construction, and (2) the downstream barriers in the lower River preclude anadromous fish passage. BioAnalysts (2000) provided the following lines of evidence to support this conclusion:
1. **There is no report in the early literature that anadromous fish occurred within the Chelan Basin before the 1900s. There is early literature indicating that salmon and steelhead did not occur in the basin.**

2. **There is no evidence that an Indian fishery occurred in the Chelan Basin before the 1900s.**

3. **The presence of westslope cutthroat trout and the absence of redband/rainbow trout and kokanee (before stocking) indicate that anadromous fish did not occur within the Chelan Basin before the 1900s.**

4. **There is no mention of anadromous fish (before stocking) in the Chelan Basin in the writings of research scientists most familiar with the area.**

5. **There are at least two physical barriers in the Chelan River.**

### 3.5.1 Cutthroat Trout

A comprehensive review of all available data collected during the CRBEIP implementation (Chelan PUD, 2019b) suggested that the presence and abundance of Cutthroat Trout in Reaches 1 through 3 were driven by stocking events of hatchery-origin fish rather than natural colonization or population growth. In addition, the habitat in Reach 1 has temperature, productivity, and morphological characteristics that are unfavorable for sustaining a viable Cutthroat Trout population. As a result, it does not appear that the habitat in Reach 1 will support a viable Cutthroat population.

#### 3.5.1.1 Abundance Patterns

The number of Cutthroat Trout present in Reach 1 closely followed the pattern and timing of stocking within the Lake and River (Figure 3-14). The number of catchable Cutthroat Trout and Rainbow Trout stocked in the Lake and River are summarized in Table 3-3 and Table 3-4. In Figure 3-14, the peak count of Cutthroat Trout in Reach 1 showed a close link to the sequence of stocking activities each year. The overall abundance of Cutthroat Trout increased noticeably between 2014 and 2018 (Figure 3-14) after catchable sized Cutthroat Trout stocking commenced (Table 3-3 and Table 3-4). In 2012 and 2013, no catchable-sized Cutthroat Trout were stocked, and the snorkel counts remained near zero. Within each year that Cutthroat Trout catchables were stocked in the Lake or River, the largest counts occurred either during or after the stocking period (Figure 3-14). While non-native Rainbow Trout were not a focal species of the CRBEIP, they have similar habitat requirements to Cutthroat Trout and their abundance in Reach 1 was also low. The number of non-native Rainbow Trout fluctuated less dramatically than Cutthroat Trout in relation to stocking efforts, and Rainbow Trout counts were generally lower than Cutthroat Trout counts after catchable stocking efforts began for Cutthroat Trout (Figure 3-14).
Figure 3-14. Cutthroat and Rainbow Trout Numbers in Reaches 1 Through 3

Table 3-3. Total Numbers of Catchable Trout Planted in Lake Chelan

<table>
<thead>
<tr>
<th>Year</th>
<th>Quantity Stocked¹</th>
<th>Species</th>
<th>Date Stocked</th>
</tr>
</thead>
<tbody>
<tr>
<td>2018</td>
<td>85,000</td>
<td>Cutthroat Trout</td>
<td>June–July</td>
</tr>
<tr>
<td>2017</td>
<td>100,000</td>
<td>Cutthroat Trout</td>
<td>June–July</td>
</tr>
<tr>
<td>2016</td>
<td>105,000</td>
<td>Cutthroat Trout</td>
<td>June–July</td>
</tr>
<tr>
<td>2015</td>
<td>85,000</td>
<td>Cutthroat Trout</td>
<td>June–July</td>
</tr>
<tr>
<td>2014</td>
<td>50,000</td>
<td>Rainbow Trout</td>
<td>April–August</td>
</tr>
<tr>
<td>2014</td>
<td>40,000</td>
<td>Cutthroat Trout</td>
<td>June–July</td>
</tr>
<tr>
<td>2013</td>
<td>51,000</td>
<td>Rainbow Trout</td>
<td>July–August</td>
</tr>
<tr>
<td>2012²</td>
<td>51,000</td>
<td>Rainbow Trout</td>
<td>July–August</td>
</tr>
</tbody>
</table>

Notes:
1. Data were obtained from the Washington Department of Fish and Wildlife at https://wdfw.wa.gov/fishing/plants/statewide/
2. Cutthroat Trout fry stocking also occurred in 2012
Table 3-4. Total Numbers of Catchable Trout Planted in the Chelan River

<table>
<thead>
<tr>
<th>Year</th>
<th>Quantity Stocked²</th>
<th>Species</th>
<th>Date Stocked</th>
</tr>
</thead>
<tbody>
<tr>
<td>2017</td>
<td>250</td>
<td>Cutthroat Trout</td>
<td>May 18</td>
</tr>
<tr>
<td>2016</td>
<td>203</td>
<td>Cutthroat Trout</td>
<td>May 3</td>
</tr>
<tr>
<td>2015</td>
<td>200</td>
<td>Cutthroat Trout</td>
<td>March 24</td>
</tr>
</tbody>
</table>

Notes:
1. Data source for this table: Maitland, 2018 (personal communication with Joe Miller, October 4, 2018)
2. Cutthroat Trout fry stocking also occurred in 2014

During all of the snorkeling efforts that were conducted during the implementation of the CRBEIP, no juvenile or young-of-the-year Cutthroat Trout were observed in Reaches 1 through 3. In addition, no Cutthroat Trout spawning was ever observed. The absence of spawning or rearing observations, across all study years, is a strong indicator that natural reproduction is not occurring in Reaches 1 through 3.

To determine whether the fish present in Reach 1 actually originated from hatchery stocking efforts, snorkelers also looked for hatchery markings on the fish observed (i.e., adipose fin clips). This evaluation was possible because each year, prior to stocking Cutthroat Trout in the Lake or River, the Washington Department of Fish and Wildlife marked the release group by clipping their adipose fins. The target marking rate for hatchery-origin Cutthroat Trout destined for the Lake and River was 80%. During snorkel surveys conducted between April and September of 2018, the presence of adipose clipped fish was noted in sampling results (BioAnalysts, 2019). Based on the estimated marking rate of fish released in the River and observation of marked fish during the snorkel surveys, the percentage of hatchery fish observed in Reach 1 was 81% and the lower River (Reach 4 and Tailrace) was 86%. The observational error rate for identifying adipose clipped fish during snorkel surveys is not known but could account for an increase or decrease in the relative proportion of putative hatchery-origin fish.

Based on these observations, the majority of the fish observed in the upper and lower reaches of the River originate from hatchery stocking (as opposed to naturally produced fish in the Lake or River). If the fish were naturally produced in the River, there would be some evidence of spawning or early rearing, but no observations of young-of-the-year or yearling Cutthroat Trout or spawning behavior were ever observed during the snorkel surveys (Chelan PUD, 2017b; BioAnalysts, 2019).

3.5.1.2 Habitat Conditions

The opportunity to create habitat suitable for Cutthroat Trout in the River was viewed as a significant challenge in the CRBEIP (Chelan PUD, 2003) because of the natural constraints on productivity within the River:

*The limiting factors analysis (R2 and IA 2000) indicated that natural conditions would be limiting to salmonid fish production in the Chelan River. These factors included unfavorable water temperatures entering the Chelan River from Lake Chelan in the summer; low nutrient levels in the water coming into the River from ultra-oligotrophic Lake Chelan and limited input of terrestrial organic matter; low abundance of invertebrates as a result of the low fertility and warm summer water temperatures; low availability of spawning gravel; and high potential for gravel scour during high flow spill events. The Chelan River receives water from Lake Chelan at*
temperatures that exceed the temperature that results in zero net growth (19°C) for trout and salmon from July through the early part of September (R2 and IA 2000). (Chelan PUD, 2003)

In particular, temperature was viewed as a primary limiting factor for Cutthroat Trout:

Water temperature is a significant, naturally occurring limiting factor for the objectives of establishing a functional aquatic ecosystem and for establishing cutthroat trout habitat in Reaches 1-3. The high water temperatures in summer are likely to limit the species diversity of benthic organisms and could prevent cutthroat trout from persisting or prospering in the summer. Ultimately, the initial water temperature coming from Lake Chelan will be the determining factor for species diversity of the benthic community, independent from the Project’s operations, because the incoming temperature is the greatest determinant of daily mean temperature. Water temperatures exceed the temperature of zero net growth of cutthroat trout for over three months every year. The water temperature is also unfavorable for production of preferred cutthroat food organisms from the benthic community. In addition, the water temperature entering the Chelan River is known to exceed the ultimate upper incipient lethal temperature for cutthroat in a significant number of years. (Chelan PUD, 2003)

Summer water temperatures in the epilimnion of the Wapato Basin regularly exceed the suitable threshold for Cutthroat Trout (greater than 19°C; Williams et al., 2009) and reached levels where lethal and sublethal impacts would be expected. Under laboratory conditions, the ultimate upper incipient lethal temperature⁹ for Cutthroat Trout is 19.6°C at 60 days and 24.1°C at 7 days (Bear et al., 2007). Cutthroat Trout may survive short-term exposure to temperatures in excess of 27°C under certain acclimation conditions (Golden 1978); however, as temperatures approach 20°C, Cutthroat Trout become lethargic and cease feeding (Bear et al., 2007).

In the shallow outlet of the Lake, the summer epilimnion extends from the surface of the Lake to depths at or near the bottom (e.g., 10 meters or ~33 feet). During summer, access to the River would therefore require Cutthroat Trout to swim through the epilimnion for a distance of about 1.5 miles (Figure 3-15). Based on the studies and monitoring efforts reviewed here, it is expected that during the warmest months, the temperatures in this region and the epilimnion, in general, would reach or exceed 19°C. The body of scientific evidence concerning the effects of high temperatures on Cutthroat Trout suggests that Cutthroat Trout would avoid these temperatures (Baldwin et al., 2002) or experience sublethal or lethal impacts as a function of increased exposure to these temperatures (Bear et al., 2007). As such, the epilimnion of the Lake likely acts as a partial or complete thermal barrier to shallow nearshore habitats within the Wapato Basin and to the River itself.

⁹ The upper incipient lethal temperature is the maximum temperature beyond which an organism cannot survive for an indefinite period of time at a given acclimation temperature.
Note: The distance between the dam and 33 feet interpolated isobath is greater than 1.5 miles.

**Figure 3-15. Interpolated Bathymetry of Lake Chelan Showing Approximate Area where a 33-Foot (~10-meter) Depth Epilimnion would Extend from the Surface to the Bottom of the Lake**
In addition to high water temperatures, the use of Reaches 1 through 3 by rearing juvenile Cutthroat Trout is limited by the low productivity of the River. The Lake provides an ultra-oligotrophic water supply to the River, and other sources of external (i.e., allochthonous) nutrients are absent or in short supply. Sources of allochthonous, marine-derived, or riparian-derived nutrients that enrich other salmonid habitats in the Pacific Northwest are non-existent in the upper River. Natural downstream passage barriers preclude anadromous fish from depositing marine-derived nutrients (e.g., Cederholm et al., 1999) in the upper River.

In addition, the limited riparian zone provides minimal opportunities for fluxes of terrestrial nutrients to the River (e.g., Baxter et al., 2005), and the presence of perennial flows is unlikely to dramatically improve the riparian vegetation in the future (Stillwater Sciences, 2001):

*The potential width of the riparian zone and density of riparian vegetation independent of baseflow conditions is constrained. The arid climate, steep moisture gradient in the soil at the active channel/floodplain boundary, and high scouring forces during peak flows likely exceed the physiological limits of long-term survival for most riparian plants.* (Stillwater Sciences, 2001)

The low productivity of the Lake and limited biomass of periphyton in its outlet may limit the establishment of robust upstream invertebrate production/populations that would otherwise provide prey for Cutthroat Trout. As noted in Section 3.4, large macroinvertebrates that typically occur in trout rearing habitats and prefer lower temperature ranges were rare or absent in the River. In addition, other potential sources of marine- and riparian-derived nutrients within Reaches 1 through 3 are absent because of the lack of anadromous fish (Section 2.1.1) and low site potential for riparian vegetation, respectively, in Reaches 1 through 3.

The interactions and feedback loops between riparian vegetation and marine-derived nutrients are important drivers of habitat function in oligotrophic systems and contribute substantially to the creation of habitat complexity necessary to support all freshwater salmonid life history stages (e.g., Naiman et al., 1999; Helfield and Naiman, 2001). In the upper River, these drivers are completely or nearly absent, and the source water for the River, the Lake, is ultra-oligotrophic. Therefore, it is not surprising that the numbers of Cutthroat Trout observed in the River remained low after the temporary effects of stocking subsided. The lack of productivity and interrelated lack of habitat complexity in the upper River likely reduce the overall carrying capacity. The combination of high temperatures superimposed on low productivity further limits the potential for establishing viable populations. This conclusion was predicted during the FERC relicensing process:

*Other factors besides flow may play a greater role in the ability of cutthroat to thrive in Reaches 1 and 2, in particular water quality and food availability. Water temperatures reach ultimate upper incipient lethal temperatures during the summer, and water spilled from Lake Chelan is ultra-oligotrophic. The decreased water quality of this reach limits the suitability of the habitat and prey production in these reaches and may limit use by adult and juvenile trout.* (Stillwater Sciences, 2001)

Because the productivity of the upper River is driven by natural processes within the Lake, significantly improving the productivity of the River would require substantial manipulation of the chemistry of the Lake, which is not reasonable or feasible.
In addition to high temperature, low productivity, and the limited availability of macroinvertebrate prey, the lack of sediment (spawning gravel) supply in the upper River and high-flow habitat attributes also limit the viability of Cutthroat Trout populations. The history and geology of the basin are unusual and contribute to the geomorphology and general lack of upstream sediment supplies:

The Chelan River is anomalous relative to other rivers because it has the flow regime of a 924-mi² (2393-km²) basin, but only derives sediment from the lower 6.4 kilometers of the river. The interception of sediment has been occurring in Lake Chelan since the Pleistocene epoch, whereas in most dammed rivers, sediment interception has been occurring over a much shorter time scale. This has a profound effect on the sediment dynamics and geomorphology of the Chelan River. Because there is no sediment supplied from upstream, sediment is delivered to the channel via local mass wasting events or erosion of the bed and banks. Fine sediments are typically transported through the system upon delivery (Chelan PUD 2000b). The substrate is very coarse and sediment from the channel bed is transported only during very high flow events. This differs from many other rivers where the majority of sediment is transported during bankfull flood events that occur about every 1.5–2 years. (Stillwater Sciences, 2001)

Specifically, the substrate composition and general channel characteristics reflect a high-energy environment shaped by periodic high flows in the spring and summer:

Substrates in the river channel in Reaches 1, 2, and 4 are extremely coarse, which result from pre-dam and current geomorphic conditions characterized by low sediment supply and high transport capacity. (Stillwater Sciences, 2001)

The geomorphology of the Chelan River is not favorable for spawning or incubation stanzas of Cutthroat Trout histories. The lack of smaller spawning gravels and high flows likely prevent spawning in the upper reaches:

Suitable spawning gravels for cutthroat are very scarce in Reaches 1 and 2 of the Chelan River (Chelan PUD 2000b). The majority of gravel in these reaches is located on the channel margins. The results of in-stream flow measurements at transects suggest that this gravel would only be available at flows exceeding 2,000 cfs (57 m3/s) (Chelan PUD 2000b), flows that occur only during spill events. Redds established in the margin would likely be dewatered once the seasonally high flows subside. (Stillwater Sciences, 2001)

The establishment of vegetation is also limited by the high flows and lack of sediment supplies:

However, periodic high flows will likely scour the low-flow vegetated fringe and prevent the long-term establishment and growth of riparian trees. Low sediment supply and high river transport capacity is expected to limit the amount of medium and fine substrates available for plant establishment under any restoration scenario. (Stillwater Sciences, 2001)

The lack of substantial riparian vegetation also decreases the rearing potential of habitats in Reach 1 and 2. Cutthroat Trout typically prefer to rear in habitats with both cover and flow heterogeneity. The lack of riparian vegetation and large wood precludes many habitat-forming processes including the development of pools and other channel complexity. The lack of wood also limits sources of available cover.
Based on the data collected during the CRBEIP implementation and other literature sources, the habitat available to Cutthroat Trout in the upper River is unfavorable for key life history components including spawning, rearing, and incubation. The dominant effects of the Lake on the high summer water temperatures and low productivity of the River limit the opportunity for feeding and growth by rearing salmonids. Natural geomorphic conditions and high flows (both historically and currently) limit the recruitment of spawning sediments and therefore preclude successful spawning or incubation. Given these life history limitations and the prevailing natural conditions driving them, establishing a viable Cutthroat population in the upper River is infeasible.

### 3.5.2 Summer Chinook Salmon

The use and colonization of newly created habitats by Summer Chinook Salmon in the lower River (i.e., habitat channel within Reach 4 and the tailrace areas) were evaluated during the implementation of the CRBEIP and reported in the 2019 BOSR (Chelan PUD, 2019b). Data from the 10-year monitoring and evaluation program demonstrated that Summer Chinook Salmon were able to access the newly created habitats and successfully complete spawning, incubation, and rearing life history stages under the flow regimes identified in the CRBEIP (Section 3.1). The passage barrier precluded Summer Chinook Salmon habitat use upstream of Reach 4.

The successful use of new habitat by Summer Chinook Salmon in the lower River was supported by the following multiple lines of evidence:

- Spawning was documented in every year of the CRBEIP monitoring effort (Figure 3-16) and the density of spawning adults was high compared to other major regional spawning areas in the Wenatchee, Methow, and Columbia rivers (Table 3-5).
- The timing of spawning was also similar to the Summer Chinook Salmon populations in the Wenatchee and Methow rivers (Figure 3-17).
- Incubation success was measured directly using artificial redds and excavation techniques, and the results exceeded the 70% target value identified in the CRBEIP. These egg-to-emergence survival rates were substantially higher than values typically observed for Chinook Salmon (e.g., 30%; Healey, 1991).
- Chinook Salmon fry and rearing juveniles were observed in the River habitat channel and tailrace in the spring months of each year (Figure 3-18). These observations provide evidence that the flows and habitat improvements implemented through the CRBEIP provided rearing habitat used by Summer Chinook Salmon.
- While detailed diet information is not available for rearing Summer Chinook, the habitat channel and tailrace had relatively high zooplankton abundance in spring months. Zooplankton provide a potential food source for rearing fish (Van den Broek et al., 2018). Conversely, zooplankton were nearly absent from Reaches 1 through 3. Van den Broek et al., (2018) suggested that pelagic zooplankton are more likely to be conveyed downstream in the penstock and subsequently transported to the tailrace and habitat channel because the penstock intake is at a higher elevation in water column than the LLO which supplies flow to Reaches 1 through 3.
- The period of juvenile habitat use in the River is aligned with regional life history patterns of Summer Chinook Salmon, where juveniles rear in tributary habitats during the spring and migrate to the mainstem Columbia River in the summer (Figure 3-19).
The productivity of the lower River also appeared to increase after the CRBEIP habitat improvements were completed (Figure 3-20). The sustained increase in natural-origin escapement (i.e., adult fish returning to the River) over the duration of the CRBEIP suggests that increases in abundance were not related to hatchery production or variability in the Columbia River run-at-large.

Table 3-5. Chelan River Habitat Channel Summer Chinook Salmon Redd Densities Compared to Other Regional Spawning Habitats

<table>
<thead>
<tr>
<th>Location</th>
<th>Years</th>
<th>Redd Density (Redds/km)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Avg.</td>
<td>Min.</td>
</tr>
<tr>
<td>Habitat Channel, Chelan River¹</td>
<td>2009-2017</td>
<td>192</td>
<td>105</td>
</tr>
<tr>
<td>Methow River²</td>
<td>2017</td>
<td>7</td>
<td>1</td>
</tr>
<tr>
<td>Wenatchee River²</td>
<td>2017</td>
<td>44</td>
<td>6</td>
</tr>
<tr>
<td>Wenatchee River²</td>
<td>1990</td>
<td>28</td>
<td>1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Redd Density (Redds/m²)</th>
<th></th>
<th>Avg.</th>
<th>Min.</th>
<th>Max.</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Habitat Channel, Chelan River¹</td>
<td>2009-2017</td>
<td>0.013</td>
<td>0.007</td>
<td>0.026</td>
<td>Hillman et al., 2018</td>
</tr>
<tr>
<td>Columbia River, Hanford Reach³</td>
<td>2013</td>
<td>N/A</td>
<td>0.0</td>
<td>0.038</td>
<td>Lindsey and Nugent, 2014</td>
</tr>
<tr>
<td>Columbia River, Hanford Reach; deep-water spawning area³</td>
<td>1986</td>
<td>0.013</td>
<td>N/A</td>
<td>N/A</td>
<td>Swan, 1989</td>
</tr>
</tbody>
</table>

Notes:
1. Density values obtained from the same location across multiple years
2. Density values obtained from all reaches sampled within a single year
3. Density point estimates obtained directly from reference
Figure 3-16. Summer Chinook Adults and Redds Observed in the Powerhouse Tailrace and Reach 4 Habitat Channel
Figure 3-17. Timing of Summer Chinook Spawning in the Chelan River Relative to Adjacent Watersheds
Figure 3-18. Subyearling and Yearling Chinook Salmon Observed in Chelan River Snorkel Surveys
Figure 3-19. Timing of Juvenile Chinook Presence in the Chelan River and Timing of Outmigration in the Methow and Wenatchee Rivers
Notes: Escapement estimates were derived by multiplying the number of redds by the estimated number of fish/redd. Fish/redd was estimated from the sex ratio of Summer Chinook Salmon sampled at Wells Dam.

**Figure 3-20. Estimated Natural-Origin Chinook Salmon Spawning Escapement in the Chelan River 2000-2017**
3.5.3 Steelhead

The colonization and use of newly created habitats by steelhead in the lower River (i.e., habitat channel within Reach 4 and the tailrace areas) were evaluated during the implementation of the CRBEIP and reported in the 2019 BOSR (Chelan PUD, 2019b). Monitoring and evaluation results provided evidence that steelhead had successfully completed spawning, incubation, and rearing life history stages under the flow regimes identified in the CRBEIP (Section 3.1). As noted in Section 3.5, steelhead habitat use was limited to the habitats downstream of Reach 3 due to natural passage barriers in Reach 3.

The successful use of new habitat in the lower River by steelhead was supported by the following multiple lines of evidence:

- Steelhead spawning was documented in every year of the CRBEIP monitoring effort except 2014\(^\text{10}\) (Figure 3-21), and the density of spawning adults was high compared to other major regional spawning areas in Washington and Oregon (Table 3-6).
- The timing of spawning was also similar to the steelhead populations in the Wenatchee and Methow rivers (Figure 3-22).
- Incubation success was measured directly using artificial redds, and the results of the 2018 egg-to-emergence evaluation indicated that incubation survival is high in the constructed habitat channel. The egg-to-emergence survival estimate for the habitat channel (74%) is more than an order of magnitude greater than what previous researchers have used as a reasonable approximation for egg-to-emergence survival in the Methow River (i.e., 6.5%; see Romine et al., 2013). On a broader scale, the egg-to-emergence survival rate in the habitat channel is more than twice as high as the value Quinn (2018) estimated for the species (29.3%).
- Snorkel surveys documented the presence of juvenile steelhead/Rainbow Trout in the lower River (Figure 3-23), which suggests that some rearing is occurring in the new habitat. Steelhead/Rainbow Trout fry/parr were observed in 4 years: 2013, 2014, 2017, and 2018. In 2013 and 2018, large numbers of steelhead/Rainbow Trout fry/parr were observed in the habitat channel snorkel surveys in the 2 months following the estimated date of steelhead/Rainbow Trout emergence. However, steelhead/Rainbow Trout fry/parr (less than 6 inches in length) appeared to leave the new habitat area soon after emergence and observations of these fish declined as temperatures increased in July and thereafter. In years where rearing fry/parr were not observed (e.g., 2016), high flows may have limited monitoring activities that could have detected juvenile fish or high flows may have moved juveniles to downstream rearing habitats (i.e., Columbia River) with lower flow velocities. Specifically, spill usually occurs in late-spring and early-summer, resulting in higher Reach 4 flows during emergence and rearing periods (Figure 3-23). These high flows limit snorkeling activity and may also cause rearing fish to move downstream to velocity refuges.
- The period of spring and summer juvenile habitat use in the River varied among years but appears to overlap with the general period in which steelhead reside in other watersheds.

\(^{10}\) The lack of spawning adults in 2014 was not unexpected because the River did not have a source of returning spawning adults prior to the CRBEIP. More specifically, between 2010 and 2014, almost all of the steelhead spawning adults in the River likely originated as strays from other tributary populations. Therefore, the fact that steelhead were not present in one of these early years is more of a reflection of the abundance of strays from other populations than the suitability of the spawning habitat.
within the region (Figure 3-24). Steelhead have complex life histories and may reside in freshwater habitat for up to 7 years prior to smolting (Peven et al., 1994).

- The productivity of the lower River also appeared to increase after the CRBEIP habitat improvements were completed (Figure 3-25). The sustained increase in natural-origin escapement over the duration of the CRBEIP suggests that increases in abundance were not related to hatchery production or variability in the Columbia River run-at-large. Despite the general success of the Reach 4 habitat enhancements, the opportunity for effective rearing during the warmest months of the year appear limited by high water temperatures. During most years, the majority of steelhead/Rainbow trout (and Cutthroat Trout) observed during the warmer months of July through September were larger fish (greater than 6 inches in length) that may have been moving downstream from the Lake or the upper reaches of the River. Based on the 2018 hatchery marking data (Section 3.5.1), it appears that the Cutthroat Trout did originate from upstream habitats. For both Cutthroat Trout and steelhead/Rainbow Trout, rearing conditions likely yield little or no growth once the temperature exceeds 19°C, as occurred by July 1 in most years of the CRBEIP implementation. There is also no reason to believe that steelhead/Rainbow Trout are specifically adapted to the warm temperatures in the River since colonization of the new habitat only occurred within the past decade. In short, the fish observed in Reach 4 during July through September are likely moving downstream or cease growing as temperatures increase.

Table 3-6. Chelan River Habitat Channel Steelhead Redd Densities Compared to Other Regional Spawning Habitats

<table>
<thead>
<tr>
<th>Location</th>
<th>Years</th>
<th>Redd Density (Redds/km)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Habitat Channel, Chelan River¹</td>
<td>2011–18</td>
<td>16 0 34</td>
<td>Hillman et al., 2018</td>
</tr>
<tr>
<td>Twisp River Mainstem (Methow Basin)²</td>
<td>2011–17</td>
<td>3 0.5 4</td>
<td>Snow et al., 2018 Table 5.15</td>
</tr>
<tr>
<td>Twisp River Tributaries (Methow Basin)²</td>
<td>2011–17</td>
<td>1 0.2 2</td>
<td>Snow et al., 2018, Table 5.15</td>
</tr>
<tr>
<td>Western Oregon and Southwest Washington³</td>
<td>2013</td>
<td>5 2 16</td>
<td>Jacobsen et al., 2013, Table 3</td>
</tr>
</tbody>
</table>

Notes:
1. Density values obtained from the Habitat Channel across multiple years
2. Density values obtained from all reaches across multiple years
3. Average density is for multiple Oregon and southwest Washington winter steelhead basins combined during 2013; Min. and Max. correspond to the lowest and highest individual basin densities observed in the region during 2013
Figure 3-21. Steelhead Adults and Redds Observed in Reach 4 Habitat Channel
Figure 3-22. Timing of Steelhead Spawning in the Chelan River Relative to Adjacent Watersheds
Figure 3-23. Juvenile Steelhead, Rainbow, and Cutthroat Trout Observed in Chelan River Snorkel Surveys
Figure 3-24. Timing of Juvenile Steelhead/Rainbow Trout Presence in the Chelan River and Outmigration Timing in the Wenatchee River

*Chelan River steelhead/rainbow fry and parr primarily observed in 2013; total numbers for other years < 5. Wenatchee River wild steelhead smolt, parr, and fry October data only available in 2013.
Note: Adult passage data were obtained from Columbia River DART (2018) and reflect the “run-at-large” passing Rocky Reach Dam. The number of adult steelhead counted at Rocky Reach Dam are from the year prior to spawning as steelhead typically return during the summer and fall of the year preceding spring spawning.

Figure 3-25. Steelhead Redds Observed in the Chelan River (Black) and Adult Steelhead Counted at Rocky Reach Dam During the Previous Year (Blue) Between 2010 and 2018.
3.5.4 Other Fish Species

The snorkel surveys conducted as part of the monitoring and evaluation program documented the presence of other fish species in the upper reaches of the River (Chelan PUD, 2019b). The native species observed included Whitefish species, Sucker species, Northern Pikeminnow, and Cyprinid fry. Non-native species observed included adult Chinook Salmon (the Lake has a population of non-anadromous Chinook Salmon; see Table 2-2), Tench, and Smallmouth Bass (Chelan PUD, 2019b).

Despite observations of some native fish species in Reach 1, the 2019 BOSR concluded that the establishment of year-round flows has not led to viable, self-sustaining populations of any native species in Reach 1 (Chelan PUD, 2019b). In general, the numbers of native species observed were low and there was no obvious increasing trend for any species over time. All native species had recent observations of (1) zero fish for an entire year of surveys, or (2) only juveniles or adults were present, but not both (i.e., Northern Pikeminnow). For a year-round, self-sustaining population to exist, observations of adults and juveniles would be expected annually. The snorkel survey data did not provide evidence of either stable numbers or an increase in abundance over time (Chelan PUD, 2019b). These conclusions were based on data collected from multiple sampling surveys in each year ranging in number from 2 to 11 events, so there were considerable opportunities under a range of environmental conditions to document each species.

For non-native Smallmouth Bass and Rainbow Trout, which were both observed regularly in the River, the average number of fishes observed during annual snorkel sampling efforts was calculated and plotted to better visualize possible trends (Figure 3-26). Non-native Smallmouth Bass did show plausible signs of colonization and establishment of a population including (1) a general increase in abundance over time, and (2) the regular presence of both juvenile and adult fish. In addition, there is no recent history of stocking Smallmouth Bass in the Lake. For Rainbow Trout, small individuals less than 6 inches were rarely observed and no fry or parr were ever observed in Reach 1. This suggests that the individuals present in the upper River likely originated from the Lake as opposed to a naturally reproducing population in the River. It appears less likely that Rainbow Trout have established a population in the River compared to Smallmouth Bass.

While the non-native species were not the focus of the CRBEIP, the presence and general abundance of Smallmouth Bass may provide some insight into habitat conditions in Reach 1. Specifically, the temperature tolerance of Smallmouth Bass is considerably higher than native salmonids. The upper incipient lethal temperature for this species is 37°C with optimum growth occurring at temperatures above 24°C (Armour, 1993). Whether or not the Smallmouth Bass present in the River are successfully reproducing or have adequate food is unknown, but they appear to be the only fish species with some level of evidence of both colonization and establishing a population.
Figure 3-26. Average Count of Smallmouth Bass per Snorkel Survey Between 2012 and 2018
4. PROPOSED REVISION OF DESIGNATED USES IN THE CHELAN RIVER

4.1 Geographic Scope of Proposed Revision

The natural upstream passage barrier in Reach 3 provides a clear demarcation between different potential aquatic life uses, with anadromous species use limited to areas downstream of the barrier (see Figure 2-1 and discussion in Section 2.1.1). In particular, anadromous salmonids cannot access Reaches 1 through 3 for spawning and rearing and therefore have access only to Reach 4 and adjacent downstream habitats. Reach 4 includes an engineered habitat channel that was constructed to assess whether salmonids can use the channel for spawning and rearing in addition to the high-flow channel and tailrace. Therefore, the proposed revisions to the designated uses are discussed in the context of two specific geographic regions of the River that are delineated by the barrier to passage in Reach 3:

- Reaches 1 through 3 – the first 3.4 miles of the River (see Figure 2-1)
- Reach 4 – the engineered habitat channel, the high-flow channel, and the tailrace (see inset in Figure 2-1)

With respect to Reach 4, it should be noted that the high-flow channel only has flows during spill conditions, and remains dry under non-spill conditions. For the purpose of the revision of designated uses, the high-flow channel is treated as being a part of Reach 4, but with the recognition that flows are ephemeral in the channel. The CRBEIP studies demonstrated that the high-flow channel remains dry during spawning periods (fall and spring for Chinook Salmon and steelhead, respectively) and is not used by salmonids for spawning or juvenile rearing. Additionally, the ramping rates identified in the 401 Certification were designed to avoid stranding of fish during the transition from spill to non-spill conditions and vice-versa in the Reach 4 habitats. Therefore, fish are not expected to make regular use of or become stranded in the high-flow channel.

4.2 Highest Attainable Uses

WAC 173-201A-020 defines designated and existing uses as follows:

“Designated uses” are those uses specified in this chapter for each water body or segment, regardless of whether or not the uses are currently attained.

“Existing uses” means those uses actually attained in fresh or marine waters on or after November 28, 1975, whether or not they are designated uses. Introduced species that are not native to Washington, and put-and-take fisheries comprised of non-self-replicating introduced native species, do not need to receive full support as an existing use.

Revisions to designated aquatic life uses that require less stringent water quality criteria must be based on a UAA as per WAC 173-201A-440(1)-(3) and 40 CFR 131.10(j)(2). USEPA’s regulation 40 CFR 131.10(g) (emphasis is original) further provides:

States may designate a use, or remove a use that is not an existing use, if the State conducts a use attainability analysis . . . that demonstrates attaining the use is not feasible because of one
of the six factors in this paragraph [40 CFR 131.10(g)]. If a State adopts a new or revised water quality standard based on a required use attainability analysis, the State shall also adopt the highest attainable use, as defined in [40 CFR] 131.3(m).

The specific feasibility factors (of the six permissible factors) on which this UAA is based are described in Section 4.3, below. USEPA defines “highest attainable use” as (40 CFR 131.3(m)):

Highest attainable use is the modified aquatic life, wildlife, or recreation use that is both closest to the uses specified in section 101(a)(2) of the [Clean Water] Act and attainable, based on the evaluation of the factor(s) in §131.10(g) that preclude(s) attainment of the use and any other information or analyses that were used to evaluate attainability. There is no required highest attainable use where the State demonstrates the relevant use specified in section 101(a)(2) of the Act and sub-categories of such a use are not attainable.

Thus, any revised aquatic life use designations for the River must reflect the highest attainable uses determined through the UAA.

The highest attainable uses for the River were assessed in the context of these requirements. The CRBEIP studies were the primary basis for determining what biological uses were successfully attained during the studies and are the highest attainable for the River (Figure 4-1). The CRBEIP evaluations focused on highest attainable aquatic life use. Other designated uses are not proposed for revision and were not specifically evaluated.

**4.2.1 Reaches 1 Through 3**

The current, default designated aquatic life use in Reaches 1 through 3 is salmonid spawning, rearing, and migration. The highest attainable aquatic life use in Reaches 1 through 3 is downstream movement of non-anadromous salmonids from the Lake to the Columbia River (Section 3.5.1). Upstream movement of salmonids from Reach 4 to Reaches 1 through 3 is prevented by a natural passage barrier (Figure 4-1). salmonids isolated in headwater systems may represent important repositories of genetic information that can contribute to the diversity and resiliency of downstream populations (Northcote, 1992), so preserving connectivity, even if only in a downstream direction, is beneficial. The River is ultraoligotrophic with limited presence of small, temperature-tolerant macroinvertebrates (Figure 4-1; Section 3.4). Non-native, Smallmouth Bass, which are well suited to warmer water temperatures, were the only fish species that were both represented by multiple age classes and appeared to be increasing in abundance over time (Section 3.5.4).
Figure 4-1. Illustration of Flow Routing Schematic and Habitat Conditions in the Chelan River
4.2.2 Reach 4
The current, default designated aquatic life use in Reach 4 is salmonid spawning, rearing, and migration. The highest attainable aquatic life use in Reach 4 is salmonid spawning, rearing, and migration that occurs from fall through spring. These conditions were made feasible through the enhanced habitat conditions created in the engineered channel (Figure 4-1).

Summer Chinook Salmon spawning was observed in both the habitat channel and the tailrace, in the fall from early-October to late-November, with peak spawning occurring in late-October (Section 3.5.2). Steelhead spawning was observed in the habitat channel during spring, from early-March to early-May, with peak spawning in April (Section 3.5.3).

Juvenile Summer Chinook numbers peak in spring, from late April through early May, with numbers falling rapidly by mid-May (Figure 3-18 and Figure 3-19), suggesting juvenile outmigration is largely completed by mid-May. Juvenile (steelhead and rainbow) trout were observed in the habitat channel through mid-summer (Section 3.5.3; Figure 3-23 and Figure 3-24), and it is reasonable to assume that some of these fish were the progeny of steelhead that had previously spawned in the Reach 4 habitats. However, it could not be definitively determined that all of the juveniles were steelhead fry that emerged in the habitat channel, or if they represented Rainbow Trout moving downstream from the Lake, or if they entered the habitat channel from the Columbia River. The increase in Rainbow Trout numbers in Reach 4 coincided with high flow periods when a similar increase was also observed in Reaches 1 through 3 of both Rainbow and Cutthroat trout (see Figure 3-14 and Figure 3-23). The 7-DADmax temperatures in the habitat channel and tailrace routinely exceed 17.5°C by mid- to late-May and 20°C by early-July (see Figure 3-5 and Figure 3-6) as a result of higher water temperature in the Lake (Section 2.1.3.1). Thus, while the habitat channel and tailrace can support a highest attainable use of salmonid spawning and rearing, such support is likely constrained in summer because of high water temperatures that naturally increase as the Lake warms.

WAC 173-201A-200(1)(a)(iii) indicates that “The key identifying characteristic” of the “salmonid spawning, rearing, and migration” use designation “is salmon or trout spawning and emergence that only occurs outside of the summer season (September 16-June 14). Other common characteristic aquatic life uses for waters in this category include rearing and migration by salmonids.” Thus, for the designated use to be fully supported, salmonid rearing and migration must be supported throughout the year, including the summer season. The discussion above shows that the default salmonid spawning, rearing, and migration use, as defined in the WAC, is not fully attainable in Reach 4, particularly from mid-May through mid-October.

4.3 Proposed Revisions to Designated Uses in the Chelan River
The proposed revisions to aquatic life use designations are illustrated in Figure 4-2 and discussed below. The systematic studies completed in the CRBEIP are the technical foundation for the proposed use change. Findings from the CRBEIP and other studies that support the proposed use change are highlighted below, with references to relevant sections where these are discussed in greater detail.
Based on the highest attainable aquatic life use assessed in the previous section, Chelan PUD proposes that Ecology revise the current default designated aquatic life use of “Salmonid spawning, rearing and migration” to the highest attainable use, “Limited Downstream Migration.” The following definition is proposed for this revised aquatic life use in Reaches 1 through 3 of the River:

The key identifying characteristic of “Limited Downstream Migration” is the downstream transit of salmonids from Lake Chelan to the Columbia River without access to significant food, cover, or other habitat attributes necessary to support spawning or rearing within Reaches 1-3 of the Chelan River.

USEPA’s regulations set forth six permissible factors on which a determination may be made that a designated use is not attainable (40 CFR 131.10(g)). Of these six, this UAA relies on the following factors:

§ 131.10 (g)(5) – Physical conditions related to the natural features of the water body, such as the lack of a proper substrate, cover, flow, depth, pools, riffles, and the like, unrelated to water quality, preclude attainment of aquatic life protection uses

This factor is used as the primary basis for the proposed aquatic life use change. As illustrated in Figure 4-1, the following physical conditions preclude attainment of the default designated aquatic life use:
1. Presence of a natural passage barrier – Steep gradients in Reach 3 are a natural upstream passage barrier for anadromous salmonids (R2 and IA, 2000; Section 2.1.1).

2. Lack of riparian cover – The natural lack of substantial riparian vegetation decreases the rearing potential of habitats. The habitat benefits from the estimated extent of maximum riparian cover are not anticipated to be significant (Herrera, 2015; Sections 3.2.3 and 3.5.1.2).

3. Lack of proper substrate – The limited sediment supply from the Lake and intermittent high flows following spring snowmelt, both of which are naturally inherent to the system and existed before any anthropogenic changes, do not provide conditions favorable for formation of spawning substrate (Stillwater Sciences, 2001; Section 3.5.1.2).

The conditions above demonstrate that salmonid spawning, rearing, and migration cannot be supported in Reaches 1 through 3 of the River. The biological data assessed and discussed above are consistent with these conditions in that no spawning or rearing of multiple age classes of cold water fish species (including salmonids and trout) were observed within Reaches 1 through 3 in nearly 10 years of systematic monitoring (Section 3.5.1.1).

§ 131.10 (g)(1) – Naturally occurring pollutant concentrations prevent the attainment of the use

While the physical conditions described above under factor (5) alone preclude the attainment of aquatic life uses higher than the proposed use, naturally high temperatures and naturally low productivity in the River also preclude the attainment of higher aquatic life uses.

The Lake has a dominant effect on productivity and temperature in the River (Section 2.1.3). The unique morphometric and geographical conditions in the Lake would have resulted in similar or possibly worse water temperatures in the River even without the Project11 (Section 2.1.3). Temperature data collected in the lower Lucerne and upper Wapato basins, which are far removed from the dam, showed temperatures in the epilimnion that routinely reached 20°C or more in peak summer conditions (Figure 2-5 and Figure 2-6). An evaluation of the bathymetric data showed that under a no-Project scenario the lower Wapato Basin would have been much shallower, and therefore subjected to greater solar heating under non-snowmelt conditions, resulting in even warmer temperatures than under current conditions (Figure 2-4 and discussion in Section 2.1.3.1).

The Lake is also ultra-oligotrophic (Pelletier et al., 1989). The nutrient-poor waters from the Lake when coupled with the lack of nutrient inputs within the River limits the macroinvertebrate diversity, and hence the food available for fish within the River (Sections 2.1.3.2 and 3.4). In addition, temperatures within the River appear to limit the establishment of a high quality benthic invertebrate community (Section 3.4) and therefore limit the attainment of cold water habitat in Reaches 1 through 3.

The temperature in the Lake is a naturally occurring condition inherent to the system that precludes the attainment of the default designated aquatic life use within the River (i.e., high

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11 As discussed in Section 2.1.3 “the Project” refers to Lake Chelan Hydroelectric Project, which includes the Lake Chelan Dam.
temperatures that are lethal for native cold water fish such as Cutthroat Trout). Even though the system is modified at present due to the presence of the Dam, existing data provide strong support that the temperature conditions in the Lake, and therefore the River, would have been similar or worse during low flow conditions in spring through fall under a pre-dam scenario.

4.3.2 Reach 4

As established in Section 4.2.2, salmonid spawning and rearing occurs from mid-October to mid-May, but water temperatures in summer that routinely exceed 20°C limit the year-round attainment of this use. Based on the observed salmonid use of the Reach 4 habitat channel and tailrace, and the observed temperatures in the Lake and River, Chelan PUD proposes that Ecology revise the aquatic life use designation for Reach 4 to “Limited salmonid spawning, rearing, and migration” as the highest attainable use. The following definition is proposed for this change to aquatic life use in Reach 4 of the River:

The key identifying characteristic of “Limited salmonid spawning, rearing, and migration” in Reach 4 of the Chelan River is salmon or trout spawning and emergence that only occurs from mid-fall to mid-spring (October 16 – May 14).

The § 131.10(g) factor (1), Naturally occurring pollutant concentrations prevent the attainment of the use, is the basis for this proposed change in the designated aquatic life use. The pollutant in this case is heat, which results in excessively high water temperatures from mid-spring through early fall. The following two natural factors contribute to these excessively high temperatures in the Reach 4 habitat channel and tailrace:

1. High temperatures in the Lake provide warm source water for Reaches 1 through 3 and the Project tailrace in Reach 4 (Section 2.1.3.1). Even though the tailrace derives the coldest available water from the Dam’s forebay, it is still 17.5°C or greater from mid-spring to early-fall because of the influence of the Lake, as evidenced by comparing temperatures at the end of Reach 4 (and in the tailrace) to the LLO temperatures in Figure 3-5 and Figure 3-6, respectively. Observed temperatures in the Wapato and lower Lucerne basins indicate that warming increases through the Wapato Basin (see Figure 2-8). These conditions would have been naturally inherent to the River even prior to the Project, with probably higher temperatures in summer than at present because of a shallower Wapato Basin (Section 2.1.3.1 and Figure 2-4).

2. Even at the estimated extent of maximum riparian cover in Reaches 1 through 3, solar heating is not anticipated to be significantly lower than what occurs at present (Herrera, 2015; Section 3.2.3). Therefore, water temperatures entering Reach 4 from Reaches 1 through 3 may continue to be at high levels that prohibit the attainment of salmonid spawning, rearing, and migration during summer.

It is important to note that the Project cannot be operated in a way that can reverse the upstream natural heating that occurs in the Lake. Thus, even though the River is a modified system, the source of pollutant (i.e., heat) is primarily the result of natural conditions that reflect the bathymetry of the Lake basin, watershed hydrology, and local climate.
5. DEVELOPMENT OF SITE-SPECIFIC AQUATIC LIFE WATER QUALITY CRITERIA

5.1 Approach to Developing Site-Specific Water Quality Criteria

Water quality criteria for the River should be reconciled to reflect the proposed revisions to the designated uses in Section 4. The water quality criteria proposed in this section are specific to the River because of the unique characteristics of the Lake and River system that result in warm conditions particularly in summer months (Figure 5-1). While dry weather and warm water conditions in summer exist in several streams in Central Washington, the combination of a long, narrow lake as the main source water, arid conditions, and a very short stream (approximately 4 river miles) that conveys a large volume of water with little to no watershed-driven sediment load makes the River unique (Figure 5-1). In addition, there are other important site-specific constraints that affect the water quality (specifically temperature) of the River, including the following:

- Lake temperature
- Limited flexibility in altering flow within Reaches 1 through 3 due to:
  - The detrimental effect of higher flows on the useable habitat within the River (Sections 2.3.3.5 and 3.2.2)
  - The need to maintain the Lake levels per FERC license requirements for protecting the existing and designated uses in the Lake (Section 2.1.3.4)
  - Greater thermal loading to the Columbia River when flow is released through Reaches 1 through 3 (Section 3.2.2)

Site-specific water quality criteria development is centered on temperature because it is the primary water quality parameter that does not meet the existing temperature criteria and also poses a limitation on aquatic habitat suitability. Other parameters, such as DO, can be affected by temperature, but in general, the observed data have shown that there are no critical water quality issues that preclude the existing default designated aquatic life use in the River besides temperature (Section 3.3). The proposed water quality criteria, however, include an alternative site-specific DO saturation criterion to the extent that temperature and atmospheric pressure preclude achievement of the DO concentration criterion.

The overall approach for developing the site-specific temperature criteria centers on maintaining the existing conditions that support the highest attainable aquatic life use in the River. The warmest temperature conditions occur from mid-May through mid-October when the lower portions of the Lake (Wapato Basin and the forebay) reach temperatures that are harmful to salmonids (Figure 5-1; Section 2.1.3.1). Because the high temperature originates in the Lake and the extent of solar heating controls further increases within the River, the site-specific criterion is developed on the basis of these two factors. Finally, the proposed criterion also considers the warming within the River in response to long-term air temperature changes projected for the region as a result of climate change (Section 3.2.5).
“Representative Mid-Summer Conditions”

1. During summer months, water temperatures may exceed salmonid tolerance limits in all habitats less than 25 ft deep in the outlet of Lake Chelan. Longitudinally, mid-summer lake surface temperatures in excess of 20°C were observed at distances of 5-10 miles from the dam in all recent years (2016-2018).

2. During July, August and September, Lake Chelan Outlet water temperatures frequently exceed salmonid thermal tolerance limits prior to entering the LLO and Generation Intake/Penstock.

3. Tailrace flows from generation are not subject to solar heating because they are conveyed through an underground penstock. Therefore, generation tailrace water temperatures remain more similar to Lake Chelan outlet temperatures as compared to the flows in the Chelan River.

4. During the warmest summer months, pump-back flow offers little thermal benefit to salmonids because the “coolest” source water in the tailrace originates from Lake Chelan and already exceeds salmonid thermal tolerance limits.

5. As the Chelan River flows downstream, surface water temperatures increase because of solar heating. This heating can account for water temperature increases of >3°C (LLO and end of Reach 3).

Figure 5-1. Illustration of Site-Specific Conditions that Result in High Mid-Summer Temperatures
5.2 Proposed Temperature Criteria

Conceptual representations of the current default temperature criterion and proposed site-specific temperature criteria for the River are shown in Figure 5-2. The application of the proposed site-specific temperature criteria follows the distinct geographic regions of the River discussed in Section 4.1. The objective of the site-specific criteria is to maintain the extent of warming within the River to current conditions after accounting for the temperature of the source water (background).

![Figure 5-2. Conceptual Illustration of Proposed Site-Specific Temperature Criteria for the Chelan River](image)

For Reaches 1 through 3 the source water is the Lake forebay, from which minimum instream flow releases occur from the LLO, and under snowmelt conditions water is spilled from the Dam. The LLO represents the coldest water available in the forebay. Therefore, the LLO is proposed as the background for Reaches 1 through 3.

For Reach 4, two distinct backgrounds apply as illustrated in Figure 5-1. The habitat channel and high-flow channel receive water predominantly from the end of Reach 3 (except for spawning and incubation periods when the pump-back flows may be optionally used to supplement flows in the habitat channel). The source water for the tailrace is the powerhouse.

The extent of allowable warming within the River will be limited to a fixed numeric value that would apply year-round and that is representative of the reasonable worst-case solar heating within
Reaches 1 through 3 and Reach 4 of the River. This will allow the maintenance of the existing
temperature regime in the River for the current range of instream flows and site-specific constraints,
but will not allow any new sources of heat that can cause an increase beyond the numeric criterion.

Determining a reasonable worst-case is relatively straightforward for Reaches 1 through 3, since
there is a clear location for the upstream background (LLO) and a single exit location (end of
Reach 3) from which the temperature change can be determined. However, for Reach 4, determining
a reasonable worst-case requires a more careful consideration of the conditions in the habitat
channel, high-flow channel, and the tailrace. The worst-case will occur for the section with the
greatest residence time. The high-flow channel has intermittent flow, typically during spill conditions
when water residence time is small. The habitat channel has year-round flows including the minimum
instream flows (80 cfs) under non-spill conditions, supplemental spawning and incubation flows (up
to 260 cfs), and a portion of the spill flows under spill conditions (Table 2-4; Figure 3-1). The tailrace
has substantially higher flows year-round (Figure 3-1) over a section that is shorter than both the
habitat and the high-flow under non-spill conditions (Figure 2-1). Thus, the habitat channel has the
lowest flows and, given the length of the channel relative to the tailrace, has the longest residence
times. Therefore, a reasonable worst-case extent of solar heating assessed for the habitat channel will
be greater than the worst-case solar heating for the high-flow channel and the tailrace. The numeric
criterion for maximum extent of temperature increase in Reach 4 was developed based on the
reasonable worst-case for the habitat channel.

5.2.1 Duration, Magnitude, and Frequency of the Numeric Criterion
Numeric criteria have three components: criteria magnitude, which defines the level of the
constituent that must be met; duration, which defines the averaging period over which the
magnitude must be met; and, frequency, which defines the length of time (return period, typically as
years) over which an excursion over the magnitude may occur (USEPA, 2017; Ecology, 2018).

The reasonable worst-case temperature increases under the current conditions derived herein for
Reaches 1 through 3 and Reach 4 are recommended for consideration as the magnitude of the
numeric criterion. With few exceptions, the duration of freshwater aquatic life use temperature
criteria in the Washington State water quality standards are specified in terms of the 7-DADMax
temperature. The same approach is adopted here for the duration component of the criterion.
WAC 173-201A-200-1(c)(iii) requires that the numeric temperature criterion must not be exceeded at
a probability frequency of more than once every 10 years. This frequency is adopted in developing
the numeric criterion for the River.

5.2.2 Statistical Approach for Determining Magnitude of the Numeric
Temperature Criterion
A statistical bootstrapping approach was adopted for determining a reasonable worst-case
temperature increase under current conditions for Reaches 1 through 3 and Reach 4. Appendix A
provides a detailed discussion of the statistical analysis that was conducted to develop the proposed
site-specific criteria. In summary, the bootstrapping analysis constructed 1,000 sets of paired,
hypothetical 365-day time series of 7-DADMax temperatures at the background (upstream) and
downstream extents by resampling from the daily maximum temperature data collected during the CRBEIP studies. From the paired background and downstream 7-DADMax values, the numeric increase within Reaches 1 through 3 and the Reach 4 habitat channel were calculated for each day. For each 365-day period, numeric temperature increases of up to 5°C were evaluated at 0.25°C increments to identify what represents a reasonable worst-case under current conditions. Finally, the anticipated water temperature increases under projected air temperature increases from climate change (from Section 3.2.5) were added to the reasonable worst-case estimates to derive the numeric criteria.

Based on the analysis above, the following reasonable worst-case temperature increases were derived:

- Reaches 1 through 3 – a maximum increase in the 7-DADMax temperature of less than 3.6°C when measured at the end of Reach 3 relative to the background (LLO)
- Reach 4 – a maximum increase in the 7-DADMax temperature of less than 1°C when measured at the end of each segment in Reach 4 over the background (background for both the habitat channel and the high-flow channel is the end of Reach 3; background for the tailrace is the powerhouse)

For both Reaches 1 through 3 and Reach 4, it is recommended that within any given year an exceedance be defined as two or more non-overlapping 7-DADMax temperature increases that are greater than the corresponding numeric criterion (see Appendix A for description of non-overlapping period). The approach is reasonable because atmospheric weather patterns typically last several days and can produce sustained warm air temperature conditions, which can result in one or more exceedances over the numeric criterion more easily. If only a single exceedance is considered, then the reasonable worst-case numeric criterion must be higher for the same set of conditions to avoid frequent exceedances. Thus, determining the exceedances on two or more non-overlapping periods within each year will provide a more robust assessment of a shift from the current temperature regime in the River while also enabling a smaller magnitude for the numeric criterion (see Appendix A).

Finally, in order to maintain the existing condition, it is recommended that the cumulative effects of any anthropogenic sources of heating within both Reaches 1 through 3 and Reach 4 be limited to a 7-DADMax of 0.3°C or less in addition to the numeric criteria proposed above.

### 5.2.3 Protection of Existing and Designated Uses

The site-specific temperature criterion proposed above for Reaches 1 through 3 is protective of the highest attainable aquatic life uses that were observed under the current conditions. Recognizing that the Lake poses the largest constraint on the conditions in Reaches 1 through 3 and that Lake temperatures routinely reach harmful and sometimes lethal levels for Cutthroat and Rainbow trout in summer, such conditions will also extend downstream into the River. Snorkeling surveys showed that Cutthroat Trout use Reaches 1 through 3 primarily for downstream transit and do not use these areas for rearing (Section 3.5.1.1). Therefore, it is anticipated that their residence within Reaches 1 through 3 will be short, and that, when temperatures in Reaches 1 through 3 become harmful, they can move farther downstream to sufficiently cooler waters either in Reach 4 or in the Columbia River (as indicated by the precipitous decline in Cutthroat Trout numbers in summer in Reaches 1 through 3, and a concomitant increase followed by a decrease in numbers in Reach 4; see Figure 3-14 and Figure 3-23). Finally, the low benthic invertebrate B-IBI scores observed during the monitoring conducted as part...
of the CRBEIP are not expected to decline from the proposed change to the designated use because the current assemblage already reflects the impacts of high temperatures (Section 3.4).

CRBEIP data have demonstrated that the high temperature conditions in the summer within Reaches 1 through 3 do not preclude the successful downstream spawning and juvenile rearing of anadromous salmonids in the Reach 4 habitat channel because such use occurs largely outside the period when temperatures are high.

Similarly, the proposed site-specific temperature criterion for Reach 4 will be protective of salmonid spawning and rearing when the use has been documented to occur (i.e., from fall through spring). Outside the October 15 to May 14 window, the uses in Reach 4 generally appear to be downstream movement of Rainbow and Cutthroat trout from upstream. Furthermore, any fish that get to the Reach 4 habitat channel from upstream will have access to the Columbia River, which will serve as an additional thermal refuge in summer, when it is cooler in the Columbia River relative to the River.

Finally, the proposed temperature criteria for Reaches 1 through 3 and Reach 4 were also developed to limit the thermal load to the Columbia River such that downstream uses in the Columbia River are not affected. In particular, higher flows through Reaches 1 through 3 will result in a greater volume of water that is subjected to solar heating within the River, and, therefore, will increase the thermal load to the Columbia River. The flows determined in the CRBEIP studies were optimal from the standpoint of maintaining useable habitat within Reaches 1 through 3 while also minimizing the thermal loading to the Columbia River (Section 2.3.3.5).

### 5.3 Other Water Quality Parameters

#### 5.3.1 Dissolved Oxygen

DO data collected in the Reach 4 habitat channel showed that the daily minimum DO has generally remained above 8.0 mg/L and at or near saturation (Section 3.3). This indicates that temperature and barometric pressure (which in turn is related to the altitude) are the primary drivers of DO levels. Therefore, a minor revision to the existing 8 mg/L criterion is proposed to account for the effects of temperature, altitude, and barometric pressure as follows:

The daily minimum DO shall not go below 8.0 mg/L; where conditions of barometric pressure, altitude, and temperature preclude attainment of the 8.0 mg/L criterion, DO levels must not be less than 90% of saturation.

A similar DO standard has been adopted for salmonid spawning and rearing in Washington State water quality standards for the lower Columbia River from its mouth to the Washington-Oregon border near Port Kelley and has been approved by USEPA (WAC 173-201A-602, Table 602).

No changes are proposed for any of the other criteria including turbidity, pH, TDG, aesthetics, toxic, radioactive, and deleterious material.
6. CONCLUSION

The Settlement Agreement, 401 Certification, and FERC license have provided a framework for evaluating the highest attainable aquatic life uses within the River. The CRBEIP is a systematic monitoring and evaluation program implemented as a condition to the FERC license and the Settlement Agreement to assess what uses are attainable in the River following restoration of year-round flows. The CRBEIP provided a broad suite of engineering and habitat enhancement actions that were designed to improve conditions for aquatic life. Chelan PUD implemented these actions and collected flow, temperature, water quality, and biological data over a 10-year period to assess the effects these actions on aquatic life within the River.

The findings from the CRBEIP studies and other site-specific data demonstrate that the highest attainable uses in the River are different in Reaches 1 through 3 and Reach 4. A natural passage barrier in Reach 3 precludes the upstream migration of salmonids from the Columbia River. The highest attainable aquatic life use documented for Reaches 1 through 3 is the downstream movement of Cutthroat and Rainbow Trout from the Lake to the Columbia River. Cutthroat Trout were not observed to use Reaches 1 through 3 for spawning. Furthermore, the absence of multiple age classes of cold water salmonids and strong correlation of fish numbers with River and Lake stocking efforts using hatchery-derived Cutthroat Trout indicated that the cold water juvenile salmonids do not rear in Reaches 1 through 3. Macroinvertebrate, riparian, and temperature data collected during the CRBEIP provide additional evidence that the habitat for spawning and rearing is very limited or non-existent. The Lake is a major driver of temperature and productivity in the River. Temperature data from the Wapato and lower Lucerne basins consistently exceeded 20°C during the summer period. Furthermore, a review of the Lake's bathymetry data showed that the lower Wapato Basin would have been warmer under a pre-dam condition in summer, leading to warmer conditions within the River, and possibly providing greater thermal loading to the Columbia River than under current conditions.

In Reach 4, the habitat channel that was constructed as part of the CRBEIP was successful in providing a suitable habitat for Summer Chinook Salmon and steelhead spawning and juvenile rearing. CRBEIP data demonstrated returning adults spawning in the habitat channel. The spawning and juvenile rearing occurred predominantly from mid-October to mid-May. High temperatures in the River from late spring through early fall, that originate from the Lake, limit the use of the habitat channel over this period for salmonids. These findings demonstrate that the highest attainable aquatic life use in Reach 4 is salmonid spawning and rearing from mid-fall through mid-spring.

Based on the findings from the CRBEIP, this UAA proposes the following revisions to the aquatic life use designations in Washington’s water quality standards to the following highest attainable use designations and associated site-specific criteria:

- Reaches 1 through 3 – Revise aquatic life use to “Limited Downstream Migration” as the highest attainable use. The key identifying characteristic of “Limited Downstream Migration” is the downstream transit of salmonids from Lake Chelan to the Columbia River without access to significant food, cover, or other habitat attributes necessary to support spawning or rearing within Reaches 1 through 3 of the Chelan River.
• Reach 4 – Revise aquatic life use to “Limited salmonid spawning, rearing, and migration” as the highest attainable use. The key identifying characteristic of “Limited salmonid spawning, rearing, and migration” in Reach 4 of the Chelan River is salmon or trout spawning and emergence that only occurs from mid-fall to mid-spring (October 16 – May 14). Other uses include limited downstream migration of salmonids from Lake Chelan and Reaches 1 through 3 of Chelan River to the Columbia River.

• This UAA also proposes the following framework for year-round site-specific temperature criteria as follows:
  - Reaches 1 through 3 – limit the extent of warming within the River to a numeric value that is expressed as the 7-DADMax temperature measured at the end of Reach 3 minus the 7-DADMax background temperature measured at the LLO.
  - Reach 4 – limit the extent of warming within the River to a numeric value that is expressed as the 7-DADMax temperature measured at the end of each segment in Reach 4 minus the 7-DADMax background temperature measured at the end of Reach 3 for the habitat channel and the high-flow channel and at the powerhouse for the tailrace.
  - For both criteria, an exceedance is two or more non-overlapping 7-DADMax temperature increases above the corresponding numeric values in any calendar year.
  - Limit the cumulative effects of any new anthropogenic sources of heating within both Reaches 1 through 3 and Reach 4, including the tailrace, to a 7-DADMax increase of 0.3°C in addition to the corresponding numeric criteria above.
  - The numeric criteria may not be exceeded at a frequency of more than once in every 10 years.

• The proposed site-specific criteria will be protective of the salmonid spawning and rearing when it occurs in Reach 4 and will also limit thermal loading to the Columbia River.

• The UAA proposes that the daily minimum DO shall not go below 8.0 mg/L; where conditions of barometric pressure, altitude, and temperature preclude attainment of the 8.0 mg/L criterion, DO levels must not be less than 90% of saturation.

• Revisions to other aquatic life use water quality parameters are not proposed.

Based on a statistical evaluation of observed temperature increases within the River, and after considering the effects of climate change on air temperature increases and its associated impacts on water temperature increases within the River, the following year-round, maximum temperature increases are recommended for consideration as the magnitude of the numeric criteria in the framework above: a 7-DADMax temperature increase of 3.6°C within for Reaches 1 through 3 and a 7-DADMax temperature increase of 1.0°C in Reach 4.
7. REFERENCES


Chelan PUD (Public Utility District No. 1 of Chelan County), 2003. Lake Chelan Hydroelectric Project Comprehensive Settlement Agreement, Final, Lake Chelan Hydroelectric Project, FERC Project No. 637.


for Marcie Clement and Bill Towey, Public Utility District No. 1 of Chelan County, March 25, 2019.


APPENDIX A

STATISTICAL EVALUATIONS OF TEMPERATURE INCREASES IN THE CHELAN RIVER TO INFORM THE DEVELOPMENT OF A SITE-SPECIFIC CRITERION
BACKGROUND

Chelan County Public Utility District No. 1 (Chelan PUD) is developing a Use Attainability Analysis (UAA) for the Chelan River (River) for revising the aquatic life uses to reflect the highest attainable use in the River (the main sections of this Report). The UAA establishes that site-specific conditions in the Chelan River-Lake Chelan system limit the attainment of the current default designated uses. One of the principal factors that limit the highest attainable use is high water temperatures originating from Lake Chelan (Lake). During the period between mid-spring through mid-fall, warm water exiting the Lake undergoes further solar heating within the River, and there are no reasonable or feasible measures to reduce heating without causing further degradation of useable aquatic habitat.

Therefore, in order to protect the current, highest attainable aquatic life uses in the River, the UAA includes recommended site-specific temperature criteria that would limit any further anthropogenic warming within the River. The recommended criteria are set at the maximum temperatures that occur as a result of solar heating in the River under the current operations of the Lake Chelan Hydroelectric Project (Project), which the UAA has determined result in the highest attainable aquatic life uses in the River. The numeric limits on the extent of solar heating within the River would apply over the background temperature at the upstream boundary of Reaches 1 through 3 and the upstream boundary of Reach 4 of the River (Figure A-1). The interpretation of background temperature is discussed below.

![Figure A-1. Chelan River Reaches and Locations of Background Site-Specific Temperature Criteria](image-url)
The Washington State Department of Ecology’s (Ecology) Water Quality Policy Guidance Document indicates that any numeric criterion for a water quality parameter represents a goal that is the measured magnitude (i.e., level of that parameter; Ecology, 2018). In addition, the numeric criterion may specify the acceptable frequency (how often this level must be met) and duration (time of exposure to this level; Ecology, 2018). In order to assess whether a water body meets the numeric temperature criterion when high frequency data are available (as is frequently the case for water temperature), the Water Quality Policy Guidance Document indicates if the magnitude is not met for two or more non-overlapping durations within a given year then the water body will be considered to have exceeded the numeric criterion (Ecology, 2018). Furthermore, Washington Administrative Code (WAC) 173-201A-200(1)(c)(iii) requires that the numeric temperature criteria specified in the rule not be exceeded at a probability frequency of more than once every 10 years.

This memorandum provides a statistical analysis of temperature data to characterize the extent of temperature increases within the River and the duration and frequency of increases. The data used for this analysis were collected between January 2010 through August 2019 in support of the Chelan River Biological Evaluation and Implementation Plan (Chelan PUD, 2011-2019).

Chelan River Reaches Considered in the UAA

The UAA considers the following two distinct sections of the River where the highest attainable aquatic life uses are different and where different upstream background conditions apply for the site-specific temperature criteria:

- For Reaches 1-3, the low-level outlet (LLO) is used as the background temperature.
- For the habitat channel and the high-flow channel in Reach 4, the background temperature is the temperature at the end of Reach 3; and for the tailrace in Reach 4, the background temperature is the temperature at the powerhouse.

In Reach 4, river water residence time in the habitat channel is greater during minimum instream flows (i.e., non-spill conditions) relative to the tailrace, which is not only shorter but also receives much higher flows from the powerhouse thereby significantly reducing the residence time therein (Figure A-1). The Reach 4 high-flow channel typically experiences flow only during spill conditions when travel times are much faster throughout the system. Therefore, the habitat channel experiences the most exposure to solar radiation of all segments in Reach 4. As a result, the limit on numeric increase in the site-specific temperature criterion for Reach 4 is developed based on the temperature increase between the end of Reach 3 and the end of the habitat channel. This increase is proposed to apply for all the other segments of Reach 4, where the actual solar heating that would occur is expected to be much lower.

**APPROACH FOR ESTIMATING TEMPERATURE INCREASE**

With few exceptions, the duration of freshwater aquatic life use temperature criteria in the Washington State water quality standards are specified in terms of the 7-day average of the daily maximum (7-DADMax) temperature. The same approach is adopted here for the duration component of the criteria. The 10-year temperature monitoring data from the LLO, the end of Reach 3, and the end of the Reach 4 habitat channel (hereafter referred as end of Reach 4) were measured hourly and
provide the daily maximum temperature from which 7-DADMax temperature and the corresponding maximum heating that has occurred within Reaches 1 through 3 and the Reach 4 habitat channel, respectively, can be calculated. However, because the data is limited to a 10-year period, it does not fully represent the range of conditions the River may experience and introduces some uncertainty in both the magnitude of the observed increase and the frequency at which such an increase may occur. To better represent the variability in the underlying population a statistical simulation approach, the bootstrapping methodology, is adopted.

**Bootstrapping Methodology**

Bootstrapping is a data-based simulation method in which samples are randomly drawn with replacement from existing data to produce a large number of hypothetical data sets that can then be used to make statistical inferences of the underlying population (Efron and Tibshirani, 1993). This is a commonly used technique for estimating the population properties without imposing restrictive structural assumptions such as a pre-specified probability model (Efron and Tibshirani, 1993; Lahiri, 2003; Kreiss and Lahiri, 2012).

For the River site-specific temperature criteria, the properties of the underlying population that are of interest are the extent of temperature increase (magnitude) within each section of the River and the frequency at which such an increase is likely to occur (the percentiles of the distribution). In its simplest form this estimation can be performed as follows:

- **Step 1.** Sample the daily maximum temperature data with replacement to construct a hypothetical 1-year\(^1\) temperature time series of daily maxima at the LLO, end of Reach 3 and end of Reach 4.

- **Step 2.** Determine the 7-DADmax temperatures and the corresponding differences for Reach 3 (LLO to end of Reach 3) and Reach 4 habitat channel (end of Reach 3 to end of Reach 4).

- **Step 3.** Bin the temperature increases from 0.3°C\(^2\) through maximum increase and determine whether there are two or more non-overlapping periods\(^3\) where the temperature increase for the corresponding bin is exceeded.

- **Step 4.** Repeat steps 1 through 3 a large number of times (typically greater than 100 and often many thousands of times) and calculate the proportion of hypothetical years when two or more non-overlapping exceedances are predicted for each temperature increase bin.

Step 4 above provides an estimate of the return period or the frequency at which a given numeric increase in temperature within each section would be exceeded. The subsequent sections discuss how the methodology above was applied to the River.

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\(^1\) To construct a 365-day time series of 7-DADmax temperatures, a 371-day time series of daily maximum temperatures must be simulated.

\(^2\) WAC 173-201A-200(1)(c)(i) allows up to a 0.3°C increase above applicable criteria for all human actions considered cumulatively and therefore was used as a minimum requirement for consideration as an increase for this analysis.

\(^3\) For the purpose of this analysis it is assumed that multiple exceedances within an overlapping 7-day period (for example on Day 1 and Day 7) will count as a single exceedance. This will account for the calculation of the 7-DADmax temperature, which is a moving average over a 7-day period. A sensitivity analysis to one or more exceedance is subsequently presented.
Application to the Chelan River

The application of bootstrapping to water temperature data must consider the underlying spatial and temporal continuity represented in the data. Spatial continuity requires that the temperature increase calculation within a given section of the River requires the same atmospheric forcing for the upstream and downstream locations. For example, if the daily maximum temperature sample drawn for End of Reach 3 is on July 1, 2010, then the corresponding LLO sample must also be from the same day to correctly account for the actual solar heating that occurred from the atmospheric conditions for that day. Similarly, weather patterns (air temperature, relative humidity, cloud cover, and wind) that drive heat exchanges between the River and the ambient air occur in a series of cold and warm fronts. Thus, the solar heating observed on any given day may be similar in magnitude to a few days before and a few days after. In other words, water temperature increases can be autocorrelated. Other temporal considerations include seasonal and interannual variability. For example, the extent of solar heating in March is typically not the same as that observed in August, and the highest observed increases may be more extreme in a dry year than in a wet year.

The number of hypothetical years used in determining the return period is an important consideration. In general, increasing the number of hypothetical 365-day periods (“years”) would reduce the variability in the estimated return period but would also progressively increase computational burden. The reduction in variability would diminish beyond a certain sample size and extending the hypothetical 365-day periods beyond that level would not lead to additional benefits.

The approaches used for reconciling spatial and temporal continuity and estimating the number of samples in the bootstrap methodology are discussed below.

Spatial Continuity

Spatial continuity in solar heating was preserved by limiting the random resampling by date rather than by location. This enabled the actual observed solar heating to be preserved during bootstrapping by using paired sets of upstream and downstream locations within the River when calculating the temperature increase.

Temporal Continuity

Autocorrelation functions for temperature increases were evaluated to assess the extent to which temporal continuity must be preserved during resampling. Figure A-2 shows the autocorrelation functions of temperature increases by month at Reaches 1 through 3 and the Reach 4 habitat channel. A high autocorrelation coefficient for a given lag indicates a need for preserving temporal continuity at that lag. Figure A-2 shows that at both river sections there is a steep decline in the autocorrelation coefficient over the first few days that typically flattens out after 3 to 5 days during most months of the year. This suggests that temporal continuity after the first several days is likely not important. On the basis of autocorrelations in Figure A-2, a lag of 4 days was selected.
The 4-day lag was implemented through a special bootstrapping method called moving block bootstrapping, in which blocks of continuous observations in the data are sampled together to construct the hypothetical sample (Kreiss and Lahiri, 2012). Thus, a hypothetical 371-day period of daily maxima will have blocks from Days 1 through 4, Days 5 through 8, and so on until Days 368 through 371. By keeping blocks of observations together (in this case over a 4-day lag), the dependence structure of the random variables at short lags is preserved, carrying the information over to the bootstrap variables (Kreiss and Lahiri, 2012). This approach has been shown to be the most accurate of the block bootstrapping methods (Lahiri, 1999; Vogel and Shallcross, 1996; Kreiss and Lahiri, 2012).

**Seasonality and Inter-Annual Variability**

Seasonal conditions were represented by limiting sampling to within a 15-day window on either side of a date for which the random sample was being drawn. For example, if resampling was being conducted
to fill the block ending on May 1 then data from April 15 through May 14 were used for drawing the sample as illustrated in Figure A-3. This approach ensured that unrepresentative conditions (such as a fall or winter sample being selected as the hypothetical May 1 sample) were avoided.

Set of Feasible Date Blocks for Selecting the Daily Maximum Temperature for April 28 to May 1 within a 30-day window

Option 1:  
15 Apr 16 Apr 17 Apr 18 Apr

Option 2:  
16 Apr 17 Apr 18 Apr 19 Apr

... 

Option 26:  
10 May 11 May 12 May 13 May

Option 27:  
11 May 12 May 13 May 14 May

Notes. The sampling strategy involves two steps as follows:
Step 1: Select a Random Year (Y) from 2010 through 2019
Step 2: Select a random option from the set of feasible options for that Year Y

Inter-annual variability was considered by evaluating exceedances for wet, dry, and average years separately, and comparing it in the context of findings from all available years of data (i.e., 2010-2019). Determination of the wet, dry, and average years were consistent with the approach used by Chelan PUD based on inflow into the Lake during the runoff period (April through July) towards maintaining its operational commitments in the Federal Energy Regulatory Commission-issued License for the Lake Chelan Hydroelectric Project (Chelan PUD, 2007). For the period of temperature record, from 2010 through 2019, the following determinations have been made by Chelan PUD (2011-2019):

- Dry Years: 2015, 2019
- Average Years: 2010, 2013, 2014, 2016, 2018

This approach allows an assessment of the frequency of exceedances that may be anticipated under a particular condition. However, it is important to note that the Washington State water quality standard requirement of exceedance of numeric criteria no more than 1 in 10 years is intended to apply over all conditions, and will therefore be the appropriate benchmark in selecting the numeric criterion. Furthermore, it is important to note that extended extreme conditions (a string of dry or wet years) are unlikely to persist. In the event that such conditions do persist to such an extent that what is considered an extreme condition (dry or wet) currently becomes an average condition in the
future due to a fundamental cause such as an underlying change in the overall climate patterns, then a numeric criterion selected based on a current condition will likely be exceeded. Under such a scenario it will be necessary to reevaluate whether the criterion selected based on a current condition continues to be attainable.

Estimating the Number of Hypothetical 365-Day Periods

A range of the number of hypothetical 365-day periods (sample sizes), from 10 through 1,000, were tested to determine a sufficient number of samples. To determine a sufficient sample size, the variability in the exceedance probability by sample size was assessed. The variance for each number of samples considered was assessed by repeating the bootstrapping simulation 30 times (trials) and the probability of exceeding a given numeric temperature increase two or more times during a year was computed for each trial. The median and range of the probability of exceedance was then compared across the 30 trials for each sample size using a boxplot to determine whether the variance had stabilized across the range of sample sizes tested. The process above was repeated for various numeric temperature increases ranging from 0.3°C to 4°C for both Reaches 1 through 3 and the Reach 4 habitat channel.

Figure A-4 shows the results for a 3°C increase at Reaches 1 through 3 and a 1°C increase at the Reach 4 habitat channel, for data sampled from all available years. Figure A-4 shows that the variance begins to stabilize after approximately 500 samples (365-day periods) in both cases, since the inter-quartile range and median of the boxplots are similar above this sample size. These patterns were representative of the variability observed for other numeric temperature increases, across both river sections, and across wet, dry, and average years. This indicates that the upper limit of the number of the samples considered (1,000 hypothetical 365-day periods) is adequate for this evaluation, and was selected for the full analysis.
Notes: Boxplots show the median (centerline), inter-quartile range (edges of the boxes), 1.5 times the interquartile range (whiskers/error bars), and outliers (circles) in the probability of exceedances based on 30 trials of 1000 hypothetical 365-day periods that were resampled from 2010-2019 temperature data.

**Figure A-4. Variability in the Probability of Two or More Exceedances of a 3°C Increase in Reaches 1 through 3 7-DADMax Temperature (top) and a 1°C Increase in the Reach 4 Habitat Channel 7-DADMax Temperature (bottom)**
RESULTS

The procedure outlined in the “Bootstrapping Methodology” section was adapted for application to the River based on the considerations discussed above. The bootstrap simulations were developed for the complete data set (2010-2019) and wet, dry, and average years as described above. For each data set, 30 trials of 1,000 hypothetical 365-day periods were generated to assess the variability in the estimated probability of exceedances at various 7-DADMax temperature increases.

Figure A-5 shows that 7-DADMax temperature increases in Reaches 1 through 3 of up to 2°C are likely to be exceeded at least twice a year under all conditions (wet, dry, or average). In dry years increases of up to 3°C were exceeded in nearly all the simulations, and increases of up to 3.75°C may be exceeded on rare occasions (in approximately 6% of the simulations). Recognizing that resampling for dry years were limited to the two dry years on record, in recreating the 1,000 hypothetical 365-day periods, the extreme conditions are overrepresented (i.e., it is unlikely in reality that we would have such a long string of extreme conditions). When the temperature increases are assessed relative to all years (which is more representative of the range of conditions likely to be encountered), the results show that a temperature increase of 3.25°C would seldom be exceeded (approximately 2% of the simulations exceeded this level; see the “All” panel in Figure A-5).

Notes: Results are based on 30 trials of 1,000 hypothetical 365-day samples drawn for each year type shown. Temperature increases shown on the x-axis represent the 7-DADMax temperature at the end of Reach 3 minus the 7-DADmax temperature at the LLO.

Figure A-5. Simulated Probabilities of Two or More Exceedances for Various Increases in Reaches 1 through 3 7-DADMax Temperature
The exceedance probabilities for Reach 4 7-DADMax temperatures are shown in Figure A-6. Because of the shorter residence time within the Reach 4 habitat channel relative to Reaches 1 through 3, the extent of solar heating within the habitat channel is smaller. Figure A-6 shows that even for dry years a temperature increase of 1.25°C would seldom be exceeded (approximately 3% of simulations exceeded this level). As with Reaches 1 through 3, recognizing that such extreme conditions may not occur for an extended period, the probability of exceedances for the increases over all years is a more realistic representation of the range of conditions. The top left panel of Figure A-6 shows that when resampled over all years in the period of record, a 7-DADMax temperature increase of 1°C or more is unlikely to be encountered in Reach 4 (approximately 0.4% of simulations exceeded this level). The results also show that approximately 50% of the simulations for the wet years exceeded 0.5°C but less than 20% of the simulations for the average year exceeded this level which seems counter-intuitive. This is likely a result of greater number of average years than wet years (5 versus 3).

Notes: Results are based on 30 trials of 1,000 hypothetical 365-day samples drawn for each year type shown. Temperature increases shown on the x-axis represent the 7-DADMax temperature at end of Reach 4 habitat channel minus the 7-DADMax at the end of Reach 3.

**Figure A-6. Simulated Probabilities of Two or More Exceedances for Various Increases in Reach 4 Habitat Channel 7-DADMax Temperature**
Sensitivity of Probability of Exceedance to Number of Exceedances

The analysis above was repeated to assess what a reasonable worst-case temperature increase would be at a one or more exceedance at each bin, i.e., even if multiple 7-DADMax temperature differences based on overlapping 7-day periods exceed the corresponding bin they would be all flagged as an exceedance. The simulated probabilities are shown in Figure A-7 and Figure A-8 for Reaches 1 through 3 and the Reach 4 habitat channel respectively. The probabilities of two or more non-overlapping exceedances discussed previously is also shown for reference. When one or more exceedances are considered, there are more exceedances for a given bin relative to two or non-overlapping exceedances because the exceedances do not need to be from non-overlapping periods and just a single exceedance is sufficient. For example, two 7-DADMax temperature increases above a certain bin that are within a 7-day window will now count as two exceedances whereas in the non-overlapping scenario this would have counted towards an exceedance only if another period outside of this 7-day window also had an exceedance over this bin.

Notes: Results are based on 30 trials of 1,000 hypothetical 365-day samples drawn for each year type shown. Temperature increases shown on the x-axis represent the 7-DADMax temperature at the end of Reach 3 minus the 7-DADmax temperature at the LLO.

**Figure A-7. Comparison of Simulated Probabilities of Two or More Non-Overlapping Exceedances and One or More Exceedance for Reaches 1 through 3**
Notes: Results are based on 30 trials of 1,000 hypothetical 365-day samples drawn for each year type shown. Temperature increases shown on the x-axis represent the 7-DADMax temperature at end of Reach 4 habitat channel minus the 7-DADMax at the end of Reach 3.

**Figure A-8. Comparison of Simulated Probabilities of Two or More Non-Overlapping Exceedances and One or More Exceedance for the Reach 4 Habitat Channel**

Given the above, a reasonable worst-case temperature increase will need to be higher when considering one or more increases above the numeric criterion as an exceedance. For example, Figure A-7 shows that under the "All" scenario approximately 50% of the simulations (i.e., 1 in 2 simulated years) showed one or more increases of 3°C or more, whereas less than 20% of those simulations (i.e., less than 1 in 5 simulated years) would have declared those as an exceedance on the basis of a non-overlapping period of two or more exceedances. Thus, for the same numeric criterion using one or more overlapping exceedance will require a shorter return period (i.e., will need to allow for more frequent exceedances) than using two or more non-overlapping exceedances.

Recognizing that the extent of solar heating within the system for a given set of instream flow conditions is independent of the numeric criterion, the choice of a higher versus a lower numeric criterion becomes a question of which of the two will provide a more effective assessment of a shift from the current reasonable worst-case. One way to perform this assessment is to compare the number of days each of the approaches identifies an exceedance that the other one does not for a comparable return period. Three metrics were calculated to compare the approaches:
1. The number of days the temperature difference exceeds the lower criterion on the basis of two non-overlapping periods but is below the higher criterion.

2. The number of days the temperature difference exceeds the higher criterion on the basis of one or more overlapping exceedances and the temperature difference did not exceed the lower criterion because these days did not meet the two non-overlapping exceedance condition.

3. Days identified as an exceedance under both approaches (i.e., on these days the temperature was above the higher criterion on the basis of a single exceedance, and also met the condition for two non-overlapping exceedances for the lower criterion).

Table A-1 shows the comparison of temperature increases for the three metrics explained above based on one trial\(^4\) of 1,000 hypothetical 365-day periods. The numeric criteria for the two approaches were paired by a comparable return period with the precision of the probabilities limited to the bin intervals used in the original bootstrap simulation. For example, a 3°C increase for two or more non-overlapping exceedances had an 8.1-year return period and the closest match for one or more exceedance at a comparable return period (13.9 years) was obtained for a 3.5°C increase. In Reaches 1 through 3, for a comparable return period a lower numeric criterion with two or more non-overlapping exceedance identifies a greater number (3°C vs 3.5°C) or about the same number of days (3.25 vs 3.75°C). In the Reach 4 habitat channel the difference in number of days is generally small between the two approaches, indicating the choice of return is the primary driver. It is interesting to note that, the number of days that are flagged as being in exceedance by both approaches is actually much smaller than each of the approaches individually. This indicates two conditions: (1) the exceedances over the higher criterion must often occur within a short period without additional exceedances that are at least as high as the lower criterion for another non-overlapping period within the same year; and (2) there are many warm days between the criteria that exceed the lower threshold but do not meet the higher one.

While the extent of solar heating within the system is independent of the numeric criterion, by requiring sustained exceedances over multiple 7-DADMax averaging periods the two or more non-overlapping condition is more robust to the occasional extreme weather pattern that may result in a single or a few overlapping but higher temperature increases. Therefore, if the lower numeric criterion on the basis of two or more non-overlapping condition is more frequently exceeded on an annual basis than what has been observed in the data collected to date, then it would be a more robust indicator of a shift in the temperature regime particularly within Reaches 1 through 3 where much of the solar heating occurs.

\(^4\) 30 trials were not repeated here as was done in the full presentation of results earlier because the variability in the probabilities were small and conclusions from the single trial will be applicable across any random trial.
Table A-1. Number of Temperature Increases Over a Lower Numeric Criterion Identified by Two or
More Non-overlapping Exceedance

| Two or More Non- | One or More | No. of Temperature Increases Identified as an |
| Overlapping      | Exceedance | Exceedance¹ |
| Exceedance       |            | > Lower Criterion but |
| Lower            | Return      | Higher         | < Higher Criterion on |
| Numeric          | Period²,³   | Numeric        | the Basis of Two or |
| Criterion        | (°C)        | Criterion      | More Non-          |
| (°C)             | (yr)        | (°C)           | Overlapping Period |
|                  |             |                | > Higher Criterion but |
|                  |             |                | Did Not Meet the Two |
|                  |             |                | or More Non-         |
|                  |             |                | Overlapping Period   |
|                  |             |                | Requirement         |
|                  |             |                | Exceedance as per Both |
|                  |             |                | Approaches         |
|                  |            |                |                    |
| Reaches 1 through 3 |            |                |                    |
| 3               | 8.1         | 3.5            | 13.9              | 267             | 146             | 6 |
| 3.25            | 55.6        | 3.75           | 50.0              | 37              | 37              | 0 |
| 3.5             | Undefined   | 4.0            | 200.0             | 0               | 5               | 0 |
| Reach 4 Habitat Channel | |           |                    |                    |
| 0.75            | 9.8         | 1.0            | 9.4               | 217             | 248             | 5 |
| 1.0             | 500.0       | 1.5            | 200.0             | 4               | 9               | 0 |

Note:
1. The results are based on the 1,000 hypothetical 365-day periods and represents the total number of exceedances over all 365,000 simulated days.
2. The probability of exceedance is the proportion of 1,000 hypothetical 365-day periods that were classified as a “year” with an exceedance for the corresponding approach. The return period is the inverse of the probability of exceedance.
3. The bin intervals are calculated at 0.25°C increments in the bootstrap simulations. Therefore, an exact pairing of the numeric criterion based on the return period is not feasible. The higher numeric criterion and its corresponding return period represents the closest match to the return period for the lower numeric criterion shown in each row. For the habitat channel there were only a few instances of the temperature increases above 1°C, which resulted in small probabilities of exceedance and therefore large return periods within a bin.

DISCUSSION AND CONCLUSION

The objective of the site-specific criterion is to prevent further warming by limiting the extent of warming in the River to that which is due to solar heating under current Project operations, which has been determined to result in the highest attainable aquatic life uses in the River. Selecting a numeric increase is therefore a balance between establishing a reasonable worst case that won’t be frequently exceeded while still being protective of the highest attainable uses. The analysis presented in this memorandum provides a range of possible limits for numerical temperature increases that may be considered for each section of the River, and the likelihood of meeting those numerical limits. From the results presented above based on the range of observed conditions represented in the bootstrapping simulations, a 7-DADMax temperature increase of 3.25°C in Reaches 1 through 3 (the level at which the probability of exceedance drops below the 10th percentile; Figure A-7) and a temperature increase of 1°C in the Reach 4 habitat channel are reasonable worst case conditions for solar heating within the River on the basis of two or more non-overlapping exceedances. If a single exceedance is considered, for the same return period a reasonable worst-case increase in Reaches 1 through 3 is a 3.75°C 7-DADMax (Figure A-7) and 1.25°C for the Reach 4 habitat channel.
(Figure A-8). However, as discussed earlier, a lower numeric criterion on the basis of two or more non-overlapping exceedance would be a more robust indicator of a shift from the current condition.

The simulations above represent conditions that were actually observed within the River. Future changes in climate are not factored into the bootstrapping analysis. Section 3.2.5 of the main document presents a more detailed analysis of the effects of climate change on the solar heating within the River through mechanistic modeling. The analysis concluded that for the projected air temperature increases over the next 8 decades the simulated additional solar heating within Reaches 1 through 3 and the Reach 4 habitat channel would be less than 0.36°C and 0.02°C, respectively (Section 3.2.5 of the main document). When viewed in light of these findings it would be prudent to consider additional temperature increases for Reaches 1 through 3 beyond those simulated in the statistical bootstrap simulations. Thus, the reasonable temperature increase for Reaches 1 through 3 after accounting for the effects of climate change would be a 7-DADMax of 3.6°C (after rounding). The projected increases under climate change are very minor for the Reach 4 habitat channel, and therefore an increase for climate change beyond those inferred from the statistical bootstrap simulations will not yield a different numeric criterion when the results are rounded.

Based on the findings of statistical simulations and the projected changes from climate change, the following increases in 7-DADMax temperatures are reasonable considerations for use in the site-specific temperature criteria proposed in the Chelan River UAA:

- Reaches 1 through 3 – a maximum increase in the 7-DADMax temperature of no more than 3.6°C when measured at the end of Reach 3 relative to the background (LLO); the numeric criterion may not be exceeded at a frequency of more than once in every 10 years
- Reach 4 – a maximum increase in the 7-DADMax temperature of no more than 1°C when measured at the end of each segment in Reach 4 over the background (end of Reach 3 for habitat channel and high-flow channel; powerhouse for the tailrace); the numeric criterion may not be exceeded at a frequency of more than once in every 10 years

For both Reaches 1 through 3 and Reach 4, it is recommended that within any given year an exceedance be defined as two or more non-overlapping 7-DADMax temperature increases, calculated as described above, that are greater than the numeric criterion.

REFERENCES


