LOST LAKE WHITE PAPER

SKAGIT RIVER HYDROELECTRIC PROJECT
FERC NO. 553

Prepared by:
Meridian Environmental, Inc.

Prepared for:
Seattle City Light

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TABLE OF CONTENTS

List of Figures

List of Tables

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1.0 INTRODUCTION

Lost Lake is a former kettle lake, located approximately 0.75 miles west of the mouth of Lightning Creek in what is now Ross Lake, the largest and uppermost reservoir associated with Seattle City Light's (City Light) Skagit River Hydroelectric Project (Figure 1.0-1). The United States Department of Agriculture (USDA) soil survey for the North Cascades National Park describes a kettle lake as "a steep-sided, usually basin- or bowl-shaped hole or depression, commonly without surface drainage in glacial-drift deposits, often containing water" (USDA and NPS, 2012). Lost Lake is typically fully submerged under normal hydroelectric operating conditions: Ross Lake full pool elevation is 1,603 feet, and Lost Lake is only exposed below an elevation of 1,505 feet, which has occurred on five occasions over the last 30 years (see Section 3.0 for more detail). When exposed, Lost Lake is roughly circular, with a depth of approximately 100 feet and diameter of approximately 700 feet, giving it a volume of approximately 867 acre-feet.

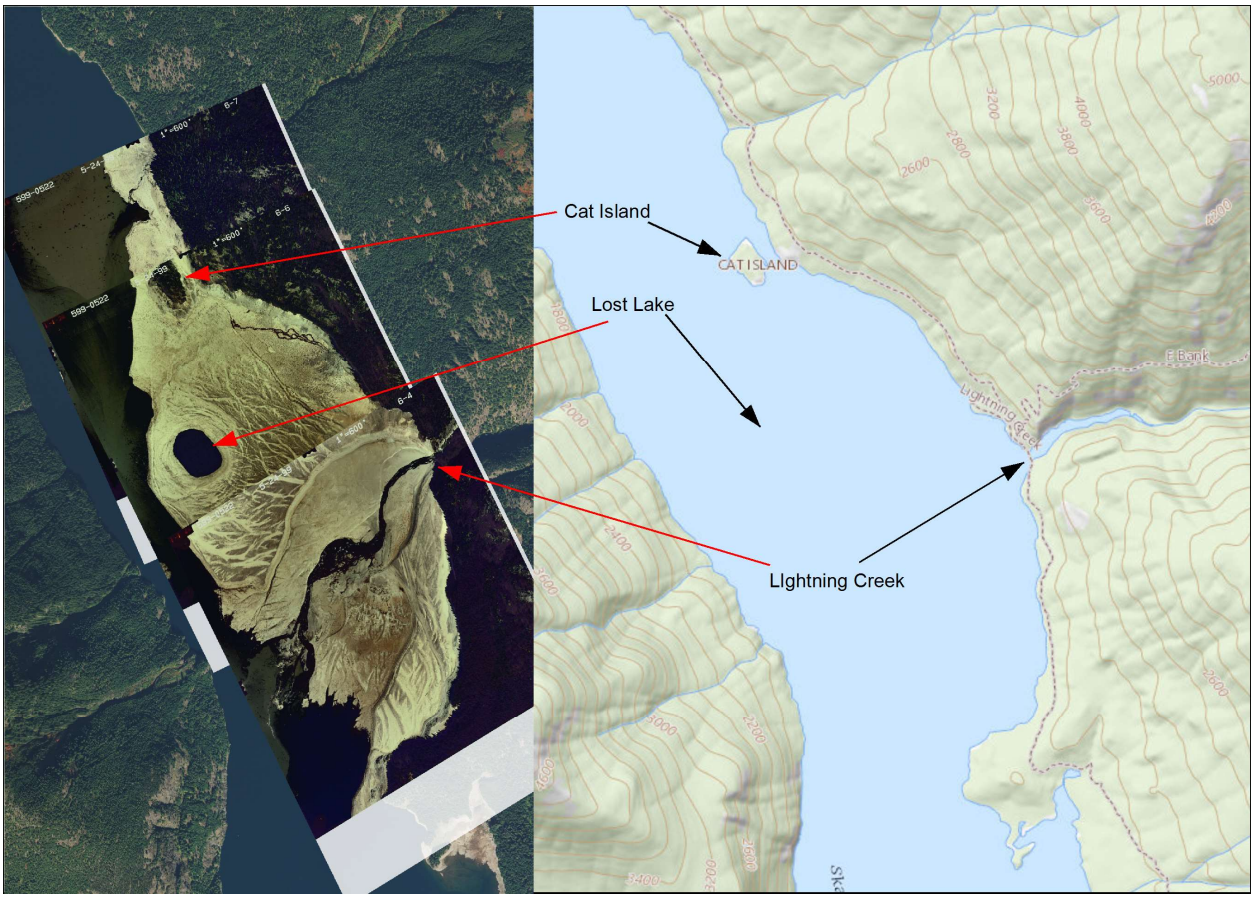

Figure 1.0-1. Lost Lake, within Ross Lake, WA. Photo at left was taken May 24, 1999 at elevation 1,486 feet; 29 feet below the Lost Lake sill elevation. Source: Seattle City Light.

Isolation of Lost Lake from Ross Lake when exposed during extreme drawdown events has the potential to entrap native Rainbow Trout (*Oncorhynchus mykiss*) and char (*Salvelinus spp.),* and other aquatic organisms inhabiting Ross Lake. The National Park Service (NPS) and other licensing participants (LPs) involved in the upcoming Skagit Hydroelectric Project relicensing have expressed a concern that this may have a negative effect on fish in Ross Lake. In response,

City Light requested a review of available data and information on Lost Lake, and prepared this White Paper to evaluate any potential fishery concerns associated with its occasional isolation from Ross Lake.

2.0 KEY QUESTIONS

An important objective of this White Paper is to determine whether exposure of Lost Lake could, at durations experienced to date, lead to water temperatures in excess of those preferred by salmonids. Related questions associated with exposure of Lost Lake include the following:

- ***History of Exposure.*** What has been the recent history of exposure of Lost Lake? When does this typically occur and for how long?
- ***Water Temperature/Dissolved Oxygen.*** Could exposure of Lost Lake accelerate warming relative to Ross Lake, or cause reduced dissolved oxygen (DO), or other effects on water quality within Lost Lake, e.g., algal blooms, anoxic conditions at depth?
- ***Exchange with Ross Lake.*** To what extent does water exchange with Ross Lake occur during exposure, or is Lost Lake hydrologically/hydraulically isolated?
- ***Entrapped Fish.*** If trapped in Lost Lake, could fish be subject to deleterious temperatures or DO concentrations, spawning delays, or reduced prey availability?

3.0 FINDINGS

Data available from City Light, United States Geological Survey (USGS), and online sources were used to address the questions identified above. Findings are discussed below.

3.1 Exposure History

A review of available Ross Lake elevation data (USGS Gage 12175000, Ross Lake near Newhalem) indicates that water surface elevations have been less than 1,505 feet, i.e., exposing Lost Lake, on 15 occasions over the 58-year period of record (September, 1961 to present). The period that reflects current reservoir operations, and thus is relevant to this review, is from 1991 to present.[1] Water surface elevation data over this 28-year period of record are presented below (Figure 3.1-1).

Ross Lake's water surface elevation was low enough to expose Lost Lake six times since 1991. With few exceptions, exposures of Lost Lake have occurred during the months of March and April. Exposure events extended into May on two occasions since 1991: to May 15 in 2008, and to May 27 in 2009. Average duration of exposure has been 42 days, with a minimum of two days and maximum of 74 days. In total, Ross Lake surface elevation has been low enough to expose Lost Lake during two percent of the 28-year period of record that reflects current operations. Identifying the cause of these events, e.g., operational or hydrologic, was beyond the scope of this paper and not apparent from the data reviewed.

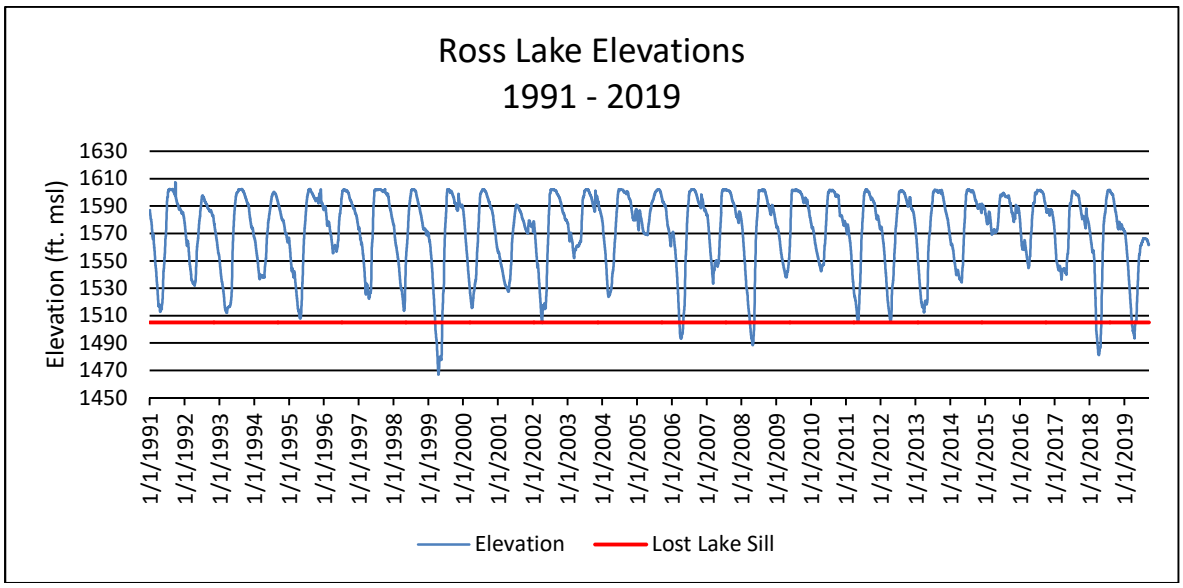

Figure 3.1-1. Daily Ross Lake elevations since 1991; horizontal line is Lost Lake sill at 1,505 feet msl. Source: USGS Gage 12175000, Ross Lake near Newhalem.

[1] The period 1991–2019 encapsulates the timeframe beginning with the finalization of the Skagit River Hydroelectric Project Settlement Agreement (City Light 1991) and the most recent water year. This period reflects existing conditions in Ross Lake, i.e., those to which fish are currently exposed, and is sufficiently long to account for current operations under a range of hydrologic conditions.

3.2 Water Temperature and Dissolved Oxygen

3.2.1 Potential Warming in Lost Lake

The potential warming of Lost Lake while isolated from Ross Lake was estimated based on known physical characteristics of Lost Lake and estimated incoming solar radiation. Water temperature in Lost Lake, as in any body of water, is a function of volume, surface area, solar radiation, and air temperature (as well as local meteorology). Lost Lake's physical features are shown below (Table 3.2-1).

Table 3.2-1. Lost Lake physical features.

Radius (m)	Area (m^2)	Depth (m)	Volume (m^3)	Kg[1]
107	35,633	30	1,068,982	1,068,981,878

[1] A cubic meter of pure water at the temperature of maximum density (3.98°C) and standard atmospheric pressure (101.325 kPa) has a mass of 1,000 kg.

Based on the Lake's physical characteristics, the energy needed to warm Lost Lake may be calculated based on the specific heat capacity of water:

> *4,200 Joules (J) per kilogram per degree Celsius (J/kg°C); or 4,200 J to raise the temperature of 1 kg of water by 1°C.*

The energy needed to raise the temperature of the Lost Lake water column (to 30 meters depth) by 1°C is 4.49×10^{12} Joules, or 1.25×10^{6} KWHr. As noted above, Lost Lake exposures occur from late March through April, or possibly mid-May (which occurred in 2008 and 2009). Therefore, incoming solar radiation in April is a reasonable approximation of incoming radiation to the lake during the exposure periods. Available solar radiation data for the location nearest to Ross Lake (Stehekin, WA) average 4.5 KWHr/m^2/day in April.[2] Lost Lake would therefore receive an average of 160,347 KWHr/day throughout the month of April.

Given the energy required to increase water temperature, incoming solar radiation during an April drawdown is a small fraction (13 percent) of the energy required to raise Lost Lake temperatures by 1°C. However, in contrast to the entire water column, incoming solar radiation during an April exposure would be sufficient to slightly warm Lost Lake's surface waters. For example, available energy in April is likely sufficient to warm the upper 4 meters of Lost Lake by 1°C (Figure 3.2-1). In summary, any solar radiation-related warming in Lost Lake, when it becomes isolated from Ross Lake, is likely to be limited to the upper few meters of the water column.

Based on several studies of key factors responsible for rising lake water temperature, air temperatures are likely to have a much larger effect on Lost Lake water temperatures than incoming solar radiation. Based on a statistical analysis of a long-term (1964–1998) record of intra- and inter-annual temperature fluctuations in Lake Washington, Arhonditsis et al. (2004) found that air temperature, along with long-term trends (Pacific Decadal Oscillation), was the best

[2] (available at https://www.solarenergylocal.com/states/washington/98852/)

predictor of lake temperatures during both warming and cooling periods. Similarly, considering air temperature, wind speed, relative humidity, cloud cover, and clear-sky solar radiation, Kettle et al. (2004) found air temperature to be the most important of the variables. Toffolon et al. (2015) found that air temperature was satisfactorily used as the sole input to a water temperature model used to predict surface temperatures of 14 lakes, including the Great Lakes and others in the Midwest and Canada.

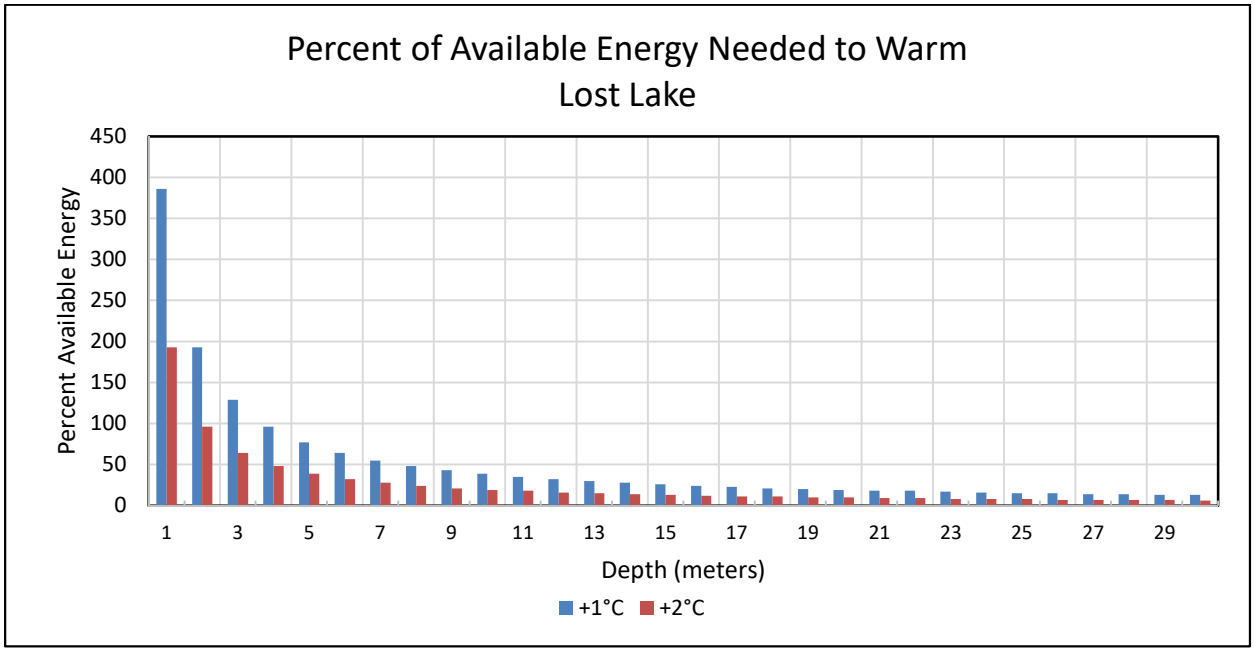

Figure 3.2-1. Percent of available solar radiation needed to increase Lost Lake temperature by 1-2° C (assuming average incoming solar radiation in April for Stehekin, WA).

3.2.2 Temperature and DO Profiles

City Light collected water temperature and DO data in Ross Lake on three occasions during the 2018 drawdown: April 17, 26, and 27, and in both Ross and Lost lakes on April 18, 2019. All measurements were made during mid-afternoon using a Hydrolab Datasonde.

Profiles of water temperatures taken in Lost Lake over a 10-day period in April 2018 (April 17-27) show that surface waters warmed by almost 7°C, with the largest change occurring from the surface to about 5 meters depth (Figure 3.2-2). The observed warming pattern is generally consistent with the theoretical analysis shown above, in that warming of Lost Lake in April 2018 was limited to the upper few meters of the water column.

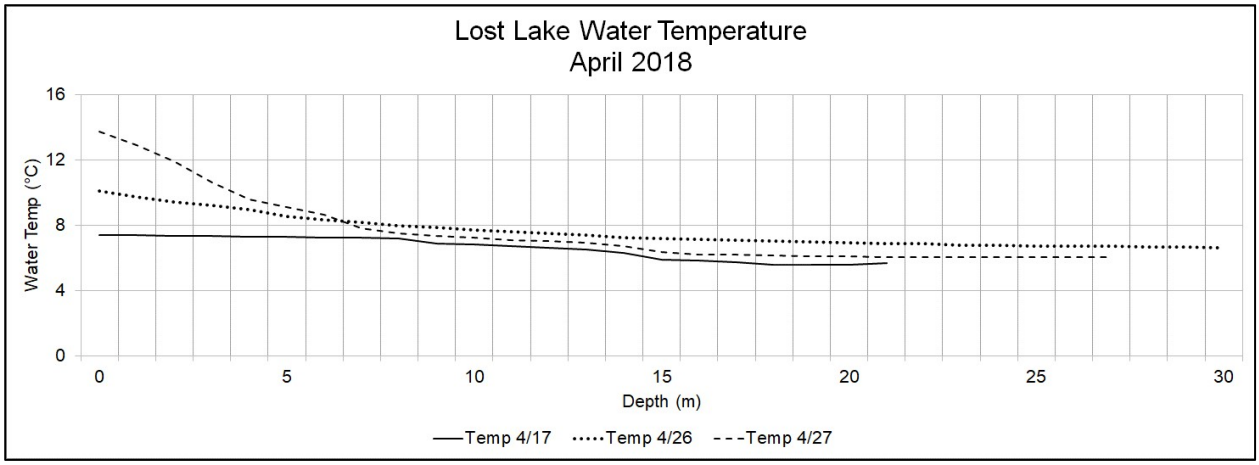

Figure 3.2-2. Temperature profiles at Lost Lake, April, 2018.

Increasing air temperatures over the period that Lost Lake was exposed in 2018 suggest that the warming over the 10-day period was influenced by steadily rising air temperatures (Figure 3.2-3). Daily maximum air temperatures during the latter half of April were much higher than during the first half of the month. As noted above, solar radiation may have contributed to warming; however, it likely played a minor role in contrast to the increasing air temperatures that occurred during this period.

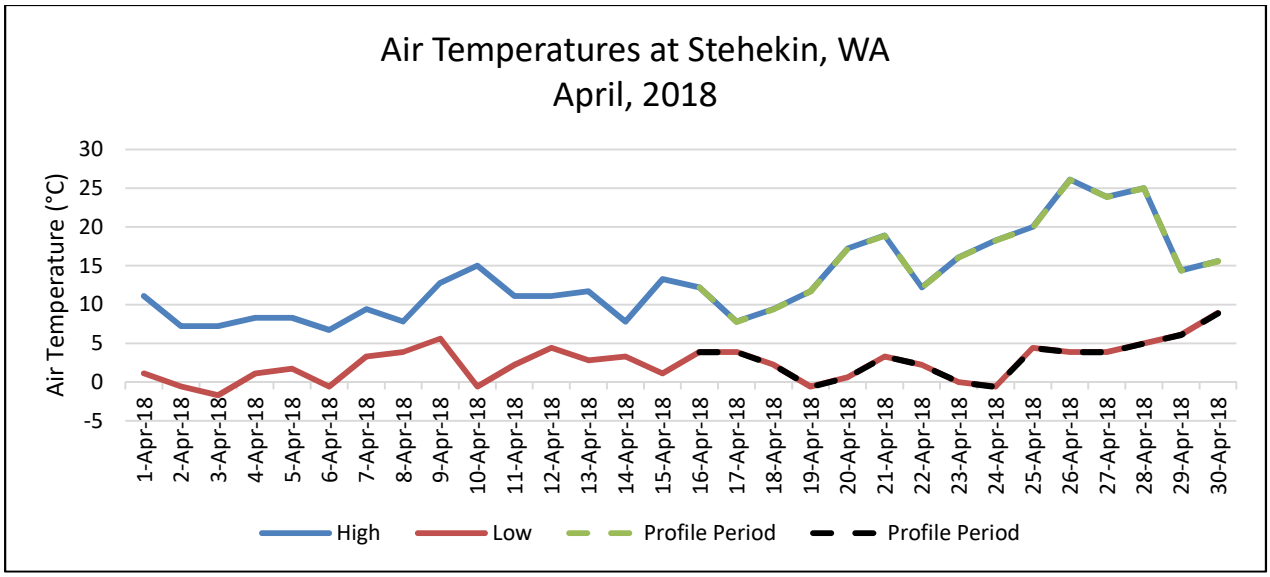

Figure 3.2-3. Air temperatures at Stehekin, WA, April, 2018.

Dissolved oxygen concentrations in Lost Lake at the beginning and end of the 2018 drawdown were above 11 mg/l throughout the water column. Slightly higher DO on April 27 may be the result of elevated primary production from the surface to a depth of about 5 meters (Figure 3.2-4).

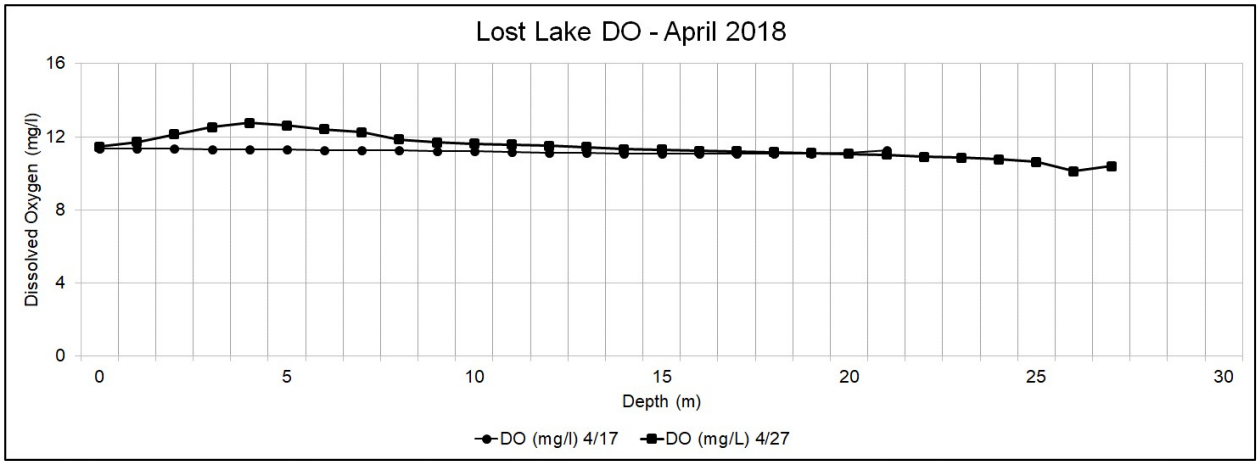

Figure 3.2-4. Dissolved oxygen profiles in Lost Lake, April, 2018.

Surface water temperatures were nearly identical in Lost Lake and Ross Lake (approximately 9°C) (Figure 3.2-5) based on data collected on April 18, 2019. However, in contrast to the relatively isothermal Ross Lake at 8-9°C, overall temperatures in Lost Lake were much colder (average approximately 5°C) and showed much more distinct stratification.

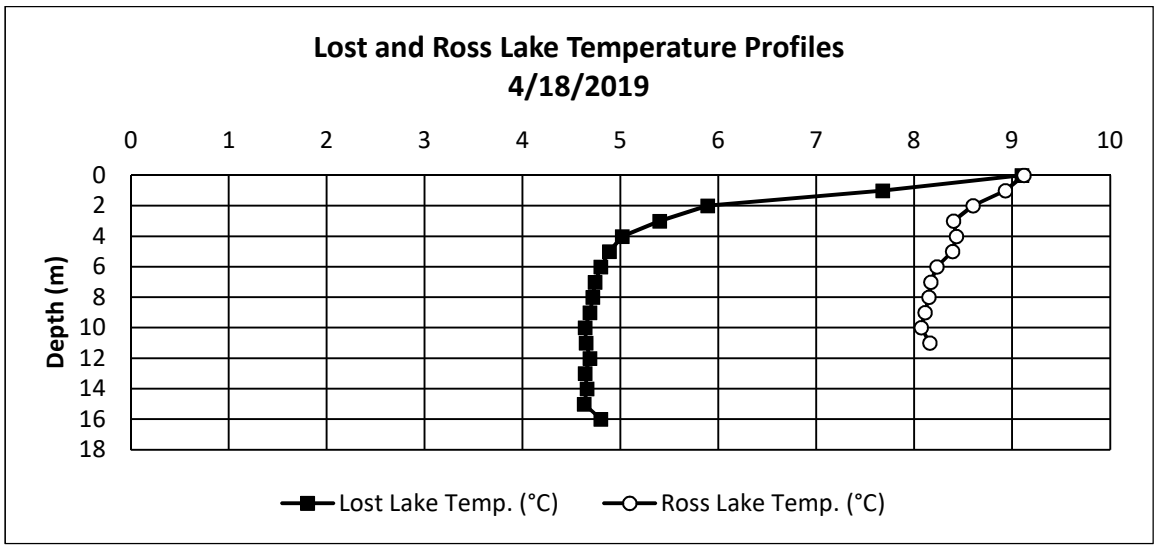

Figure 3.2-5. Ross and Lost Lake temperature profiles, April 18, 2019.

Colder temperatures in Lost Lake are likely a result of a lack of mixing with surface waters and a much more stable water column relative to Ross Lake. The observed patterns may be a function of the long, uninterrupted fetch on Ross Lake that likely prevents and disrupts thermal stratification (at least in spring) and thereby maintains a well-mixed (and oxygenated) water column. In contrast, the small surface area of Lost Lake has little exposure to wind. Lost Lake is also deeper than Ross Lake at this location by about five meters, and thus may possess a larger bank of comparatively dense, cold water. In addition, Lost Lake may be in contact with colder, deeper groundwater or spring inputs.

The DO profile of Lost Lake in April 2019 also points to a lack of wind effects in contrast to Ross Lake. Surface readings were similar to Ross Lake at about 9.5 mg/l, but concentrations at depth were lower than in Ross Lake (Figure 3.2-6). Dissolved oxygen concentrations measured in Lost Lake in 2018 (Figure 3.2-4) were substantially more uniform and higher than those measured in 2019 (Figure 3.2-6).

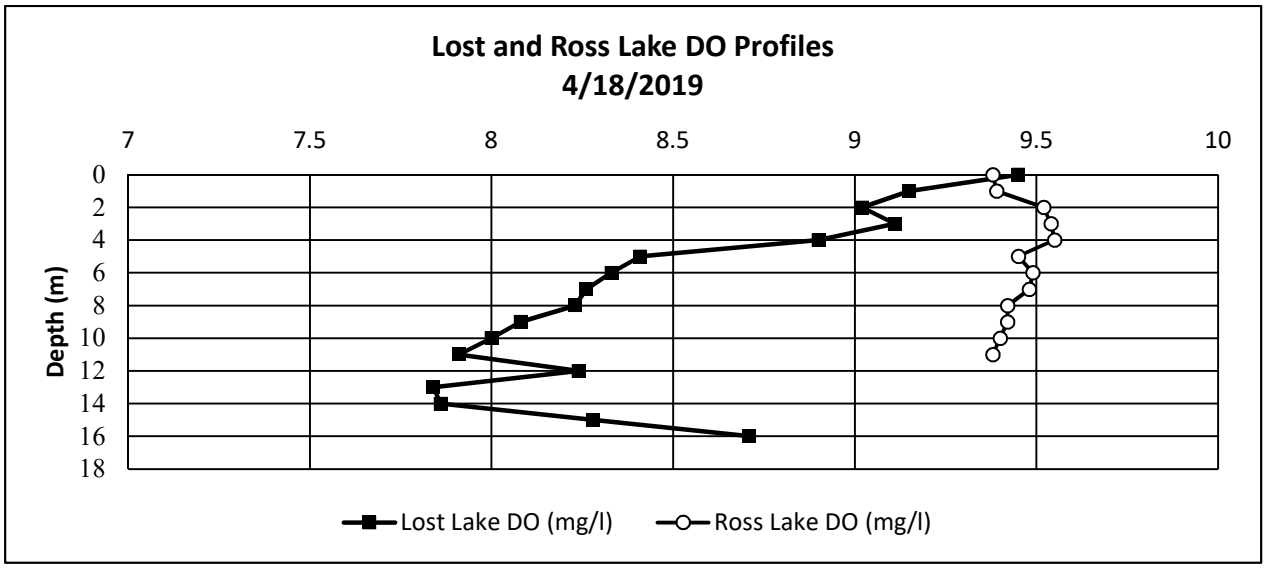

Figure 3.2-6. Ross and Lost Lake dissolved oxygen profiles, April 18, 2019.

3.3 Exchange with Ross Lake

Mapped soils within North Cascades National Park closest to Lost Lake include Thorton-Ragged-Ledeir complex (6014) and Damnation-Ragged-Rock outcrop complex (7003) (USDA and NPS, 2012). These complexes are mapped on the west side of Ross Lake, across from the mouth of Lightning Creek. Parent materials of both complexes consist of volcanic ash over glacial drift or alluvium; complexes 6014 and 7003 are characterized as well drained with high or very high capacity to transmit water. Soils on the bottom of Ross Lake are likely more compacted; however, materials comprising the walls of Lost Lake, particularly on the west side closest to Ross Lake, are likely similar in nature to adjacent soil complexes/parent materials in this area.

Survey data collected by City Light in 2018 showed that water surface elevations of both water bodies were nearly identical on four occasions during a period of exposure in March/April (Figure 3.3-1). Lost Lake was slightly higher in elevation on March 21 (by approximately 0.5 foot), and elevations dropped along with Ross Lake on March 29 and April 4, reaching the same elevation on April 17. These data indicate a high degree of hydraulic connectivity between Ross and Lost lakes during the 2018 drawdown; survey data are unavailable for 2019.

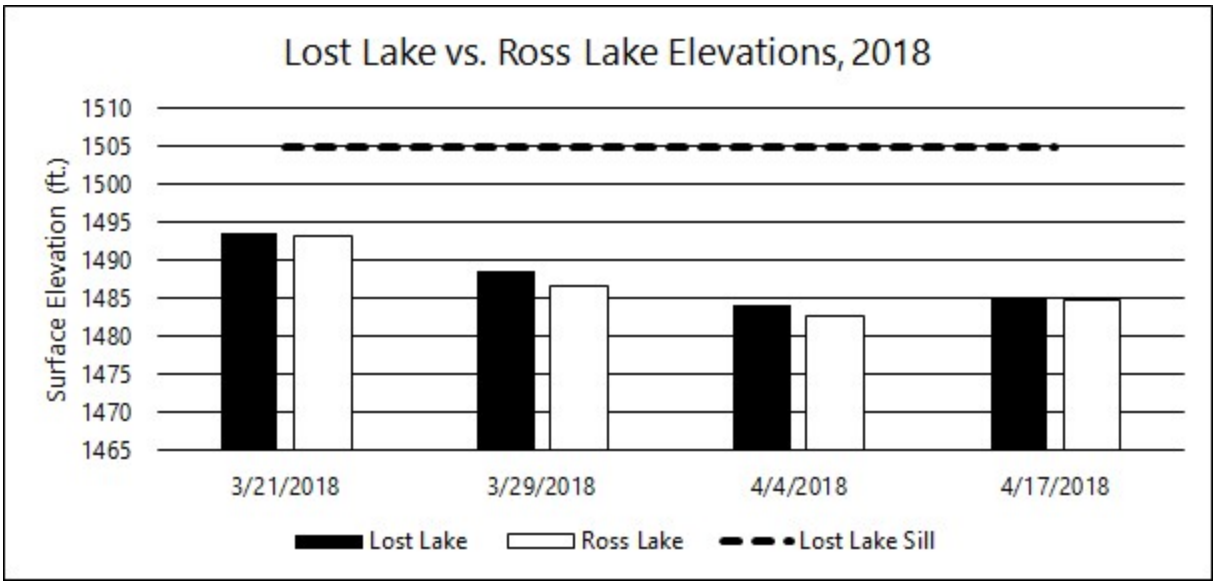

Figure 3.3-1. Water surface elevations at Ross and Lost lakes, March and April, 2018. Lost Lake is exposed below elevation of 1,505 feet msl.

3.4 Fish Entrapment

Entrapment of fish is likely to occur during periods of Lost Lake exposure. Species known to inhabit Ross Lake include native Rainbow Trout, Bull Trout (*Salvelinus confluentus*), Dolly Varden (*S. malma*), non-native Redside Shiner (*Richardsonius balteatus*), Brook Trout, (*Salvelinus fontinalis*), and Westslope/Yellowstone Cutthroat Trout (*Oncorhynchus clarkii*). Bull Trout, Dolly Varden, and Rainbow Trout display an adfluvial life history in Ross Lake. Rainbow Trout spawn in the tributaries in May and June; following spawning, some migrate to the lake, while others remain residents in the tributaries (Derenne, 2014). Native char (Bull Trout and Dolly Varden) begin to migrate towards spawning areas in late summer from mid- to late-September (SCL, 2011). Pre-spawning adults have been observed to stage at the mouth of spawning tributaries and also move up to and hold in pools while they ripen (SCL, 2011). Native char spawn in late-September through late-November, then migrate back downstream to Ross Lake shortly after spawning (SCL, 2011). Based on available data, the primary spawning areas for both Rainbow Trout and Bull Trout are likely the upper Skagit River drainage in Canada (Triton 2016). These species could be present in Lost Lake during periods of exposure.

As discussed above, temperatures measured in Lost Lake during exposure were supportive of salmonids, including native char (EPA, 2007). With the exception of an April 27, 2018 surface reading (13.8 °C), temperatures were less than 12°C. In a USGS study of Bull Trout movement to and from a reservoir in southwest Idaho, thermal refuge was defined as water that was 15°C and cooler (Maret and Schultz, 2013). For reference, the Washington Department of Ecology (Ecology) native char rearing and spawning standard for rivers and streams is 12°C.

DO levels measured in 2019 were lower than those observed in 2018, averaging 8.5 mg/l throughout the Lost Lake water column, in contrast to values near 11 mg/l in 2018. For reference, the Ecology DO standard in streams and rivers for native char is 9.5 mg/l, and the salmonid

spawning, rearing, and migration standard is 8 mg/l (Ecology State water quality standards, WAC 173-201A-200). DO measured in 2018 was therefore supportive of all salmonids (and non-salmonids) that may have been present in Lost Lake at the time. DO levels measured in 2019 were reduced, but to a level unlikely to stress native char, given reported Bull Trout DO minimum requirements of 6.5 mg/l (Maret and Schultz, 2013).

Rainbow Trout trapped in Lost Lake during exposure (which is rare) are unlikely to be prevented from accessing spawning areas on time, unless exposure persists through May or early June. Native char spawn in the fall, a period when Lost Lake exposure does not occur, so there is no risk of spawning disruption for Bull Trout. In general, Ross Lake elevations necessary to expose Lost Lake have occurred in early spring, prior to movement of adfluvial fish to tributaries.

Given the relatively large volume of Lost Lake, availability of zooplankton, macroinvertebrate and forage fish would likely be similar in terms of species composition and densities to those in Ross Lake. Eckmann (2016) found Redside Shiner to be the most common prey item (and only fish species) observed in the stomachs of adfluvial Bull Trout collected from Ross Lake. It is unlikely that there are changes in trophic and/or size structure of fish trapped within Lost Lake, particularly given the cold spring temperatures. Feeding rates are likely to be lower than at temperatures associated with maximum consumption (16°C for Bull Trout per Mesa et al, 2012). Whether prey resources could become limiting over the period of exposure is unknown.

4.0 SUMMARY

Lost Lake, a kettle lake that is normally inundated by Ross Lake, becomes isolated when water surface elevations drop below 1,505 feet msl. These events are relatively rare, having occurred on five occasions since 1990 for periods ranging from approximately 30 to 60 days. Concerns associated with the isolation of Lost Lake include warming during exposure, reduction in DO, and potential effects on trapped fish.

The influence of solar radiation on Lost Lake water temperatures is likely minor in contrast to air temperature (Arhonditsis et al., 2004; Kettle et al., 2004; Toffolon et al., 2015). Review of three temperature profiles collected when Lost Lake was exposed in April 2018 shows warming to about 5 meters, with the remainder of the water column (20-30 meters) under 9°C. Temperatures in Lost Lake were colder than Ross Lake in 2019, and Lost Lake exhibited distinct thermal stratification. Differences in temperature between Ross and Lost Lakes in 2019 are likely due to wind effects; Ross Lake is exposed to a significant fetch that prevents thermal stratification, while Lost Lake sees little effect of wind energy and more easily stratifies.

Dissolved oxygen levels in Lost Lake were high (approximately 11 mg/l) throughout the water column when measurements were made along two profiles in 2018. Somewhat lower DO levels (average 8.5 mg/l) were observed in Lost Lake in 2019 in comparison to Ross Lake, despite lower temperatures in Lost Lake. As noted above, this may reflect greater wind/fetch effects on Ross Lake causing a more well-mixed water column.

Available data indicate temperature and DO levels in Lost Lake are unlikely to stress trapped fish over the periods of exposure that have occurred to date (mid-March through April/early-May). Other water quality issues are unlikely; algal blooms were not apparent in either 2018 or 2019, suggesting similar nutrient regimes and biological activity in Lost and Ross Lakes.

Parent materials of soils in the area are comprised of volcanic ash over glacial drift or alluvium, and soil types are considered well drained with high or very high capacity to transmit water (USDA and NPS, 2012). Materials comprising the walls of Lost Lake, particularly on the west side closest to Ross Lake, are likely similar in nature to adjacent soil complexes/parent materials in this area. Survey data collected during April 2018 suggest a high degree of connectivity; elevations were very similar and changes in Lost Lake mirrored those in Ross Lake. These comparisons suggest a high degree of hydraulic connectivity between the two water bodies.

As noted above, delayed access to spawning areas for Rainbow Trout may occur if they become trapped in Lost Lake and drawdowns extend into May. Rainbow Trout spawn in May through June. Native char spawning would be unaffected.

Potential changes in prey availability within Lost Lake relative to Ross Lake are unlikely given the relatively large volume of Lost Lake. Zooplankton, macroinvertebrate, and forage fish species would likely be similar in terms of species composition and densities to those in Ross Lake.

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