# *Boundary Hydroelectric Project (FERC No. 2144)*

# *Temperature Attainment Plan*

**Seattle City Light**

**Revised**
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## 1 INTRODUCTION

As part of the relicensing of the Boundary Hydroelectric Project (Project), Federal Energy Regulatory Commission (FERC) No. 2144, Seattle City Light (SCL) must obtain Clean Water Act (CWA), Section 401 water quality certification from the Washington Department of Ecology (Ecology). This document describes SCL's Temperature Attainment Plan (Plan) for the Project in support of Ecology's issuance of a Section 401 certification.

The Pend Oreille River is listed on Ecology's 303(d) list as being impaired for temperature. Ecology has prepared a Temperature Total Maximum Daily Load (TMDL) for the river (Ecology 2011). As required by WAC 173-201A-510(5)(c), SCL must address the temperature load allocations identified in the TMDL as part of the 401 certification of the Project.

The following sections include a summary of temperature modeling and analyses conducted for the Project area by SCL as part of relicensing and by Ecology during development of its Temperature TMDL. Following the discussion of analyses is a description of SCL's approach to temperature attainment, monitoring, and evaluation of success in achieving attainment. SCL commits to implement the terms of the Plan as set forth below.

## 2 REGULATORY CONTEXT

### 2.1. Washington Water Quality Standards

Ecology adopted use-based standards in 2003 that were approved by the U.S. Environmental Protection Agency (EPA) in 2006. These uses are defined in WAC 173-201A-200. Designated beneficial uses in the mainstem Pend Oreille River from the U.S.-Canada border (RM 16.0) to the Idaho border (RM 87.7) are:

- Aquatic Life Use: Salmonid Spawning, Rearing, and Migration
- Recreation Use: Primary Contact Recreation
- Water Supply Uses: Domestic, Industrial, Agricultural, and Stock Water Supply
- Miscellaneous Uses: Wildlife Habitat, Fish Harvesting, Commerce and Navigation, Boating, and Aesthetic Values

The applicable temperature standard for the Pend Oreille River from Canada to the Idaho border is for protection of the designated Aquatic Life Use (Ecology 2006). In the Temperature TMDL, the standard has two parts: Part 1, which applies when natural temperatures are over 20 ˚C, and Part 2, which applies when temperatures are under 20 ˚C. Ecology defines parts 1 and 2 of the temperature standard on page 7 of the Temperature TMDL (Ecology 2011) as follows:

> "Part 1: Temperature shall not exceed a 1-day maximum (1-DMax) of 20.0˚C due to human activities. When natural conditions exceed a 1-DMax of 20.0˚C, no temperature increase will be allowed which will raise the receiving water temperature by greater than 0.3˚C;
>
> "Part 2: Nor shall such temperature increases, at any time, exceed t = 34/(T + 9) where:
>
> t = the allowable temperature increase; and
> T = the background temperature measured at a point unaffected by the discharges. The Pend Oreille River is affected by discharges from dams in both Washington and Idaho, so the modeled natural condition, which represents the unaffected river, is used to define T in this TMDL."

Temperatures in the Pend Oreille River upstream of the Project area (i.e., water entering the Project from Box Canyon Reservoir) at times exceed the applicable numeric water quality standard of 20 ˚C daily maximum temperature. During development of the Pend Oreille River Temperature TMDL, Ecology and SCL produced CE-QUAL-W2 models[1] to estimate natural temperature conditions by removing all known human heat influences ("Natural Condition"). Temperatures throughout the Pend Oreille River can reach 25 ˚C in the summer months, in excess of the numeric standard of 20 ˚C. During the period when natural conditions are above 20 ºC, the natural conditions provision is the applicable water quality standard (i.e., numeric criteria is Natural Condition + 0.3 ˚C). Accordingly, modeled temperatures were used to evaluate summer temperature conditions in the Pend Oreille River relative to the Natural Condition (Khangaonkar et al. 2009, Ecology 2011). In addition to the analysis of summer temperature conditions, Ecology's TMDL also includes an analysis of fall temperature conditions under Part 2 of the standard. A discussion of these analyses is provided in Section 3 of this Plan.

## 2.2. Pend Oreille River Temperature TMDL

Analysis of the Existing Condition relative to the Natural Condition temperatures was applied in developing the Temperature TMDL and evaluating compliance with Part 1 and Part 2 of the water quality standard. Using the CE-QUAL-W2 model, data from representative years[2] (2004-2005) were also used to simulate and compare summer temperatures under the modeled Natural Condition and the modeled Existing Condition without Boundary Project. The TMDL indicates that daily maximum temperatures in areas of the Boundary Reservoir are not in compliance with the water quality standard for temperature, and that at times the Boundary Project contributes to impaired temperature conditions in the Pend Oreille River. Based on these analyses, Ecology formulated temperature load allocations for the Boundary Project under Part 1 and for the Boundary reaches under Part 2 (see Section 3 of this Plan for a discussion of the analyses and load allocations contained in the TMDL).

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[1] Ecology developed a CE-QUAL-W2 model for the reach of the Pend Oreille River from the Washington / Idaho state line to Box Canyon Dam forebay, and SCL developed a CE-QUAL-W2 model for the reach from the tailrace of the Box Canyon Dam to Boundary Dam tailrace.

[2] During the development of the Pend Oreille River temperature model, EPA, Ecology, the Kalispel Tribe, and the Idaho Department of Environmental Quality (IDEQ) reviewed data from the historical record and determined that 2004 and 2005 were representative of critical conditions for temperature.

SCL's actions under this attainment plan will help to achieve the temperature allocations assigned to SCL in the TMDL. If the TMDL targets and water quality criteria are not met by the end of this compliance period, Ecology and SCL will follow WAC 173-201A-510(5)(g) to identify further necessary actions.

## 3 TEMPERATURE ANALYSIS

Modeling (CE-QUAL-W2) shows that Existing Condition summer temperatures in Boundary Reservoir are frequently within the range of the modeled Natural Condition or cooler (Table 3-1). Greater detail can be found in Section 4.5.2.2.2 of SCL's License Application Exhibit E and in Khangaonkar et al. (Temperature Modeling and Alternative Operations Analyses for Boundary Hydroelectric Project – Clean Water Act 401 Certification Support, 2009), which are incorporated herein by reference (see Appendix 1).

Four modeling conditions examined in support of SCL's License Application and the Pend Oreille River Temperature TMDL are described (Table 3-2 and Khangaonkar et al. 2009). In order to determine whether water quality standards are met in the Pend Oreille River, Ecology compared the Natural and Existing model-predicted temperatures conditions. As a part of its License Application and 401 Application, SCL provided analyses comparing the Existing Condition and the Existing Condition without the Boundary Project in order to determine the temperature contribution of the Boundary Project to the existing summer temperature condition in the Pend Oreille River (Section 5 of Khangaonkar et al. [2009]). Finally, SCL compared an operations alternative (1,974-foot Run of River Condition) to the Existing Condition (see Section 4.1.1 below and Section 6 of Khangaonkar et al. 2009).

**Table 3-1.** Summary of SCL's frequency analysis results regarding the summer temperature effects at the Metaline Pool, Boundary Forebay, and Boundary Tailrace stations.

| **Frequency Analysis Results** | **Surface[3] Daily Maximum Temperature (ΔT)** |
|---|---|
| **Effects of All Sources**<br><br>Range of cumulative temperature differences between the Existing and Natural Conditions (Existing Condition - Natural Condition) | **Metaline Pool**<br>Existing Condition difference is between -0.59 ºC (lower than Natural) and +0.50 ºC (higher than Natural) (License Application Exhibit E, Figure E.4-24). |
| | **Boundary Forebay**<br>Existing Condition difference is between -0.35 ºC (lower than Natural) and +0.76 ºC (higher than Natural) (License Application Exhibit E, Figure E.4-24). |
| | **Boundary Tailrace**<br>Existing Condition difference is between -1.15ºC (lower than Natural) and +0.19 ºC (higher than Natural) (License Application Exhibit E, Figure E.4-24). |
| **Effects of Removing Boundary Dam**<br><br>Range of cumulative temperature differences between the Existing Condition and Existing without Boundary Condition (Existing Condition – Existing without Project Condition) | **Metaline Pool**<br>Existing Condition difference is between -0.32 ºC (lower than Existing without Boundary Dam) and +0.07 ºC (higher than Existing without Boundary Dam) (License Application Exhibit E, Figure E.4-28). |
| | **Boundary Forebay**<br>Existing Condition is between +0.01 ºC and +0.58 ºC (all higher than Existing without Boundary Dam) (License Application Exhibit E, Figure E.4-28). |
| | **Boundary Tailrace**<br>Existing Condition difference is between -0.14 ºC and -0.88 ºC (all lower than Existing without Boundary Dam) (License Application Exhibit E, Figure E.4-28). |

[3] The term "surface" in SCL's analysis refers to the top layer of the CE-QUAL-W2 model. At Metaline Pool, Boundary Forebay and Boundary Tailrace, the top layer is 1m, 2m and 1m thick, respectively. SCL's analyses of temperature effects considered both surface temperatures and flow-weighted temperatures (Khangaonkar et al. 2009 at 10).

**Table 3-2.** Model conditions for temperature analyses (Khangaonkar et al. 2009).

| Model Condition | Pend Oreille River Dams | Point Sources | Shade |
|---|---|---|---|
| Existing Condition | All | All | Existing |
| Natural Condition | None | None | Potential Natural Vegetation |
| Existing Without Boundary Project Condition | Albeni Falls, Box Canyon, Seven Mile | All | Existing |
| Run-of-River 1,974-foot Condition | All | All | Existing |

Ecology's analysis for the TMDL indicates that daily maximum temperatures in areas of the Boundary Reservoir are not in compliance with Part 1 and Part 2 of the water quality standard for temperature, and that at times the Boundary Project contributes to impaired temperature conditions in the Pend Oreille River.

The TMDL states that in the Boundary Dam forebay, Part 1 of the temperature standard was exceeded by an average (2004, 2005) of 0.59 ˚C. For Part 2 of the standard, Ecology analyzed temperatures between 20 ˚C and 12 ˚C, with the 12 ˚C lower limit applied because bull trout use the river for migration in the early fall and are sensitive to temperatures above that level. During the period associated with these temperatures (September - October), the TMDL finds that Part 2 of the standard was exceeded for all of the Boundary Project reaches, with the level of maximum exceedance increasing longitudinally from 0.14 ˚C at Metaline to 0.53 ˚C at the Boundary Dam tailrace (see Table 11 of the TMDL for an account of Part 1 and Part 2 exceedances as identified by Ecology).

When natural condition river temperatures are greater than 20 ˚C (July and August), Ecology's load allocation for the Boundary Project has been set at 0.12 ˚C above the natural temperature condition (an equivalent allocation was assigned to the Box Canyon Project). The TMDL states that the magnitude of the allocations reflects the interrelationship of the Box Canyon and Boundary projects' temperature impacts and associated cumulative impacts in the watershed. The temperature reduction required to achieve the load allocation for the Boundary Project is 0.88 ˚C, based on 2004 modeling results. This reduction applies during July and August in the forebay, which is the area of maximum temperature impairment. When river temperatures are under 20 ˚C in late summer and early fall (September through October), the TMDL identifies the following allocations for the Boundary Project reaches: Metaline, 0.14 ˚C; Slate, 0.24 ˚C; Boundary forebay, 0.61 ˚C; and Boundary tailrace, 0.53 ˚C (see Table 15 of the TMDL for a list of Part 1 and Part 2 load allocations, by reach, for hydroelectric facilities on the Pend Oreille River).

The TMDL identifies load allocations by Project to address Part 1 of the temperature standard, whereas for Part 2 of the standard, allocations are identified by reach. For Part 2, all activities completed to reduce water temperatures will cumulatively help achieve the reductions. Because of their cumulative interrelated effects, the Box Canyon and Boundary Projects are required to "equally share" the temperature allocations identified to achieve compliance with Part 2 of the standard in the four Boundary reaches (TMDL at p. 79).

# 4 TEMPERATURE ATTAINMENT PLAN

As noted above, Ecology has stated in its Temperature TMDL for the Pend Oreille River (Ecology 2011) that areas of the Pend Oreille River in the Boundary Project area are not in compliance with the water quality standard for temperature, and that at times the Boundary Project contributes to impaired temperature conditions. SCL's analysis of three locations in the Project area (Boundary Tailrace, Boundary Forebay, and Metaline Pool) shows that modeled summer surface daily maximum temperatures are the same or cooler with the Project than without it at the Boundary Tailrace and Metaline Pool stations. The model analysis also shows that the Existing Condition temperatures at times are higher at the Forebay station than the modeled temperatures for the Existing Condition without Boundary Project Condition (see Table 3-1).

Under WAC 173-201A-510(5)(b), dams contributing to a violation of the water quality standards must develop a water quality attainment plan that provides a detailed strategy for achieving compliance. To meet commitments under the Boundary Relicensing Settlement Agreement, SCL has prepared this Temperature Attainment Plan (TAP) that summarizes analyses completed and outlines actions that will be implemented during the first ten years of the new license term that will contribute to temperature improvement goals in the Pend Oreille watershed to address the temperature effects in the Boundary Reservoir. This TAP meets the requirements of WAC 173-201A-510(5)(b). Ecology has suggested that riparian plantings and fish habitat improvements in tributaries to the reservoir, including enhancing and protecting thermal refugia in the Reservoir's tributary delta areas and erosion control measures and associated riparian plantings on the mainstem Pend Oreille River (see Section 4.1.2), will help meet the temperature improvement goals for the Pend Oreille River.

## 4.1. Reasonable and Feasible Improvements

This Plan evaluates potential operational and non-operational approaches to addressing temperature effects in the Boundary Reservoir. The results of an alternative operations analysis (see Section 4.1.1 below) indicate that during summer, rather than reducing or eliminating the daily maximum temperature effect observed, the most extreme change in operations possible consistent with physical Project constraints ("run-of-river" at lower forebay elevation) would marginally worsen surface temperature conditions. There do not appear to be operational changes that could lower daily maximum temperatures in the Boundary Reservoir during this period (Khangaonkar et al. 2009). Accordingly, implementation of non-operational measures to improve aquatic habitat conditions (see Section 4.1.2 below) are the only reasonable and feasible improvements identified for implementation in this Plan.

### 4.1.1. Operations Analysis

Due to the daily maximum temperatures seen at the Boundary Dam Forebay station, Ecology requested that SCL investigate whether there were operational changes that could lower daily maximum temperatures (for greater detail, see 4.5.2.2.2 of SCL's License Application Exhibit E and Khangaonkar et al. [2009]). SCL developed an alternative operational scenario to model expected temperatures if the Project were to be operated under "run-of-river" conditions and at a constant forebay elevation of 1,974 feet NAVD 88 during summer months ("1,974-foot Run-of-

River Condition")[4]. The 1,974-foot Run-of-River Condition is the most extreme variant on current operations possible given the physical constraints of the Project (i.e., it maintains the forebay level as low as possible without causing cavitation damage to the units from continued operation). It therefore provides an important outer bound to compare to the current operations scenario ("Existing Condition"). The 1,974-foot Run-of-River Condition was designed to evaluate whether temperature benefits would be provided by reducing the surface area of the reservoir and reducing warm water accumulation in the forebay.

There is no significant difference between the Existing Condition and the 1,974-foot Run-of-River Condition for modeled surface daily maximum temperatures at Metaline Pool or Boundary Tailrace. The only difference between the two conditions was warming of summer surface[5] daily maximum temperatures at the Boundary Forebay station under the 1974-foot Run-of-River Condition relative to the Existing Condition. These results indicate that, rather than reducing or eliminating the limited daily maximum temperature effect observed at the Forebay station under the Existing Condition, the most extreme change in operations possible, consistent with physical constraints, would instead marginally worsen conditions at the Forebay. Accordingly, the modeling results indicate that summer daily maximum temperatures in the Boundary Reservoir cannot be lowered using operational changes.

### 4.1.2. Pend Oreille Watershed Aquatic Habitat Improvement Projects

As noted above, the water quality standard for temperature in the Pend Oreille River was established to protect the aquatic life designated beneficial use. The Fish and Aquatics Management Plan (FAMP) outlines measures to be taken to protect and improve aquatic habitat in tributaries to Boundary Reservoir (SCL 2010a). The settlement parties reviewed all available information on fish use and habitat in the mainstem Pend Oreille River, and its tributaries (Section 4.5.3 of the License Application Exhibit E summarizes Fish and Aquatics Resources information). The parties identified the suite of tributary measures identified in this section of the Temperature Attainment Plan as the most effective combination of measures intended to address Project water quality impacts on fish and aquatic resources.

Included in these tributary measures are plans to be implemented pursuant to agreements between SCL and the Pend Oreille PUD for removal of the Mill Pond Dam on Sullivan Creek and related habitat restoration, and cold water release from Sullivan Lake. Both of these measures are expected to improve temperature and other aquatic habitat conditions in Sullivan Creek and its delta in the Boundary Reservoir. Other tributary aquatic habitat measures include riparian plantings that will increase tributary shade, which should thereby reduce stream temperatures. Tributary measures also include physical habitat modifications designed to improve habitat for salmonids, which could improve temperatures by creating pools (i.e., deeper water that may experience lower diel fluctuations in temperature than the shallow water habitats currently present). These tributary habitat improvements would also have a direct positive effect on designated beneficial uses, i.e., salmonid spawning and rearing. Finally, reductions in tributary temperature could improve the quality of thermal refugia at the mouths of tributaries in

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[4] The exact operational parameters used for this scenario are described in Khangaonkar et al. (2009).

[5] For the Boundary Forebay location "surface" refers to the top layer of the CE-QUAL-W2 model, which is 2m thick at this location.

Boundary Reservoir, which could improve salmonid habitat in the reservoir at the tributary deltas during summer. In addition to tributary habitat measures, several erosion sites on the mainstem Pend Oreille River were identified for stabilization and associated riparian planting.

#### *4.1.2.1. Tributary Aquatic Habitat Improvements, Including Riparian Plantings*

As required under the FAMP, and in coordination with the Fish and Aquatics Work Group (FAWG), aquatic habitat improvements will be conducted following issuance of the new Project license in the tributary reaches described below, or as modified by the FAWG and described in the FAMP annual reports. Mill Pond dam removal and habitat restoration is described in Section 4.1.2.1.1, and the Sullivan Lake cold water release is described in Section 4.1.2.2 below. Riparian plantings will also be conducted during the first 10 years following issuance of the new Project license in several tributary reaches, as detailed Section 4.1.2.1.1. Riparian plantings will increase tributary shade, which should thereby reduce stream temperatures. Reductions in tributary temperature could improve the quality of thermal refugia at the mouths of tributaries in Boundary Reservoir, which could improve salmonid habitat at the tributary deltas during summer. Other physical habitat modifications that are designed to improve habitat for salmonids, and could improve temperatures by creating pools (i.e., deeper water that may experience lower diel fluctuations in temperature than the shallow water habitats currently present), would also have a direct positive effect on designated beneficial uses, i.e., salmonid spawning and rearing.

These measures will be implemented in coordination with other fish and aquatics Protection, Mitigation, and Enhancement measures detailed in the FAMP. The timelines for implementation presented below were established to reflect the inter-related nature of implementation.

##### 4.1.2.1.1. Tributary Habitat Improvements

Mill Pond Dam Removal and Stream Channel Restoration

As part of the proposed surrender of its license for the Sullivan Creek Project, within five years of FERC's issuance of the License Surrender Order, the Pend Oreille County Public Utility District (POPUD) will remove Mill Pond Dam and the associated log crib dam, manage sediment, restore the stream channel, implement site restoration measures, and conduct short-term monitoring and maintenance in the Mill Pond Affected Area (see Mill Pond Decommissioning Plan [POPUD 2010a]). The Affected Area shall include the stream channel, floodplain, and upland areas, from immediately downstream of Mill Pond Dam to Outlet Creek, and shall include any areas impacted by restoration or construction activity. These measures will increase the extent of habitat connectivity for native salmonids and improve aquatic habitat and water quality in Sullivan Creek, the largest tributary to Boundary Reservoir. Through an Interlocal Agreement for Mill Pond Decommissioning between SCL and the POPUD, SCL will implement the Mill Pond Decommissioning Plan. SCL will perform this work as the contractor of the PUD for the time period when the facilities and area are subject to the PUD's Sullivan Creek Project license.

Specific measures related to site restoration at the Mill Pond site as described in the Mill Pond Dam Removal and Restoration: Alternatives Analysis and Evaluation of Recommended Alternative Report (McMillen 2010) are designed to meet the following objectives:

- Restore the Mill Pond reservoir inundated area. Restoration shall include revegetation of the inundated area to plant communities consistent with the site and surrounding vegetation. The inundated area is defined as the area when the water surface elevation is 2,520 feet NAVD 88, i.e., the average water surface elevation when the concrete dam was completed.
- Restore the Affected Area, to a self-functioning system consistent with the Sullivan Creek channel upstream and downstream of Mill Pond. The restored stream channel, floodplain, and upland area will be designed to function up to, and including a flood event having a 100-year flood recurrence interval.
- Provide for the prevention, suppression, containment, eradication and/or control of invasive, non-native plant species in the Affected Area.
- Stabilize sediment left in place within the Affected Area.
- Deposit sediment material removed during site restoration in locations and at elevations to avoid mobilization and transport into the restored stream channel during flows up to, and including a flood event having a 100-year flood recurrence interval. Permanently dispose of sediment not left in place or utilized in restoration efforts at a non-National Forest Service (NFS) site.
- Implement floodplain and upland area restoration measures to prevent erosion and run-off of sediment materials into the restored stream channel during large rain events.
- Initiate stream restoration activities as soon as practicable after the start of dam removal activities so that the restoration and removal activities occur concurrently.
- Restore Sullivan Creek between Mill Pond and the confluence with Outlet Creek in a downstream direction.
- Remove Mill Pond dam and the associated crib dam in dry conditions behind the coffer dam.
- Restore the Affected Area, including any wetland areas receiving temporary direct impacts from equipment trampling. These areas shall be planted with native vegetation and restored to their pre-construction condition upon completion of restoration activities.

Following completion of the restoration effort described in the Mill Pond Decommissioning Plan, and after FERC jurisdiction over the site through the Sullivan Creek Project license ends, SCL will continue to monitor and maintain the Mill Pond area (see Section 4.2.3).

## Stream and Riparian Improvements in Sullivan Creek RM 2.3 to RM 3.0 and North Fork Sullivan Creek

This measure will be implemented in Sullivan Creek, within 10 years of license issuance, from approximately 265 feet downstream of the confluence of Sullivan Creek and North Fork Sullivan Creek (RM 2.3) to RM 3.0 and consists primarily of streambank and channel enhancement but also includes riparian planting. The objectives are to decrease bank erosion on the right bank, provide instream structure to create pools and enhance deposition and retention of spawning gravel, decrease the channel width-to-depth ratio, and promote the riparian buffer along the right bank. If permitting or other issues prevent implementation of this measure over portions of the reach within 10 years after license issuance, funds equivalent to what would have been expended will be allocated to other measures in tributaries to Boundary Reservoir as determined in consultation with the FAWG and subject to the approval of the USFS for activities that occur on NFS lands.

A brief site visit that included biologists and engineers from the USFS and the SCL relicensing team suggested that the objectives could be achieved through road relocation/reconstruction or stream channel diversion. Stream channel diversion could be accomplished through the addition of log jam structures, rock barb structures, and LWD. The log jam and the barbs are anticipated to move the thalweg of Sullivan creek at least 10 feet towards the center of the channel and create at least a 10-feet wide vegetative riparian zone. This action would promote deposition of stream sediment along the existing bank; thus, reducing bank angles and providing a low lying bench appropriate for natural regeneration or riparian planting of willows and other native woody plants. SCL shall undertake additional post-license planning to add substance and detail to the conceptual plan developed in the field and to ensure that modifications do not cause adverse downstream impacts. This plan will be developed in consultation with the FAWG and subject to approval of the USFS. Implementation of this plan will result in completion of the following activities within 10 years after license issuance between RM 2.3 and 3.0:

- Design and construction of seven engineered LWD jams (1,100 cubic feet volume each)
- Placement of 10 to 20 boulders (average of 3 feet in diameter)
- Channel modifications
- Riparian plantings
- Streambank modifications at two locations (475 feet long and 317 feet long) where Sullivan Lake Road is hydrologically connected to the creek. Modifications will include decreasing the bank angle through flow redirection, structural techniques, and/or biotechnical techniques.
- Either road relocation/reconstruction or stream channel diversion at one site on Sullivan Creek (County Road 9345 in SCL Segment 4; RM 2.5-3.0).

Boulders will primarily be placed in clusters, but could also be used to anchor LWD pieces. Selection of specific structural elements and their placement will be determined as part of post-

license planning and design work, will generally follow WDFW guidelines in Saldi-Caromile et al. (2004), and will require approval of the FAWG prior to implementation.
SCL will also replace the culvert at the Sullivan Lake Road stream crossing of North Fork Sullivan Creek and place LWD in North Fork Sullivan Creek from the mouth to the North Fork Sullivan Creek Dam (RM 0.25) by License Year 15. Instream LWD placement will include 70 pieces of LWD. Of these pieces, at least 6 shall be 12 inches or greater in diameter and a minimum of 35 feet in length. The final number and size of LWD to be placed into North Fork Sullivan Creek will be approved by the FAWG and consider site-specific conditions.

Large Woody Debris Placement and Road Improvements in Sullivan Creek and Selected Tributaries Upstream of the Confluence with Outlet Creek

This measure will be implemented in Sullivan Creek and select tributaries upstream of the confluence with Outlet Creek at RM 5.3. SCL will place LWD in Sullivan Creek by Year 10 of the new license term in the amounts listed below:

- Outlet Creek to Rainy Creek – 681 pieces, of which 136 will be greater than or equal to 12 inches in diameter and 35 feet in length.
- Rainy Creek to Gypsy Creek – 330 pieces, of which 46 will be greater than or equal to 12 inches in diameter and 35 feet in length.
- Gypsy Creek to the end of fish bearing waters – 728 pieces, of which 76 will be greater than or equal to 12 inches in diameter and 35 feet in length.

Engineered log jams will account for a portion of LWD. The number of LWD jams will be determined as part of post-license planning and subject to approval by the FAWG.

SCL will implement the following road improvements along the 12 miles of Sullivan Creek Road between the mouth of Outlet Creek and Leola Creek:

- Sullivan Creek Road – Approximately 6.5 miles of road (described in Table 5.4-5) shall be reconstructed, including resurfacing with 4 inches of gravel, re-grading to divert storm water to the inside ditch, and the replacing of deficient/adding up to 35 new storm water ditch relief culverts including sediment traps or energy dissipaters as needed to reduce delivery of road-related erosion to streams. Two cutslope slides located approximately 1.5 and 1.7 miles, respectively from the junction with Sullivan Lake Road (MP 12) (described in Table 5.4-5), shall be stabilized by removing slumped material installing drainage, re-vegetating, and installing retaining structures while maintaining road width.
- Kinyon Creek – Replace FS Road 2220 culvert with a fish passable structure.
- Stony Creek – Replace FS Road 2200 culvert with a fish passable structure.
- Unnamed creek downstream of Cascade Creek– Replace culvert with a multi-plate arch structure.

Table 5.4-5 of the FAMP identifies road lengths using GIS. Preliminary estimates identify 34,190 feet of road to be regarded. This estimate will be verified during implementation planning.

SCL will implement the following road and habitat improvements in the Sullivan Creek basin upstream of Outlet Creek:

- Johns Creek – Remove the FS Road 505 culvert and implement streambank restoration within the road imprint. Replace FS Road 500 culvert with a fish-passable structure.
- Rainy Creek – Remove fish barrier at the mouth of the creek.
- Streambank stabilization near Cascade Creek – Create three engineered LWD jams from LWD currently causing bank instability; supplement with boulders and rock barbs/vanes.
- Channel and weir rehabilitation near the mouth of the unnamed creek downstream of Cascade Creek – Augment existing log weirs and redirect flows to the thalweg of the channel.

### Habitat Protection, Riparian Improvement, and Stream Channel Enhancement in Sullivan Creek RM 0.30 to RM 0.54

This measure consists of two components, riparian improvement and stream channel enhancement, that will be implemented in Sullivan Creek between RM 0.3 to RM 0.54 within 10 years of license issuance. If permitting, landowner permission, or other issues prevent implementation of this measure over portions of the reach, funds equivalent to what would have been expended will be allocated to tributary measures as determined in consultation with the FAWG and subject to the approval of the USFS if they occur on NFS lands.

Riparian improvements will be implemented along the left bank for up to 1,200 feet of stream to improve shade, potential instream LWD, and erosion control. Activities in some sections of the reach would depend on obtaining easements from non-SCL landowners. Selection of specific plant species and planting locations will be determined as part of post-license planning and design work to be approved by the FAWG and following WDFW guidelines.

Stream channel enhancement will improve instream spawning and rearing habitat and channel conditions along 1,200 feet of stream via LWD (> 4 inches in diameter and > 6.6 feet long) placement (15 to 20 pieces), large boulder placement (5 to 10 boulders), and channel modification. Addition of structural elements will contribute to pool formation, retention of LWD, and retention of coarse sediment suitable for salmonid spawning. Structural elements along the left bank will help stabilize the streambank, protecting downstream property owners and decreasing bank erosion. Selection of specific structural elements and their placement will be determined as part of post-licensing implementation planning, be subject to approval by the FAWG, USFS, and Ecology, and generally follow WDFW guidelines. LWD replenishment will occur on an eight-year basis throughout the term of the license.

#### *4.1.2.2. Cold Water Release Structure at Sullivan Dam*

The POPUD and SCL have jointly examined the feasibility to utilize cold water releases from Sullivan Lake to cool water temperatures in Sullivan Creek and provide cooler water input to the Pend Oreille River and have evaluated some of the physical and potential biological effects of such withdrawals on Sullivan Lake. The evaluation demonstrates that, in conjunction with the Mill Pond Dam Removal and Stream Channel Restoration described in Section 4.1.2.1.1, a gravity water supply 48 inches in diameter, with fish screens at the inlet and using an existing low-level outlet from Sullivan Dam, is an effective method to cool water temperatures and improve native salmonid habitat conditions in Outlet and lower Sullivan creeks and provide cooler water input to the Pend Oreille River while minimizing adverse effects on Sullivan Lake (see Cold Water Release Facility Plan [POPUD 2010b]).

The cold water release facility described in the Cold Water Release Facility Plan (POPUD 2010b) is intended to address beneficial uses for Outlet and lower Sullivan Creeks by improving native salmonid habitat conditions relative to existing conditions and condition projected in the future without the cold water release and the removal of Mill Pond Dam. The projected temperature improvements (Snyder 2009) from the cold water release from June 1 through the time Sullivan Lake de-stratification (turnover) occurs address the biological requirements for some of the life stages of bull trout that are expected to occur in lower Sullivan Creek. The projected temperature improvements from the cold water release also address the needs of life stages of westslope cutthroat trout in lower Sullivan Creek that occur during the above time-periods.

SCL shall fund its share of the cost of design, permitting, construction, monitoring, operation, and maintenance of the cold water facility described in McMillen 2010 as required under the Cold Water Release Memorandum of Agreement between SCL and POPUD. It is anticipated that construction work for the cold water release will be completed within three years of FERC's issuance of the Sullivan Creek Project License Surrender Order.

#### *4.1.2.3. Mainstem Habitat Improvement*

The settlement parties reviewed all available information on fish use and habitat in the mainstem Pend Oreille River and its tributaries (Section 4.5.3 of the License Application Exhibit E as revised March 2010). As described above, settlement parties identified tributary habitat improvements as the most effective non-operational actions to address Project effects to fisheries resources and found limited non-operational opportunities for habitat improvements on the mainstem Pend Oreille River. However, many of the measures identified in Section 4.1.2.1 occur in the tributary deltas in the Reservoir and directly benefit the mainstem. In addition, during relicensing, SCL conducted a detailed survey of the riparian plant and shrub community along the mainstem shoreline areas of Boundary Reservoir (Inventory of Riparian Trees and Shrubs Final Report, SCL 2009). The measures identified in Section 4.1.2.3.2 are the opportunities for riparian planting along the mainstem that were identified and would be consistent with habitat management and improvement goals.

#### *4.1.2.3.1. Mainstem Large Woody Debris at Tributary Deltas*

As detailed in the FAMP, SCL will enhance tributary delta habitat by providing additional cover for salmonids holding in coldwater refugia at tributary mouths. LWD jams will be placed and maintained in the thalweg in the upper delta regions of four tributaries to Boundary Reservoir. Two LWD jams will be placed at the Sullivan Creek delta and one LWD jam will be placed at the deltas of Sweet, Slate, and Linton creeks (total of 5 LWD jams)[6]. The Sullivan Creek logjams will have a total volume of not less than 1,700 cubic feet, while each LWD jam in Slate, Sweet, and Linton creeks will have a volume of not less than 530 cubic feet.

The specific location and design of the LWD jams will be determined during implementation planning by SCL, in consultation with the FAWG and subject to approval by the FAWG. LWD jams will be located in the upper ends of tributary deltas to minimize use by non-salmonids. Orientation and construction of each LWD jam will be based on site-specific hydraulic and channel conditions.

#### *4.1.2.3.2. Mainstem Erosion Control Measures and Riparian Plantings*

The following measures, including revegetation, will be implemented to reduce ongoing erosion along the shoreline of Boundary Reservoir. Greater detail regarding the analysis of the Boundary Reservoir for erosion and selection of these sites for improvement action is provided in the Erosion Study Final Report (SCL 2009). More detail on the implementation of these measures, and ongoing erosion monitoring in the Project area, is provided in the Terrestrial Resources Management Plan (SCL 2010b).

- *Erosion Site 17W1 (Forebay Recreation Area)* – Bank erosion at this site will be controlled by installing seeded erosion control blankets or turf reinforcement mats. Minor slope grading prior to installation is recommended. Toe protection is not required; however, the erosion control fabric should be anchored at the toe of the slope and at the top of the bank. Controlling surface erosion from the recreation area will also reduce future bank erosion. Runoff from the picnic area currently flows in a drainage swale that discharges at the bank and contributes to erosion. Armoring the outlet of the swale where it discharges to the bank, or rerouting the swale to discharge closer to the boat ramp, would reduce bank erosion.

- *Erosion Site 19W9 (BLM Boundary Recreation Area)* – Bank erosion at this site will be controlled by a combination of biotechnical stabilization techniques. Various measures such as tree revetments, live cribwalls, live siltation, coconut logs, and native rock could be installed to protect the toe of the bank. The bank itself will be revegetated using brushlayering, branch packing, and/or live cribwalls. Any stabilization technique should be carefully planned to minimize further destruction of established vegetation on the bank. The site could be further improved by constructing more formal public access to

[6] Placement of LWD dams in deltas will take place within the first 10 years following license issuance, except in the Sullivan Creek delta, which at the direction of the FAWG, **may** take place after the tenth year, depending on the influence of Mill Pond Dam removal (see page 39 of the FAMP).

the reservoir using terraced log cribwalls and eliminating the existing casual trails by revegetating the trails and blocking access with downed trees or other natural materials.

- *Erosion Site 21W19 (Dispersed Recreation Day Use/Overnight Campsite on BLM-Managed Land)* – Bank erosion at this site will be controlled by a combination of biotechnical stabilization techniques such as brushlayering, branch packing, and/or live cribwalls. Native rock should be used to help protect the toe of the bank. Other soft toe protection techniques also might be used; however, the soft, friable nature of the bank toe should be considered when designing the toe protection. Constructing more formal public access using terraced log cribwalls and minimizing the number of access points to the reservoir would reduce the amount of human-caused bank erosion.

## 4.2. Monitoring

### 4.2.1. Mainstem and Tributary Temperature Monitoring

SCL will use a hobo-temp (or similar device) to collect continuous mainstem temperature data from June through October at the locations shown in Table 4.2-1 (mainstem locations cited in the table correspond approximately to original monitoring stations used to calibrate the CE-QUAL-W2 temperature model). Mainstem temperature data collection will complement data collected by Ecology at its Metaline Falls station. Temperature data collection will be conducted at depth intervals in the Boundary Forebay. Due to safety concerns, SCL will work with Ecology to confirm the location of the Boundary tailrace monitoring station. The final tailrace location will be identified in the QAPP. SCL will collect data annually unless the frequency is modified through the annual QAPP review described in Section 4.2.2. These data will be provided to Ecology.

**Table 4.2-1.** Mainstem temperature monitoring locations in the Project area.

| Site | Project River Mile |
|---|---|
| Metaline Pool | 28.4 |
| Slate Creek Pool | 22.5 |
| Boundary Dam Forebay | 17.0 |
| Boundary Dam Tailrace | 16.1 |

SCL will also conduct continuous temperature monitoring (with a hobo-temp or similar device) at one location in each of the following tributary deltas: Sullivan Creek, Sweet Creek, and Linton Creek. The specific locations of temperature monitoring within these deltas will be determined during discussions with the WQWG and FAWG following issuance of the new Project license. Data will be collected annually from June through October, unless the frequency is modified through the annual QAPP review described in Section 4.2.2.

SCL will share equally (with the POPUD) the cost of monitoring associated with the cold water release structure at Sullivan Dam (Section 4.1.2.2). Continuous water temperature monitoring stations will be installed and maintained at two locations on Sullivan Creek: upstream of its confluence with Outlet Creek and at least 300 feet downstream of the confluence with Outlet Creek.

SCL will conduct monitoring of water and air temperatures at a single location in lower Sullivan Creek, i.e., downstream of the current location of Mill Pond but upstream of the delta. The specific location to be monitored will be determined during discussions with the WQWG and FAWG following issuance of the new Project license. Data will be collected annually from June through October, unless the frequency is modified through the annual QAPP review described in Section 4.2.2.

### 4.2.2. QAPP

Within six months of the issuance of the new Project license, SCL will submit a Temperature Monitoring Quality Assurance Project Plan (QAPP) to Ecology for approval. The QAPP shall follow the Guidelines for Preparing Quality Assurance Project Plans for Environmental Studies (July 2004 Ecology Publication Number 04-03-030) or its successor.

The QAPP shall contain, at a minimum, a list of parameter(s) to be monitored, a map of sampling locations, and descriptions of the purpose of the monitoring, sampling frequency, sampling procedures and equipment, analytical methods, quality control procedures, data handling and data assessment procedures, and reporting protocols.

SCL shall review and update the QAPP annually based on a yearly review of data and data quality. Ecology may also require future revisions to the QAPP based on monitoring results, regulatory changes, changes in project operations and/or the requirements of Total Maximum Daily Load. Implementation of the monitoring program shall begin as soon as Ecology has provided the Licensee with written approval of the QAPP. Changes to the QAPP need written approval by Ecology before taking effect. Ecology may unilaterally require implementation of the QAPP.

### 4.2.3. Tributary Aquatic Habitat Improvement Monitoring

Compliance monitoring will occur within one year following implementation of measures identified in Section 4.1.2.1 and any repairs that are needed during the term of the license. Protocols for collecting compliance information will be developed by the FAWG as part of implementation planning. At a minimum, compliance monitoring will include documentation collected during implementation of the measure, such as survey data, records of purchased materials (LWD pieces, ballast, etc), and photographs of each site before and after measures or repairs are implemented.

SCL will conduct effectiveness monitoring beginning in the eighth year following implementation and every eight years thereafter. The purpose of the effectiveness monitoring will be to assess the tributary improvement measure's condition to determine if structural repairs, log replenishment, additional plantings, or non-native plant removal is needed to maintain the measure's designed functions. Criteria for determining whether a measure needs remediation will be determined during post-license planning and is subject to approval of the FAWG. The results of the effectiveness monitoring will be used to support adaptive management and adjustments to the measure at eight-year intervals. If a treatment falls below established success levels, SCL will develop a plan for remediation within 60 days, for approval of the FAWG, to correct the deficiencies. SCL shall begin implementing these remediation measures within 30-days of permit approval or as determined appropriate by the FAWG. Subsequent compliance monitoring will occur as determined by the FAWG.

SCL will monitor the Mill Pond Dam site and maintain the site to remediation design specifications following completion of dam removal and restoration efforts. SCL will monitor the Mill Pond Dam site to assess stream channel, floodplain, and upslope conditions to determine if any structures or plantings fall below the success levels established during implementation planning for the decommissioning of Mill Pond Dam (SCL 2010a). In consultation with the FAWG, SCL will adaptively manage the site and adjust and implement stream restoration components to maintain remediation benefits.

## 4.3. Compliance Schedule

The following table summarizes the actions to occur in this attainment plan.

**Table 4.3-1.** Timeline of Activities**.**

| Activity | Schedule |
|---|---|
| Mill Pond Dam Removal and Stream Channel Restoration | Within five years of license issuance of the License Surrender Order for the Sullivan Creek Project |
| Stream and Riparian Improvements in Sullivan Creek RM 2.3 to RM 3.0 and North Fork Sullivan Creek | Within 10 years of license issuance |
| LWD placement and Road improvements in Sullivan Creek and Selected tributaries upstream of the confluence with Outlet Creek | By year 10 of the new license term |
| Habitat protection, riparian improvement, and stream channel enhancement in Sullivan Creek RM 0.30 to RM 0.54 | Within 10 years of license issuance |
| Cold Water Release Structure at Sullivan Dam | Within three years of the issuance of the License Surrender Order for the Sullivan Creek Project |
| Mainstem LWD at tributary deltas; two at Sullivan, one at Sweet, Slate, and Linton Creeks | Will take place within the first 10 years following license issuance, except in the Sullivan Creek delta, which at the direction of the FAWG, may take place after the tenth year, depending on the influence of Mill Pond Dam removal (see page 39 of the FAMP). |
| Mainstem erosion control measures and riparian plantings | Year 7 following license issuance. |

The current schedule for riparian plantings and aquatic habitat improvements is described in Section 4.1.2. Greater detail regarding the timeline and approach for implementing these measures can be found in the FAMP.

In its annual reports to Ecology, SCL will provide a table of summarized annual temperature monitoring data from sites in the Boundary Reservoir mainstem, from the deltas of Sullivan, Sweet, and Linton creeks, and at locations within Sullivan Creek (see Section 4.2.1). In addition, the annual report will summarize implementation of the aquatic habitat measures as discussed in Section 4.4.

As discussed in Sections 4 and 4.1, the Pend Oreille watershed aquatic habitat improvement measures described in this Plan are the only reasonable and feasible improvements that have been identified for addressing the Project's limited temperature effects in the Boundary Reservoir. At the end of the 10-year compliance period, SCL will have completed all the actions outlined in Section 4.1. Although implementation of all reasonable and feasible improvements as outlined above may not result in significant changes in daily maximum temperatures in the Boundary Reservoir, SCL anticipates that their implementation will result in significant improvements in aquatic habitat within tributaries, at the select erosion stabilization sites, and at tributaries' mouths in Boundary Reservoir, and therefore improve conditions for the aquatic life designated beneficial uses.

### 4.4. Annual Attainment Measure Implementation Reports

SCL will provide Ecology with annual reports, beginning after license issuance, as required by its 401 certification from Ecology. Annual reports will detail the implementation of riparian plantings, erosion stabilization, and other aquatic habitat enhancement measures, as well as monitoring associated with these measures.

# 5 REFERENCES

Breithaupt, S.A. and T. Khangaonkar. 2007. Temperature Modeling of the Pend Oreille River, Boundary Hydroelectric Project, CE-QUAL-W2 Model Calibration Report. Battelle, Pacific Northwest Division, Richland, WA. September 2007.

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Khangaonkar, T., S.A. Breithaupt, and T. Kim. 2009. Temperature modeling and alternative operations analyses for Boundary Hydroelectric Project - CWA 401 Certification Support. Battelle, Pacific Northwest Division, Seattle, WA. August 2009.

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POPUD. 2010b. Sullivan Creek Project FERC No. 2225 Cold Water Release Facility Plan, prepared for PUD No. 1 of Pend Oreille County, EES Consulting, Kirkland, WA. February 2010.

SCL. 2009. Updated Study Report for the Boundary Hydroelectric Project (FERC No. 2144). Seattle, Washington. March 2009. Available online at: http://www.seattle.gov/light/news/issues/bndryRelic/br_document.asp.

SCL. 2010a. Fish and Aquatics Management Plan. Seattle, Washington. March 2010.

SCL. 2010b. Terrestrial Resources Management Plan. Seattle, Washington. March 2010.

Snyder, J. 2009. Sullivan Lake Dam Outflow Temperature Impacts Model. EES Consulting, Kirkland, WA. November 2009.

## Appendix 1: Temperature modeling and alternative operations analyses for Boundary Hydroelectric Project - CWA 401 Certification Support

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| | | | |
|---|---|---|---|
| Date: | **August 19, 2009** | Project No.: | **57415** |
| To: | **Christine Pratt / Seattle City Light** | Internal Distribution: | **File/LB** |
| From: | **Tarang Khangaonkar, Stephen Breithaupt, and Taeyun Kim** | | |
| Subject: | **Temperature Modeling and Alternative Operations Analyses for Boundary Hydroelectric Project - CWA 401 Certification Support** | | |

# 1.0 Introduction

Seattle City Light (SCL) is currently engaged in a relicensing effort for the Boundary Hydroelectric Project. The Boundary Project is located on the Pend Oreille River in northeastern Washington State. The Project is owned and operated by SCL and was first licensed in 1961 by the Federal Energy Regulatory Commission (FERC). The existing license (FERC No. 2144) expires in 2011. SCL has adopted the Integrated Licensing Process (ILP) and has completed studies in preparation for the development of supporting documentation for its proposed operations. The studies focused on determining and evaluating the impacts of the Project and ultimately will be used to develop proposed protection, mitigation and enhancement measures to address impacts as the Project continues to operate under a new license. SCL will file its License Application with FERC on September 30, 2009.

The potential effect of hydropower on water quality is of importance to FERC as well as the Washington State Department of Ecology (Ecology). The FERC process relies on the Clean Water Act (CWA) Section 401 Water Quality Certificate to ensure that the regulatory requirements in connection with water quality compliance will be met. The 401 Water Quality Certificate is issued by Ecology and is a FERC requirement prior to the issuance of a new license for any hydropower project. The purpose of the 401 Water Quality Certificate process is to assess any water quality impacts of the Project and its continued operations and assure its compliance with Washington's water quality standards. Although several water quality variables are of interest on the Pend Oreille River, temperature is the water quality variable evaluated in this memorandum.

For the Pend Oreille River in Washington, the numerical temperature criterion is a daily maximum temperature of 20˚C, unless the temperature would be above 20˚C under Natural Conditions, in which case the criterion is Natural Conditions + 0.3˚C. Temperatures have been observed above the 20°C criterion at several locations in the Pend Oreille River. Consequently, the river was included in the CWA Section 303(d) list as impaired for temperature subject to further analysis of the Natural Condition. Ecology is currently developing a total maximum daily load (TMDL) (heat load limit) for the main stem of the river from the Idaho border to the international boundary with Canada, exclusive of waters within the Kalispel Reservation, to further assess compliance and, as necessary, to bring river temperatures into compliance with Washington Water Quality Standards. SCL has participated in the TMDL development process as a partner, conducting temperature modeling in the Boundary Reach of the Pend Oreille River, through a contract with Battelle–Pacific Northwest Division.

As part of the Pend Oreille River TMDL for temperature, Ecology has conducted the modeling for the Pend Oreille River upstream of Box Canyon Dam to the Idaho border. Ecology is coordinating with the Idaho Department of Environmental Quality (IDEQ), the Kalispel Tribe and the EPA to address the interstate and tribal temperature TMDL for the Pend Oreille River in Washington, including the Kalispel Reservation, and in Idaho. SCL developed a predictive model of temperature (using the model CE-QUAL-W2) for the Boundary Reservoir and the Pend Oreille River from the tailrace of Box Canyon Dam to the international boundary downstream of the Boundary Dam (Breithaupt and Khangaonkar 2007).[1]

This memorandum presents the results of a temperature impact assessment using the aforementioned Pend Oreille River and Boundary Reservoir temperature models, in support of the relicensing and the 401 certification processes for Boundary Dam. To assess the impact of the Boundary Project on temperature, the temperature model was first applied to establish the current temperature condition (Existing Condition). Next it was used to compare these temperature conditions to a modeled case simulating the Natural Condition in the Pend Oreille River. The Natural Condition and Existing Condition temperatures were then compared to a modeled case simulating the Existing Condition without Boundary Project. Finally, at Ecology's request, SCL investigated whether there were operational changes that could lower surface daily maximum temperatures in Boundary Reservoir. To do so, SCL evaluated the temperature effects of the most extreme operational modification possible consistent with operational constraints in order to provide an outer bound on possible alternative operational scenarios relative to current operations. The alternative operations analysis involved modeling of temperature conditions assuming run-of-river operations at a forebay elevation of 1974 feet NAVD 88 during summer months. For each condition analyzed, SCL evaluated temperature conditions at three locations within the Boundary Project: at the Metaline Pool station, which is located in the upper reservoir above Metaline Falls; at the Boundary forebay station, which is located just upstream of the dam; and at the Boundary tailrace station, which is located just downstream of the dam.

Collectively, the simulations described above are consistent with what SCL understands Ecology to be examining as part of its temperature TMDL assessment and what SCL understands Ecology will examine in its 401 assessment.[2] In this memorandum, the predicted temperatures are compared to the Existing Condition to assess any differences from current condition, as well

[1] Breithaupt, S.A. and T. Khangaonkar. September 2007. Temperature Modeling of the Pend Oreille River, Boundary Hydroelectric Project CE-QUAL-W2 Model Calibration Report. Prepared for Seattle City Light by Battelle—Pacific Northwest Division.
[2] July 28, 2009 letter from D. Marcie Mangold (Ecology) to Barbara Greene (SCL) re: Boundary Hydroelectric Project No. 2144; Response to July 1, 2009 Letter Operations Analysis to Accompany Final Application for Section 401 Certification.

as compared to the Natural Condition temperatures to assess compliance with the temperature standard.[3]

SCL is utilizing a frequency analysis approach for assessing the effect of different scenarios on temperature because it is a better indicator of actual changes in stream temperature than comparison of instantaneous temperature results (i.e., comparing temperatures at the same day/time). A comparison of instantaneous temperature results between two scenarios could lead to erroneous conclusions about changes in the stream temperatures. Using an instantaneous comparison, it would not be possible to determine whether flow through the system was truly heated, or whether instead this was simply due to differences in travel times. In contrast, the frequency analysis approach used here looks at peak temperatures during the critical period and evaluates whether the cumulative distribution of high temperatures as a group has increased or decreased in magnitude and frequency. The frequency analysis method recognizes that hydropower operations are not necessarily a heat source in the literal sense but can cause a redistribution of heat within the system. A detailed description and justification of the frequency analysis method is provided in Section 2 of this memorandum.

SCL is also analyzing daily maximum temperatures throughout the water column using flow weighting. The flow-weighted approach is more representative of temperatures throughout the water body because it takes into account conditions found in the entire water column, rather than using only temperatures from the water surface. A detailed description and justification of the flow-weighted approach is provided in Section 3 of this memorandum.

This memorandum is organized as follows:

- Section 2 describes the frequency analysis methodology utilized by SCL for the assessment of temperatures in the Boundary Reach of the Pend Oreille River.
- Section 3 presents the flow-weighted approach for assessing the daily maximum temperatures in the Boundary Reach.
- Section 4 presents and compares the model runs for the Existing Condition (with all dams and point sources present on the Pend Oreille River) for 2004 through 2005 and the Natural Condition (without dams or point sources) for the same 2004 through 2005 period.
- Section 5 presents the model run for the Existing Condition without Boundary Project. This describes the effects of the Existing condition with the Albeni Falls, Box Canyon and Seven Mile Dams present but with the Boundary Project removed from the model. Comparisons are made to the Natural and Existing Conditions.
- Section 6 presents the alternative operations analysis, including evaluation of an alternative operations scenario consisting of run-of-river operations with a drawdown to 1974 feet NAVD 88 elevation during the summer.
- Section 7 presents the conclusion of all the above evaluations.

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3 The focus of the evaluation is the summer period (7/9/2004 through 9/4/2004 and 7/8/2005 through 9/8/2005) when Existing Condition temperatures were > 20ºC. During this period the applicable temperature criteria was Natural River temperature +0.3˚C

# 2.0 Frequency Analysis Approach for Temperature Assessment

The water quality criterion for temperature in the Pend Oreille River (WRIA 62, WAC 173-201A-602, Table 602, WRIA 62, Pend Oreille River, note 1) is as follows:

> *Temperature shall not exceed a 1-DMax of 20.0°C due to human activities. When natural conditions exceed a 1-DMax of 20.0°C, no temperature increase will be allowed which will raise the receiving water temperature by greater than 0.3°C . . .*

In other words, when the natural temperatures exceed 20˚C, the applicable criterion is the natural temperature + 0.3˚C. Natural conditions are estimated using numerical models applied to stream conditions simulated without human influence.

Assessments of compliance with the criterion have sometimes been done by direct comparisons between existing and natural temperatures for a specific day and at a specific location. This approach is appropriate for systems in which the hydrologic regime has not been altered and river flow and stage in the existing and natural conditions may be assumed to be the same (e.g., for an industrial or other point-source discharge that does not alter flow). However, in the case of systems like the Pend Oreille River, the placement of dams for hydropower generation has regulated the hydrologic response of the system, such that flows through the river system are different from the natural condition; the peak flow is earlier and larger in the Natural Condition than in the Existing Condition. The Boundary Project also operates in a peaking mode. Peaking mode operations have daily variation in flow with the highest flow during peak-electricity demand in the day and near-zero flow at night. This pulsing of discharge produces fluctuating velocities and water levels throughout the Boundary Reservoir, which alter the travel time of flow. Comparing the temperature of the Existing Condition of the Boundary Reach at a specific location and time with the Natural Condition at that same location and time results in comparison of two different parcels of water because of a significant travel time difference referred to as *lag time*.

When we compare temperatures under the Natural Condition to those under the Existing Condition, we observe this lag time effect; it is the result of two separate phenomena, travel time lag and thermal inertia. A natural river is typically shallow and well mixed and has high velocities resulting in relatively short travel or residence times. In contrast, impounded systems are deeper, of slower velocity, less well mixed vertically, and have longer residence times. In the Boundary Reservoir, this effect is illustrated with the simulation of a pulse test conducted for low summer flow conditions of approximately 11,400 cfs. Figure 2-1 shows the lag time of flow through the system, with the tracer depicting the time for a pulse to travel through the Boundary Reach for the unimpounded river (Natural) and the impounded river (Existing).[4] For the Boundary Reach, the Natural Condition has a short travel time (around 0.5 day), while the

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[4] Similar results would be observed in a comparison of the Existing without Boundary Condition to the Existing Condition.

Existing Condition has a longer travel time (around 3 days). Therefore, a parcel of water leaving the Box Canyon Dam, with Boundary Dam in place (Existing Condition), lags behind that in the unimpounded river (Natural Condition) by about 2.5 days (3.1 – 0.5 = 2.6) due to the difference in travel time.

Temperature response in a reservoir also lags that in a natural river due to *thermal inertia*. A reservoir holds a considerably larger mass of water relative to a natural stream of the same length. As a result, an unimpounded river heats up much faster in response to an atmospheric forcing while a reservoir takes longer to reach the equilibrium temperature. This is illustrated in Boundary Reservoir with the help of a heat wave simulation (Figure 2-2). A hypothetical atmospheric heat pulse was applied to the existing and natural systems for a period of 7 days. The existing system with the Boundary Reservoir in place responds slowly to the atmospheric temperature increase relative to the natural system. The effect is also notable after the heat pulse is removed and the atmospheric temperatures return to the previous values. The Existing Condition takes longer to heat up and longer to recover. Figure 2-2 shows the results of this heat pulse analysis for surface water temperatures in the Pend Oreille River system at the Boundary Dam forebay location (RM 17.5). The thermal inertia lag in the Boundary Reservoir for the summer low-flow conditions is about 4.5 days. Note that in the Natural Condition, the daily temperature amplitude is much larger than in the Existing (impounded) Condition; this also reflects the thermal inertia differences.

During low-flow summer conditions, the lag effect due to a combination of travel time lag (2.5 days) and thermal inertia lag (4.5 days) is about 7 days.[5] Therefore, a comparison of instantaneous temperature values would be comparing two parcels of water separated by 7 days. This would provide an incorrect estimate of any true increase or decrease in temperature caused by heating or cooling of water. By failing to account for lag time and thermal inertia, a comparison of recorded daily maximum temperatures in the Existing Condition with the temperatures from the same days in the Natural Condition would result in an exaggerated apparent change in temperature. In reality, the corresponding peak temperature in the Natural Condition during the same period is found to reach about the same peak temperature as under the Existing Condition, it just occurs on a different day. Added complexity is induced by the fact that the lag effect is a function of daily flow rate, which not only fluctuates on a day-to-day basis, but also includes diurnal fluctuations due to the peaking mode operation of Boundary Dam.

Frequency analysis is an effective approach that has been used to address this lag time effect when comparing temperature data for different hydrologic scenarios. This approach pools all data during the period when natural temperatures exceed the numeric water quality criterion. This generally corresponds to the peak summer months of June, July, August, and September. The justification for this approach is that during the summer period, water temperatures higher than the numeric criteria occur naturally. Temperatures in the Existing Condition in Boundary Reach also exceed the 20˚C criterion, although, the timing of these peak temperatures is slightly altered from the Natural Condition due to the lag effects described above. To assess actual

[5] Note that the lag time of 7 days derived through this numerical experiment corresponds to a specific Pend Oreille River flow of 11,400 cfs. The lag time would likely vary as a function of river flow and is unrelated to the metric of 7-day average of daily maximum temperatures (7-DADM) used in temperature compliance analysis in other parts of Washington.

temperature changes under these circumstances, it is more informative and meaningful to evaluate whether the high temperatures in the Existing Condition were higher or lower due to Project operations or whether they occurred more or less frequently compared to the Natural Condition.

The frequency analysis approach for assessing temperature impairment has been used by the Oregon Department of Environmental Quality (ODEQ) on the Willamette River.[6] Figure 2-3 shows an example analysis conducted along a reach of the Willamette River using flow-weighted temperatures over a stated period. Instead of being plotted as a time series of temperature, the data are represented as a cumulative frequency plot of exceedance temperatures along with their percentile frequencies. Both the project and no-project conditions are shown, and the differences in the temperatures at each quantile are shown. In Washington, frequency analysis technique was used successfully by U.S. EPA to show that temperatures at Bonneville Dam exceed the 20˚C criterion more frequently (impounded) than in Natural Conditions (unimpounded).[7]

To provide a more reliable comparison of temperatures under different scenarios and to address the lag effects inherent in such a comparison, the temperature analyses in Boundary Reservoir were conducted using a frequency analysis approach.

The frequency analysis of temperature data was conducted using the following steps:

1. The daily maximum temperatures for the periods July 9, 2004 to September 4, 2004 and July 8, 2005 to September 8, 2005, when observed temperatures were above 20 ˚C, were sorted from highest to lowest. This was done for the Existing and Natural Conditions, as well as for the alternative scenarios consisting of the Existing Condition without Boundary Project and the alternative operations analysis (run-of-river operations with a drawdown to 1974 feet elevation). The cases were developed using identical periods so they all would have the same number of daily maximum temperature values.
2. A rank value was assigned to each temperature value. The highest value was assigned the number 1 and the lowest the number N (the total number of values in the period).[8]
3. A percentage of the rank value based on the total number of values in the given time period was computed. This is the frequency of occurrence of the value (sometimes referred to as percentile or quantile).
4. To find the difference in temperature at each frequency value, the temperature of the reference scenario was subtracted from the case under consideration.
5. The maximum positive and negative difference between the cases being compared was noted.

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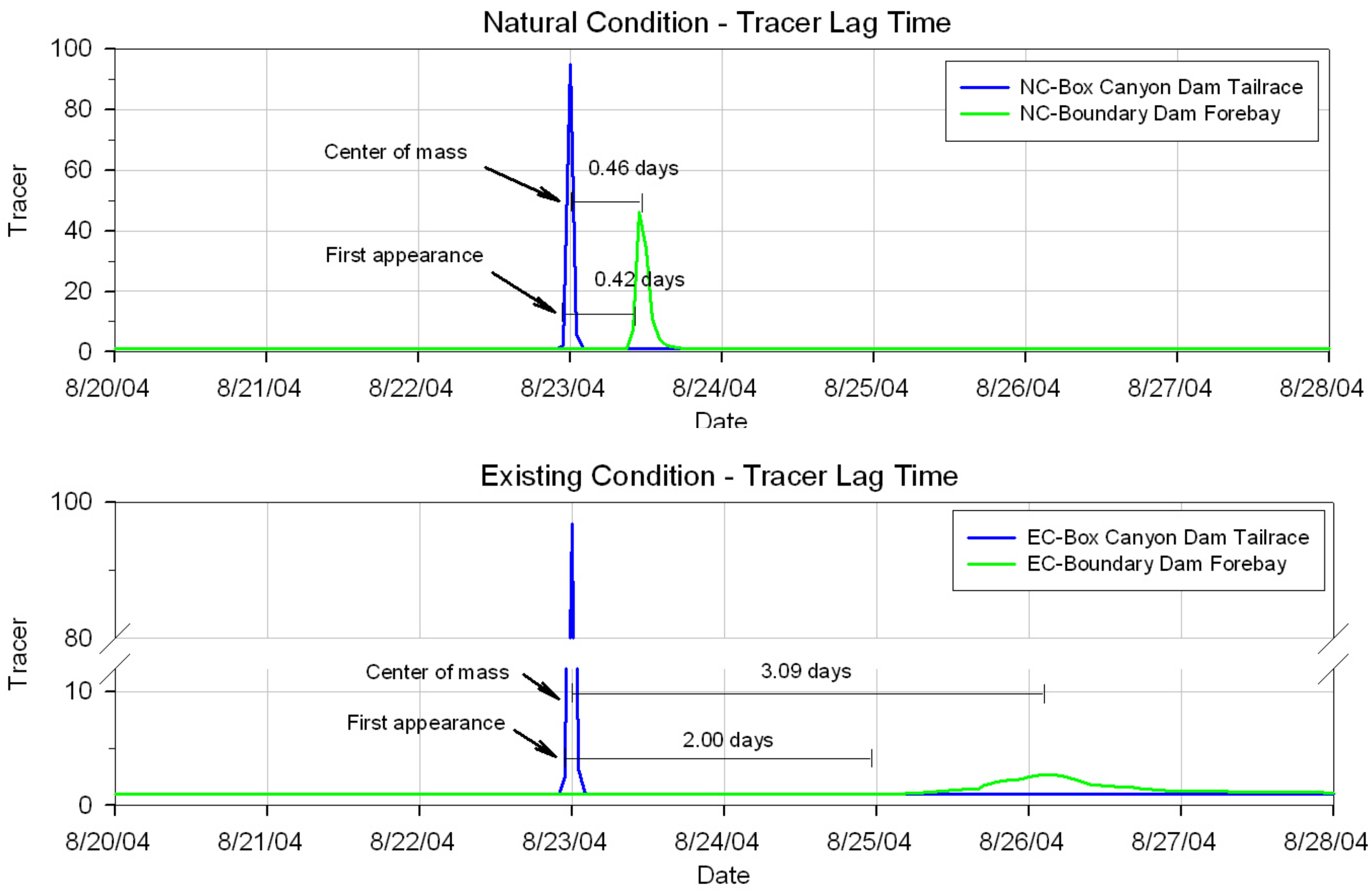
[6] ODEQ. September 2006. *Willamette Basin TMDL*. Chapter 4 – Temperature Mainstem TMDL and Subbasin Summary.

[7] U.S. EPA. October 18, 2001. Problem Assessment for the Columbia/Snake River Temperature TMDL. *Preliminary Draft.*

[8] For example, the Existing Condition at the Boundary Reservoir forebay N is 118 for the 2004 through 2005 period.




Notes:

1. A tracer pulse is applied at the Box Canyon tailrace, tracked through the reservoir, and sampled at the Boundary Dam Forebay.
2. Parcels of water at the Forebay station for the Natural Condition arrive 2 to 3 days sooner than for the Existing Condition. At any time in the Forebay, the parcels of water for the Natural and Existing Condition are not the same.

**Figure 2-1**

Travel-Time Lag Through the Boundary Reservoir Reach

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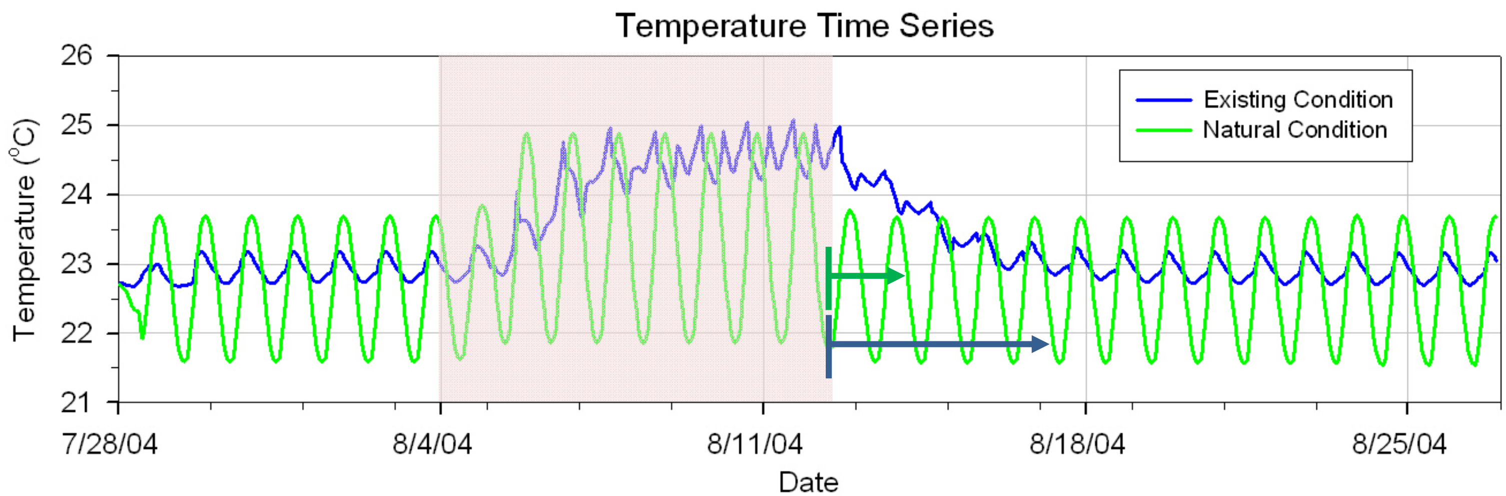


Notes:

1. This plot is a demonstration of the thermal lag (inertia) of Boundary Reservoir with the longer response time of the Existing Condition (as indicated by the blue arrow).
2. Constant inflow temperature from Box Canyon Dam was input. Variation in meteorological data was the same for each day.
3. An atmospheric heat pulse (from increased solar radiation) was applied after 7 days (8/4) to the whole system. After 7 more days (8/11), the atmospheric conditions were returned to the previous condition, thus shutting off the heat pulse. The duration of the pulse is shown by the shading.
4. Daily variations for the Natural Condition are larger than for the Existing Condition in which Boundary Reservoir dampens the daily variation.
5. The Natural Condition (as a river) responds within 1 day (green arrow), while the Existing Condition (as a reservoir) takes approximately 4 to 5 days to respond (blue arrow).

**Figure 2-2**

Surface Temperatures with a Hypothetical Heat Pulse at the Forebay Station of the Boundary Reach for the Existing and Natural Conditions

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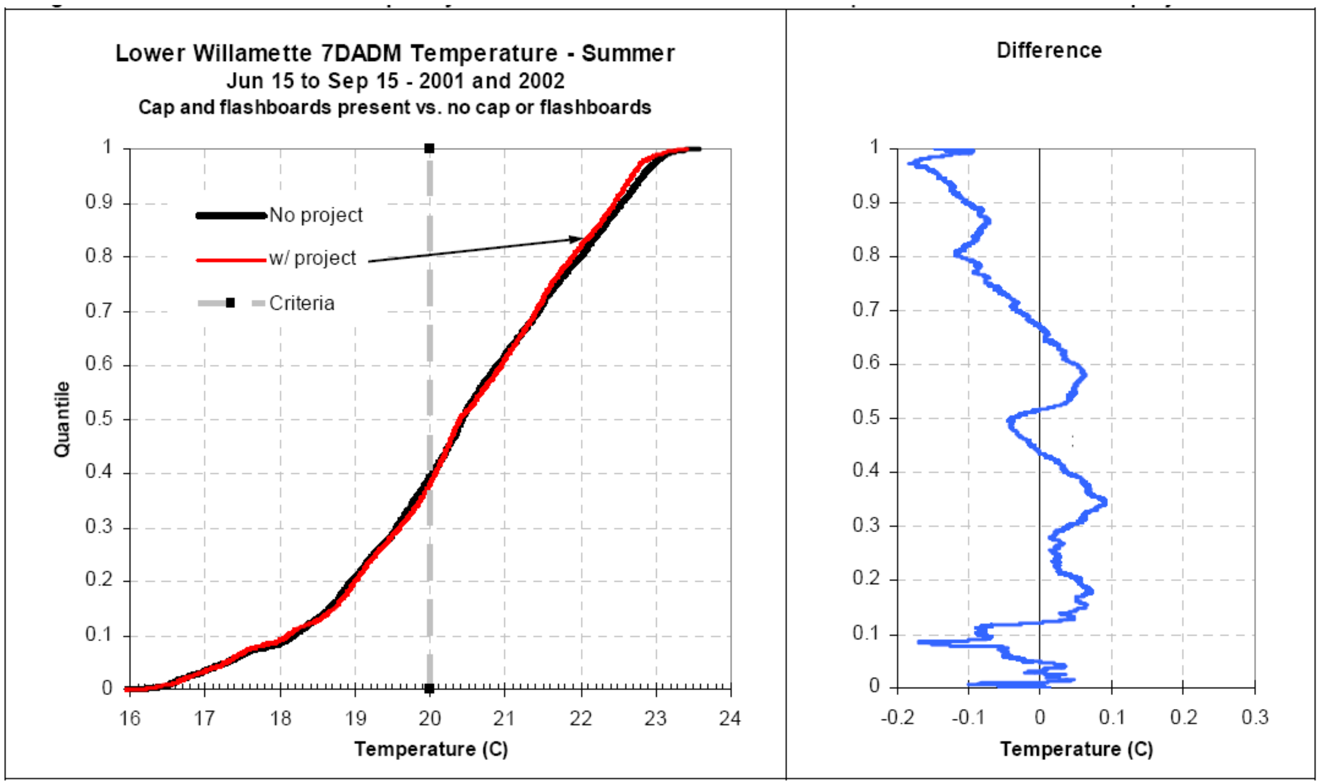


Notes:

1. The frequency is indicated by the term quantile. The flow-weighted temperatures are pooled over time (June 15 through September 15 and over length (Lower Willamette River, OR).
2. The difference in temperature at each frequency is obtained by subtracting the No Project values from the w/ Project values.
3. The figure was taken from the Willamette Basin TMDL Chapter 4 - Temperature-Mainstream TMDL and Sub-Basin Summary (ODEQ September, 2006). Cap and flashboards refers to the use of structures used to raise the water levels.

**Figure 2-3**

Example of Temperature Frequency Analysis from the Willamette River Total Maximum Daily Load

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# 3.0 Flow-Weighted Approach for Temperature Assessment

Ecology has indicated in the TMDL process that it expects to use the approach of considering only surface temperatures for compliance assessment in the Pend Oreille River. Ecology's proposed analysis would focus on data extracted from the model's top layer (upper 2 m). SCL believes that temperature analysis using flow-weighting of temperatures present throughout the water column, rather than just the highest temperature in the water column, is the more appropriate approach for this river reach that is consistent with the state temperature standards. The flow-weighted maximum temperature is more representative of the temperature conditions and distribution throughout the entire water body of the Reservoir; the highest temperature in the water column is not. Specifically, the flow-weighted daily maximum takes into account the presence of waters at depth, as well as waters at the surface, and therefore is more representative of actual conditions. By taking the entire water column into account, this analysis can provide information on whether a project is actually adding heat to the water body as opposed to just changing the distribution of heat.

The Boundary Reservoir is well mixed and the vertical variation of temperature is relatively small. This is unlike reservoirs formed by high-head dams or lakes with long residence times that can show significant temperature stratification. The observations at Boundary Dam show only a small difference in both modeled and measured temperatures from the surface waters to the bottom waters (Figure 3-1), even during the times of maximum temperature gradient on August 17, 2004 and August 1, 2005. The difference in temperature from top to bottom was about 2°C for both those dates. This shows that Boundary Reservoir does not stratify during the summer periods and that the reservoir is well mixed.

The temperature data were processed to compute flow-weighted temperature values as follows:

$$T_W = \sum_{l=1}^{n} (T_l \times Q_l) / Q_T$$

where $l$ is a layer of the water column ($l$=1, 2,.., n), $T_W$ is the flow-weighted temperature, $T_l$ is the temperature at the layer, $Q_l$ is the flow rate at the layer, and $Q_T$ is the total flow. This means that the temperature of the whole reservoir at the forebay is not simply an average of the temperatures in each layer of the forebay. Rather it considers the flow in each layer. Because the reservoir is wider at the top than at the bottom, the surface layers have bigger cross-sectional area (and more volume) than the bottom layers. Also, the velocity in the surface layers is greater than in the bottom. Consequently, the flow in the surface layers, the $Q_l$ in the equation, will be larger than in the bottom layers. In the equation, the effect on the flow-weighted temperature ($T_w$) also accounts for cooler temperatures in the bottom layers. Accordingly, the overall effect is a smaller temperature value than the surface temperature. In the case of the Boundary Reservoir at the forebay, the surface layer is 2-m thick, and its cross-section area is 5.5% of the total cross-sectional area, and the flow of the surface layer contributes 4.5% to the total flow in the water column.

The approach of using flow-weighted temperatures to assess compliance with water quality standards for reservoirs is not new. It has been implemented at various locations in the states of Washington and Oregon. In the Willamette River TMDL (ODEQ September 2006) the temperature analysis was conducted using flow-weighted temperatures over most of the Middle and Lower Willamette River segments including the reservoirs and pools.

In the State of Washington, the same approach of computing flow-weighted temperatures using the CE-QUAL-W2 model has been used to assess water quality compliance as part of the Rocky Reach Hydropower Project's 401 Certification process (Ecology 2006).[9,10]

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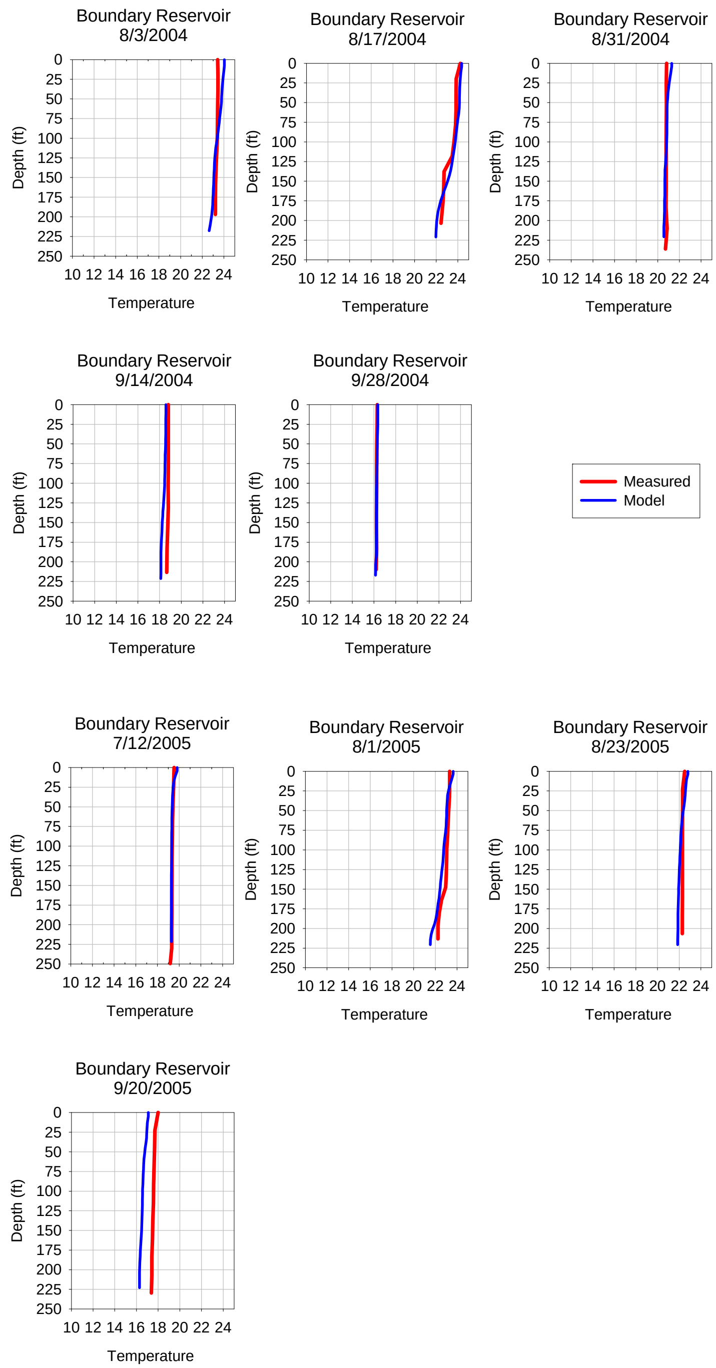
[9] Ecology. March 17, 2006. Rocky Reach Hydroelectric Project (FERC No. 2145). 401 Certification/Order No. 3155.

[10] Rocky Reach Settlement Agreement. March 2006. Chapter 2: Rocky Reach Water Quality Management Plan of the Rocky Reach Comprehensive Plan: Attachment B to the Rocky Reach Settlement Agreement.

2004

2005




Notes:

1. The temperature profiles plots are from Breithaupt and Khangaonkar (2007).
2. The temperature profiles show little variation in temperature over depth.

**Figure 3-1**

Temperature Profiles at the Boundary Dam Forebay

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# 4.0 Temperature Assessment: Evaluation of Existing and Natural Conditions

As described in Section 1, summer temperatures in the Pend Oreille River including Boundary Reservoir exceed the 20˚C temperature criterion in the Existing Condition as well as in the Natural Condition. Therefore, the compliance assessment is based on increases in temperature relative to the Natural Condition + 0.3˚C. Hence, the modeling of the Natural Condition is important for compliance assessment and TMDL and load allocation calculations. Ecology conducted model runs in collaboration with SCL and Battelle. The temperature data evaluations conducted for this technical memorandum use the results from the Natural and the Existing Condition models that were set up by Battelle and updated by Ecology.[11] The analyses conducted in Sections 4 and 5 are based on Ecology's model applications conducted for the Pend Oreille River TMDL temperature assessment.

Table 4-1 provides the model configuration for the Existing and Natural Conditions.[12] Under the Natural Condition, all dams were removed (Boundary, Box Canyon, Albeni Falls, and Seven-Mile), no point sources remained, and shade was increased to an estimated potential natural vegetation (PNV) level.

**Table 4-1**
Existing and Natural Condition Configuration

| Case | Pend Oreille River Dams | Point Sources | Shade |
|---|---|---|---|
| **Existing** | All | All | Existing |
| **Natural** | None | None | PNV |

The modeling of the Existing Condition is described briefly in Section 4.1. The model setup for the Natural Condition is described in detail in Section 4.2, because it has not yet been documented as has been done for the Existing Condition (Breithaupt and Khangaonkar 2007). Section 4.3 presents the comparison between the Existing and Natural Conditions using flow-weighted temperatures; Section 4.4 does the same using surface temperatures.

## 4.1 Existing Condition

The Existing Condition represents the model calibration conditions for 2004 and 2005. The model simulation has been presented previously in the calibration report (Breithaupt and Khangaonkar 2007) and is not repeated in this memorandum. However, the setup and application of the model for the Natural Condition (unimpounded condition) has not been documented previously and is described in Section 4.2.

[11] Files for the Existing and Natural Conditions were received via e-mail communication from Mr. Paul Picket of Ecology on 5/4/2007.
[12] Pickett, P. May 10, 2007. Boundary Dam Temperature Modeling. Presentation to the Pend Oreille River TMDL Watershed Advisory Group.

Throughout this memorandum, comparison of temperature conditions are presented at three separate locations in the study domain: the Metaline Pool station (RM 27.1), the Boundary Reservoir forebay station (RM 17.5), and the Boundary Dam tailrace station (RM 16.9). The locations of these stations are shown in Figure 4-1. The Boundary forebay station typically has the highest surface water temperatures within the Boundary Reach.

## 4.2 Model Setup for the Natural Condition

The model presented in the calibration report (Breithaupt and Khangaonkar 2007) was constructed for the Existing Condition; that is, with the Boundary Reservoir and other upstream and downstream projects in place, assuming normal operating conditions. The Natural Condition corresponds to the Boundary Reach as it existed prior to reservoir construction and without other upstream or downstream projects. Due to the high bed slope in the Boundary Reach, it was necessary to represent the system as a sequence of four river reaches.

The modifications made by Battelle to construct the Natural Condition (unimpounded) inputs were as follows:

- Removed the model input for Boundary Dam.
- Computed the overall bed slope of the river reaches from bathymetry data (Breithaupt and Khangaonkar 2007) and input for each model reach:
  - above Metaline Falls – slope = 0.00038 for RM 33.9 to 27.0
  - below Metaline Falls – slope = 0.00203 for RM 27.0 to 26.0
  - Canyon Reach – slope = 0.00500 for RM 26.0 to 17.0
  - below Boundary Dam – slope = 0.00398 for RM 17.0 to 16.0.
- Included major drops in bed elevation at the Canyon Reach as spillways (or broad-crested weirs):
  - RM 22.0
  - RM 19.5
  - RM 17.2
- Removed the balance flows used in the Existing Condition to match the water surface elevations of Boundary Reservoir.

To represent the removal of Boundary Dam and other upstream and downstream projects for the Natural Condition, three changes were made to the model inputs by Ecology:

1. The shade was changed to that estimated as the potential natural vegetation.
2. The downstream boundary condition for hydrodynamics was changed to a stage-flow relationship to remove the backwater effect due to Seven Mile Dam, downstream of Boundary Dam (this essentially means that Seven Mile Dam was removed).

3. The upstream boundary conditions for flow and temperature were taken from the Natural Condition models for the Box Canyon and Albeni Falls reaches of the Pend Oreille River.[13] (Note that the timing of the unregulated flow in the Natural Condition is significantly different from that of the Existing Condition.)

Figure 4-2 shows the thalweg elevation and the simulated Natural Condition water surface elevation profile for September 11, 2005, when the flow was 4,800 cfs (136.2 $m^3$/s). As expected, this shows the river characteristics for the Natural Condition in the lower reservoir having much shallower depths than for the Existing Condition. At Metaline Pool and in the tailrace, there is very little change in depth between the Natural and Existing Conditions. The consequences of the shallower depth in the lower reservoir for the Natural Condition are an increase in velocity (for a given flow) and a decrease in residence time. Taken together, both the depth and velocity will influence the water temperature of the Pend Oreille River.

## 4.3 Comparison between Existing and Natural Conditions - Flow-Weighted Temperatures

Figures 4-3 a, b, and c present continuous time series comparisons of flow-weighted daily maximum temperatures for the Existing and Natural Conditions at Metaline Pool, Boundary forebay, and Boundary tailrace stations, respectively from January 2004 to September 2005. Note that the Natural Condition temperatures climb above the Existing Condition temperatures beginning in July of 2004 and 2005 at all stations, and that they also drop below the Existing Condition temperatures beginning in August of 2004 and 2005 at all stations. This was a result of the temperature lag of Boundary Reservoir discussed in Section 2.

Figures 4-4 a, b, and c present plots of the frequency distribution of the flow-weighted daily maximum temperatures for the Existing and Natural Conditions, as well as the differences between the frequency values. The data are from the summer periods of 2004 and 2005 when the temperatures from the Existing Condition were greater than 20ºC. Existing Condition temperatures were greater than 20ºC approximately from July 9 through September 4, 2004. In 2005, temperatures were greater than 20ºC approximately from July 8 through September 8.

The frequency analysis method predicts maximum temperature differences of 0.50˚C, 0.20˚C, and 0.19˚C between the Existing and Natural Conditions at the Metaline Pool station, Boundary Dam forebay station and, Boundary tailrace station (Table 4-2 a, b, and c), respectively. The difference between Existing and Natural Conditions includes the influence of upstream and downstream projects, the Box Canyon Dam, Albeni Falls, and Seven-Mile Dams, as well as the Boundary Project. Further analysis is required to identify the influence of the Boundary Project alone (described in Section 5).

In the frequency distribution plots (Figure 4-4 a, b, and c), note that the maximum difference does not occur with the maximum temperatures (>23ºC) but with the lower temperatures (≈21ºC) that occur as temperatures begin to decrease in the late summer. During the time of the highest temperatures (early summer), the Natural Condition temperatures are significantly higher than for

[13] Files for the Existing and Natural Conditions were received via e-mail communication from Mr. Paul Picket of Ecology on 5/4/2007.

the Existing Condition. As temperatures begin to fall during the late summer, the Natural Condition with its shorter lag time responds more quickly than the Existing Condition. Consequently, the temperature difference (Existing minus Natural) in this range of temperature is higher, even though no heating has occurred. The differences are attributed to slower cooling in the Existing Condition.

Temperature conditions were evaluated through analysis of the number of days during which maximum temperatures were above 20°C and peak annual temperatures under each condition were analyzed. Figures 4-5 a, b, and c present the number of days in which flow-weighted daily maximum temperatures are above 20°C, as well as peak annual flow-weighted temperatures, for the Existing and Natural Conditions at Metaline Pool, Boundary forebay, and Boundary tailrace stations, respectively. As already mentioned, in the Boundary Reservoir the temperatures are above the 20˚C criterion during July, August, and September in 2004 and 2005. However, as shown in Figures 4-5 a, b, and c, there were actually more days under the Natural Condition with flow-weighted temperatures higher than 20ºC at all stations than under the Existing Condition. For example, in the Boundary forebay station in 2004, 52 days are above 20ºC in the Existing Condition, and in 2005, 54 days are above the criterion. In comparison, the Natural Condition had 63 days in 2004 and 60 days in 2005 that are above 20ºC at the Boundary forebay station. Also, at all stations, the peak annual flow-weighted temperatures in the Natural Condition were higher than those in the Existing Condition (Figure 4-5 a, b, and c).

**Table 4-2**
Summary of Maximum Flow-Weighted Temperature Differences from Frequency Analysis Comparing Existing Condition with the Natural Condition

**a. Metaline Pool**

| Case | Maximum ΔT relative to the Natural Condition using Flow-Weighted Temperature from Frequency Analysis (Case-Natural) | Maximum ΔT relative to Existing Conditions using Flow-Weighted Temperature from Frequency Analysis (Existing-Case) |
|---|---|---|
| **Existing** | 0.50ºC[1] | 0.0ºC |

**b. Boundary Forebay**

| Case | Maximum ΔT relative to the Natural Condition using Flow-Weighted Temperature from Frequency Analysis (Case-Natural) | Maximum ΔT relative to Existing Conditions using Flow-Weighted Temperature from Frequency Analysis (Existing-Case) |
|---|---|---|
| **Existing** | 0.20ºC[1] | 0.0ºC |

**c. Boundary Tailrace**

| Case | Maximum ΔT relative to the Natural Condition using Flow-Weighted Temperature from Frequency Analysis (Case-Natural) | Maximum ΔT relative to Existing Conditions using Flow-Weighted Temperature from Frequency Analysis (Existing-Case) |
|---|---|---|
| **Existing** | 0.19ºC[1] | 0.0ºC |

Notes:
Period covered by the frequency analysis is July 9, 2004 to September 4, 2004 and July 8, 2005 to September 8, 2005 when Existing Condition > 20ºC.
[1] This represents the largest difference between the maximum flow-weighted temperature cumulative frequency distributions for the Existing Condition (with all the dams in place) and Natural Condition.

## 4.4 Comparison between Existing and Natural Conditions - Surface Temperatures

Figures 4-6 a, b, and c present the instantaneous comparison of surface maximum daily temperatures for the Existing and Natural Conditions at Metaline Pool, Boundary forebay, and Boundary tailrace stations, respectively. As with the flow-weighted temperatures, note that the Natural Condition surface temperatures climb above the Existing Condition temperatures beginning in July of 2004 and 2005 at all stations, and that they also drop below the Existing Condition temperatures beginning in August of 2004 and 2005 at all stations. This was a result of the temperature lag of Boundary Reservoir discussed in Section 2.

Figures 4-7 a, b, and c present plots of the frequency distribution of the daily maximum surface temperatures for the Existing and Natural Conditions and the differences between the frequency values. The data, as in the previous subsection, are from the summer periods of 2004 and 2005 when the temperatures from the Existing Condition were greater than 20ºC. Existing Condition temperatures were greater than 20ºC from July 9 through September 4, 2004. In 2005, temperatures were greater than 20ºC from July 8 through September 8.

The frequency analysis method predicts maximum surface temperature differences of 0.50˚C, 0.76˚C, and 0.19˚C between the Existing and Natural Conditions at the Metaline Pool station, Boundary Dam forebay station and, Boundary tailrace stations respectively (Table 4-3 a, b, and c). The difference between Existing and Natural Conditions includes the influence of upstream and downstream projects, the Box Canyon Dam, Albeni Falls Dam and Seven Mile Dam, as well as the Boundary Project. Further analysis is required to identify the influence of the Boundary Project alone (described in Section 5).

Figures 4-8 a, b, and c present the number of days in which surface daily maximum temperatures are above 20$^{o}$C, as well as peak annual surface temperatures, for the Existing and Natural Conditions at Metaline Pool, Boundary forebay, and Boundary tailrace stations, respectively. As already mentioned, in the Boundary Reservoir the temperatures are above the 20 ˚C criterion during July, August, and September in 2004 and 2005. However, as shown in Figures 4-8 a, b, and c, at all stations, there were actually the same or more days under the Natural Condition with surface daily maximum temperatures higher than 20ºC. For example, at the forebay station of the Boundary Reservoir, in 2004, 58 days were above 20ºC in the Existing Condition, while in 2005, 60 days were above the criterion. In comparison, the Natural Condition had 63 days in 2004 and 60 days in 2005 that were above 20ºC. Also, at all stations, the highest surface temperatures in the Natural Condition were higher than those in the Existing Condition (Figure 4-8 a, b, and c).

**Table 4-3**
Summary of Maximum Surface Temperature Differences from Frequency Analysis Comparing Existing Condition with the Natural Condition

**a. Metaline Pool**

| Case | Maximum ΔT relative to the Natural Condition using Surface Temperature from Frequency Analysis (Case-Natural) | Maximum ΔT relative to Existing Conditions using Surface Temperature from Frequency Analysis (Existing-Case) |
|---|---|---|
| **Existing** | 0.50ºC[1] | 0.0ºC |

**b. Boundary Forebay**

| Case | Maximum ΔT relative to the Natural Condition using Surface Temperature from Frequency Analysis (Case-Natural) | Maximum ΔT relative to Existing Conditions using Surface Temperature from Frequency Analysis (Existing-Case) |
|---|---|---|
| **Existing** | 0.76ºC[1] | 0.0ºC |

**c. Boundary Tailrace**

| Case | Maximum ΔT relative to the Natural Condition using Surface Temperature from Frequency Analysis (Case-Natural) | Maximum ΔT relative to Existing Conditions using Surface Temperature from Frequency Analysis (Existing-Case) |
|---|---|---|
| **Existing** | 0.19ºC[1] | 0.0ºC |

Notes:
Period covered by the frequency analysis is July 9, 2004 to September 4, 2004 and July 8, 2005 to September 8, 2005 when Existing Condition > 20ºC
[1] This represents the largest difference between the maximum surface temperature cumulative frequency distributions for the Existing Condition (with all the dams in place) and Natural Condition.

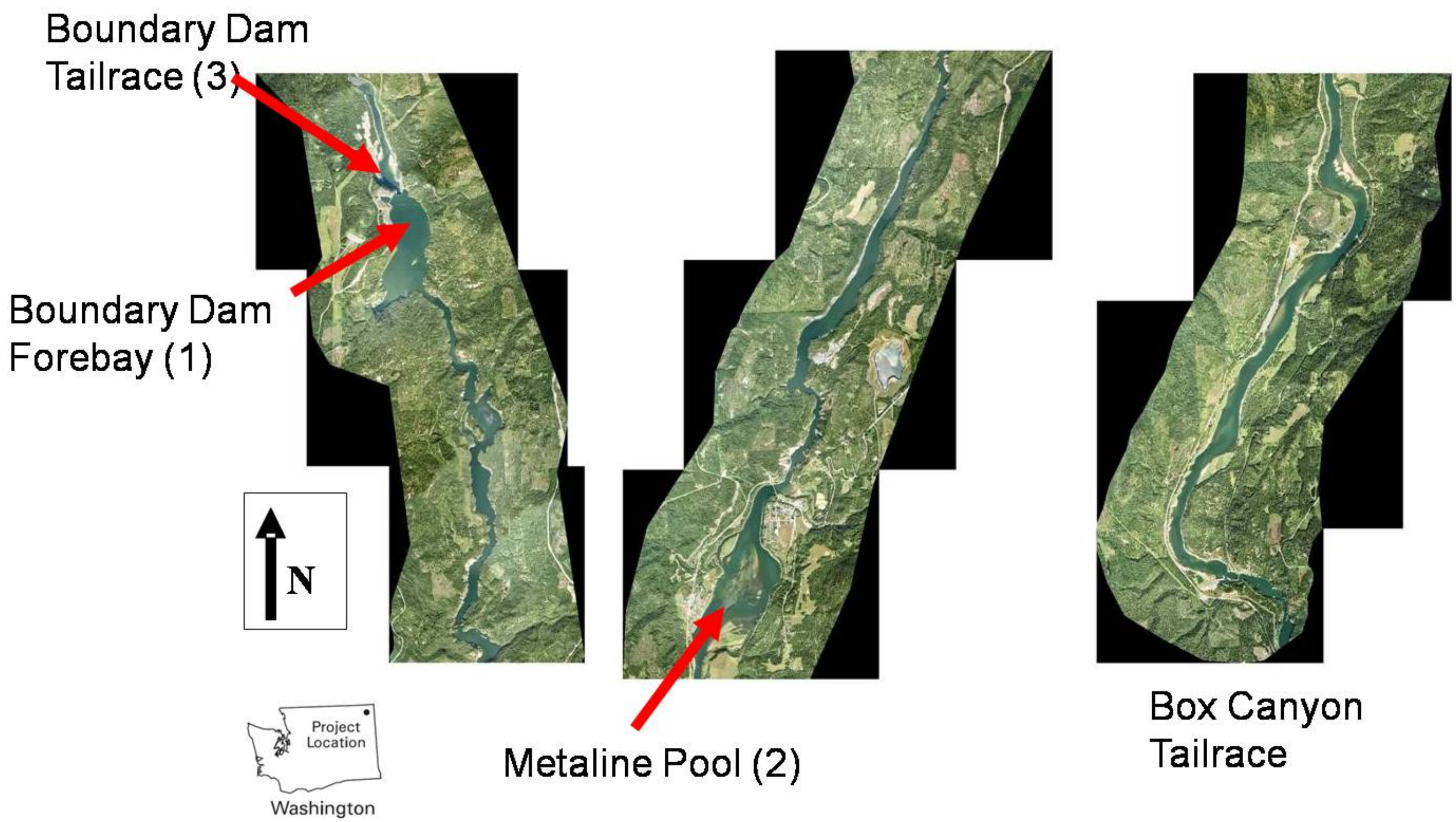


**Figure 4-1**

Locations of Metaline Pool, Boundary Dam Forebay, and Boundary Dam Tailrace stations

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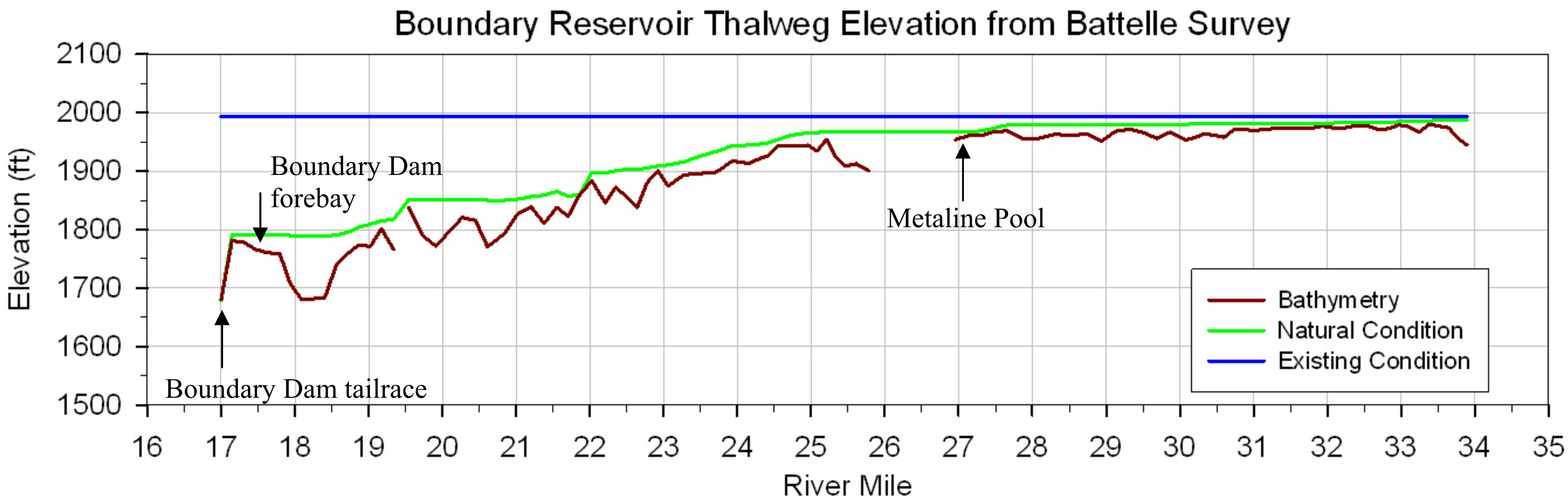


Notes:

1. This plot shows the effect on the water surface elevations from the removal of Boundary Dam in the Boundary Reach of the Pend Oreille River. Water depths are shallower than for the Existing Condition when Boundary Dam is present.
2. The results are for September 11, 2005, when the flow was 4,800 cfs (136.2 $m^3/s$).
3. Bathymetry data are the thalweg elevations of the channel from Breithaupt and Khangaonkar (2007).
4. Normal operating high pool elevation = 1994 ft (NAVD 88).

**Figure 4-2**

Water Surface Profile for the Natural Condition

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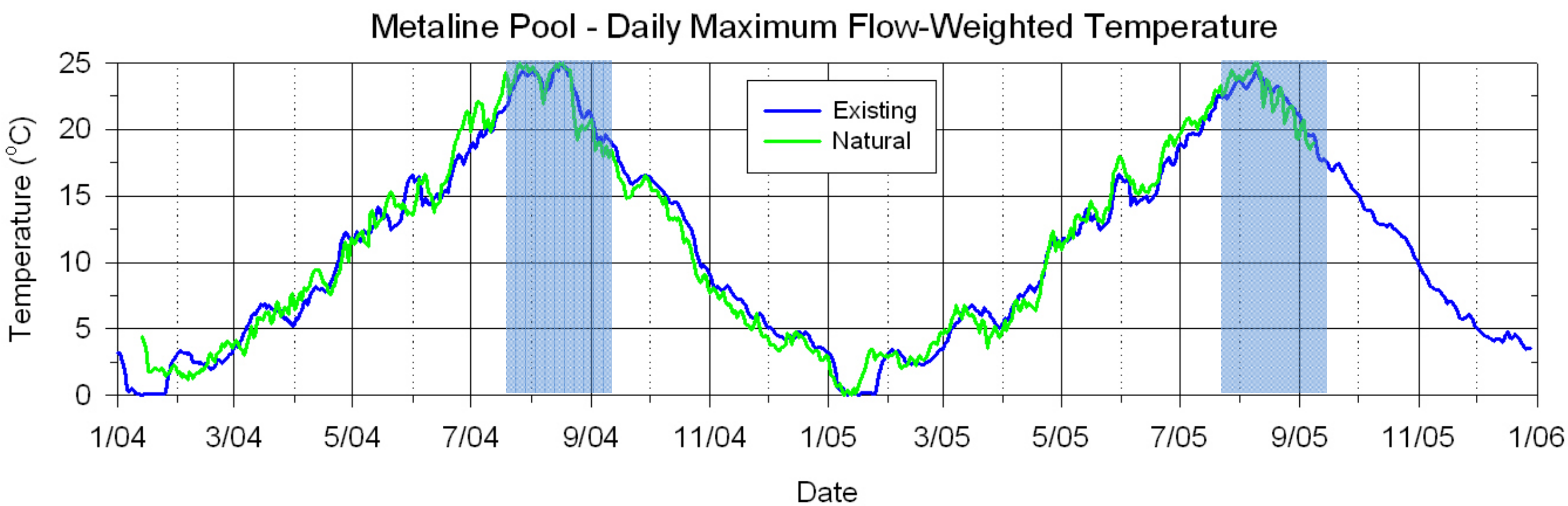



Notes:

1. Daily maximum flow-weighted temperature is

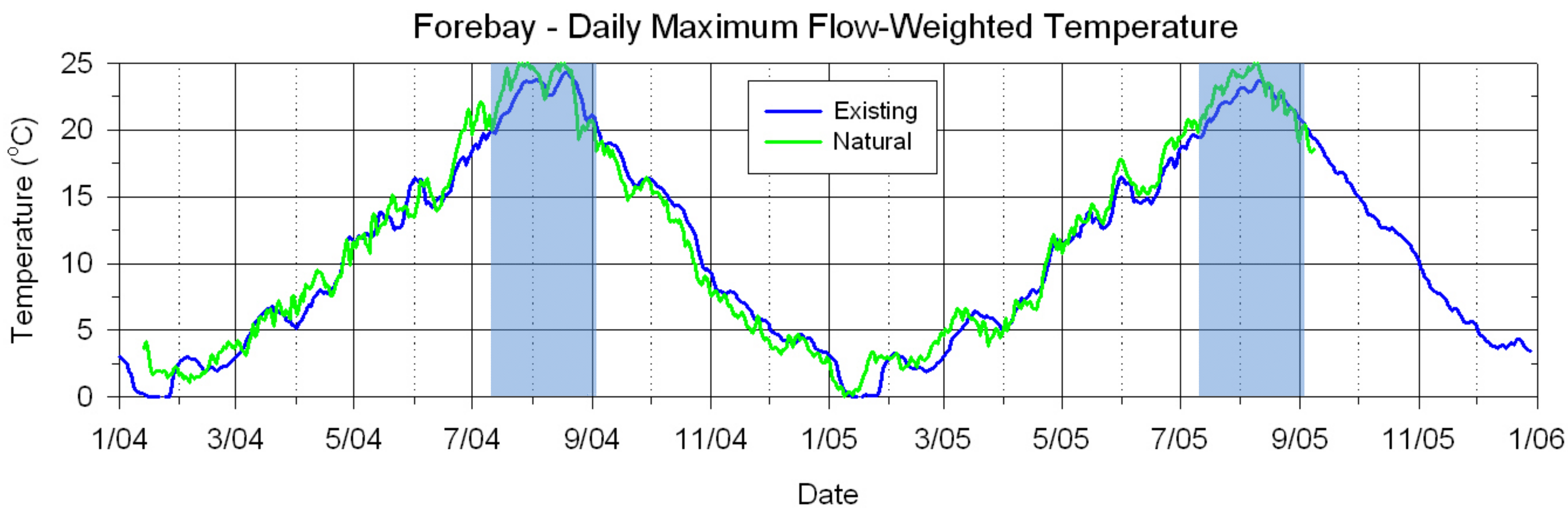
$$T_W = \sum_{l=1}^{n} (T_l \times Q_l) / Q_T$$

   where $l$ is a layer of water column ($l$=1, 2,.., n), $T_W$ is the flow-weighted temperature, $T_l$ is the temperature at the layer, $Q_l$ is the flow rate at the layer, and $Q_T$ is the total flow.
2. The period when the Existing Condition temperature is over 20ºC is indicated by the shading.

**Figure 4-3**a

Daily Maximum Flow-Weighted Temperatures for the Existing and Natural Conditions at Metaline Pool

Seattle City Light
Seattle, WA




Notes:

1. Daily maximum flow-weighted temperature is

$$T_W = \sum_{l=1}^{n} (T_l \times Q_l) / Q_T$$

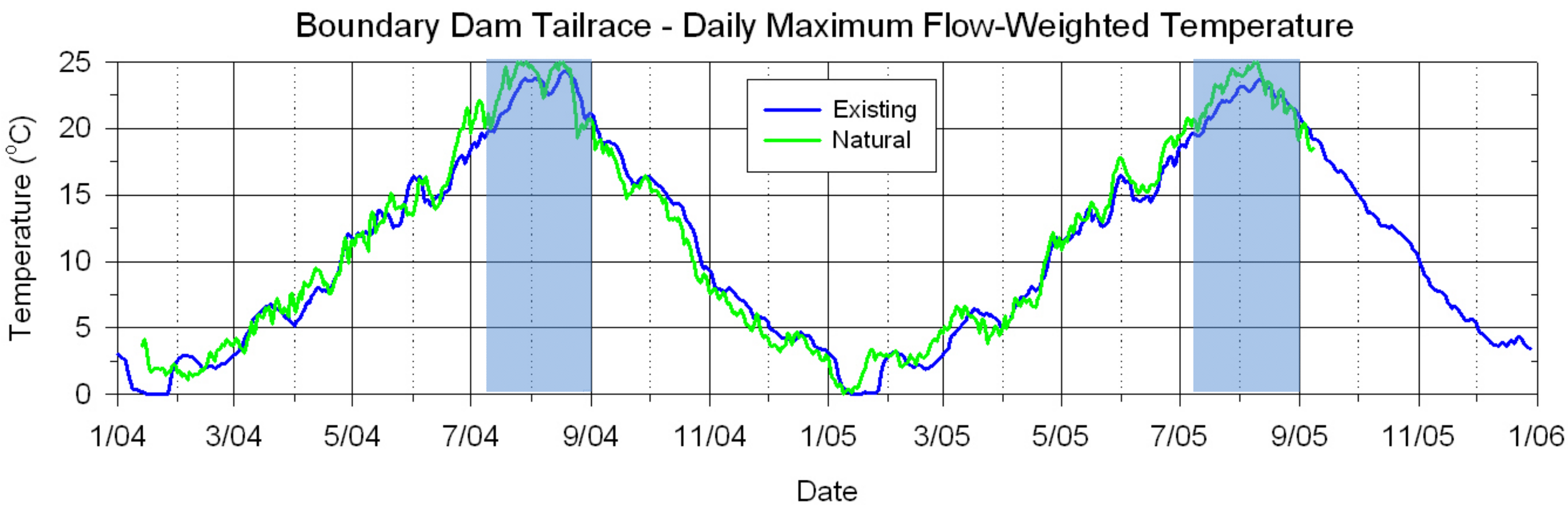
where $l$ is a layer of water column ($l$=1, 2,.., n), $T_W$ is the flow-weighted temperature, $T_l$ is the temperature at the layer, $Q_l$ is the flow rate at the layer, and $Q_T$ is the total flow.

2. The period when the Existing Condition temperature is over 20ºC is indicated by the shading.

**Figure 4-3**b

Daily Maximum Flow-Weighted Temperatures for the Existing and Natural Conditions at Boundary Dam Forebay

Seattle City Light
Seattle, WA




Notes:

1. Daily maximum flow-weighted temperature is

$$T_W = \sum_{l=1}^{n} (T_l \times Q_l) / Q_T$$

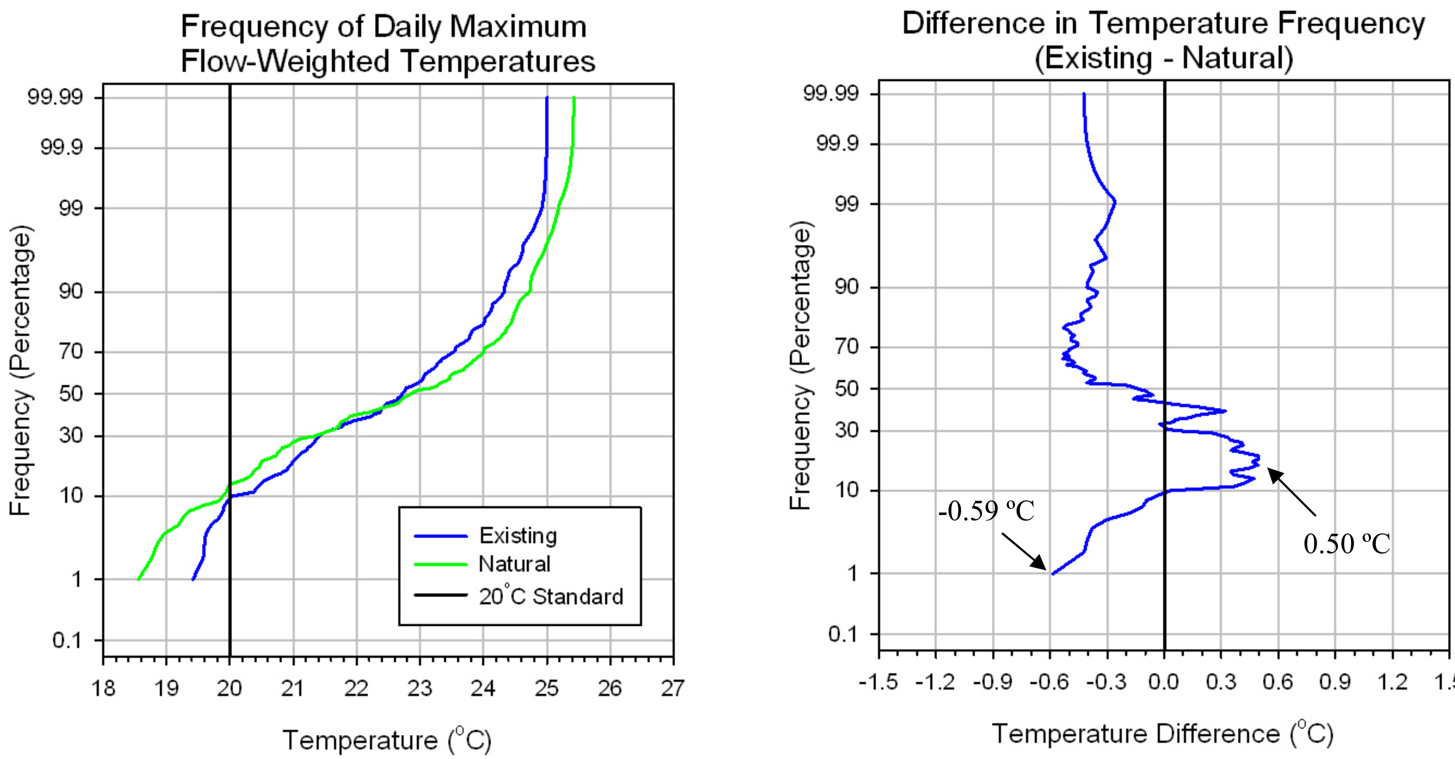
where $l$ is a layer of water column ($l$=1, 2,.., n), $T_W$ is the flow-weighted temperature, $T_l$ is the temperature at the layer, $Q_l$ is the flow rate at the layer, and $Q_T$ is the total flow.

2. The period when the Existing Condition temperature is over 20ºC is indicated by the shading.

**Figure 4-3c**

Daily Maximum Flow-Weighted Temperatures for the Existing and Natural Conditions at Boundary Dam Tailrace

Seattle City Light
Seattle, WA



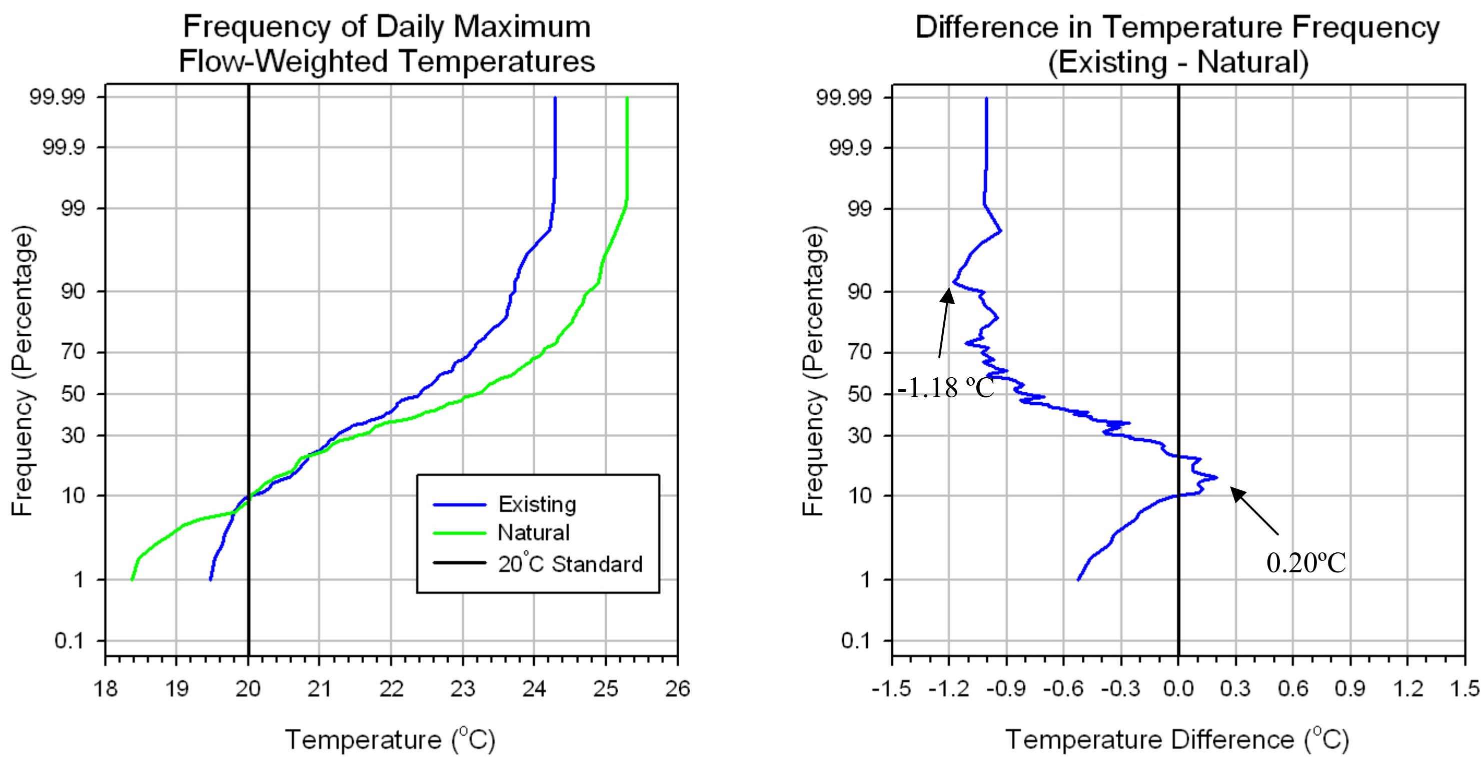

Notes:

1. Frequency distributions of the maximum flow-weighted temperatures are from model results obtained from Ecology.
2. The difference in temperature at each frequency is obtained by subtracting the Natural Condition values from the Existing Condition values. (When Natural Condition is < 20ºC, the Natural temperature is replaced by the value 20ºC.)
3. The period covered by the frequency analysis was July 9, 2004 to September 4, 2004 and July 8, 2005 to September 8, 2005.
4. Flow-weighted temperature differences are between -0.59ºC and +0.50ºC due to all the dams on the Pend Oreille River.

**Figure 4-4**a

Frequency Distributions of the Daily Maximum Flow-Weighted Temperatures for the Existing and Natural Conditions at Metaline Pool

Seattle City Light
Seattle, WA




Notes:

1. Frequency distributions of the maximum flow-weighted temperatures are from model results obtained from Ecology.
2. The difference in temperature at each frequency is obtained by subtracting the Natural Condition values from the Existing Condition values. (When Natural Condition is < 20ºC, the Natural temperature is replaced by the value 20 ºC.)
3. The period covered by the frequency analysis was July 9, 2004 to September 4, 2004 and July 8, 2005 to September 8, 2005.
4. Flow-weighted temperature differences are between -1.18 ºC and +0.20ºC due to all the dams on the Pend Oreille River.

**Figure 4-4b**

Frequency Distributions of the Daily Maximum Flow-Weighted Temperatures for the Existing and Natural Conditions at Boundary Dam Forebay

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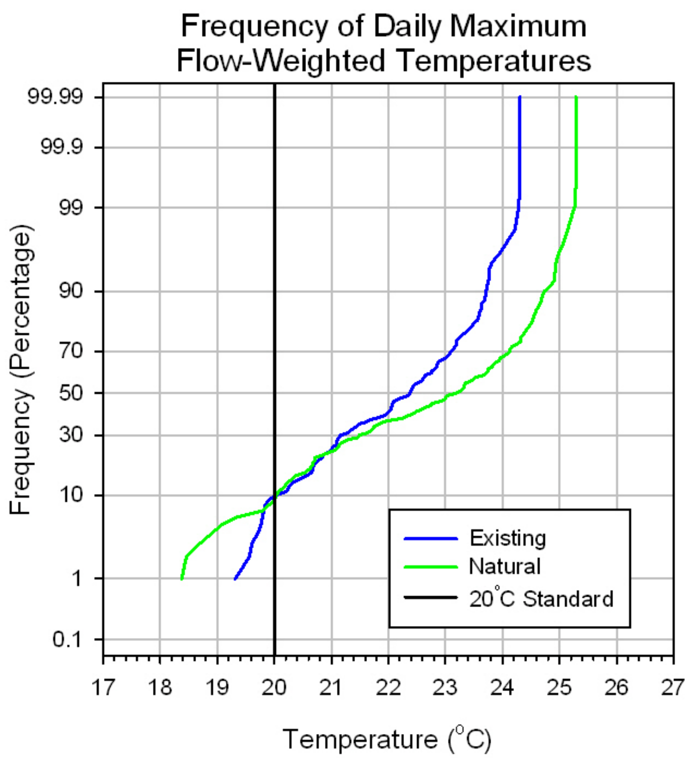
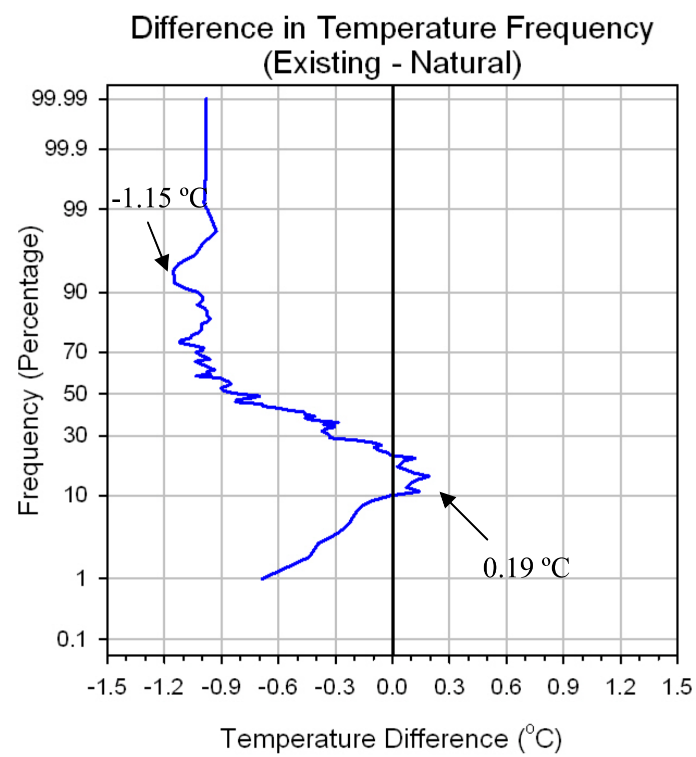
Seattle, WA




Notes:

1. Frequency distributions of the maximum flow-weighted temperatures are from model results obtained from Ecology.
2. The difference in temperature at each frequency is obtained by subtracting the Natural Condition values from the Existing Condition values. (When Natural Condition is < 20ºC, the Natural temperature is replaced by the value 20ºC.)
3. The period covered by the frequency analysis was July 9, 2004 to September 4, 2004 and July 8, 2005 to September 8, 2005.
4. Flow-weighted temperature differences are between -1.15ºC and +0.19ºC due to all the dams on the Pend Oreille River.

**Figure 4-4c**

Frequency Distributions of the Daily Maximum Flow-Weighted Temperatures for the Existing and Natural Conditions at Boundary Dam Tailrace

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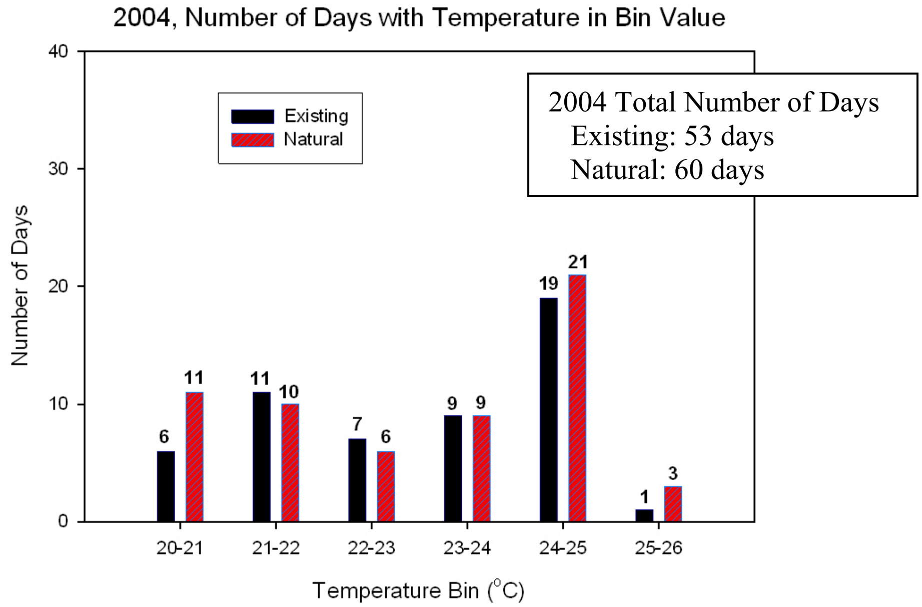
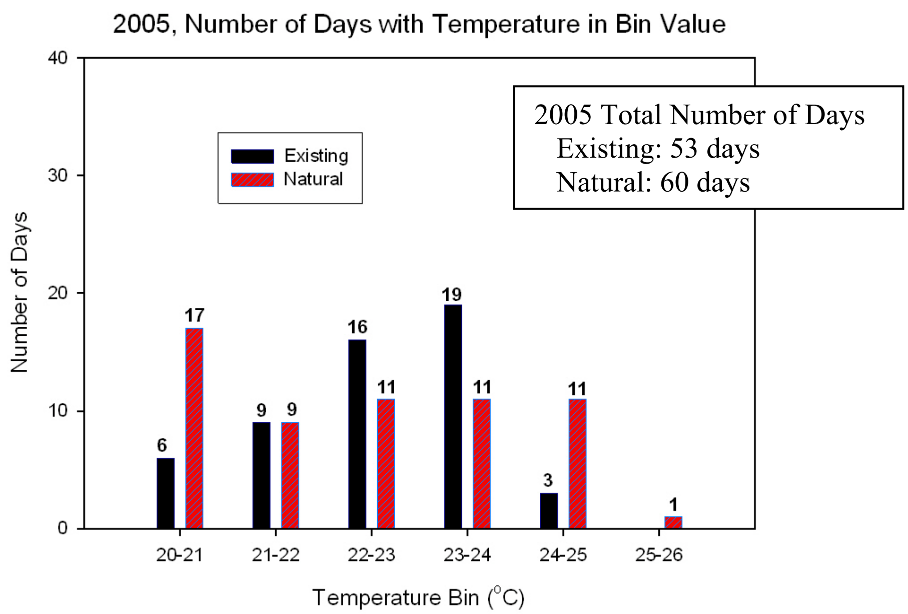
Seattle, WA



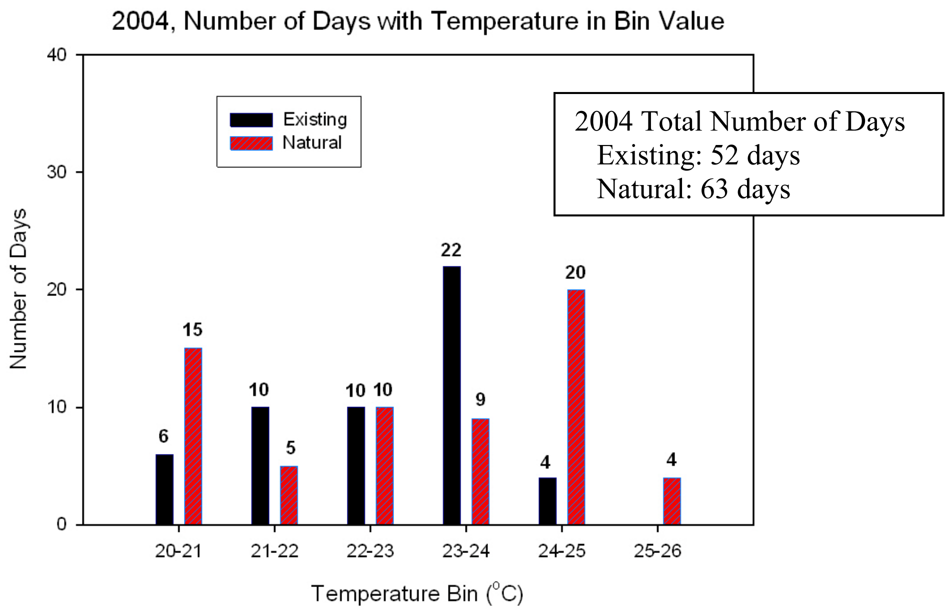



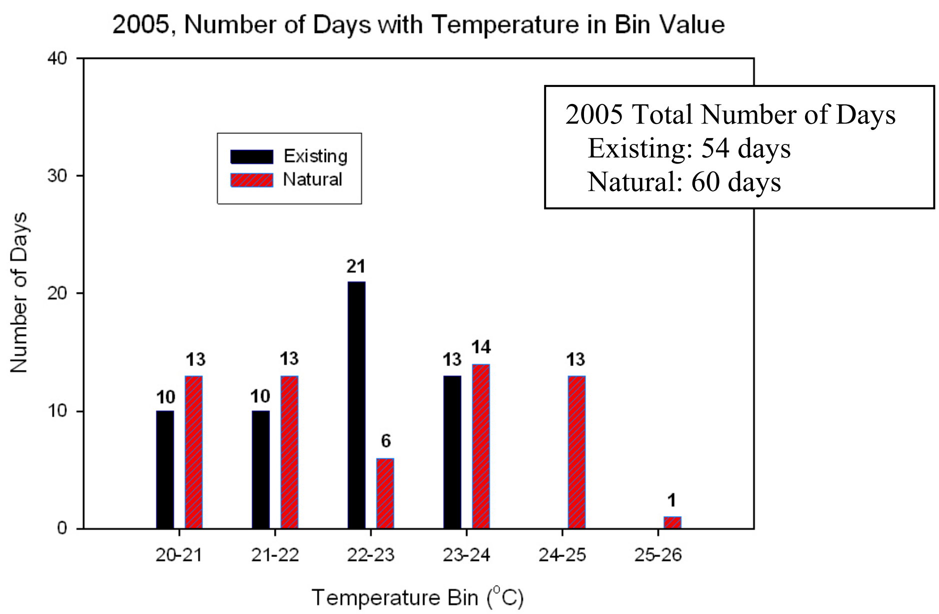

Notes:
1. The total number of days for 2004 and 2005 was
   Existing – 106 days
   Natural – 120 days
2. Peak annual flow-weighted temperature at the Metaline Pool
   2004 – Existing: 25.01ºC & Natural: 25.43ºC
   2005 – Existing: 24.40ºC & Natural: 25.14ºC

**Figure 4-5a**

Number of Days the Daily Maximum Flow-Weighted Temperatures Exceeded 20ºC at the Metaline Pool for 2004 and 2005

Seattle City Light
Seattle, WA



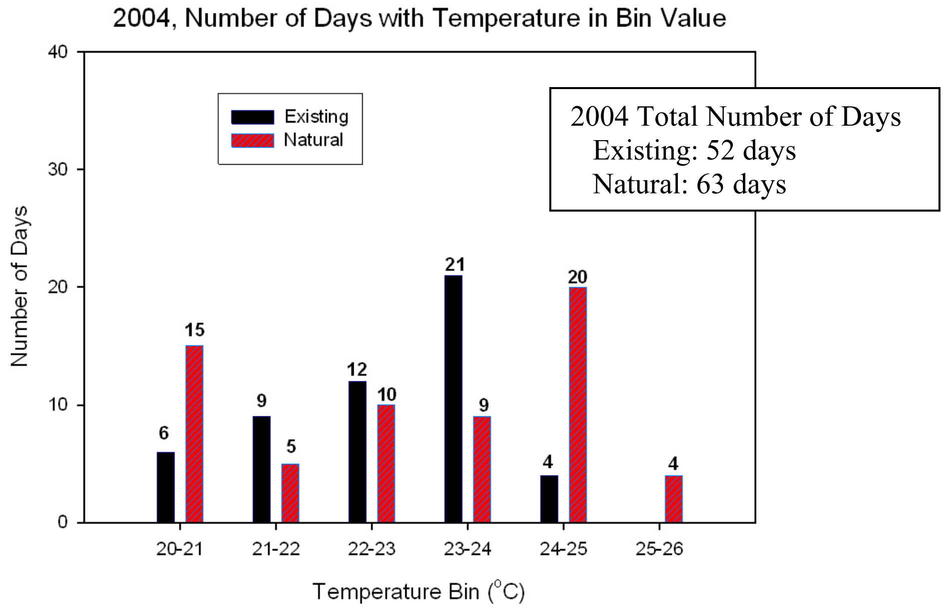

Notes:

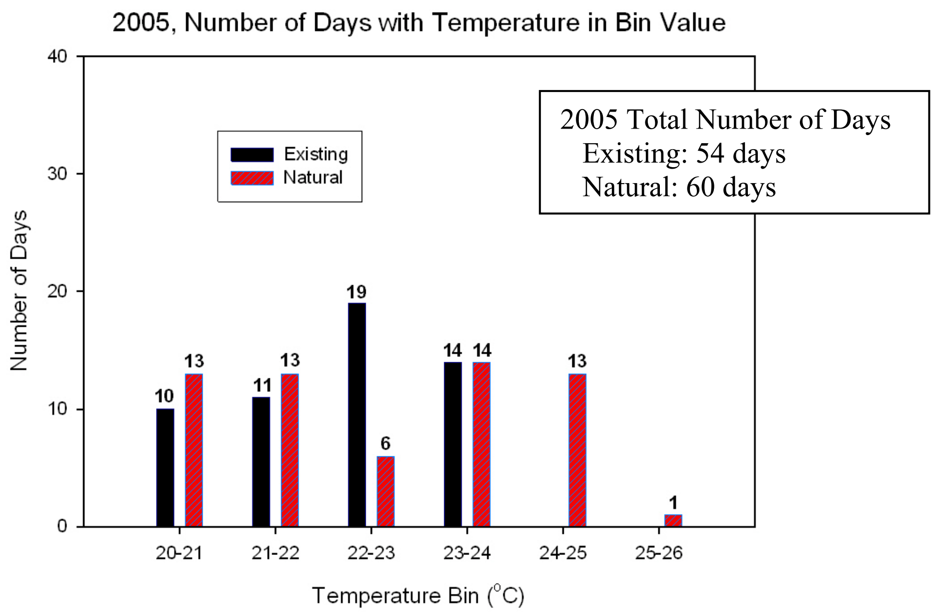
1. The total number of days for 2004 and 2005 was
   Existing – 106 days
   Natural – 123 days
2. Peak annual flow-weighted temperature at the Boundary Dam Forebay
   2004 – Existing: 24.29ºC & Natural: 25.29ºC
   2005 – Existing: 23.72ºC & Natural: 25.15ºC

**Figure 4-5**b

Number of Days the Daily Maximum Flow-Weighted Temperatures Exceeded 20ºC at the Boundary Dam Forebay for 2004 and 2005

Seattle City Light
Seattle, WA



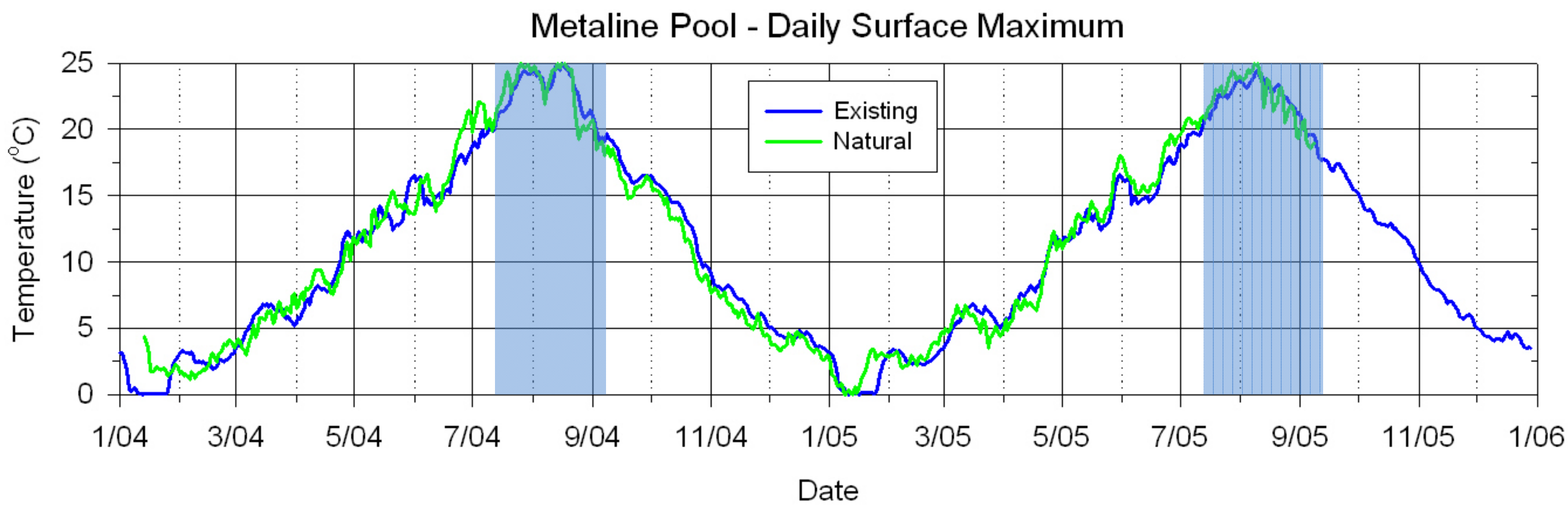

Notes:

1. The total number of days for 2004 and 2005 was
   Existing – 106 days
   Natural – 123 days
2. Peak annual flow-weighted temperature at the Boundary Dam Tailrace
   2004 – Existing: 24.31ºC & Natural: 25.29ºC
   2005 – Existing: 23.71ºC & Natural: 25.15ºC

**Figure 4-5c**

Number of Days the Daily Maximum Flow-Weighted Temperatures Exceeded 20ºC at the Boundary Dam Tailrace for 2004 and 2005

Seattle City Light
Seattle, WA

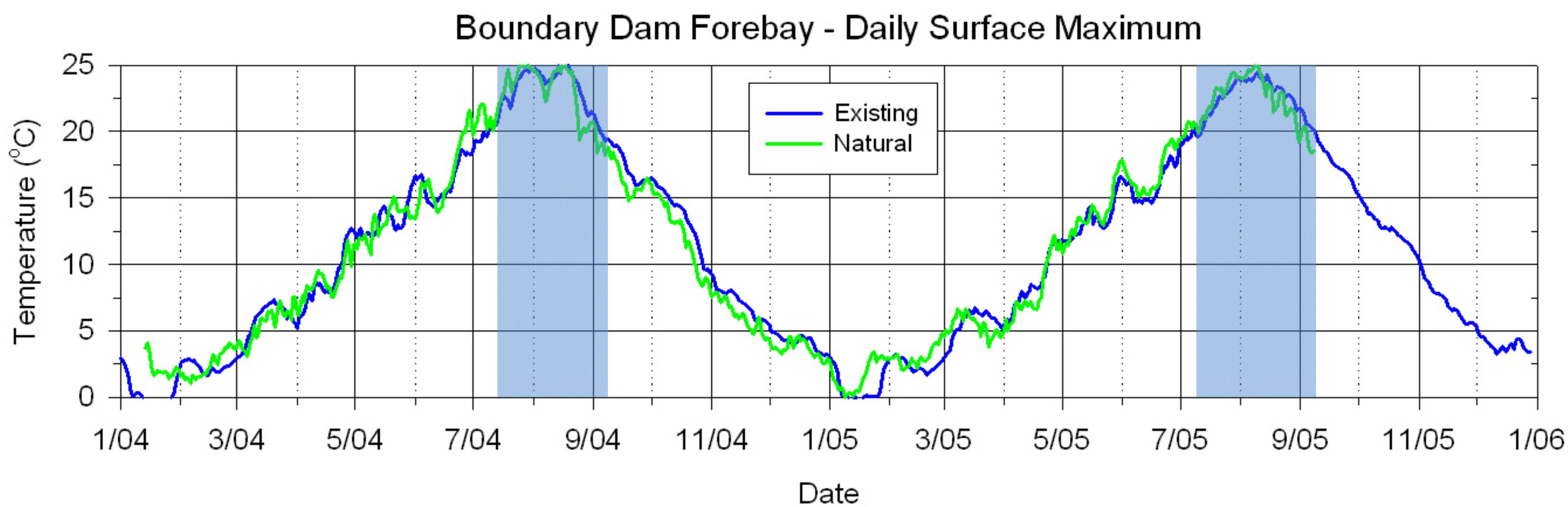



Notes:
1. Daily maximum temperatures are from the surface layer of the models.
2. The period when the Existing Condition temperature is over 20ºC is indicated by the shading.

**Figure 4-6**a

Daily Maximum Surface Temperatures for the Existing and Natural Conditions at Metaline Pool

Seattle City Light
Seattle, WA




Notes:

1. Daily maximum temperatures are from the surface layer of the models.
2. The period when the Existing Condition temperature is over 20ºC is indicated by the shading.

**Figure 4-6**b

Daily Maximum Surface Temperatures for the Existing and Natural Conditions at Boundary Dam Forebay

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Seattle, WA

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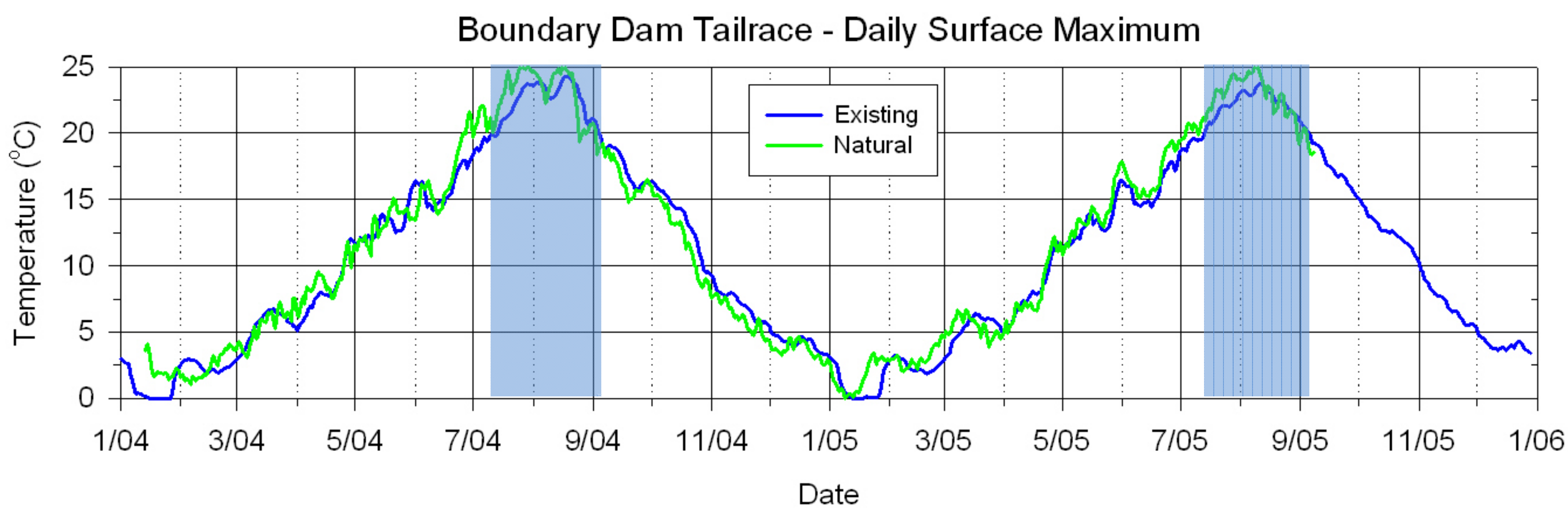
The Business of Innovation



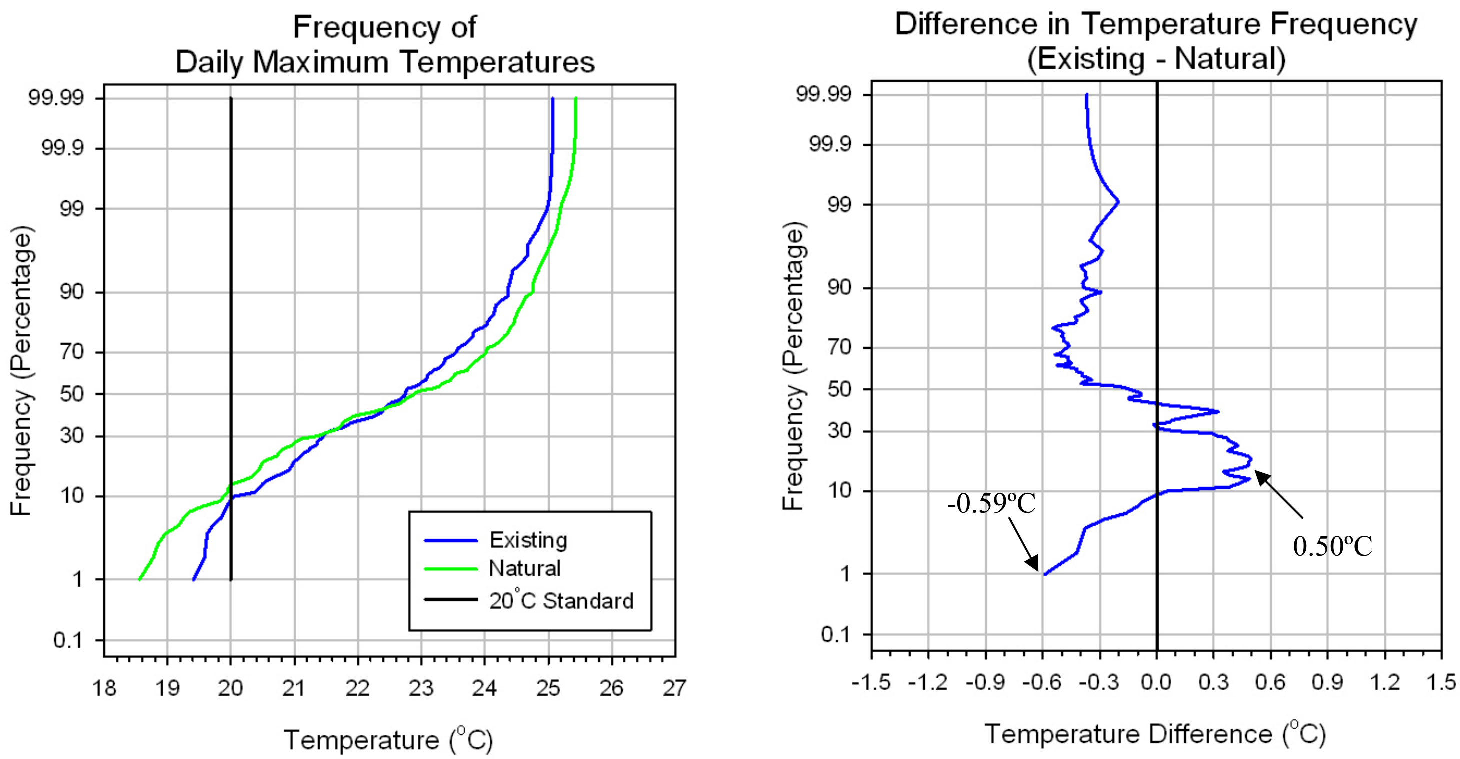

Notes:

1. Daily maximum temperatures are from the surface layer of the models.
2. The period when the Existing Condition temperature is over 20ºC is indicated by the shading.

**Figure 4-6c**

Daily Maximum Surface Temperatures for the Existing and Natural Conditions at Boundary Dam Tailrace

Seattle City Light
Seattle, WA



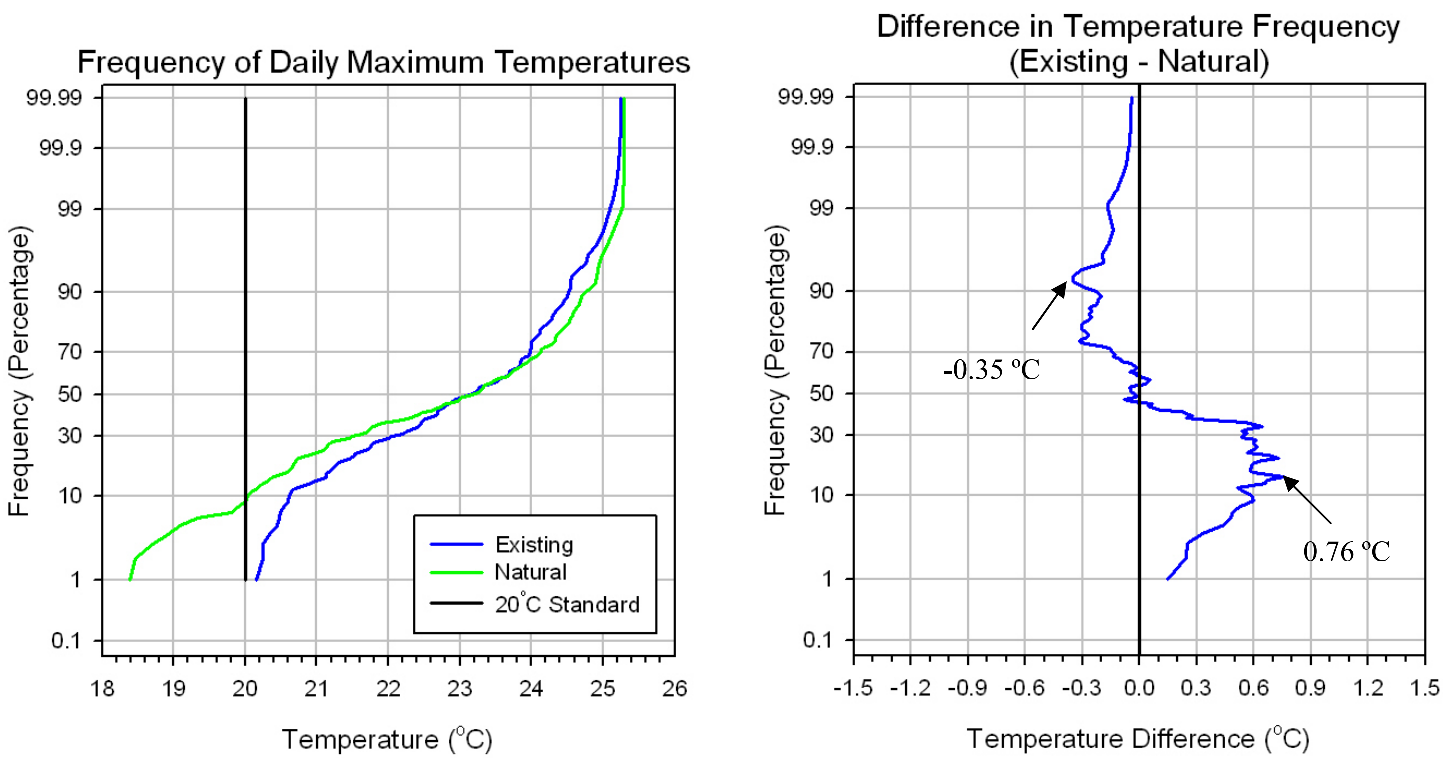

Notes:

1. Frequency distributions of the daily maximum temperatures from the surface layer of the models are from model results obtained from Ecology.
2. The difference in temperature at each frequency is obtained by subtracting the Natural Condition values from the Existing Condition values. (When Natural Condition is < 20ºC, the Natural temperature is replaced by the value 20ºC.)
3. The period covered by the frequency analysis was July 9, 2004 to September 4, 2004 and July 8, 2005 to September 8, 2005 when Existing Condition > 20ºC.
4. Surface temperature differences are between -0.59 ºC and +0.50ºC due to all the dams on the Pend Oreille River.

**Figure 4-7**a

Frequency Distributions of the Daily Maximum Surface Temperatures for the Existing and Natural Conditions at Metaline Pool

Seattle City Light
Seattle, WA



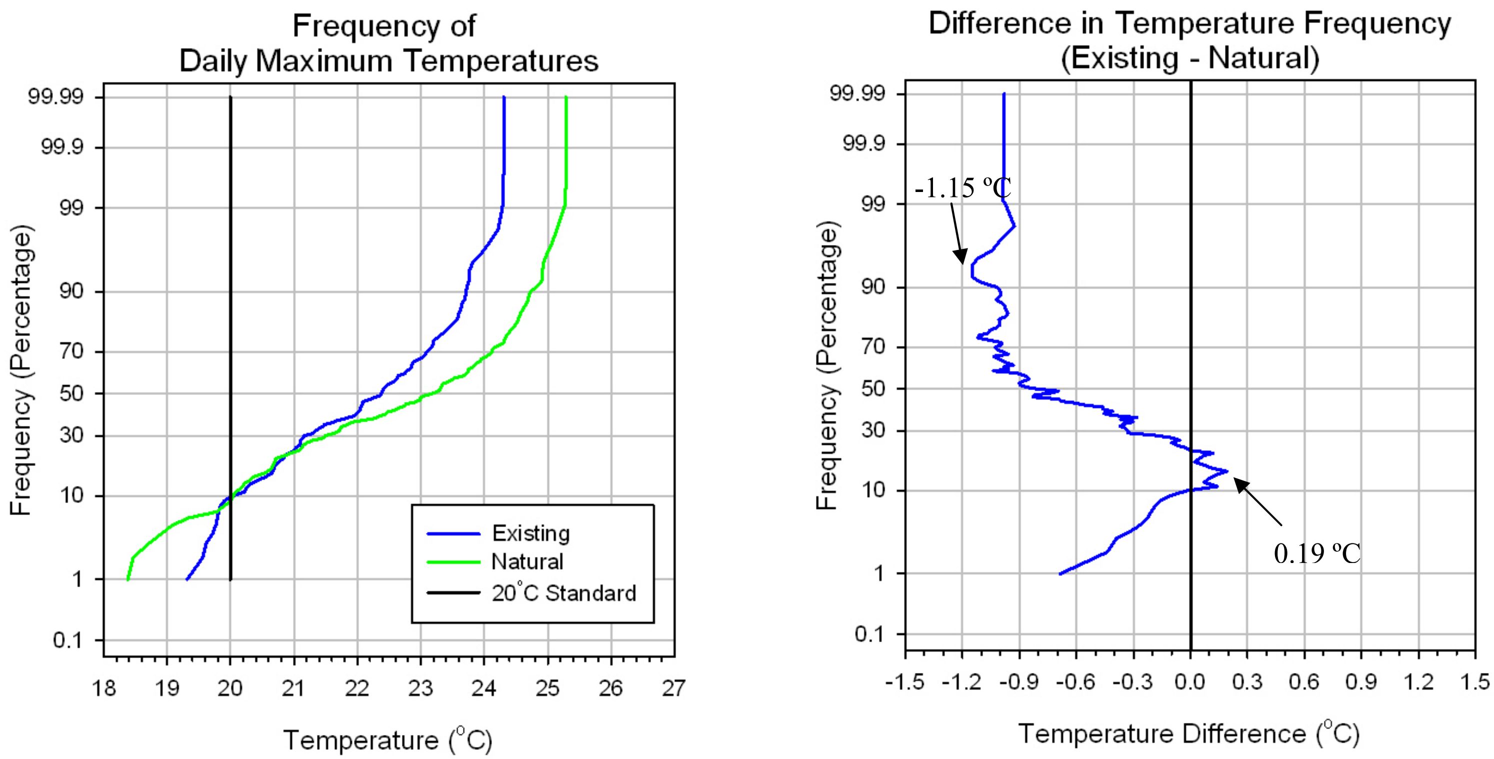

Notes:

1. Frequency distributions of the daily maximum temperatures from the surface layer of the models are from model results obtained from Ecology.
2. The difference in temperature at each frequency is obtained by subtracting the Natural Condition values from the Existing Condition values. (When Natural Condition is < 20ºC, the Natural temperature is replaced by the value 20ºC.)
3. The period covered by the frequency analysis was July 9, 2004 to September 4, 2004 and July 8, 2005 to September 8, 2005 when Existing Condition > 20ºC.
4. Surface temperature differences are between -0.35ºC and +0.76ºC due to all the dams on the Pend Oreille River.

**Figure 4-7b**

Frequency Distributions of the Daily Maximum Surface Temperatures for the Existing and Natural Conditions at Boundary Dam Forebay

Seattle City Light
Seattle, WA



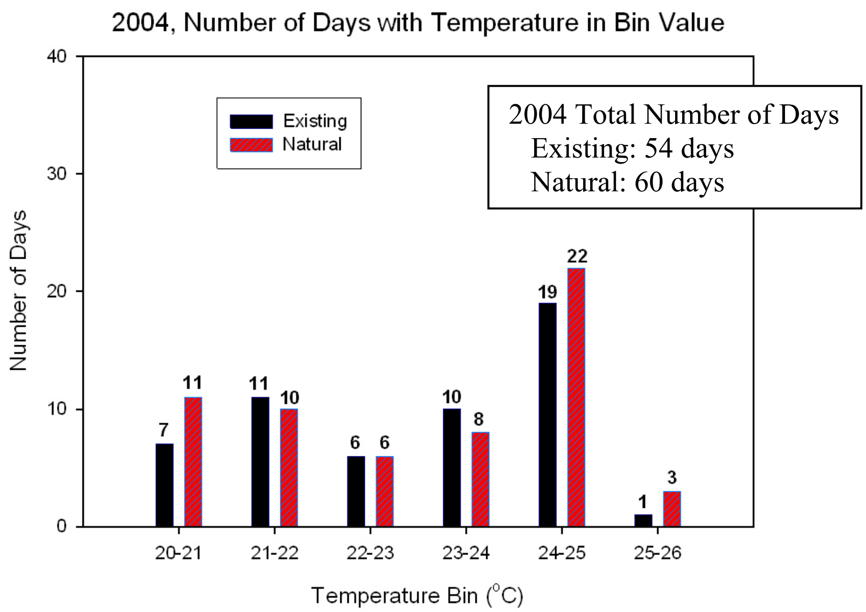

Notes:

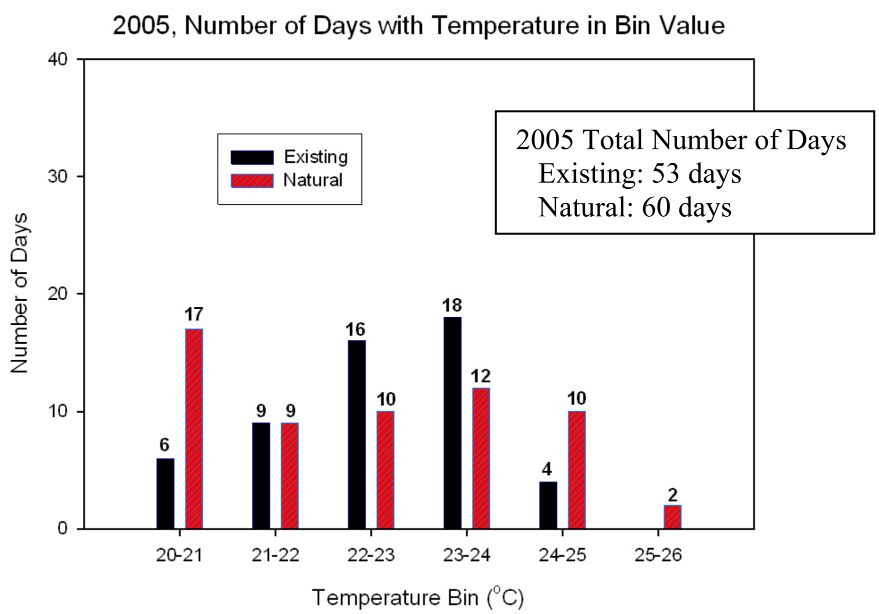
1. Frequency distributions of the daily maximum temperatures from the surface layer of the models are from model results obtained from Ecology.
2. The difference in temperature at each frequency is obtained by subtracting the Natural Condition values from the Existing Condition values. (When Natural Condition is < 20ºC, the Natural temperature is replaced by the value 20ºC.)
3. The period covered by the frequency analysis was July 9, 2004 to September 4, 2004 and July 8, 2005 to September 8, 2005 when Existing Condition > 20ºC.
4. Surface temperature differences are between -1.15 ºC and +0.19 ºC due to all the dams on the Pend Oreille River.

**Figure 4-7c**

Frequency Distributions of the Daily Maximum Surface Temperatures for the Existing and Natural Conditions at Boundary Dam Tailrace

Seattle City Light
Seattle, WA



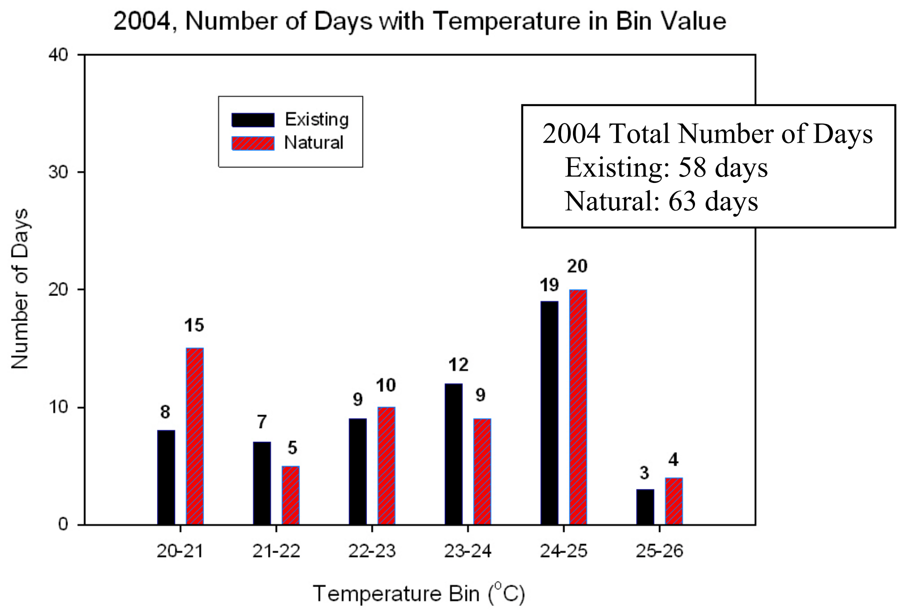

Notes:

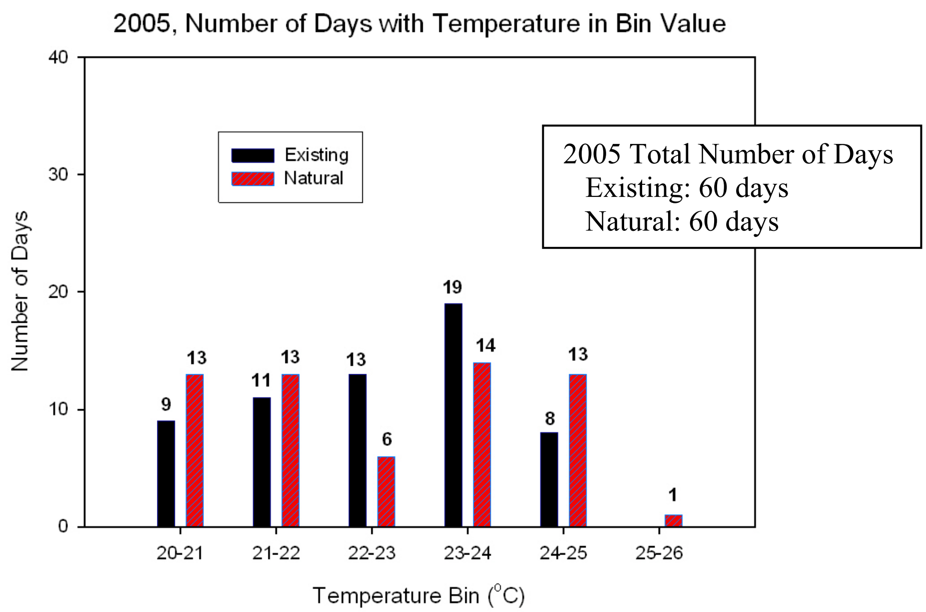
1. The total number of days for 2004 and 2005 was
   Existing – 107 days
   Natural – 120 days
2. Peak annual surface temperature at the Metaline Pool
   2004 – Existing: 25.07ºC & Natural: 25.44ºC
   2005 – Existing: 24.41ºC & Natural: 25.17ºC

**Figure 4-8a**

Number of Days the Daily Maximum Surface Temperatures Exceeded 20ºC at the Metaline Pool for 2004 and 2005

Seattle City Light
Seattle, WA



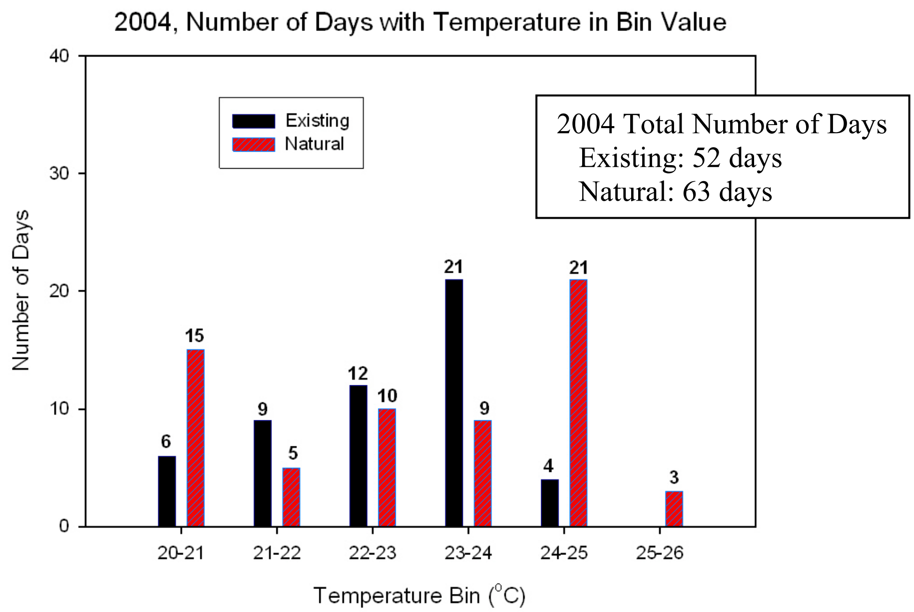

Notes:

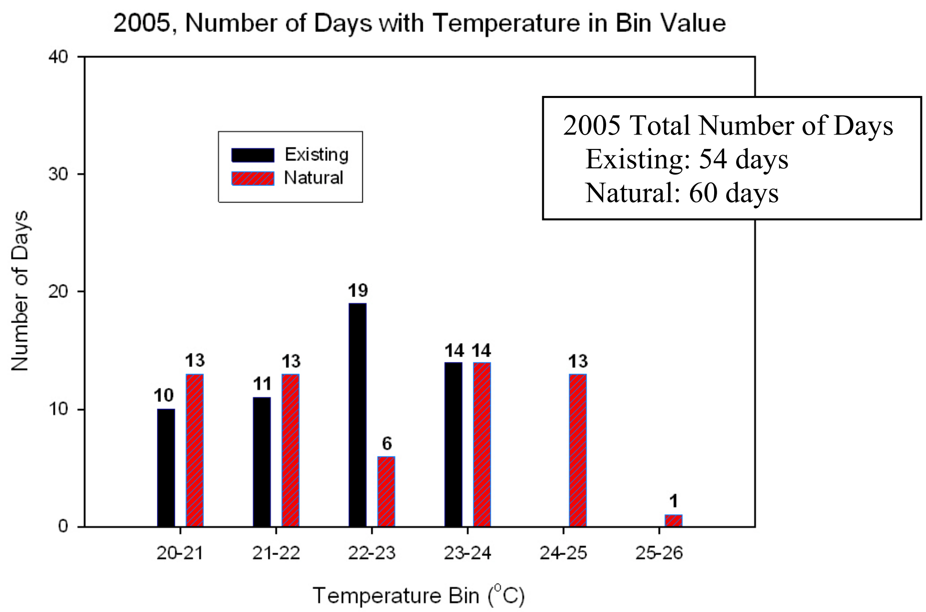
1. The total number of days for 2004 and 2005 was
   Existing – 118 days
   Natural – 123 days
2. Peak annual surface temperature at the Boundary Dam Forebay
   2004 – Existing: 25.25ºC & Natural: 25.29ºC
   2005 – Existing: 24.55ºC & Natural: 25.15ºC

**Figure 4-8**b

Number of Days the Daily Maximum Surface Temperatures Exceeded 20ºC at the Boundary Dam Forebay for 2004 and 2005

Seattle City Light
Seattle, WA




Notes:

1. The total number of days for 2004 and 2005 was
   Existing – 106 days
   Natural – 123 days
2. Peak annual surface temperature at the Boundary Dam Tailrace
   2004 – Existing: 24.31ºC & Natural: 25.29ºC
   2005 – Existing: 23.71ºC & Natural: 25.15ºC

**Figure 4-8c**

Number of Days the Daily Maximum Surface Temperatures Exceeded 20ºC at the Boundary Dam Tailrace for 2004 and 2005

Seattle City Light
Seattle, WA

# 5.0 Evaluation of the Existing Condition without Boundary Project

As described in Section 4, the temperature differences between Existing and Natural Conditions at the Boundary Dam forebay using the frequency analysis approach was 0.20˚C with the flow-weighted temperatures and 0.76˚C for the surface temperatures. However, these differences are not entirely due to Boundary Reservoir as they also include the influence of upstream reservoirs on the river temperatures.

As a result, separating out the Boundary Reservoir contribution requires examination of the *Existing Condition without Boundary Project.*[14] This analysis simulates the changes in temperature response in Boundary Reach without Boundary Dam but with the upstream and downstream dams (Albeni Falls, Box Canyon and Seven-Mile[15]) present; this corresponds to temperature change that would occur if Boundary Dam alone were to be removed. The effects of the upstream and downstream dams can be estimated by comparing model simulations for the Natural Condition to those for the Existing Condition without Boundary Project. Similarly, the effects of the Boundary Project can be estimated by comparing model simulations for the Existing Condition to those for the Existing Condition without Boundary Project.

Table 5-1 provides the model configurations for the Existing Condition, Natural Condition, and Existing Condition without Boundary Project.[16] Under the Existing Condition without Boundary Project, only the Boundary Dam was removed, all the point sources were present, and the shade was the same as for the Existing Condition.

**Table 5-1**
Model Configurations for Existing Condition, Natural Condition, and Existing without Boundary Project

| Case | Pend Oreille River Dams | Point Sources | Shade |
|---|---|---|---|
| **Existing** | All | All | Existing |
| **Natural** | None | None | PNV |
| **Existing without Boundary Project** | Albeni Falls, Box Canyon, Seven-Mile | All | Existing |

Section 5.1 presents the comparison using flow-weighted temperatures; Section 5.2 does the same using surface temperatures.

[14] This was referred to as Alternative 4 in the list of proposed alternatives to be examined by Ecology as part of the Pend Oreille TMDL (Pickett 2007).
[15] Seven Mile Dam is not explicitly simulated. However, in the *Existing Condition* and in the *Existing without Boundary Project Condition*, the water surface elevation specified at the downstream boundary at U.S. Canadian border includes the backwater effect of Seven Mile Dam.
[16] Pickett, P. May 10, 2007. Boundary Dam Temperature Modeling. Presentation to the Pend Oreille River TMDL Watershed Advisory Group.

## 5.1 Flow-Weighted Temperature Evaluation

Figures 5-1 a, b, and c show time series comparisons of the daily maximum flow-weighted temperatures for the Natural Condition and the Existing Condition without Boundary Project at Metaline Pool, Boundary forebay, and Boundary tailrace stations, respectively. The peak temperatures in the Existing Condition without Boundary Project are similar to but slightly lower than the Natural Condition peaks (24-25˚C). Figures 5-2 a, b, and c present plots of the frequency distribution of the daily maximum temperatures for the Existing Condition without Boundary Project and the Natural Condition at Metaline Pool, Boundary forebay, and Boundary tailrace stations, respectively. The maximum differences in temperature at Metaline Pool, Boundary forebay and Boundary tailrace stations were 0.61˚C, 0.40˚C and 0.41˚C, respectively. These differences could be interpreted as the potential effect of upstream and downstream impoundments without the presence of Boundary Reservoir. When compared with the Existing Condition results of 0.50˚C, 0.20˚C and 0.19˚C at the same locations (Table 5-2 a, b, and c) , it can be seen that there was no improvement in the temperature difference with removal of Boundary Dam, but rather, it was actually worse. This occurred because without the Boundary Project the Boundary Reach is an unimpounded river system, with the relatively shallow and well-mixed water column subject to heating. This is in contrast to the Existing Condition in which only the surface layers are subject to summer heating, with the lower depths remaining relatively cool. It is the cooler water in the bulk of the Boundary Reservoir that keeps the flow-weighted temperature low.

The comparisons of the time series of daily maximum flow-weighted temperatures between the Existing Condition without Boundary Project and the Existing Condition are shown in Figures 5-3 a, b, and c. The frequency distributions of the daily maximum flow-weighted temperatures for the Existing Condition without Boundary Project and the Existing Condition at the Metaline Pool, Boundary forebay, and Boundary tailrace stations are shown in Figures 5-4 a, b, and c, respectively. The comparison of these two cases shows any potential change that might occur with the removal of Boundary Dam. These results show that, at all stations, the flow-weighted temperatures for the Existing Condition were the same or lower across the frequency range than for the Existing without Boundary Project. For example, the maximum difference in temperature for the frequency distributions was -0.15˚C at the Boundary forebay station. The negative value for the difference shows that, with the Boundary Dam removed, there would be no improvement in the temperature relative to the Existing Condition, but rather that flow-weighted temperatures would become higher with Boundary dam removed. The results of this comparison (Existing Condition to Existing Condition without Boundary Project) indicate that the Boundary Project is not contributing to the increases in flow-weighted temperatures observed when comparing Existing Conditions to Natural Conditions,

A summary of the maximum temperature differences discussed above for all the cases examined is presented in Table 5-2 a, b, and c corresponding to Metaline Pool, Boundary forebay, and Boundary tailrace stations, respectively. The comparison to the Natural Condition represents the difference relative to the water quality criterion,[17] while the comparison to the Existing Condition represents the change relative to the Existing Condition. For example, the 0.4˚C was

[17] The water quality criterion is the 1-DMax of 20.0°C or the Natural Condition + 0.3°C, whichever is greater. However, differences presented are not adjusted to account for the 0.3°C human use allowance.

the maximum temperature difference for the Existing without Boundary Project above the Natural Condition at the Boundary forebay station, that is, without Boundary Dam but with the upstream dams present. It also included the effect of the Boundary Reach simulated as a river. Similarly, the -0.15˚C temperature difference at Boundary forebay station for the Existing without Boundary Project compared to the Existing Condition shows there would be no improvement from removing the dam. Because these differences were from cumulative frequency distributions, they will not necessarily be additive. Because the distributions were pooled data from the analysis period and were ranked from high to low, there is not necessarily an exact one-to-one correspondence to dates. In Table 5-2 a, b, and c, we have reported the maximum temperature difference without any adjustment or accounting for the 0.3˚C human use allowance.

Figures 5-5 a, b, and c show the number of days that flow-weighted daily maximum temperatures were above 20ºC, and the peak annual flow-weighted temperatures, in Metaline Pool, Boundary forebay, and Boundary tailrace stations, respectively for the Existing Condition, Natural Condition ,and Existing Condition without Boundary Project. At all stations, the number of days with flow-weighted temperatures above 20ºC were the lowest in the Existing Condition, and were higher in both the Existing Condition without Boundary Project and in the Natural Condition. For example, for the Existing Condition without Boundary Project, 57 days were above 20ºC in 2004, and in 2005, 55 days were higher than 20ºC at the Boundary forebay location (Figure 5-5 b). In comparison, in 2004, 52 days were higher than 20ºC in the Existing Condition, while in 2005, 54 days were above 20ºC. The Natural Condition had 63 days in 2004 and 60 days in 2005 that were higher than 20ºC. Also, the peak annual flow-weighted daily maximum temperatures were lower at all stations in the Existing Condition than those in either the Natural Condition or the Existing without Boundary Project.

The data from Figures 5-5 a, b, and c are summarized in Table 5-3 a, b, and c. They indicate that, at all locations, the Existing Condition had fewer days with flow-weighted temperatures above 20ºC, and had lower peak annual flow-weighted temperatures than did the Natural Condition or the Existing Condition without Boundary Project. Accordingly, the Boundary Project does not increase the number of days with flow-weighted temperatures above 20ºC or increase the peak annual flow-weighted daily maximum temperatures.

## 5.2 Surface Temperature Evaluation

Figures 5-6 a, b, and c show a comparison of the time series of the daily maximum surface temperatures for the Natural Condition and the Existing Condition without Boundary Project at Metaline Pool, Boundary forebay, and Boundary tailrace stations, respectively. The peak temperatures in the Existing Condition without Boundary Project were relatively unchanged from the Natural Condition peaks (≈ 25˚C). Figures 5-7 a, b, and c present plots of the frequency distribution of the daily maximum surface temperatures for Existing Condition without Boundary and the Natural Condition at Metaline Pool, Boundary forebay, and Boundary tailrace stations respectively. For example, the maximum difference in temperature was 0.40˚C at the Boundary forebay station. This difference could be interpreted as the potential effect of upstream impoundments at the Boundary Dam forebay station without the presence of Boundary Reservoir.

The comparison of the time series of the daily maximum surface temperatures between the Existing Condition without Boundary Project and the Existing Condition is shown in Figures 5-8 a, b and c at Metaline Pool, Boundary forebay, and Boundary tailrace stations, respectively. The frequency distributions of the daily maximum surface temperatures for the Existing Condition without Boundary Project and the Existing Condition are shown in Figure 5-9 a, b, and c at Metaline Pool, Boundary forebay, and Boundary tailrace stations, respectively. These results show that the surface temperatures for the Existing Condition and the Existing without the Boundary Project were similar. At the Metaline Pool station, the results are nearly indistinguishable, with a maximum temperature difference of 0.07 ºC. At the Boundary forebay station, the maximum difference in daily maximum surface temperatures from frequency distributions was 0.58˚C. At the Boundary tailrace station, the maximum difference was -0.14 ºC, indicating that daily maximum surface temperatures were lower at all times in the Existing Condition compared to the Existing Condition without Boundary Project.

A summary of the maximum temperature differences for all the cases examined is presented in Table 5-4 a, b, and c. The comparison to the Natural Condition represents the difference relative to the water quality criterion,[18] while the comparison to the Existing Condition represents the potential change relative to the Existing Condition. For example, the 0.40˚C was the maximum temperature difference at Boundary forebay for the Existing without Boundary Project above the Natural Condition, that is, without Boundary Dam but with the upstream dams present. It also included the effect of the Boundary Reach simulated as a river. The 0.58˚C temperature difference at Boundary forebay for the Existing Condition without Boundary Project was the simulated improvement over the Existing Condition due to removing the dam. Because these differences are from cumulative frequency distributions, they will not necessarily be additive. Because the distributions were pooled data from the analysis period and were ranked from high to low, there is not necessarily an exact one-to-one correspondence to dates. In Table 5-4 a, b, and c, we have reported the maximum temperature difference without any adjustment or accounting for the 0.3˚C human use allowance.

Figures 5-10 a, b, and c show number of days surface daily maximum temperatures are above 20ºC, and the peak annual surface temperatures, in Metaline Pool, Boundary forebay, and Boundary tailrace stations, respectively for the Existing Condition, Natural Condition and Existing Condition without Boundary Project. At the Boundary forebay station, in the Existing Condition without Boundary Project, 57 days in 2004, and in 2005, 55 days are above the 20ºC criterion (Figure 5-10 b). In comparison, in 2004, 58 days are above 20ºC in the Existing Condition, while in 2005, 60 days are above 20ºC. The Natural Condition had 63 days in 2004 and 60 days in 2005 that are above 20ºC at the Boundary forebay location. Also, the highest temperatures in the Existing Condition without the Boundary Project at the Boundary forebay station were lower than the Existing Condition in 2004, but higher in 2005. At the Metaline Pool and Boundary tailrace stations, there were the same or less number of days above 20ºC in the Existing Condition as compared to either the Existing Condition without Boundary Project or the Natural Condition. Similarly, peak annual surface temperatures at Metaline Pool and the Boundary tailrace were effectively the same as or lower in the Existing Condition as compared to either the Existing Condition without Boundary Project or Natural Condition.

[18] The water quality criterion is the 1-DMax of 20.0°C or the Natural Condition + 0.3°C, whichever is greater. However, differences presented are not adjusted to account for the 0.3°C human use allowance.

The data from Figures 5-10 a, b and c are summarized in Table 5-5a, b, and c. They indicate that, at all locations, both the Existing Condition and the Existing Condition without Boundary Project had fewer days with surface temperatures above 20ºC, and had lower peak annual surface temperatures, than did the Natural Condition. Relative to the Existing Condition, it appears that some improvement in the number of days with surface daily maximum temperatures above 20ºC could be achieved at the Boundary forebay station by removing Boundary Dam. However, doing so would not improve surface daily maximum temperatures at the Metaline Pool station, and would actually worsen surface daily maximum temperature conditions at the Boundary tailrace station.

**Table 5-2**
Summary of Maximum Flow-Weighted Temperature Differences from Frequency Analysis Comparing the Existing Condition, the Natural Condition, and the Existing Condition without Boundary Project

**a. Metaline Pool**

| Case | Maximum ΔT relative to the Natural Condition using Flow-Weighted Temperature from Frequency Analysis (Case-Natural) | Maximum ΔT relative to Existing Conditions using Flow-Weighted Temperature from Frequency Analysis (Existing-Case) |
|---|---|---|
| **Existing** | 0.50ºC[1] | 0.0ºC |
| **Existing without Boundary Project** | 0.61ºC[2] | 0.01ºC[3] |

**b. Boundary Forebay**

| Case | Maximum ΔT relative to the Natural Condition using Flow-Weighted Temperature from Frequency Analysis (Case-Natural) | Maximum ΔT relative to Existing Conditions using Flow-Weighted Temperature from Frequency Analysis (Existing-Case) |
|---|---|---|
| **Existing** | 0.20ºC[1] | 0.0ºC |
| **Existing without Boundary Project** | 0.40ºC[2] | -0.15ºC[3] |

**c. Boundary Tailrace**

| Case | Maximum ΔT relative to the Natural Condition using Flow-Weighted Temperature from Frequency Analysis (Case-Natural) | Maximum ΔT relative to Existing Conditions using Flow-Weighted Temperature from Frequency Analysis (Existing-Case) |
|---|---|---|
| **Existing** | 0.19ºC[1] | 0.0ºC |
| Existing without Boundary Project | 0.41ºC[2] | -0.14ºC[3] |

Notes:
The period covered by the frequency analyses is July 9, 2004 to September 4, 2004 & July 8, 2005 to September 8, 2005 when Existing Condition > 20ºC, Existing = all dams are present, Natural = no dams are present, Existing without Boundary Project = no Boundary Dam, Box Canyon Dam present, and Albeni Falls Dam present
[1] This represents the largest difference between the maximum flow-weighted temperature cumulative frequency distributions for the Existing Condition (with all dams in place) and Natural Condition.
[2] This represents the largest difference between the maximum flow-weighted temperature cumulative frequency distributions for the Existing without Boundary Project Condition and the Natural Condition. This shows the effect of upstream dams without Boundary Dam present.
[3] This represents the difference between the maximum flow-weighted temperature cumulative frequency distributions for the Existing without Boundary Project Condition and the Existing Condition. This shows the potential temperature difference associated with removal of the Boundary Project compared to Existing Conditions.

**Table 5-3**

Summary of the Number of Days Flow-Weighted Temperatures above 20°C , and the Peak Annual Flow-Weighted Temperatures, Comparing the Existing Condition, the Natural Condition and the Existing Condition without Boundary Project

**a. Metaline Pool**

| Case | Number of Days Temperature Exceeds 20°C | | Peak Annual Temperature (°C) | |
|---|---|---|---|---|
| | Flow-Weighted Temperature | | Flow-Weighted Temperature | |
| | 2004 | 2005 | 2004 | 2005 |
| Natural | 60 | 60 | 25.43 | 25.14 |
| Existing | 53 | 53 | 25.01 | 24.40 |
| Existing without Boundary Project | 54 | 56 | 25.04 | 24.61 |

**b. Boundary Forebay**

| Case | Number of Day Temperature Exceeds 20°C | | Peak Annual Temperature (°C) | |
|---|---|---|---|---|
| | Flow-Weighted Temperature | | Flow-Weighted Temperature | |
| | 2004 | 2005 | 2004 | 2005 |
| Natural | 63 | 60 | 25.29 | 25.15 |
| Existing | 52 | 54 | 24.29 | 23.72 |
| Existing without Boundary Project | 57 | 55 | 25.07 | 24.68 |

**c. Boundary Tailrace**

| Case | Number of Day Temperature Exceeds 20°C | | Peak Annual Temperature (°C) | |
|---|---|---|---|---|
| | Flow-Weighted Temperature | | Flow-Weighted Temperature | |
| | 2004 | 2005 | 2004 | 2005 |
| Natural | 63 | 60 | 25.29 | 25.15 |
| Existing | 52 | 54 | 24.31 | 23.71 |
| Existing without Boundary Project | 57 | 55 | 24.87 | 24.34 |

**Table 5-4**
Summary of Maximum Surface Temperature Differences from Frequency Analysis Comparing the Existing Condition, the Natural Condition, and the Existing Condition without Boundary Project

**a. Metaline Pool**

| Case | Maximum ΔT relative to the Natural Condition using Surface Temperature from Frequency Analysis (Case-Natural) | Maximum ΔT relative to Existing Conditions using Surface Temperature from Frequency Analysis (Existing-Case) |
|---|---|---|
| Existing | 0.50ºC[1] | 0.0ºC |
| Existing without Boundary Project | 0.63ºC[2] | 0.07ºC[3] |

**b. Boundary Forebay**

| Case | Maximum ΔT relative to the Natural Condition using Surface Temperature from Frequency Analysis (Case-Natural) | Maximum ΔT relative to Existing Conditions using Surface Temperature from Frequency Analysis (Existing-Case) |
|---|---|---|
| Existing | 0.76ºC[1] | 0.0ºC |
| Existing without Boundary Project | 0.40ºC[2] | 0.58ºC[3] |

**c. Boundary Tailrace**

| Case | Maximum ΔT relative to the Natural Condition using Surface Temperature from Frequency Analysis (Case-Natural) | Maximum ΔT relative to Existing Conditions using Surface Temperature from Frequency Analysis (Existing-Case) |
|---|---|---|
| Existing | 0.19ºC[1] | 0.0ºC |
| Existing without Boundary Project | 0.41ºC[2] | -0.14ºC[3] |

Notes:
The period covered by the frequency analyses is July 9, 2004 to September 4, 2004 & July 8, 2005 to September 8, 2005 when Existing Condition > 20ºC, Existing = all dams are present, Natural = no dams are present, Existing without Boundary Project = no Boundary Dam, Box Canyon Dam present, and Albeni Falls Dam present
[1] This represents the largest difference between the maximum surface temperature cumulative frequency distributions for the Existing Condition (with all dams in place) and Natural Condition.
[2] This represents the largest difference between the maximum surface temperature cumulative frequency distributions for the Existing Condition without Boundary Project and the Natural Condition. This shows the effect of upstream dams without Boundary Dam present.
[3] This represents the difference between the maximum surface temperature cumulative frequency distributions for the Existing Condition without Boundary Project and the Existing Condition. This shows the potential temperature difference associated with removal of the Boundary Project compared to Existing Conditions.

**Table 5-5**

Summary of the Number of Days Surface Temperatures are above 20ºC, and the Peak Annual Surface Temperatures, Comparing the Existing Condition, the Natural Condition and the Existing Condition without Boundary Project

**a. Metaline Pool**

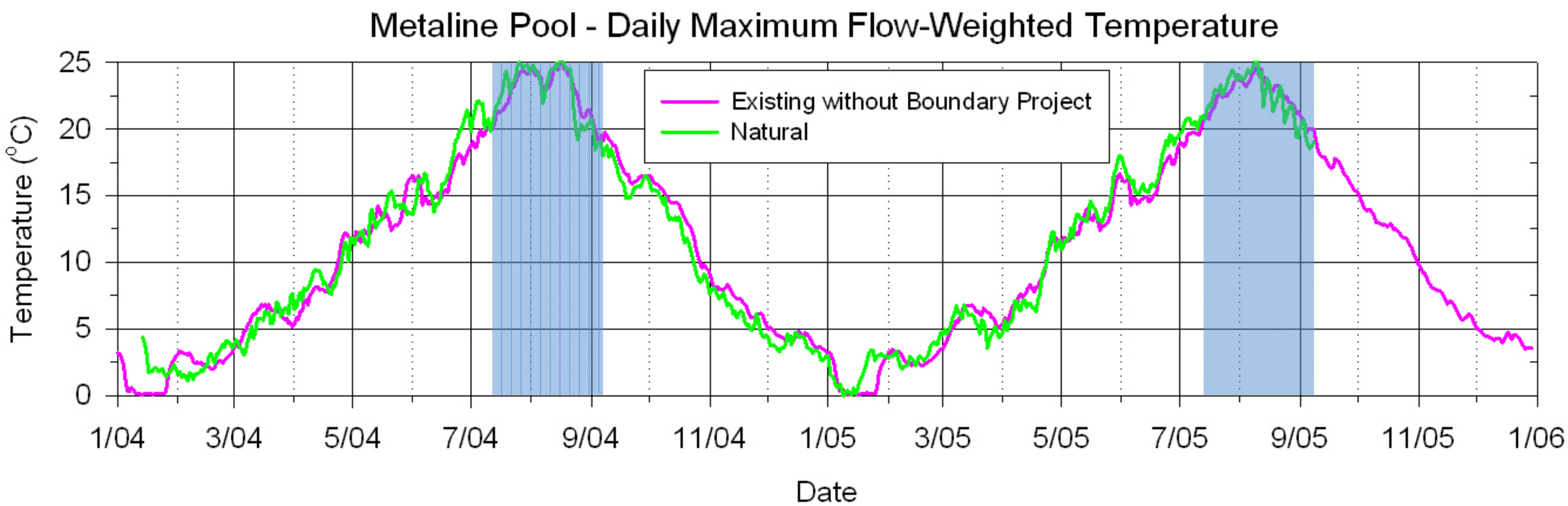
| Case | Number of Day Temperature Exceeds 20°C | | Peak Annual Temperature (°C) | |
|---|---|---|---|---|
| | Surface Temperature | | Surface Temperature | |
| | 2004 | 2005 | 2004 | 2005 |
| Natural | 60 | 60 | 25.44 | 25.17 |
| Existing | 54 | 53 | 25.07 | 24.41 |
| Existing without Boundary Project | 54 | 57 | 25.04 | 24.62 |

**b. Boundary Forebay**

| Case | Number of Day Temperature Exceeds 20°C | | Peak Annual Temperature (°C) | |
|---|---|---|---|---|
| | Surface Temperature | | Surface Temperature | |
| | 2004 | 2005 | 2004 | 2005 |
| Natural | 63 | 60 | 25.29 | 25.15 |
| Existing | 58 | 60 | 25.25 | 24.55 |
| Existing without Boundary Project | 57 | 55 | 25.07 | 24.68 |

**c. Boundary Tailrace**

| Case | Number of Day Temperature Exceeds 20°C | | Peak Annual Temperature (°C) | |
|---|---|---|---|---|
| | Surface Temperature | | Surface Temperature | |
| | 2004 | 2005 | 2004 | 2005 |
| Natural | 63 | 60 | 25.29 | 25.15 |
| Existing | 52 | 54 | 24.31 | 23.71 |
| Existing without Boundary Project | 57 | 55 | 25.14 | 24.77 |




Notes:

1. Existing without Boundary Project = No Boundary Dam, Box Canyon Dam present, and Albeni Falls Dam present. The designation as Existing without Boundary Project is from Ecology's TMDL analyses.
2. Daily maximum flow-weighted temperature is

$$T_W = \sum_{l=1}^{n} (T_l \times Q_l) / Q_T$$

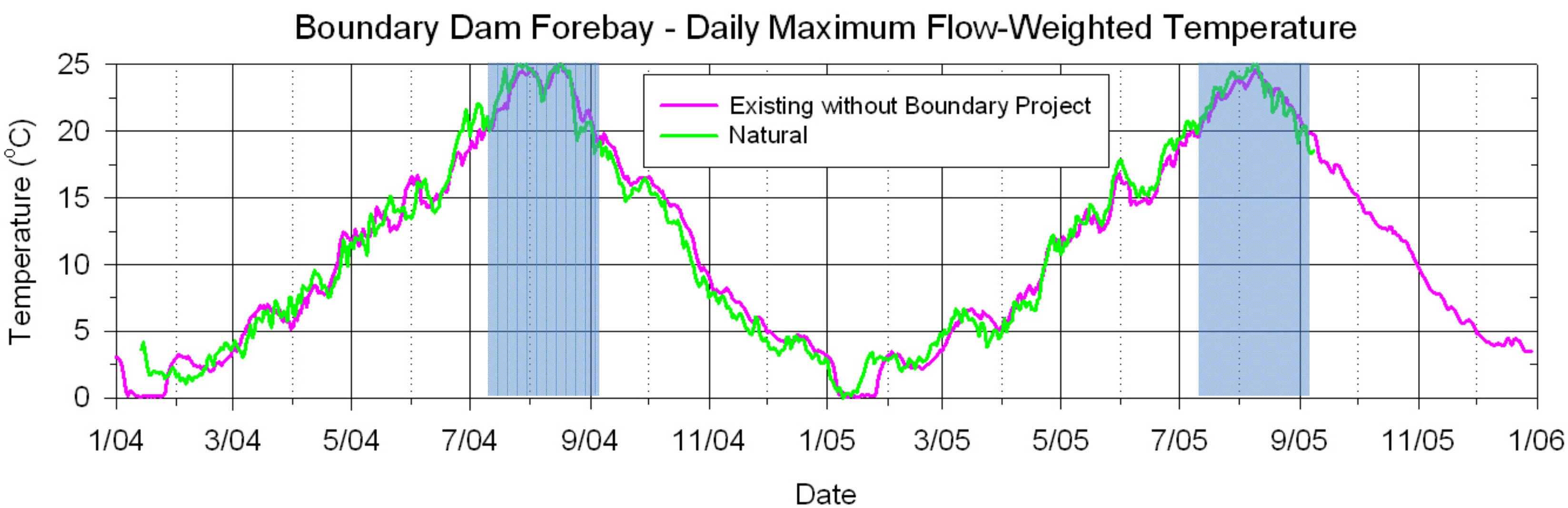
where $l$ is a layer of water column ($l$=1, 2,.., n), $T_W$ is the flow-weighted temperature, $T_l$ is the temperature at the layer, $Q_l$ is the flow rate at the layer, and $Q_T$ is the total flow.

3. The period when the Existing Condition without Boundary Project temperature is over 20ºC is indicated by the shading.

**Figure 5-1**a

Daily Maximum Flow-Weighted Temperatures for the Existing Condition without Boundary Project and the Natural Condition at Metaline Pool

Seattle City Light
Seattle, WA




Notes:

1. Existing without Boundary Project = No Boundary Dam, Box Canyon Dam present, and Albeni Falls Dam present. The designation as Existing without Boundary Project is from Ecology's TMDL analyses.
2. Daily maximum flow-weighted temperature is

$$T_W = \sum_{l=1}^{n} (T_l \times Q_l) / Q_T$$

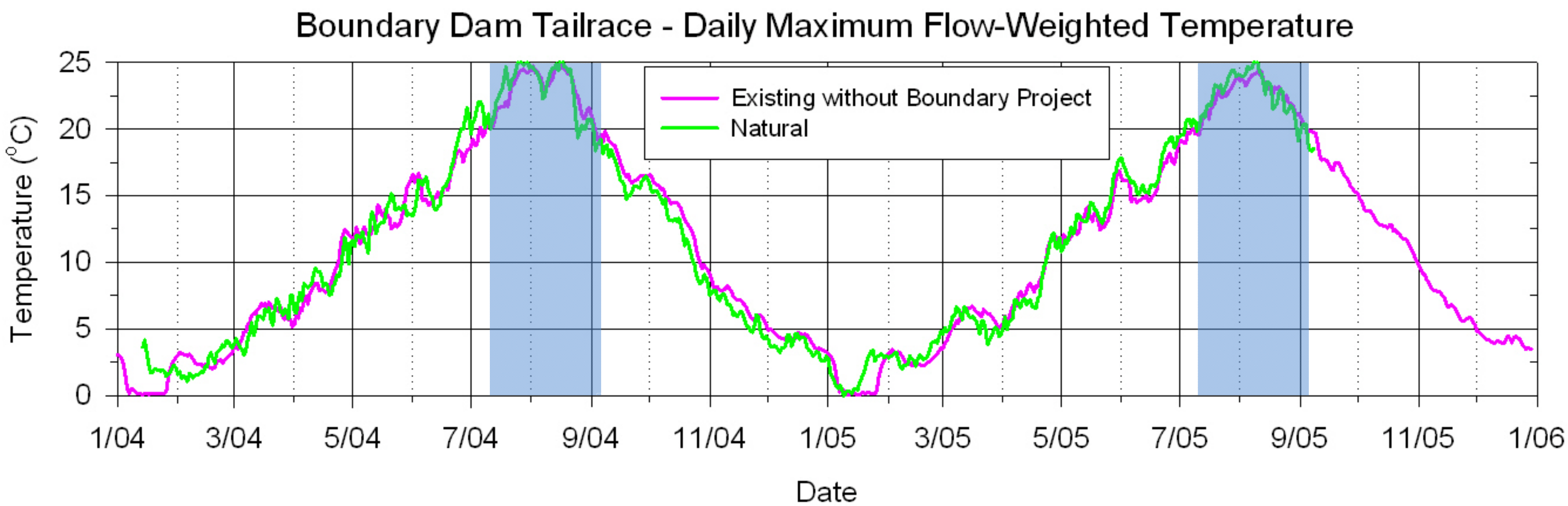
where $l$ is a layer of water column ($l$=1, 2,.., n), $T_W$ is the flow-weighted temperature, $T_l$ is the temperature at the layer, $Q_l$ is the flow rate at the layer, and $Q_T$ is the total flow.

3. The period when the Existing without Boundary Project temperature is over 20ºC is indicated by the shading.

**Figure 5-1**b

Daily Maximum Flow-Weighted Temperatures for the Existing Condition without Boundary Project and the Natural Condition at Boundary Dam Forebay

Seattle City Light
Seattle, WA




Notes:

1. Existing without Boundary Project = No Boundary Dam, Box Canyon Dam present, and Albeni Falls Dam present. The designation as Existing without Boundary Project is from Ecology's TMDL analyses.
2. Daily maximum flow-weighted temperature is

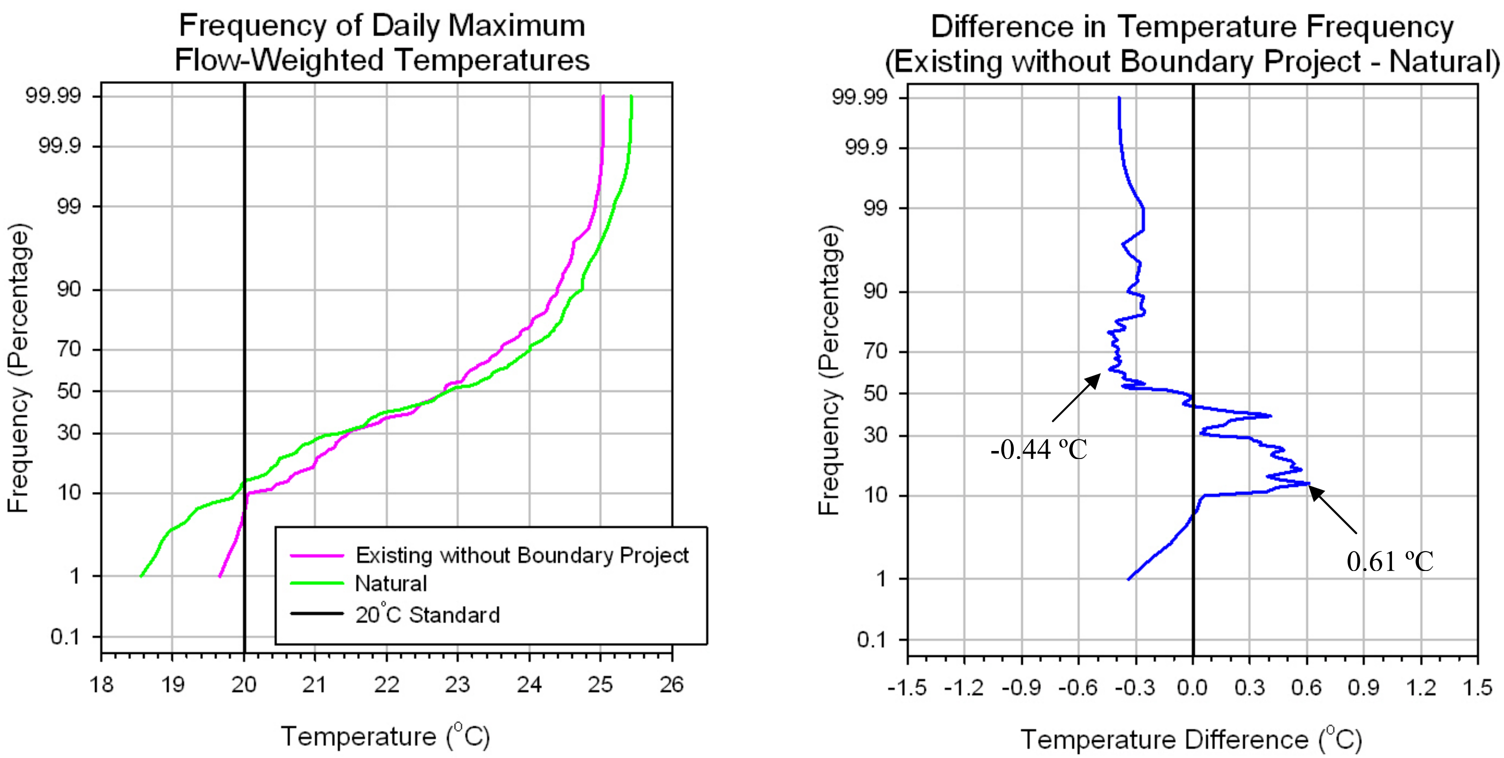
$$T_W = \sum_{l=1}^{n} (T_l \times Q_l) / Q_T$$

   where $l$ is a layer of water column ($l$=1, 2,.., n), $T_W$ is the flow-weighted temperature, $T_l$ is the temperature at the layer, $Q_l$ is the flow rate at the layer, and $Q_T$ is the total flow.
3. The period when the Existing without Boundary Project temperature is over 20ºC is indicated by the shading.

**Figure 5-1**c

Daily Maximum Flow-Weighted Temperatures for the Existing Condition without Boundary Project and the Natural Condition at Boundary Dam Tailrace

Seattle City Light
Seattle, WA

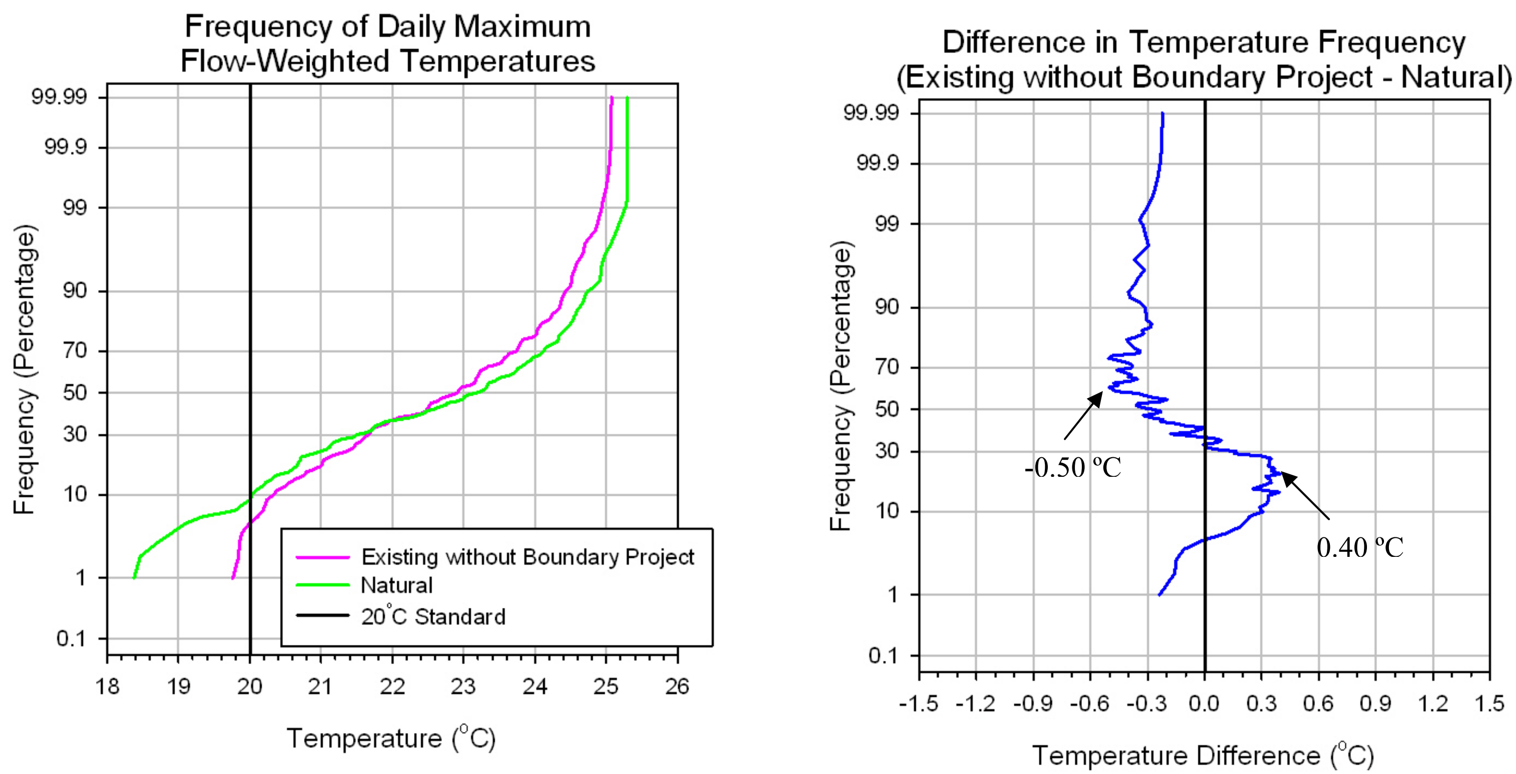



Notes:
1. Frequency distributions of the maximum flow-weighted temperatures are from model results obtained from Ecology.
2. The difference in temperature at each frequency is obtained by subtracting the Natural Condition values from the Existing without Boundary Project values. (When Natural Condition is < 20ºC, the Natural temperature is replaced by the value 20ºC.)
3. The period covered by the frequency analysis was July 9, 2004 to September 4, 2004 and July 8, 2005 to September 8, 2005.
4. Flow-weighted temperature differences are between -0.44 ºC and +0.61 ºC due to upstream dams (Box Canyon and Albeni Falls) on the Pend Oreille River.

**Figure 5-2a**

Frequency Distribution of the Daily Maximum Flow-Weighted Temperatures for the Existing Condition without Boundary Project and the Natural Condition at Metaline Pool

Seattle City Light
Seattle, WA



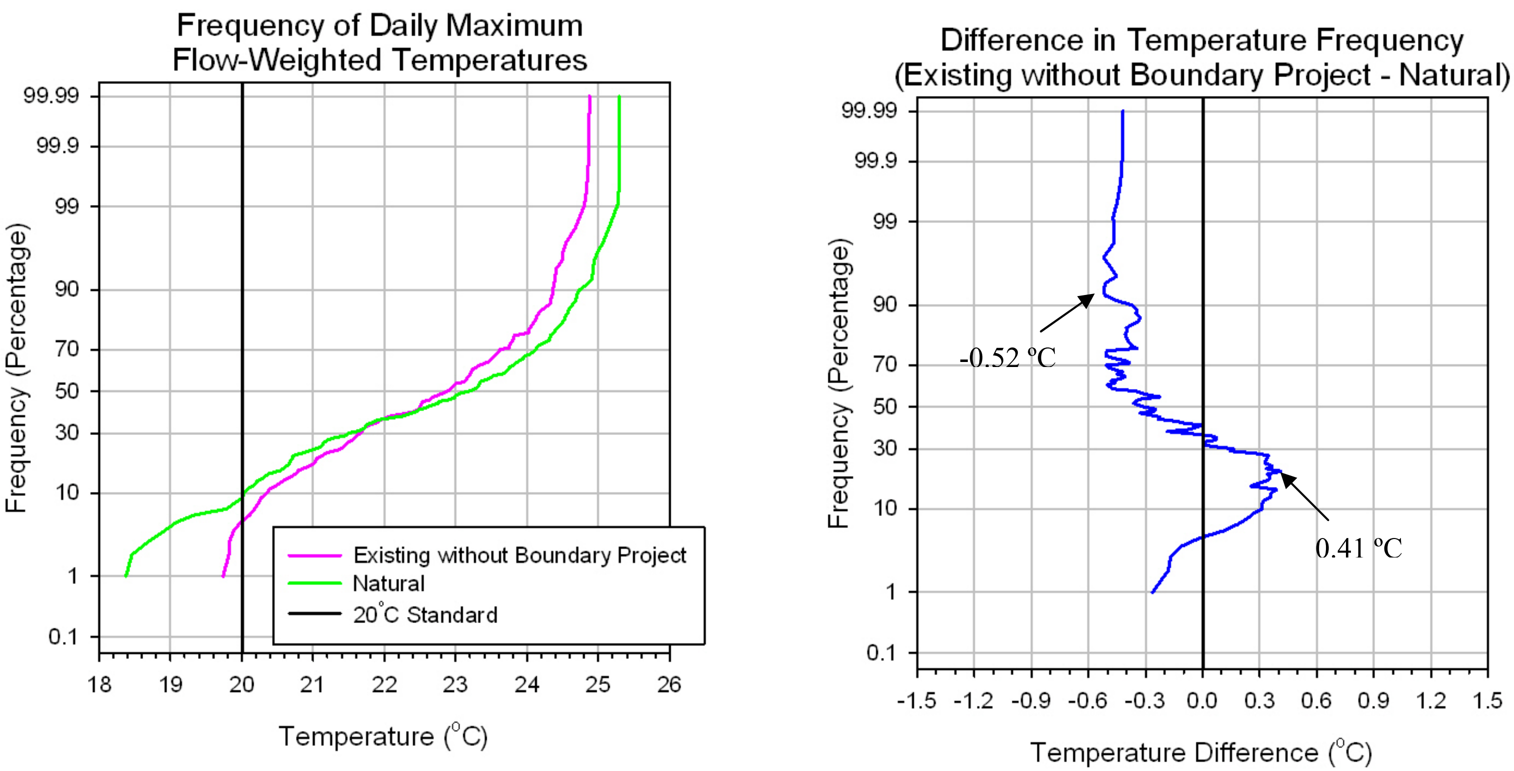

Notes:

1. Frequency distributions of the maximum flow-weighted temperatures are from model results obtained from Ecology.
2. The difference in temperature at each frequency is obtained by subtracting the Natural Condition values from the Existing without Boundary Project values. (When Natural Condition is < 20ºC, the Natural temperature is replaced by the value 20ºC.)
3. The period covered by the frequency analysis was July 9, 2004 to September 4, 2004 and July 8, 2005 to September 8, 2005.
4. Flow-weighted temperature differences are between -0.50ºC and +0.40ºC due to upstream dams (Box Canyon and Albeni Falls) on the Pend Oreille River.

**Figure 5-2**b

Frequency Distribution of the Daily Maximum Flow-Weighted Temperatures for the Existing Condition without Boundary Project and the Natural Condition at Boundary Dam Forebay

Seattle City Light
Seattle, WA



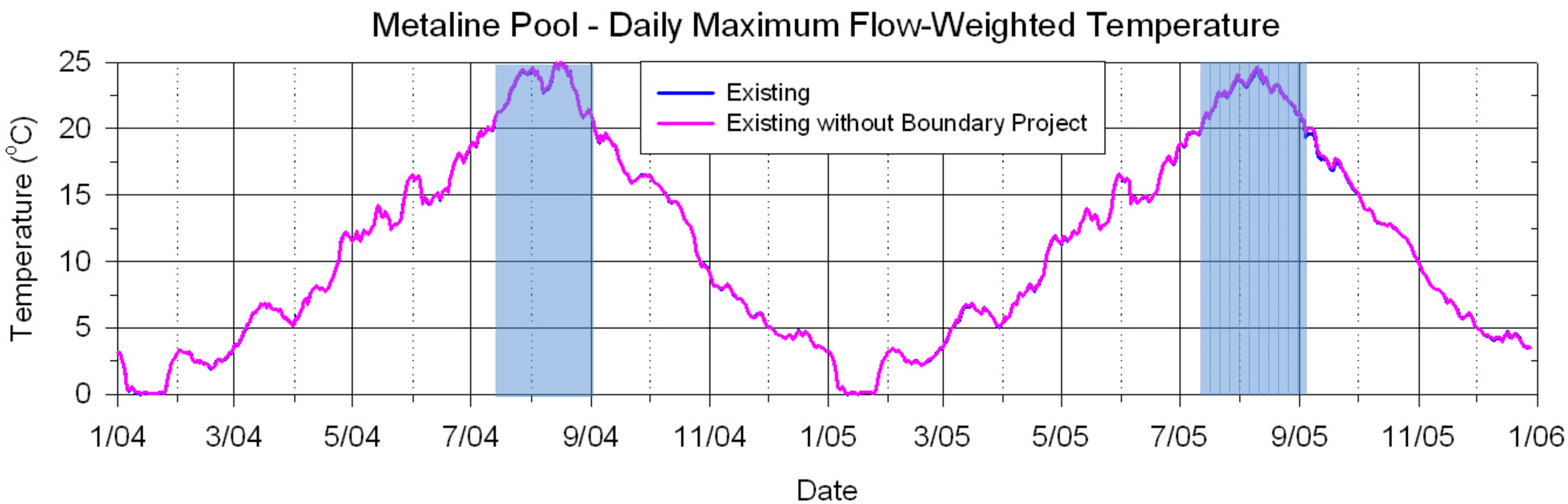

Notes:

1. Frequency distributions of the maximum flow-weighted temperatures are from model results obtained from Ecology.
2. The difference in temperature at each frequency is obtained by subtracting the Natural Condition values from the Existing without Boundary Project values. (When Natural Condition is < 20ºC, the Natural temperature is replaced by the value 20ºC.)
3. The period covered by the frequency analysis was July 9, 2004 to September 4, 2004 and July 8, 2005 to September 8, 2005.
4. Flow-weighted temperature differences are between -0.52ºC and +0.41ºC due to upstream dams (Box Canyon and Albeni Falls) on the Pend Oreille River.

**Figure 5-2c**

Frequency Distribution of the Daily Maximum Flow-Weighted Temperatures for the Existing Condition without Boundary Project and the Natural Condition at Boundary Dam Tailrace

Seattle City Light
Seattle, WA




Notes:

1. Existing without Boundary Project = No Boundary Dam, Box Canyon Dam present, and Albeni Falls Dam present.
2. Daily maximum flow-weighted temperature is

$$T_W = \sum_{l=1}^{n} (T_l \times Q_l) / Q_T$$

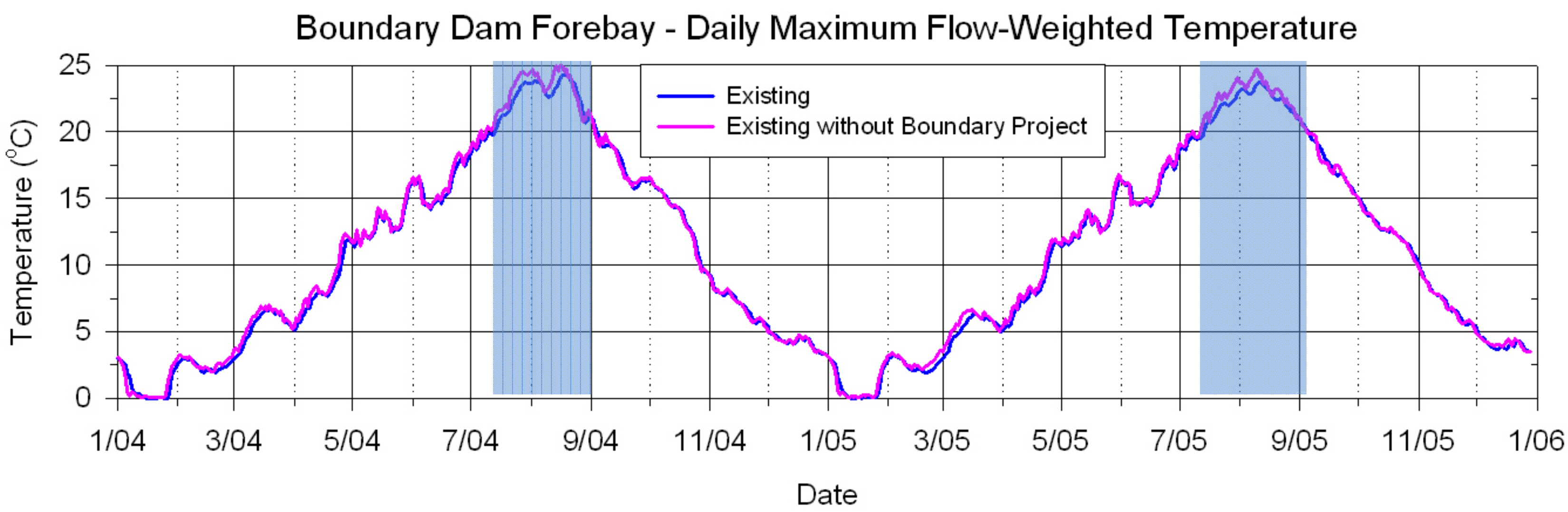
where $l$ is a layer of water column ($l$=1, 2,.., n), $T_W$ is the flow-weighted temperature, $T_l$ is the temperature at the layer, $Q_l$ is the flow rate at the layer, and $Q_T$ is the total flow.

3. The period when the Existing without Boundary Project temperature is over 20ºC is indicated by the shading.

**Figure 5-3**a

Daily Maximum Flow-Weighted Temperatures for the Existing Condition and Existing Condition without Boundary Project at Metaline Pool

Seattle City Light
Seattle, WA




Notes:

1. Existing without Boundary Project = No Boundary Dam, Box Canyon Dam present, and Albeni Falls Dam present.
2. Daily maximum flow-weighted temperature is

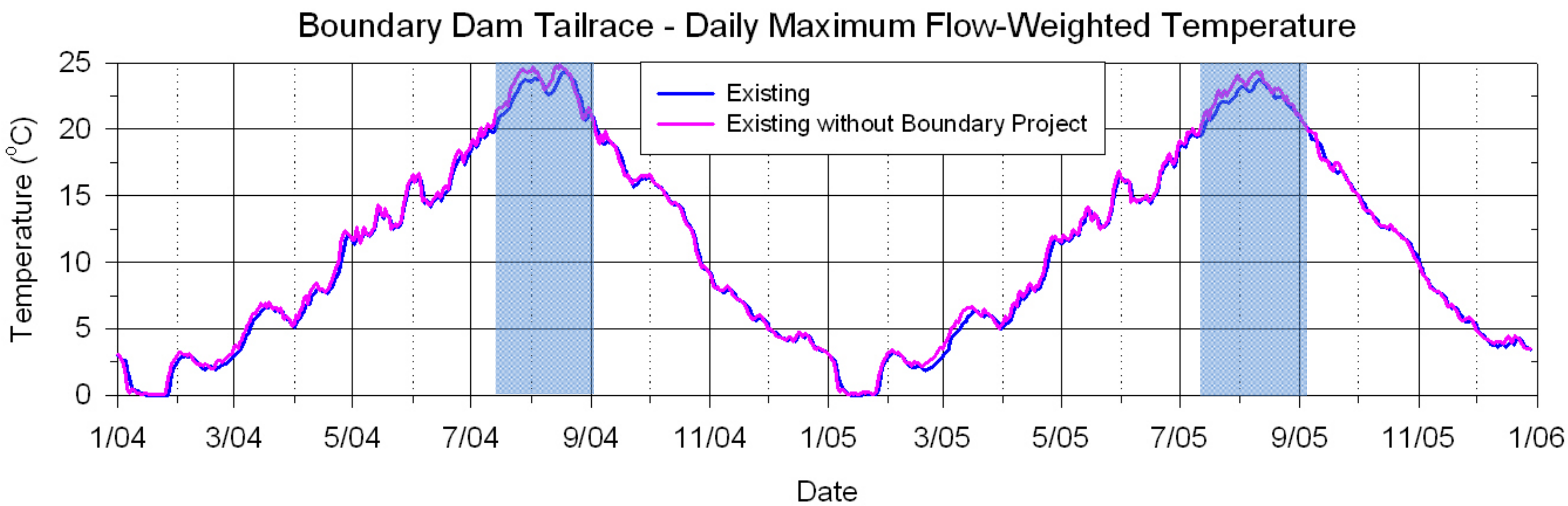
$$T_W = \sum_{l=1}^{n} (T_l \times Q_l) / Q_T$$

where *l* is a layer of water column (*l*=1, 2,.., n), $T_W$ is the flow-weighted temperature, $T_l$ is the temperature at the layer, $Q_l$ is the flow rate at the layer, and $Q_T$ is the total flow.
3. The period when the Existing without Boundary Project temperature is over 20ºC is indicated by the shading.

**Figure 5-3**b

Daily Maximum Flow-Weighted Temperatures for the Existing Condition and Existing Condition without Boundary Project at Boundary Dam Forebay

Seattle City Light
Seattle, WA




Notes:

1. Existing without Boundary Project = No Boundary Dam, Box Canyon Dam present, and Albeni Falls Dam present.
2. Daily maximum flow-weighted temperature is

$$T_W = \sum_{l=1}^{n} (T_l \times Q_l) / Q_T$$

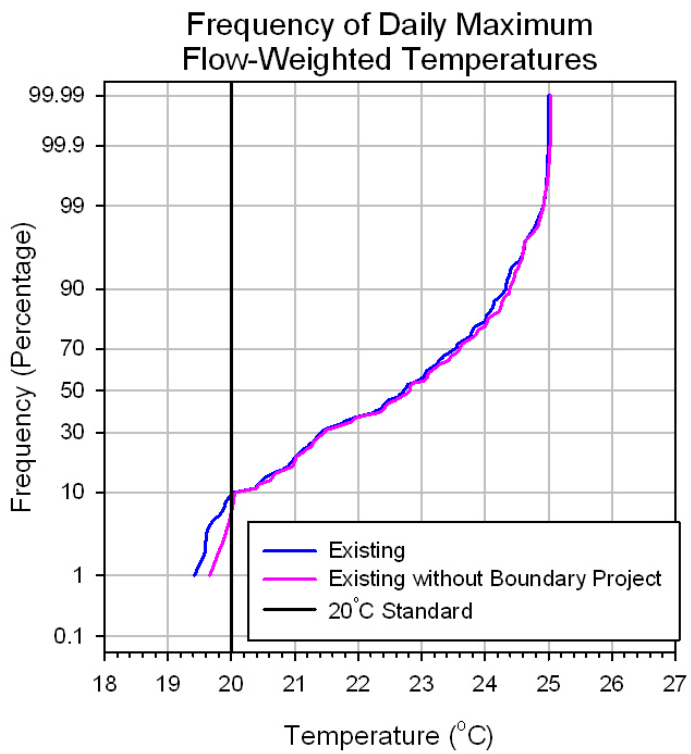
where $l$ is a layer of water column ($l$=1, 2,.., n), $T_W$ is the flow-weighted temperature, $T_l$ is the temperature at the layer, $Q_l$ is the flow rate at the layer, and $Q_T$ is the total flow.

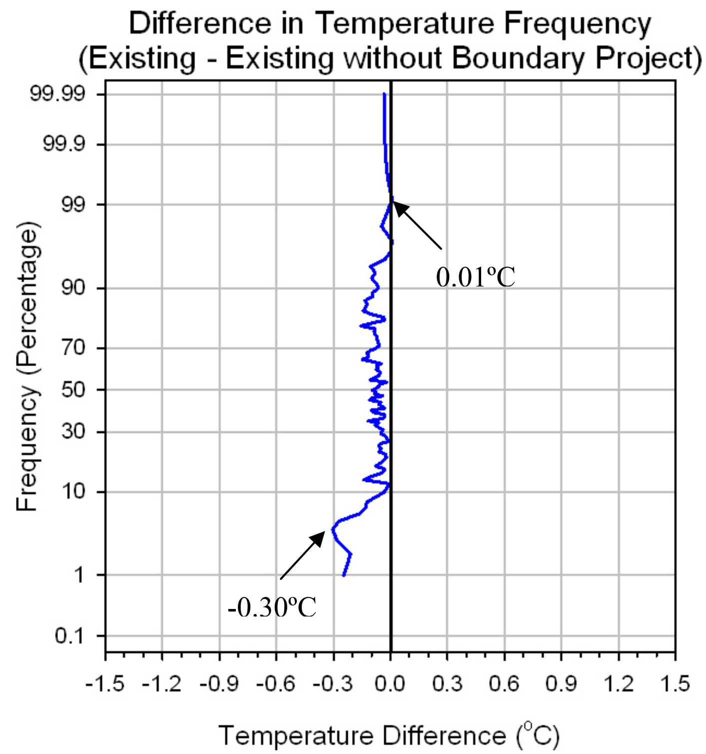
3. The period when the Existing without Boundary Project temperature is over 20ºC is indicated by the shading.

**Figure 5-3c**

Daily Maximum Flow-Weighted Temperatures for the Existing Condition and Existing Condition without Boundary Project at Boundary Dam Tailrace

Seattle City Light
Seattle, WA



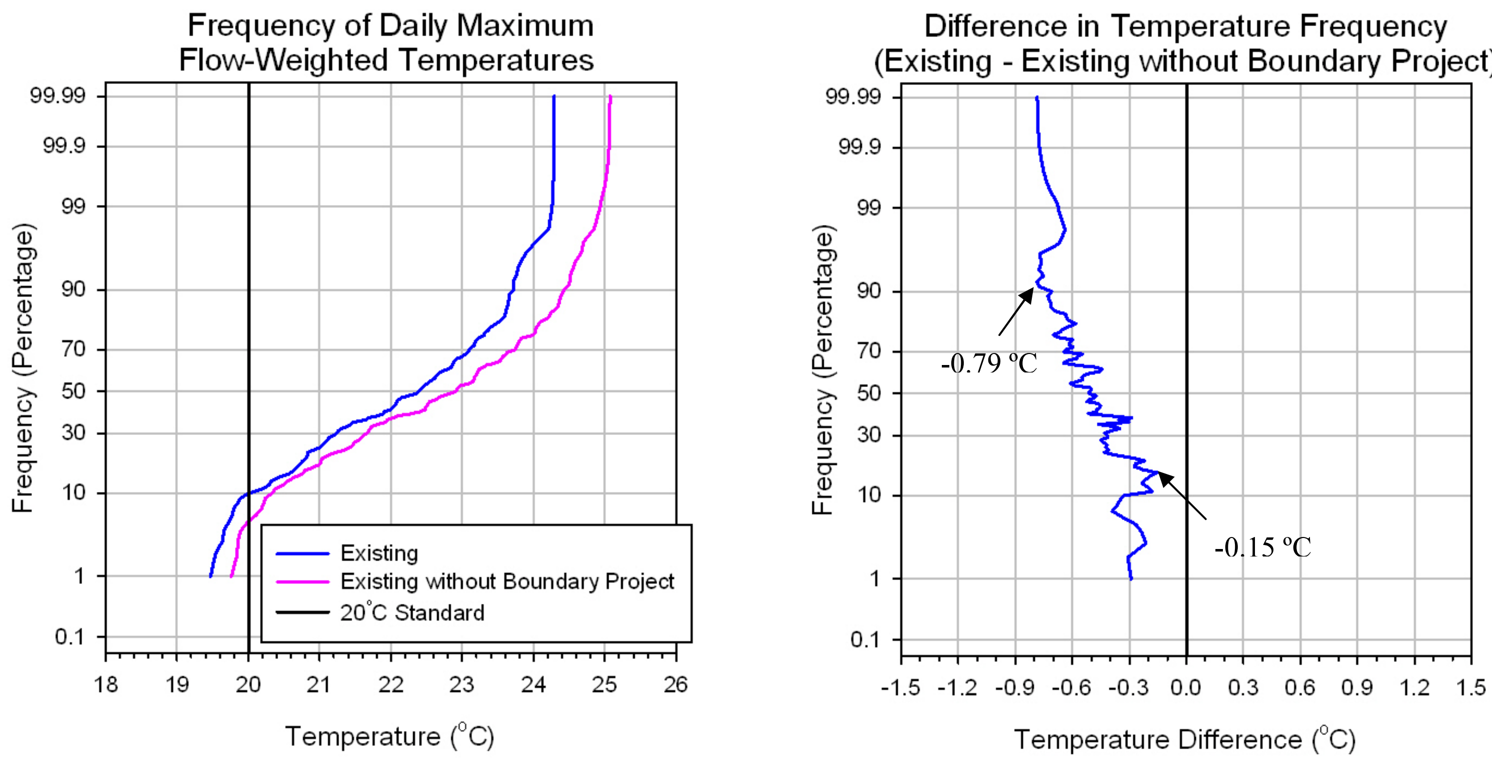

Notes:

1. Frequency distributions of the maximum flow-weighted temperatures are from model results obtained from Ecology.
2. The difference in temperature at each frequency is obtained by subtracting the Existing without Boundary Project values from the Existing Condition values.
3. The period covered by the frequency analysis was July 9, 2004 to September 4, 2004 and July 8, 2005 to September 8, 2005.
4. Existing Condition flow-weighted temperatures differences are between -0.30ºC and +0.01ºC relative to the Existing Condition without Boundary Project.

**Figure 5-4**a

Frequency Distribution of the Daily Maximum Flow-Weighted Temperatures for the Existing Condition without Boundary Project and the Existing Condition at Metaline Pool

Seattle City Light
Seattle, WA



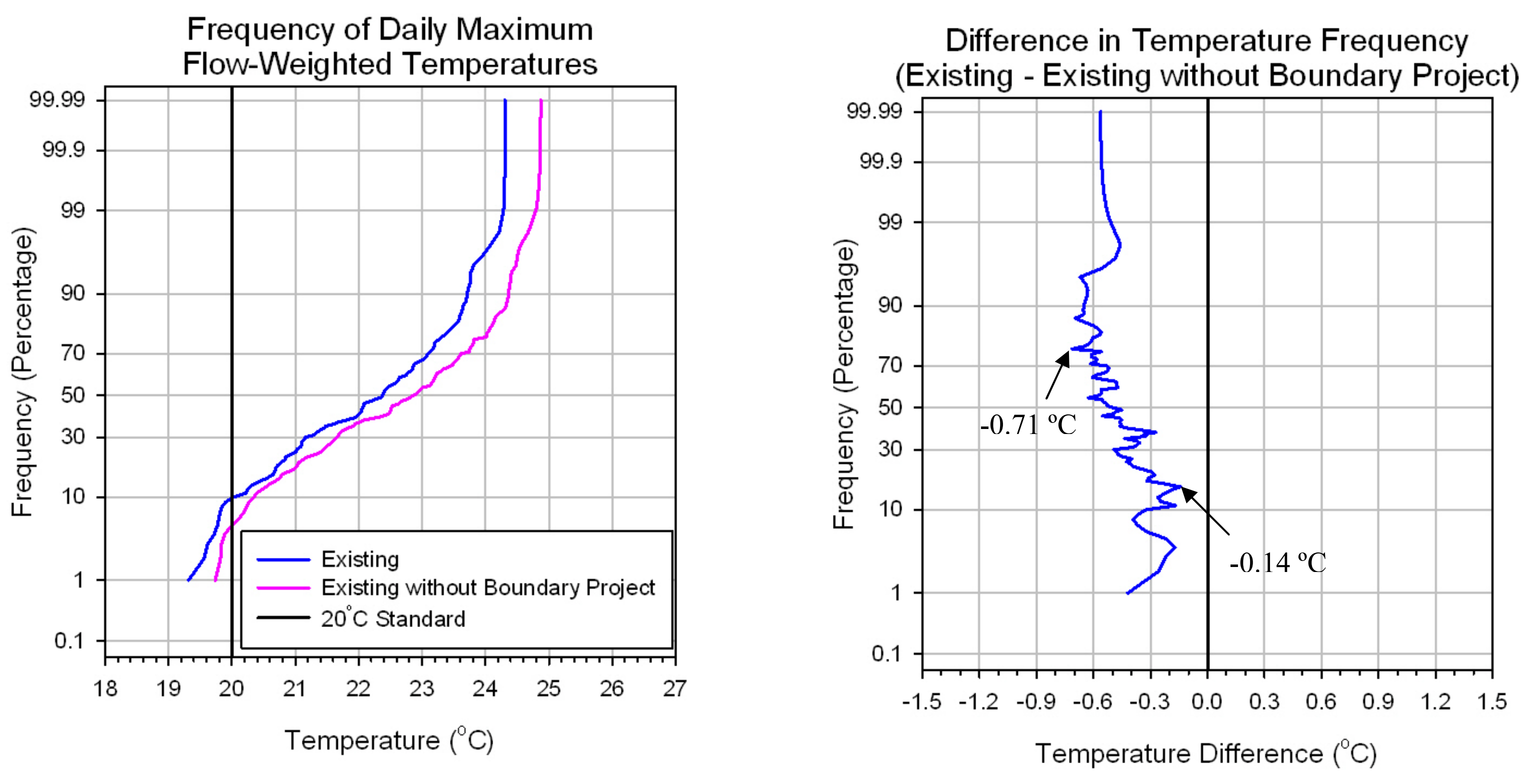

Notes:

1. Frequency distributions of the maximum flow-weighted temperatures are from model results obtained from Ecology.
2. The difference in temperature at each frequency is obtained by subtracting the Existing without Boundary Project values from the Existing Condition values.
3. The period covered by the frequency analysis was July 9, 2004 to September 4, 2004 and July 8, 2005 to September 8, 2005.
4. Existing Condition flow-weighted temperatures are between 0.15ºC and 0.79ºC lower than the Existing Condition without Boundary Project.

**Figure 5-4**b

Frequency Distribution of the Daily Maximum Flow-Weighted Temperatures for the Existing Condition without Boundary Project and the Existing Condition at Boundary Dam Forebay

Seattle City Light
Seattle, WA




Notes:

1. Frequency distributions of the maximum flow-weighted temperatures are from model results obtained from Ecology.
2. The difference in temperature at each frequency is obtained by subtracting the Existing without Boundary Project values from the Existing Condition values.
3. The period covered by the frequency analysis was July 9, 2004 to September 4, 2004 and July 8, 2005 to September 8, 2005.
4. Existing Condition flow-weighted temperatures are between 0.14ºC and 0.71ºC lower than the Existing Condition without Boundary Project.

**Figure 5-4c**

Frequency Distribution of the Daily Maximum Flow-Weighted Temperatures for the Existing Condition without Boundary Project and the Existing Condition at Boundary Dam Tailrace

Seattle City Light
Seattle, WA

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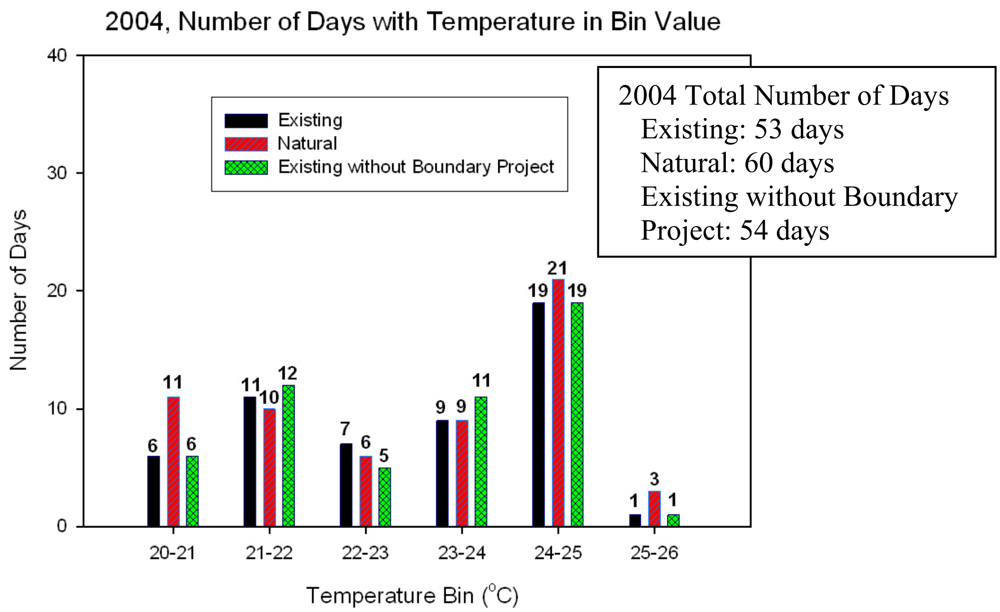
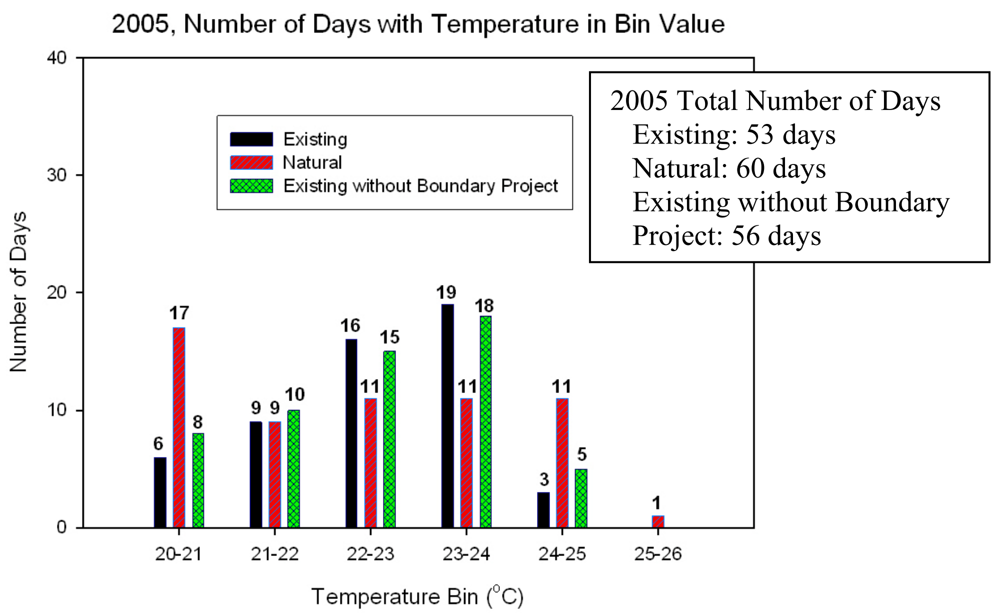


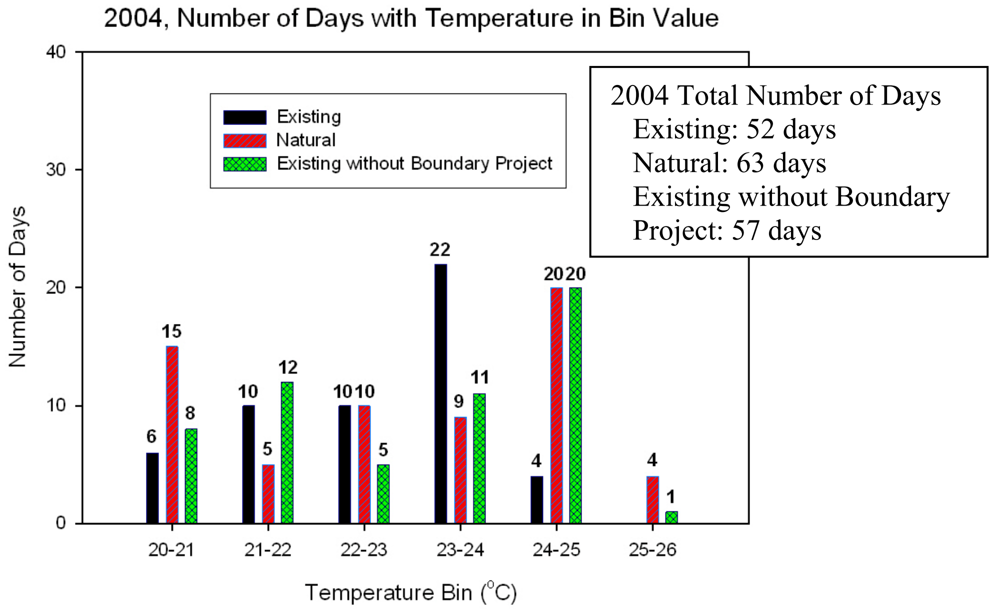

Notes:

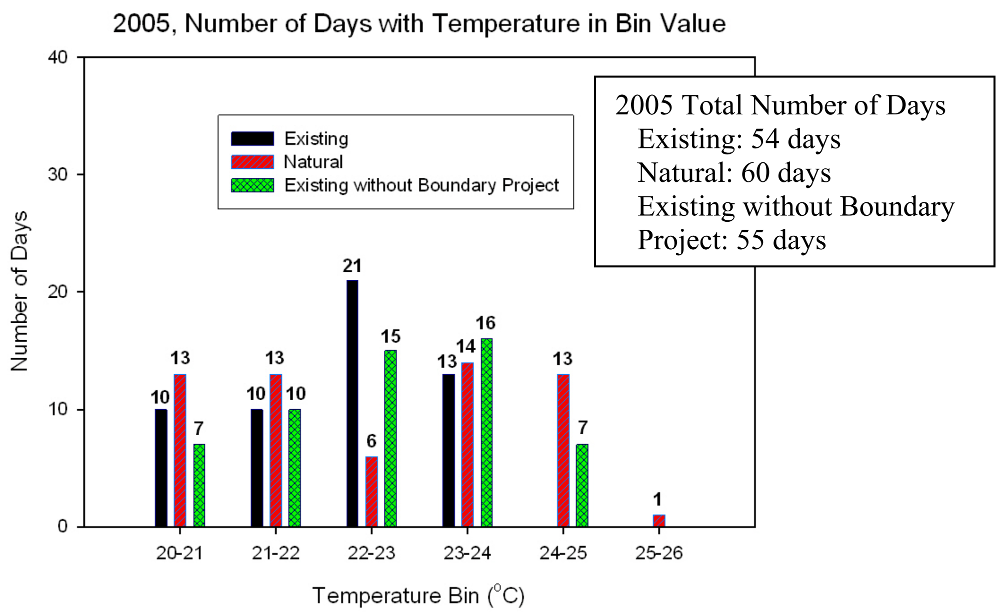
1. The total number of days for 2004 and 2005 was
   Existing – 106 days, Natural – 120 days, and
   Existing without Boundary Project – 110 days
2. Peak annual flow-weighted temperatures at the Metaline Pool
   Existing – 2004: 25.01ºC & 2005: 24.40ºC
   Natural – 2004: 25.43ºC & 2005: 25.14ºC
   Existing without Boundary Project
   – 2004: 25.04ºC & 2005: 24.61ºC

**Figure 5-5a**

Number of Days the Daily Maximum Flow-Weighted Temperatures Exceeded 20ºC at the Metaline Pool for 2004 and 2005

Seattle City Light
Seattle. WA



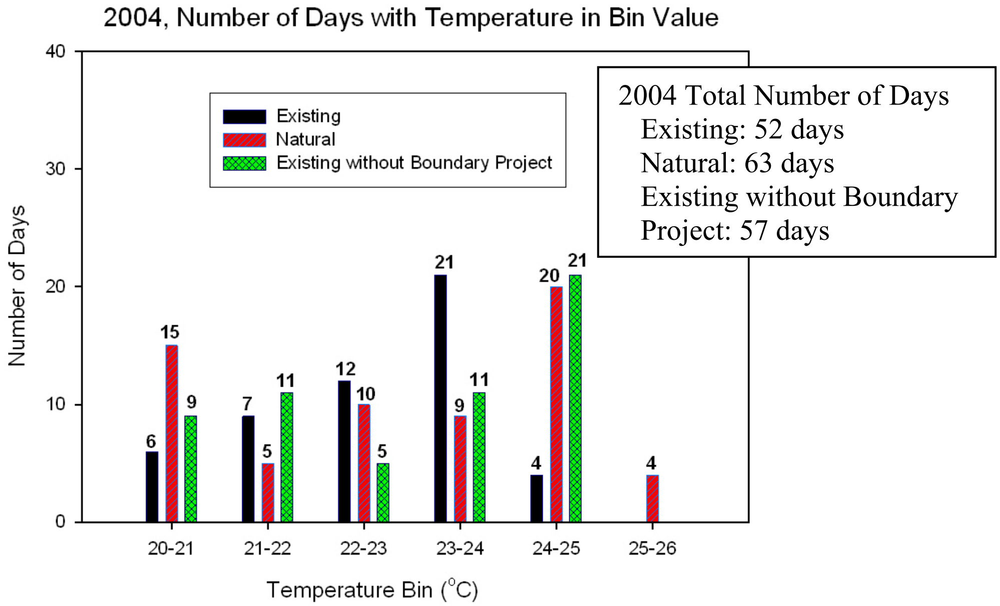

Notes:

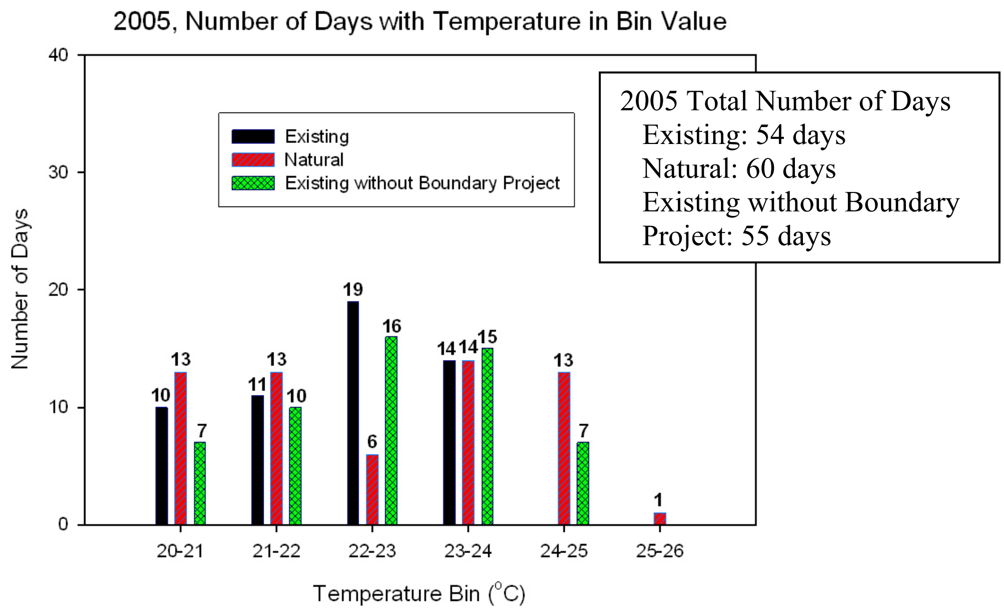
1. The total number of days for 2004 and 2005 was
   Existing – 106 days, Natural – 123 days, and
   Existing without Boundary Project – 112 days
2. Peak annual flow-weighted temperatures at the Boundary Dam Forebay
   Existing – 2004: 24.29ºC & 2005: 23.72ºC
   Natural – 2004: 25.29ºC & 2005: 25.15ºC
   Existing without Boundary Project
   – 2004: 25.07ºC & 2005: 24.68ºC

**Figure 5-5b**

Number of Days the Daily Maximum Flow-Weighted Temperatures Exceeded 20ºC at the Boundary Dam Forebay for 2004 and 2005

Seattle City Light
Seattle. WA



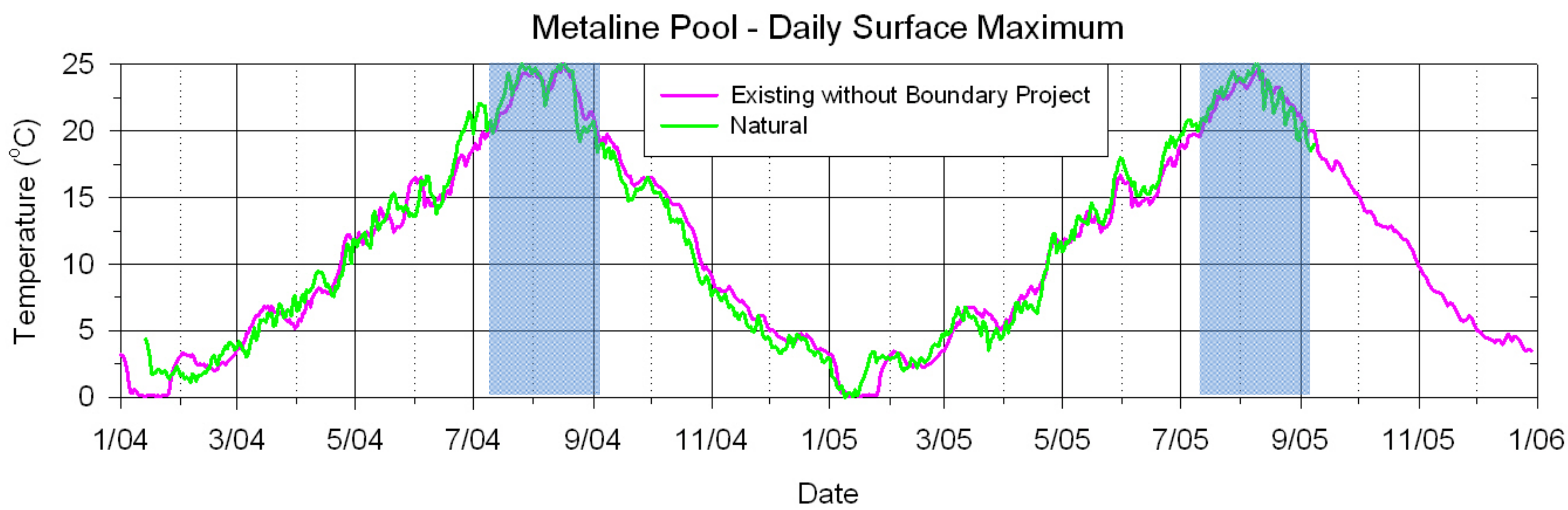

Notes:

1. The total number of days for 2004 and 2005 was
   Existing – 106 days, Natural – 123 days, and
   Existing without Boundary Project – 112 days
2. Peak annual flow-weighted temperatures at the Boundary Dam Tailrace
   Existing – 2004: 24.31ºC & 2005: 23.71ºC
   Natural – 2004: 25.29ºC & 2005: 25.15ºC
   Existing without Boundary Project
   – 2004: 24.87ºC & 2005: 24.34ºC

**Figure 5-5c**

Number of Days the Daily Maximum Flow-Weighted Temperatures Exceeded 20ºC at the Boundary Dam Tailrace for 2004 and 2005

Seattle City Light
Seattle, WA




Notes:

1. Existing without Boundary Project = No Boundary Dam, Box Canyon Dam present, and Albeni Falls Dam present. The designation as Existing without Boundary Project is from Ecology's TMDL analyses.
2. Daily maximum temperatures are from the surface layer of the models.
3. The period in which the Existing without Boundary Project temperature is over 20ºC is indicated by the shading.

**Figure 5-6**a

Daily Maximum Surface Temperatures for the Existing Condition without Boundary Project and the Natural Condition at Metaline Pool

Seattle City Light
Seattle, WA

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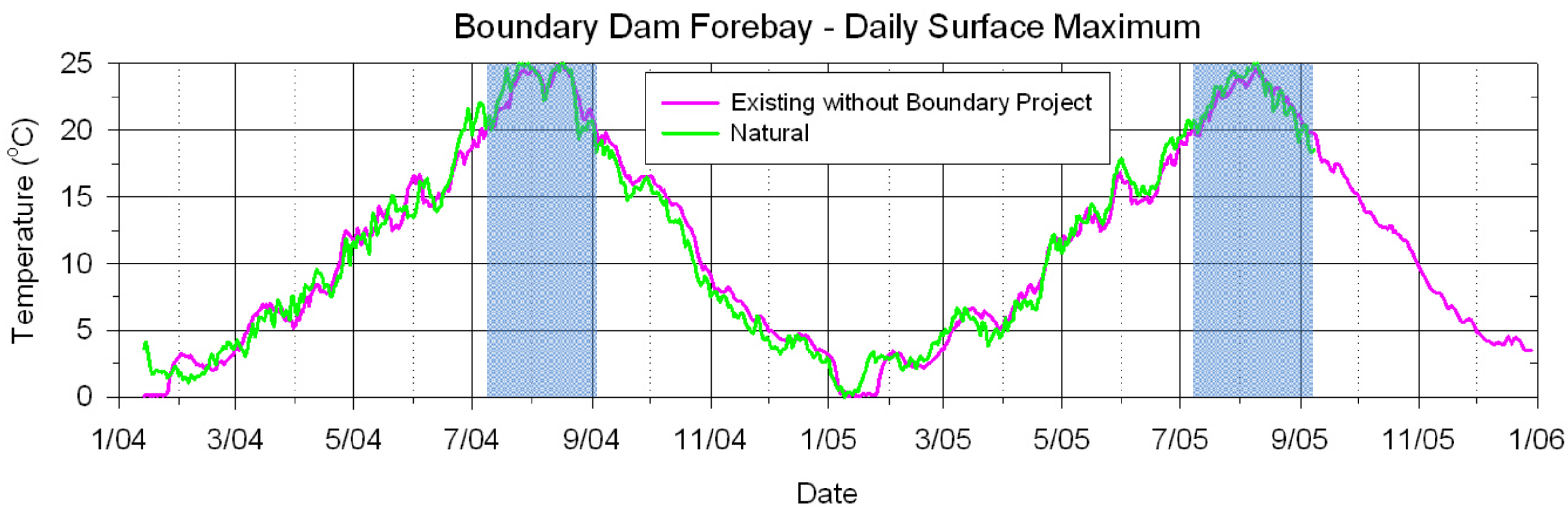


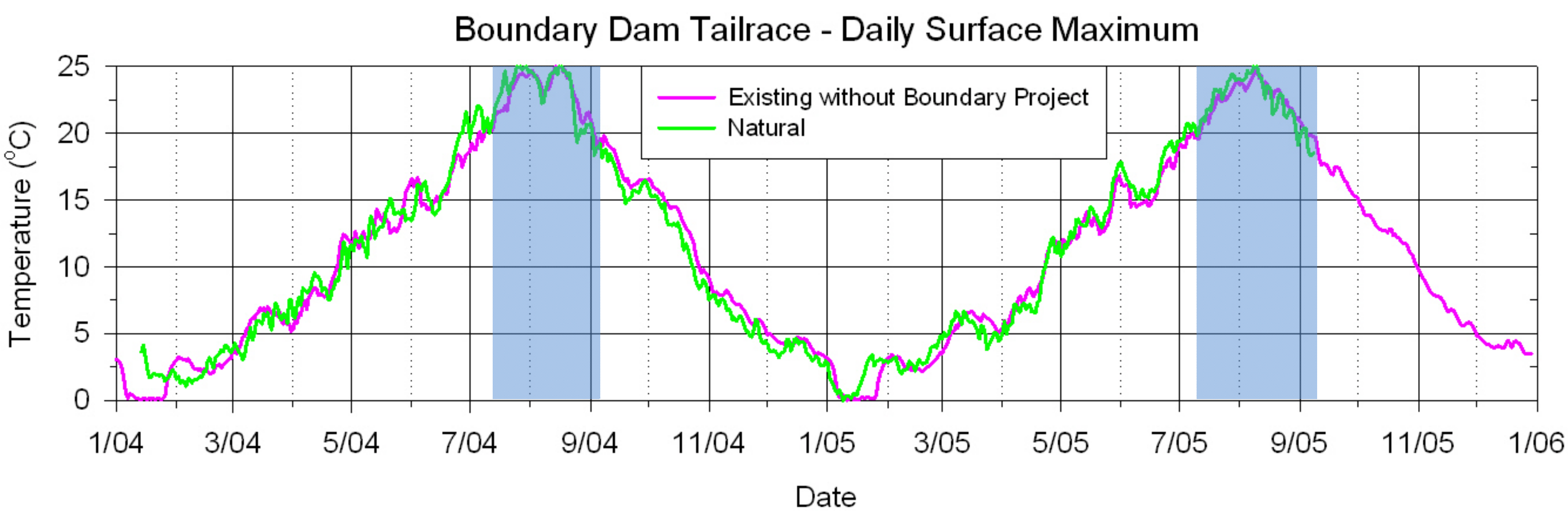

Notes:

1. Existing without Boundary Project = No Boundary Dam, Box Canyon Dam present, and Albeni Falls Dam present. The designation as Existing without Boundary Project is from Ecology's TMDL analyses.
2. Daily maximum temperatures are from the surface layer of the models.
3. The period in which the Existing without Boundary Project temperature is over 20ºC is indicated by the shading.

**Figure 5-6**b

Daily Maximum Surface Temperatures for the Existing Condition without Boundary Project and the Natural Condition at Boundary Dam Forebay

Seattle City Light
Seattle, WA

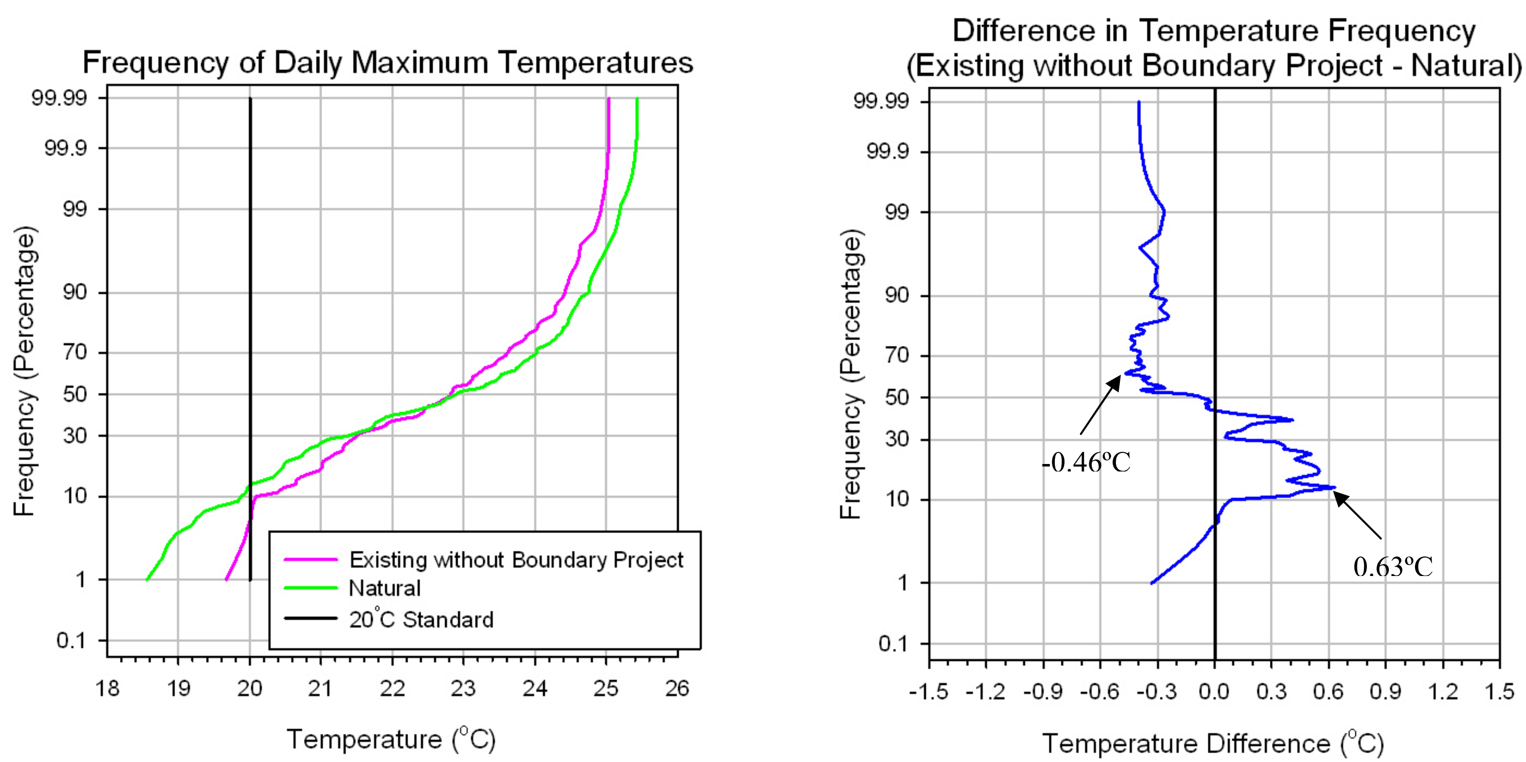



Notes:
1. Existing without Boundary Project = No Boundary Dam, Box Canyon Dam present, and Albeni Falls Dam present. The designation as Existing without Boundary Project is from Ecology's TMDL analyses.
2. Daily maximum temperatures are from the surface layer of the models.
3. The period in which the Existing without Boundary Project temperature is over 20ºC is indicated by the shading.

**Figure 5-6c**

Daily Maximum Surface Temperatures for the Existing Condition without Boundary Project and the Natural Condition at Boundary Dam Tailrace

Seattle City Light
Seattle, WA



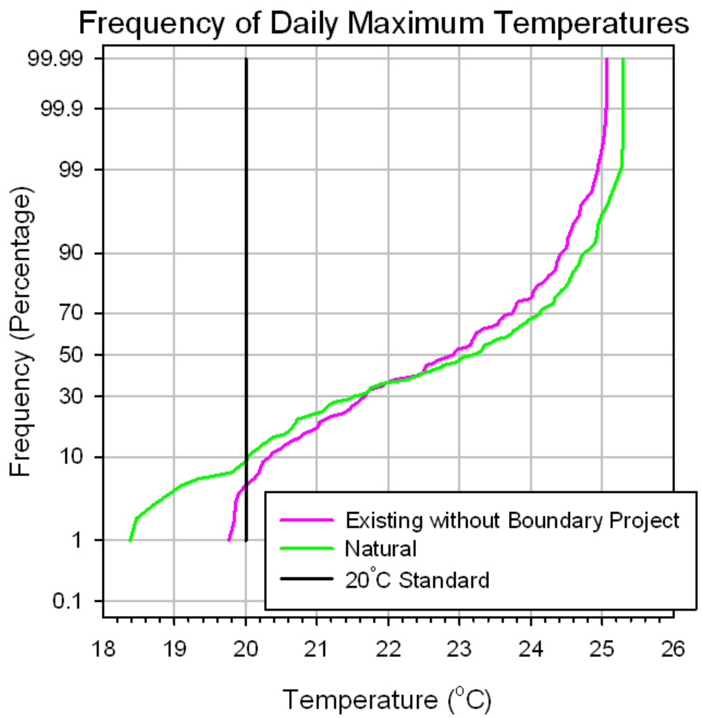

Notes:

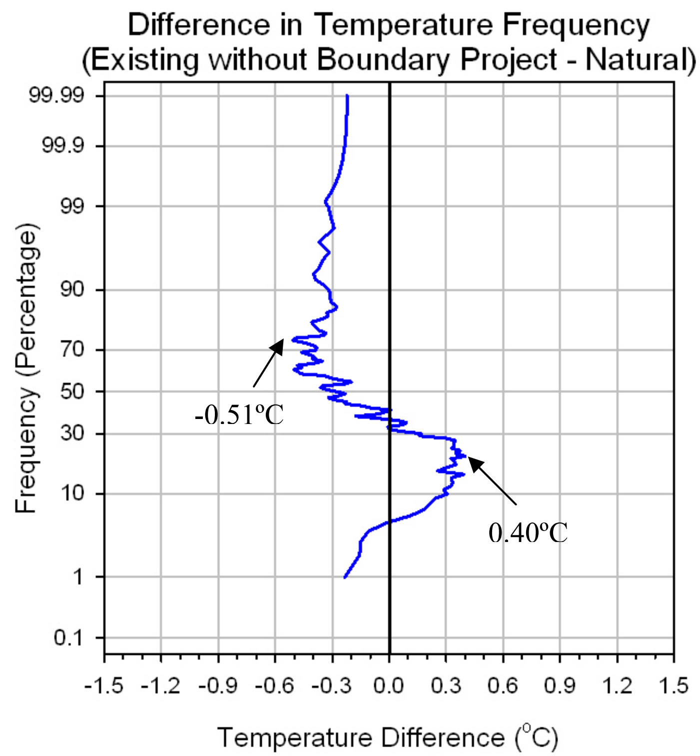
1. Existing without Boundary Project = No Boundary Dam, Box Canyon Dam present, and Albeni Falls Dam present.
2. The difference in temperature at each frequency is obtained by subtracting the Natural Condition values from the Existing without Boundary Project values. (When Natural Condition is < 20ºC, the Natural temperature is replaced by the value 20ºC.)
3. The period covered by the frequency analysis was July 9, 2004 to September 4, 2004 and July 8, 2005 to September 8, 2005.
4. Surface temperature differences are between -0.46ºC and +0.63ºC due to upstream dams (Box Canyon and Albeni Falls) on the Pend Oreille River.

**Figure 5-7a**

Frequency Distribution of Daily Maximum Surface Temperatures for the Existing Condition without Boundary Project and the Natural Condition at Metaline Pool

Seattle City Light
Seattle, WA



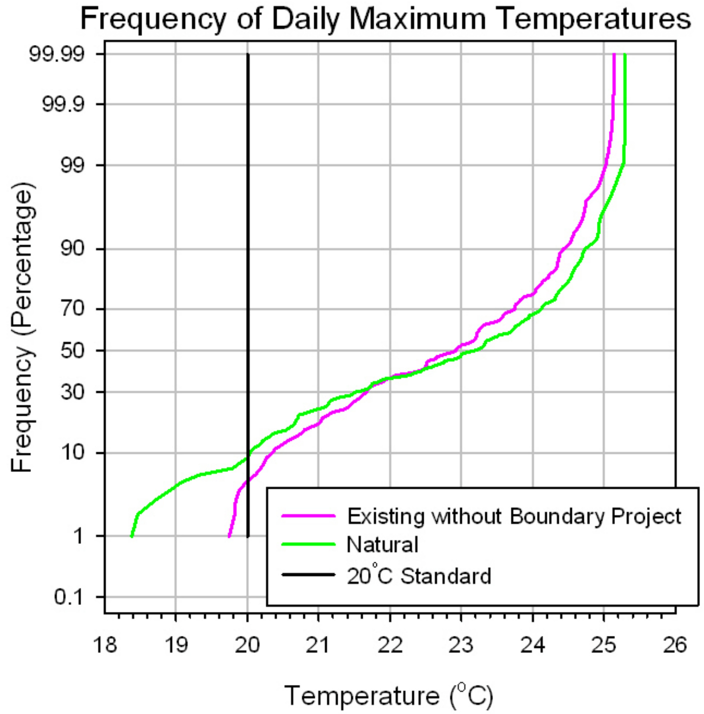

Notes:

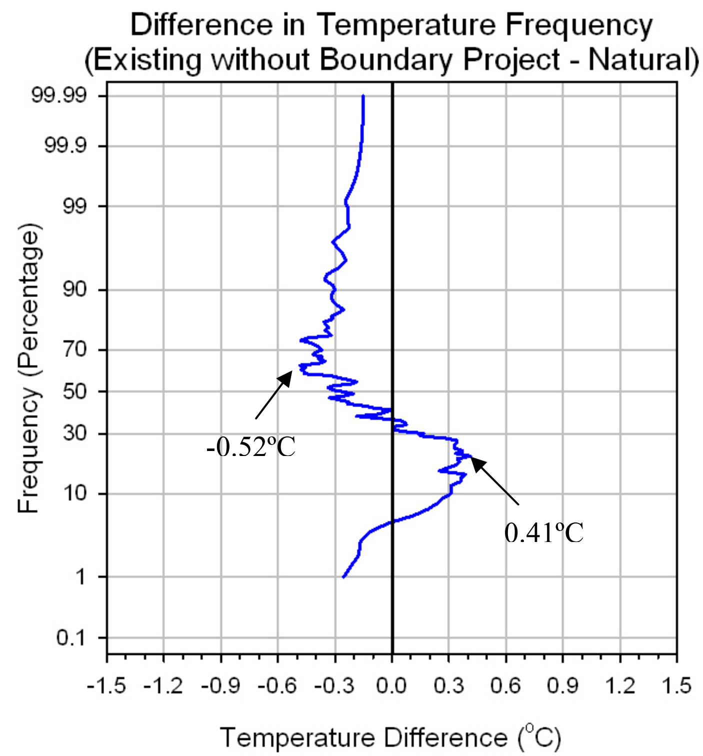
1. Existing without Boundary Project = No Boundary Dam, Box Canyon Dam present, and Albeni Falls Dam present.
2. The difference in temperature at each frequency is obtained by subtracting the Natural Condition values from the Existing without Boundary Project values. (When Natural Condition is < 20ºC, the Natural temperature is replaced by the value 20ºC.)
3. The period covered by the frequency analysis was July 9, 2004 to September 4, 2004 and July 8, 2005 to September 8, 2005.
4. Surface temperature differences are between -0.51ºC and +0.40ºC due to upstream dams (Box Canyon and Albeni Falls) on the Pend Oreille River.

**Figure 5-7**b

Frequency Distribution of Daily Maximum Surface Temperatures for the Existing Condition without Boundary Project and the Natural Condition at Boundary Dam Forebay

Seattle City Light
Seattle, WA



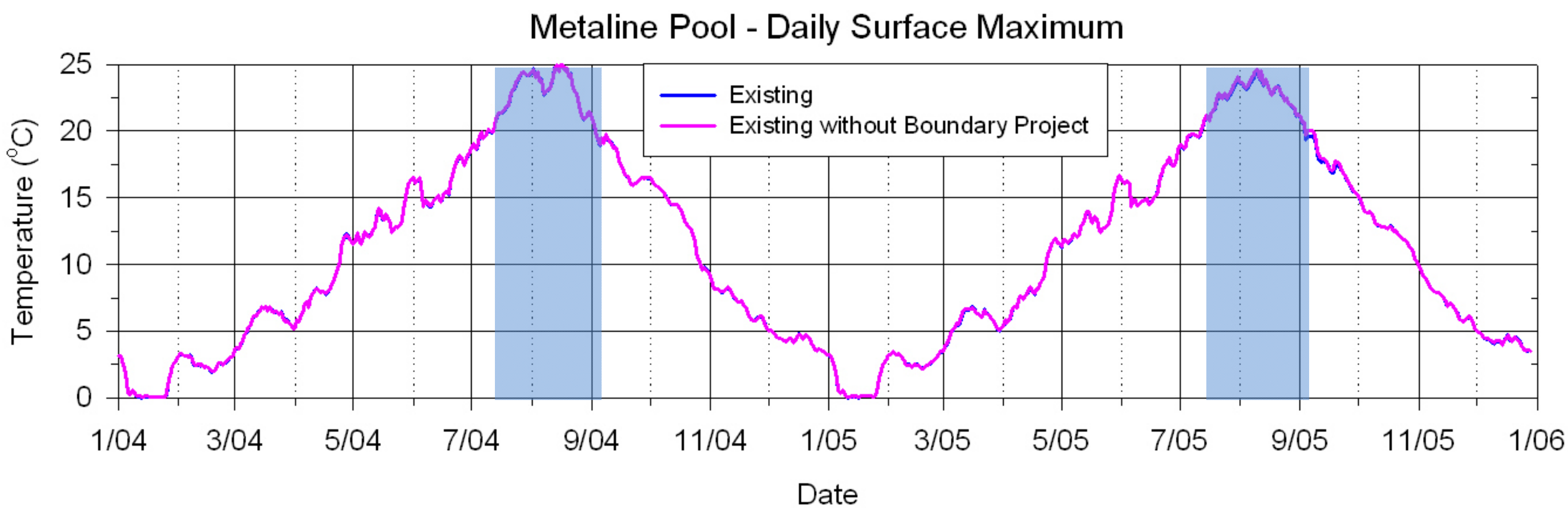

Notes:

1. Existing without Boundary Project = No Boundary Dam, Box Canyon Dam present, and Albeni Falls Dam present.
2. The difference in temperature at each frequency is obtained by subtracting the Natural Condition values from the Existing without Boundary Project values. (When Natural Condition is < 20ºC, the Natural temperature is replaced by the value 20ºC.)
3. The period covered by the frequency analysis was July 9, 2004 to September 4, 2004 and July 8, 2005 to September 8, 2005.
4. Surface temperature differences are between -0.52ºC and +0.41 ºC due to upstream dams (Box Canyon and Albeni Falls) on the Pend Oreille River.

**Figure 5-7c**

Frequency Distribution of Daily Maximum Surface Temperatures for the Existing Condition without Boundary Project and the Natural Condition at Boundary Dam Tailrace

Seattle City Light
Seattle, WA



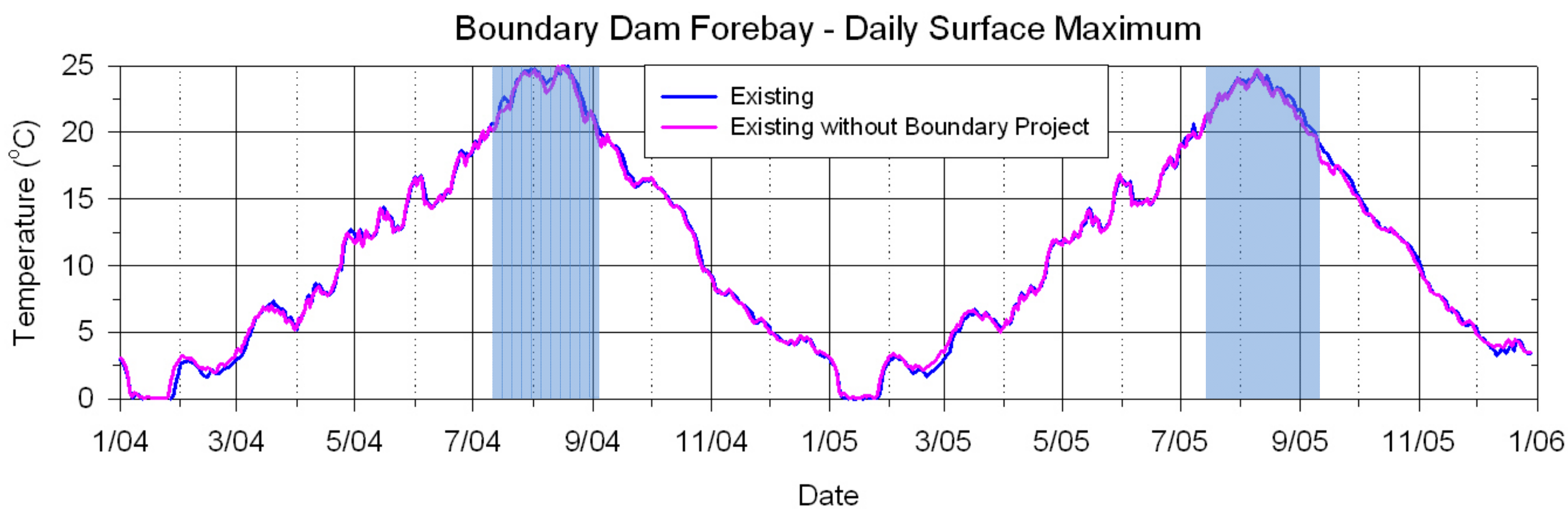

Notes:

1. Existing without Boundary Project = No Boundary Dam, Box Canyon Dam present, and Albeni Falls Dam present.
2. Daily maximum temperatures are from the surface layer of the models.
3. The period when the Existing without Boundary Project temperature is over 20ºC is indicated by the shading.

**Figure 5-8**a

Daily Maximum Surface Temperatures for the Existing Condition and Existing Condition without Boundary Project at Metaline Pool

Seattle City Light
Seattle, WA

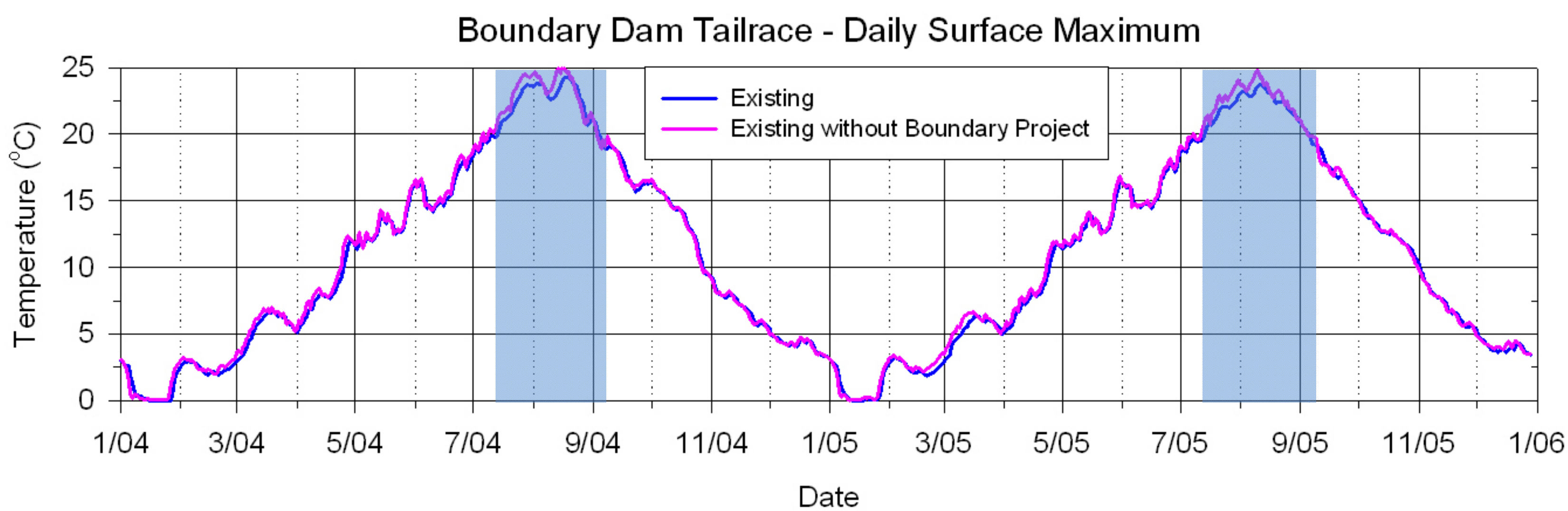



Notes:
1. Existing without Boundary Project = No Boundary Dam, Box Canyon Dam present, and Albeni Falls Dam present.
2. Daily maximum temperatures are from the surface layer of the models.
3. The period when the Existing without Boundary Project temperature is over 20ºC is indicated by the shading.

**Figure 5-8**b

Daily Maximum Surface Temperatures for the Existing Condition and Existing Condition without Boundary Project at Boundary Dam Forebay

Seattle City Light
Seattle, WA

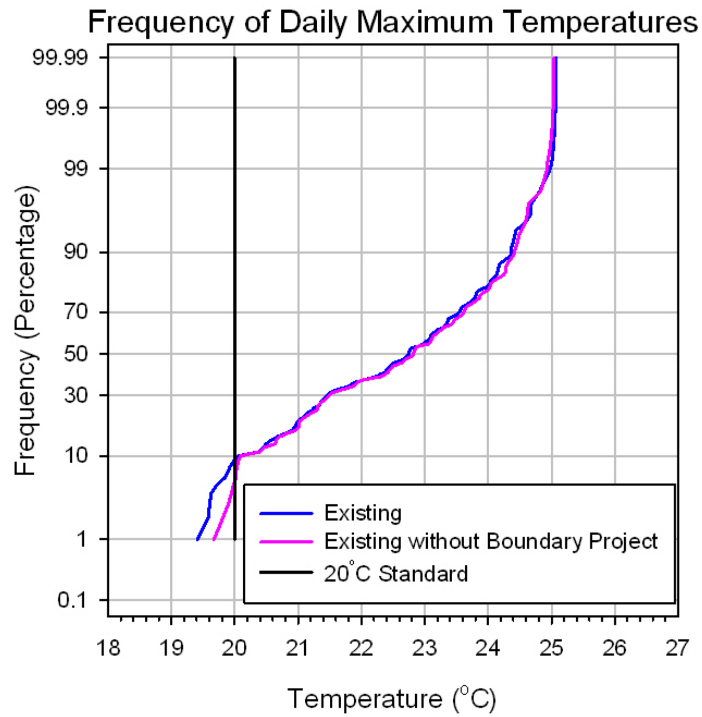


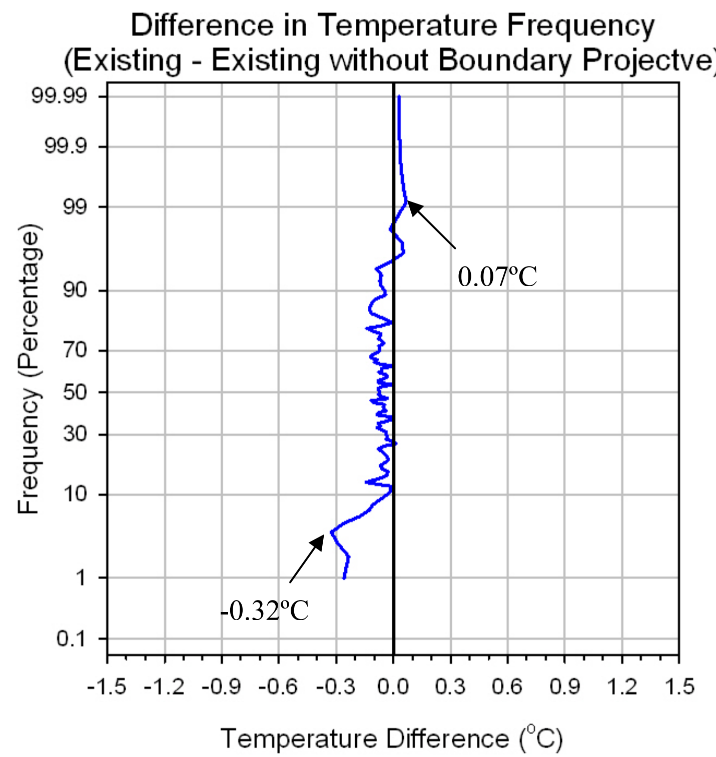

Notes:
1. Existing without Boundary Project = No Boundary Dam, Box Canyon Dam present, and Albeni Falls Dam present.
2. Daily maximum temperatures are from the surface layer of the models.
3. The period when the Existing without Boundary Project temperature is over 20ºC is indicated by the shading.

**Figure 5-8c**

Daily Maximum Surface Temperatures for the Existing Condition and Existing Condition without Boundary Project at Boundary Dam Tailrace

Seattle City Light
Seattle, WA



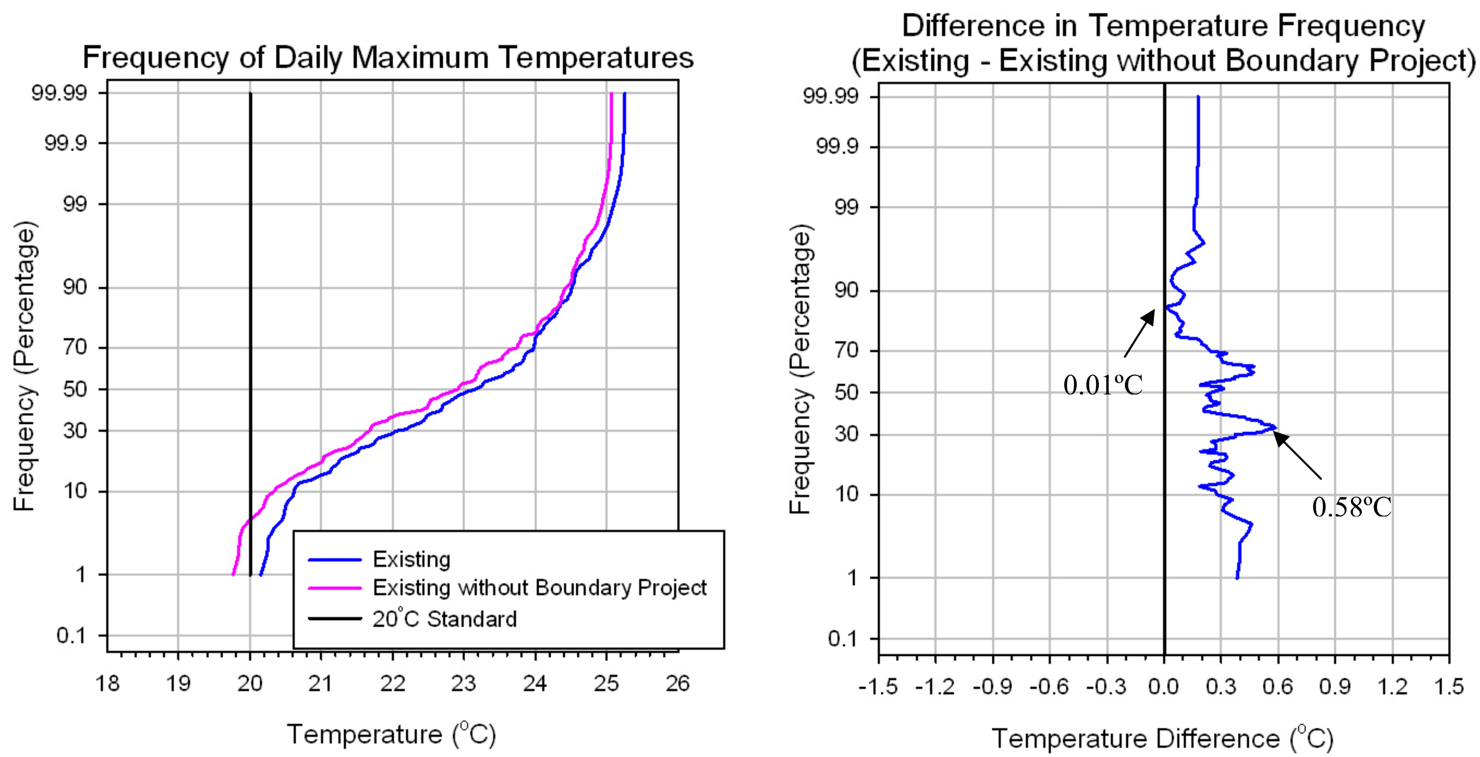

Notes:

1. Existing without Boundary Project = No Boundary Dam, Box Canyon Dam present, and Albeni Falls Dam present.
2. The difference in temperature at each frequency is obtained by subtracting the Existing without Boundary Project values from the Existing Condition values.
3. The period covered by the frequency analysis was July 9, 2004 to September 4, 2004 and July 8, 2005 to September 8, 2005 when Existing Condition > 20ºC.
4. Existing Condition surface temperature differences are between -0.32ºC and +0.07ºC relative to the Existing Condition without Boundary Project.

**Figure 5-9**a

Frequency Distributions of the Daily Maximum Surface Temperatures for the Existing Condition and Existing Condition without Boundary Project at Metaline Pool

Seattle City Light
Seattle, WA



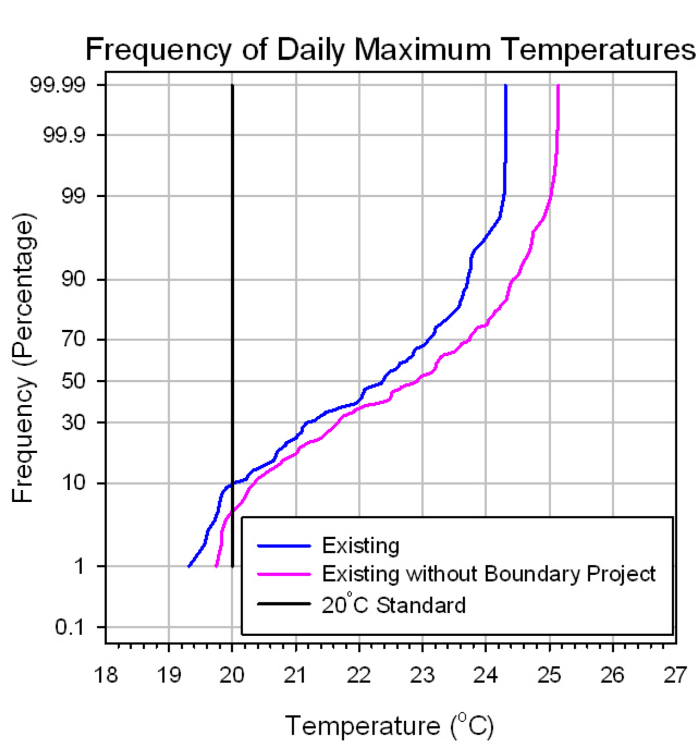

Notes:

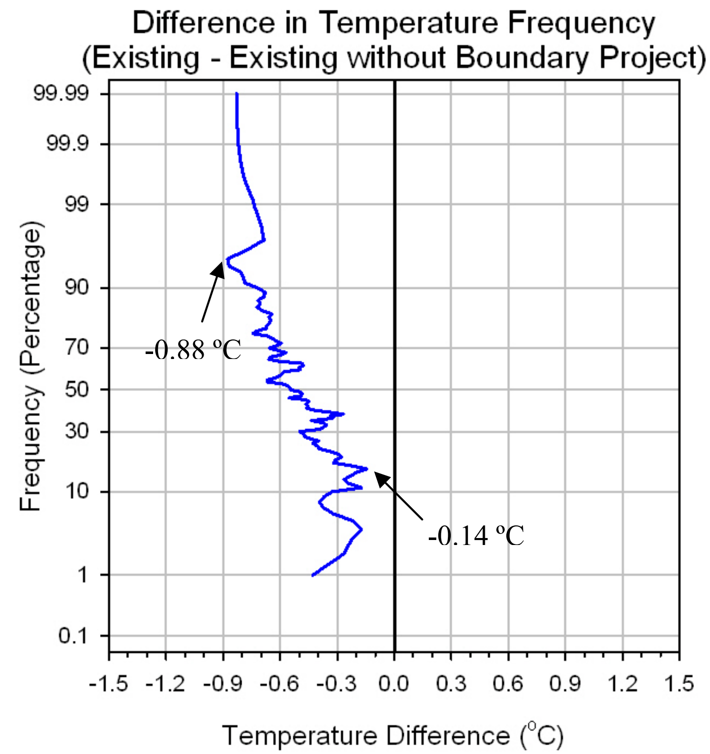
1. Existing without Boundary Project = No Boundary Dam, Box Canyon Dam present, and Albeni Falls Dam present.
2. The difference in temperature at each frequency is obtained by subtracting the Existing without Boundary Project values from the Existing Condition values.
3. The period covered by the frequency analysis was July 9, 2004 to September 4, 2004 and July 8, 2005 to September 8, 2005 when Existing Condition > 20ºC.
4. Existing Condition surface temperatures are between 0.01ºC and 0.58ºC higher than the Existing Condition without Boundary Project.

**Figure 5-9**b

Frequency Distributions of the Daily Maximum Surface Temperatures for the Existing Condition and Existing Condition without Boundary Project at Boundary Dan Forebay

Seattle City Light
Seattle, WA



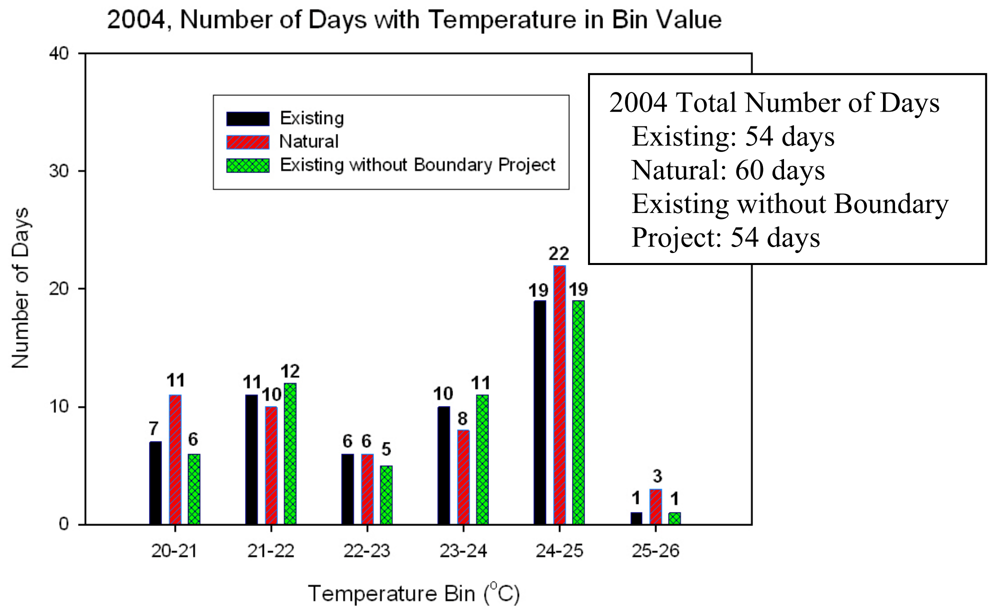

Notes:

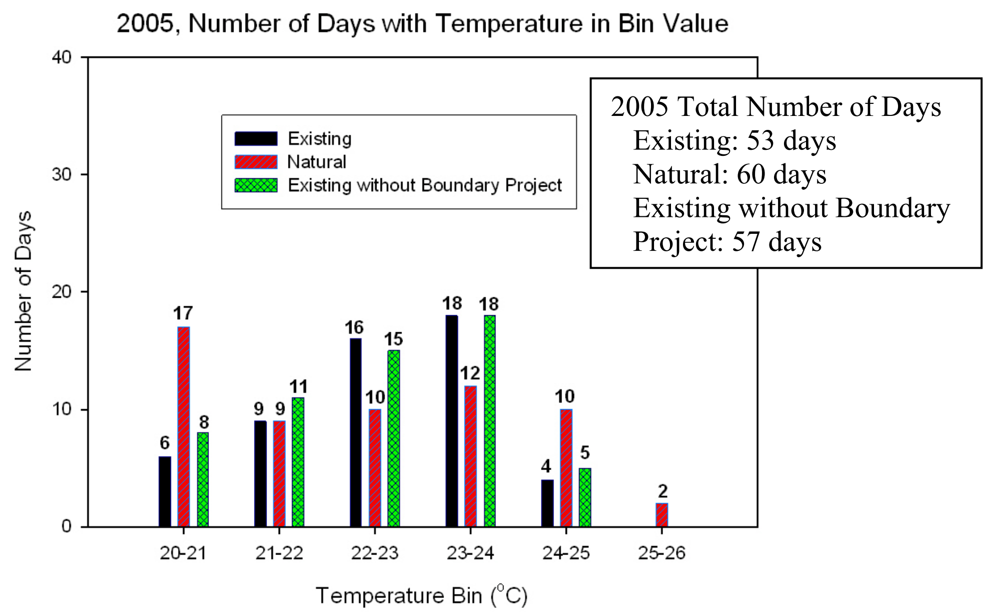
1. Existing without Boundary Project = No Boundary Dam, Box Canyon Dam present, and Albeni Falls Dam present.
2. The difference in temperature at each frequency is obtained by subtracting the Existing without Boundary Project values from the Existing Condition values.
3. The period covered by the frequency analysis was July 9, 2004 to September 4, 2004 and July 8, 2005 to September 8, 2005 when Existing Condition > 20ºC
4. Existing Condition surface temperatures are between 0.14ºC and 0.88ºC lower than the Existing Condition without Boundary Project.

**Figure 5-9c**

Frequency Distributions of the Daily Maximum Surface Temperatures for the Existing Condition and Existing Condition without Boundary Project at Boundary Dam Tailrace

Seattle City Light
Seattle, WA



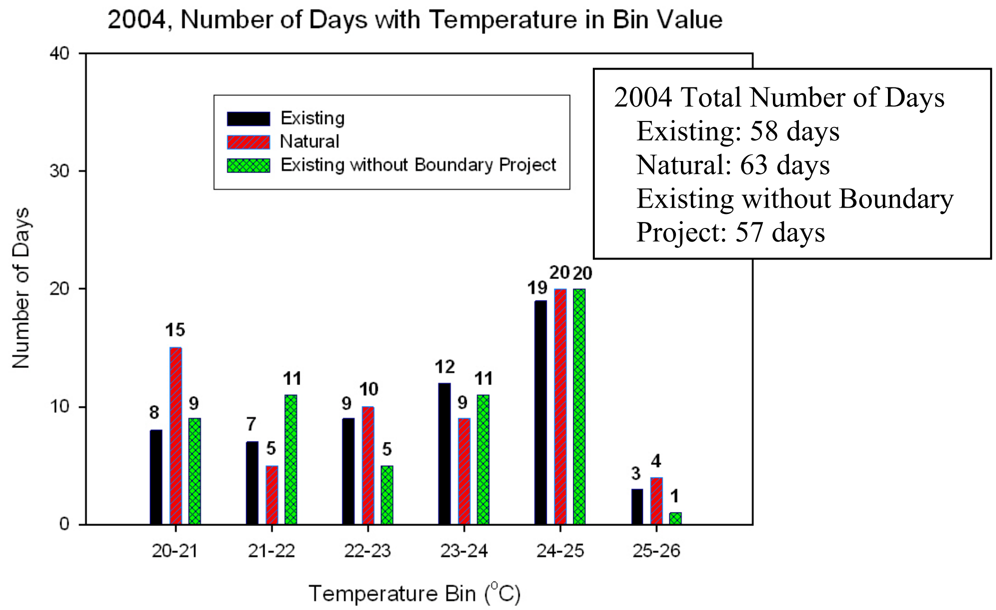

Notes:

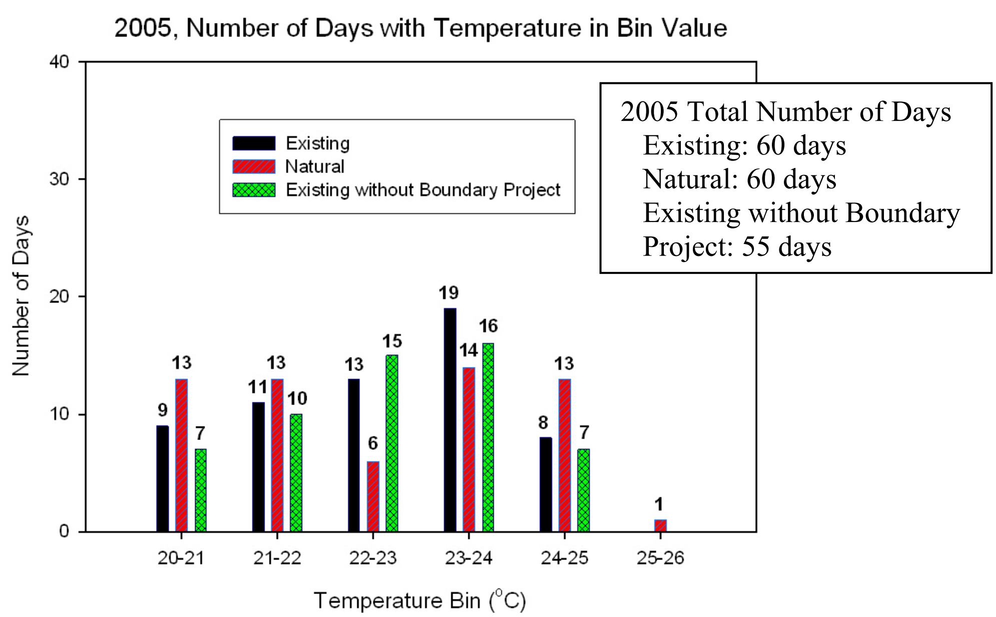
1. The total number of days for 2004 and 2005 was
   Existing – 107 days, Natural – 120 days, and
   Existing without Boundary Project – 111 days
2. Peak annual surface temperatures at the Metaline Pool
   Existing – 2004: 25.07ºC & 2005: 24.41ºC
   Natural – 2004: 25.44ºC & 2005: 25.17ºC
   Existing without Boundary Project
   – 2004: 25.04ºC & 2005: 24.62ºC

**Figure 5-10a**

Number of Days the Daily Maximum Surface Temperatures Exceeded 20ºC at the Metaline Pool for 2004 and 2005

Seattle City Light
Seattle, WA



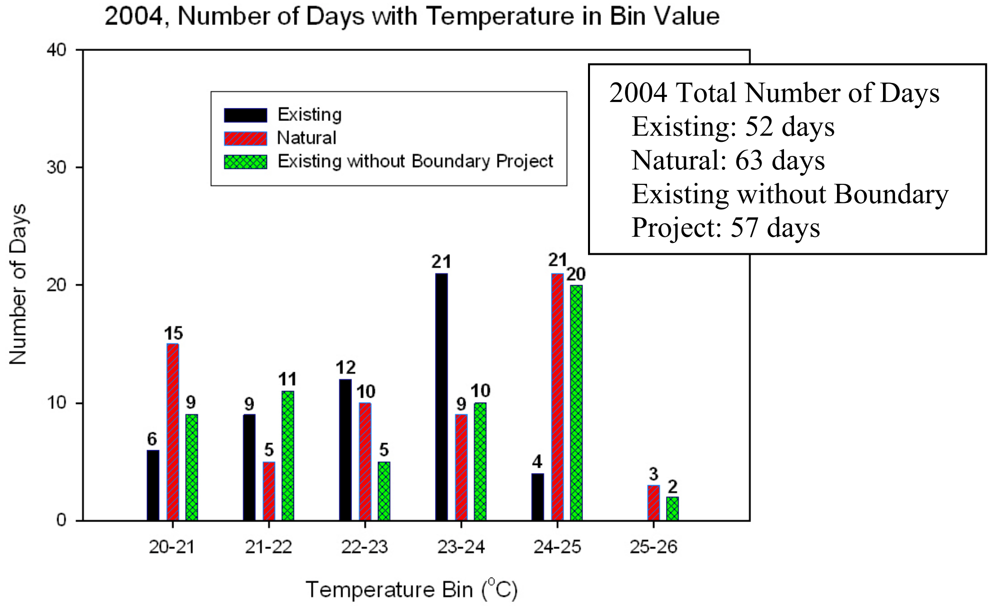

Notes:

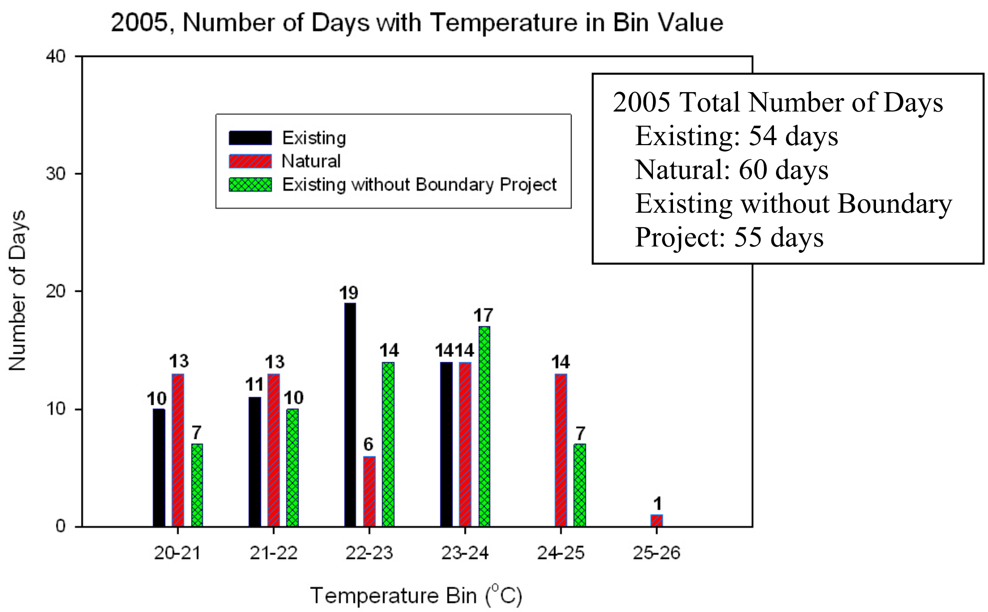
1. The total number of days for 2004 and 2005 was
   Existing – 118 days, Natural – 123 days, and
   Existing without Boundary Project – 112 days
2. Peak annual surface temperatures at the Boundary Dam Forebay
   Existing – 2004: 25.25ºC & 2005: 24.55ºC
   Natural – 2004: 25.29ºC & 2005: 25.15ºC
   Existing without Boundary Project
   – 2004: 25.07ºC & 2005: 24.68ºC

**Figure 5-10b**

Number of Days the Daily Maximum Surface Temperatures Exceeded 20ºC at the Boundary Dam Forebay for 2004 and 2005

Seattle City Light
Seattle, WA




Notes:

1. The total number of days for 2004 and 2005 was
   Existing – 106 days, Natural – 123 days, and
   Existing without Boundary Project – 112 days
2. Peak annual surface temperatures at the Forebay station
   Existing – 2004: 24.31ºC & 2005: 23.71ºC
   Natural – 2004: 25.29ºC & 2005: 25.15ºC
   Existing without Boundary Project – 2004: 25.14ºC & 2005: 24.77ºC

**Figure 5-10c**

Number of Days the Daily Maximum Surface Temperatures Exceeded 20ºC at the Boundary Dam Tailrace for 2004 and 2005

Seattle City Light
Seattle, WA

# 6.0 Alternative Operations Analysis: Run-of-river operation with a drawdown to 1974 feet

In this section, at Ecology's request, we present an alternative operations analysis to investigate whether there are any operational changes that could provide significant improvement in surface temperatures in Boundary Reservoir, and particularly at the Boundary forebay station. To do so, SCL evaluated the temperature effects of the most extreme operational modification possible consistent with operational constraints in order to provide an outer bound on possible alternative operational scenarios relative to current operations. The alternative operations scenario that SCL modeled involves run-of-river operation at water surface elevation of 1974 feet NAVD88. It was developed through professional judgment and input from scientists involved in the relicensing of the Boundary Hydroelectric Project on the expectation that it would improve surface water temperature conditions.

In this alternative operations scenario, the forebay of Boundary Dam would be drawn down to an elevation of 1974 NAVD88 during the summer months of July and August. During this period, the dam would be operated in the run-of-river mode where outflow would equal the inflow having accounted for travel time differences. During other months the project would be operated as in the Existing Condition. The elevation of 1974 NAVD88 was selected based on input from SCL engineering staff that this is the lowest drawdown elevation feasible before encountering cavitation constraints that can lead to damage to the Project. The expectation was that lowering the water surface elevation would improve temperature response by (a) reducing travel time, (b) reducing surface area, and (c) reducing warm water accumulations in the forebay.

Table 6-1 provides the model configurations for the Existing Condition, Natural Condition, Existing Condition without Boundary Project, and Run-of-River, 1974 ft Elevation scenario.

**Table 6-1**
Model Configurations for Existing Condition, Natural Condition, Existing Condition without Boundary Project, and Run-of-River, 1974 ft Elevation scenario

| Case | Pend Oreille River Dams | Point Sources | Shade |
|---|---|---|---|
| **Existing** | All | All | Existing |
| **Natural** | None | None | PNV |
| **Existing without Boundary Project** | Albeni Falls, Box Canyon and Seven-Mile | All | Existing |
| **Run-of-river, 1974 Elevation** | All | All | Existing |

Section 6.1 presents the comparison using flow-weighted temperatures; Section 6.2 does the same using surface temperatures.

## 6.1 Flow-Weighted Temperature Evaluation

Figures 6-1 a, b, and c show time series comparisons of the daily maximum flow-weighted temperatures for the Natural Condition and the Run-of-river, 1974 Elevation operational alternative at Metaline Pool, Boundary forebay, and Boundary tailrace stations, respectively. The peak temperatures in the Run-of-river, 1974 Elevation operation are slightly lower than the Natural Condition peaks (24-25˚C). These results are very similar to the Existing Condition operation. Figures 6-2 a, b, and c present plots of the frequency distribution of the daily maximum flow-weighted temperatures for the Run-of-river, 1974 Elevation operation and the Natural Condition at Metaline Pool, Boundary forebay, and Boundary tailrace stations, respectively. For example, the maximum difference in temperature at Boundary forebay station was 0.15˚C. When compared with the difference between Existing Condition and Natural conditions of 0.20˚C (Table 6-2), it can be seen that there was a minor improvement in the Run-of-river scenario, with the temperature difference of 0.05˚C (0.20˚C - 0.15˚C = 0.05˚C). In contrast, at the Metaline Pool and Boundary tailrace stations, this same comparison indicates that conditions are slightly worse under the Run-of-river scenario than under the Existing Condition, with temperature differences of -0.09˚C (0.50˚C - 0.59˚C) and -0.06˚C (0.10˚C - 0.16˚C) at the Metaline Pool and Boundary tailrace stations, respectively (Table 6-2).

The comparisons of the time series of daily maximum flow-weighted temperatures between the Run-of-river, 1974 Elevation operation and the Existing Condition at the Metaline Pool, Boundary forebay, and Boundary tailrace stations are shown in Figures 6-3 a, b, and c, respectively. The frequency distributions of the daily maximum flow-weighted temperatures for the Run-of-river, 1974 Elevation operation and the Existing Condition at the Metaline Pool, Boundary forebay, and Boundary tailrace stations are shown in Figures 6-4 a, b, and c, respectively. The comparison of these two cases shows potential changes that might occur with the incorporation of the Run-of-river, 1974 Elevation operation compared to current operations. These results show that the flow-weighted temperatures for the Existing Condition were very similar to the temperatures predicted for the Run-of-river, 1974 Elevation operation. The maximum differences in temperature for the frequency distributions were 0.08˚C, 0.16˚C and 0.19˚C at the Metaline Pool, Boundary forebay and Boundary tailrace stations, respectively. However, the differences fluctuated around 0 (see Figures 6-4 a, b and c) indicating that from a practical perspective there was little or no real improvement in conditions.

A summary of the maximum temperature differences for all the cases examined is presented in Table 6-2 a, b, and c corresponding to Metaline Pool, Boundary forebay, and Boundary tailrace stations, respectively. The comparison to the Natural Condition represents the difference relative to the water quality criterion,[19] while the comparison to the Existing Condition represents the change relative to the Existing Condition. In the Tables 6-2 a, b, and c, we have reported the maximum temperature difference without any adjustment or accounting for the 0.3˚C human use allowance.

Figures 6-5 a, b, and c show number of days that daily maximum flow weighted temperatures are above 20ºC and the peak annual flow-weighted temperatures, in Metaline Pool, Boundary

[19] The water quality criterion is the 1-DMax of 20.0°C or the Natural Condition + 0.3°C, whichever is greater. However, differences presented are not adjusted to account for the 0.3°C human use allowance.

forebay, and Boundary tailrace stations, respectively. For example, at the Boundary forebay location, for the Run-of-river, 1974 Elevation operation, 52 days were above 20ºC in 2004, and in 2005, 53 days were above 20ºC (Figure 6-5 b). In comparison, in 2004, 52 days were above 20ºC in the Existing Condition, while in 2005, 54 days were above 20ºC. The Natural Condition had 63 days in 2004 and 60 days in 2005 that were above 20ºC. Therefore, the Run-of-river, 1974 Elevation operation did not result in any significant improvement in the number of days that flow weighted maximum temperatures would be above 20ºC as compared to Existing Condition. Similarly, under the Existing Condition, the peak annual flow-weighted temperatures at all stations were effectively the same or lower than under the Run-of-river scenario or any of the other Conditions.

As shown most clearly in Figures 6-4 a, b, and c, even changing to the extreme alternative operations scenario of Run-of-river, 1974 Elevation does not result in any significant improvement in flow-weighted temperatures at any of the locations in the reservoir.

## 6.2 Surface Temperature Evaluation

Figures 6-6 a, b, and c show a comparison of the time series of the daily maximum surface temperatures for the Natural Condition and the Run-of-river, 1974 Elevation operation at Metaline Pool, Boundary forebay, and Boundary tailrace stations, respectively. The peak surface temperatures in the forebay are similar ≈25˚C. Relative to Natural Condition, the peak surface temperatures in the tailrace and the Metaline Pool station appear to be a little cooler under the Run-of-river scenario (but similar to Existing Condition). Figures 6-7 a, b, and c present plots of the frequency distribution of the surface daily maximum temperatures for Run-of-river, 1974 Elevation operation and the Natural Condition at Metaline Pool, Boundary forebay, and Boundary tailrace stations, respectively. For example, the maximum difference in temperature was 0.94˚C at Boundary forebay station. It is notable that this difference has increased from the value of 0.76˚C of difference between the Existing and Natural Condition using the frequency analysis method (See section 4.4 and Table 6-3).

The comparison of the time series of the daily maximum surface temperatures between the Run-of-river, 1974 Elevation operation and the Existing Condition is shown in Figures 6-8 a, b, and c at Metaline Pool, Boundary forebay, and Boundary tailrace stations, respectively. The peak temperatures in the Run-of-river, 1974 Elevation operation were relatively unchanged from the Existing Condition peaks (≈ 25˚C), especially at the Metaline Pool and Boundary Tailrace stations but appeared to get slightly warmer in the Boundary Forebay station under the Run-of-river scenario. The frequency distributions of the daily maximum surface temperatures for the Run-of-river, 1974 Elevation operation and the Existing Condition are shown in Figure 6-9 a, b, and c at Metaline Pool, Boundary forebay, and Boundary tailrace stations respectively. These results show that the surface temperatures for the Existing Condition and the Run-of-river, 1974 Elevation operation were very similar in the Metaline Pool and Boundary Tailrace stations, again oscillating around 0 as was the case for flow-weighted temperatures (section 6.1, Figures 6-4 a, b and c). In contrast, at the Boundary forebay station, the surface daily maximum temperatures in the Run-of-river scenario were consistently warmer relative to the Existing Condition (Figure 6-9 b). The difference in surface daily maximum temperature at the Boundary forebay station from frequency distributions ranged from -0.07˚C to -0.55˚C, indicating that the Run-of-river, 1974

Elevation alternative operation scenario would cause maximum surface temperatures to be warmer than they are under the Existing Condition by between 0.07˚C and 0.55˚C throughout the entire critical summer period.

A summary of the surface daily maximum temperature differences for all the cases examined is presented in Table 6-3 a, b, and c. Figures 6-10 a, b, and c show number of days that daily maximum flow weighted temperatures were above the 20ºC, and the peak annual surface water temperatures, in Metaline Pool, Boundary forebay, and Boundary tailrace stations, respectively. For example, at the Boundary forebay station, for the Run-of-river, 1974 Elevation operation, 59 days were above 20ºC in 2004, and in 2005, 60 days were above the 20ºC criterion (Figure 6-10 b). In comparison, in 2004, 58 days were above 20ºC in the Existing Condition, while in 2005, 60 days were above 20ºC. The Natural Condition had 63 days in 2004 and 60 days in 2005 that were above 20ºC. Similarly, peak annual surface temperatures under the Run-of-river alternative operations scenario were effectively the same as or higher than peak annual surface temperatures under the Existing Condition at all stations.

As shown most clearly in Figures 6-9 a, b, and c, even changing to the extreme alternative operations scenario of Run-of-river, 1974 Elevation does not result in any significant improvement in surface temperatures at the Metaline Pool or tailrace locations. At the Boundary forebay location, which was the impetus for the alternative operations analysis, changing to the Run-of-river, 1974 Elevation scenario actually results in an increase in surface daily maximum water temperatures throughout the entire critical summer period. Accordingly, change of Project operations to run-of-the-river does not improve surface temperatures conditions.

**Table 6-2**
Summary of Maximum Flow-Weighted Temperature Differences from Frequency Analysis Comparing the Existing Condition, the Natural Condition, and the Run-of-river, 1974 Elevation operation

**a. Metaline Pool**

| Case | Maximum ΔT relative to the Natural Condition using Flow-Weighted Temperature from Frequency Analysis (Case-Natural) | Maximum ΔT relative to Existing Conditions using Flow-Weighted Temperature from Frequency Analysis (Existing-Case) |
|---|---|---|
| **Existing** | 0.50ºC[1] | 0.0ºC |
| **Run-of-river, 1974 Elevation operation** | 0.59ºC[2] | 0.08ºC[3] |

**b. Boundary Forebay**

| Case | Maximum ΔT relative to the Natural Condition using Flow-Weighted Temperature from Frequency Analysis (Case-Natural) | Maximum ΔT relative to Existing Conditions using Flow-Weighted Temperature from Frequency Analysis (Existing-Case) |
|---|---|---|
| **Existing** | 0.20ºC[1] | 0.0ºC |
| **Run-of-river, 1974 Elevation operation** | 0.15ºC[2] | 0.16ºC[3] |

**c. Boundary Tailrace**

| Case | Maximum ΔT relative to the Natural Condition using Flow-Weighted Temperature from Frequency Analysis (Case-Natural) | Maximum ΔT relative to Existing Conditions using Flow-Weighted Temperature from Frequency Analysis (Existing-Case) |
|---|---|---|
| **Existing** | 0.10ºC[1] | 0.0ºC |
| **Run-of-river, 1974 Elevation operation** | 0.16ºC[2] | 0.19ºC[3] |

Notes:
The period covered is July 9, 2004 to September 4, 2004 & July 8, 2005 to September 8, 2005. Existing = all dams are present, Natural = no dams are present, Run-of-river, 1974 Elevation operation = as stated with all dams present
[1] This represents the largest difference between the maximum flow-weighted temperature cumulative frequency distributions for the Existing Condition (with all dams in place) and Natural Condition.
[2] This represents the largest difference between the maximum flow-weighted temperature cumulative frequency distributions for the Run-of-river 1974 elevation. and the Natural Condition.
[3] This represents the largest difference between the maximum flow-weighted temperature cumulative frequency distributions for the Run-of-river 1974 elevation and the Existing Condition. This shows the potential temperature difference associated with Run-of-river 1974 elevation alternative operations scenario compared to Existing Conditions.

**Table 6-3**
Summary of Maximum Surface Temperature Differences from Frequency Analysis comparing the Existing Condition, the Natural Condition, and the Run-of-river, 1974 Elevation operation

**a. Metaline Pool**

| Case | Maximum ΔT relative to the Natural Condition using Surface Temperature from Frequency Analysis (Case-Natural) | Maximum ΔT relative to Existing Conditions using Surface Temperature from Frequency Analysis (Existing-Case) |
|---|---|---|
| **Existing** | 0.50ºC[1] | 0.0ºC |
| **Run-of-river, 1974 Elevation operation** | 0.60ºC[2] | 0.13ºC[3] |

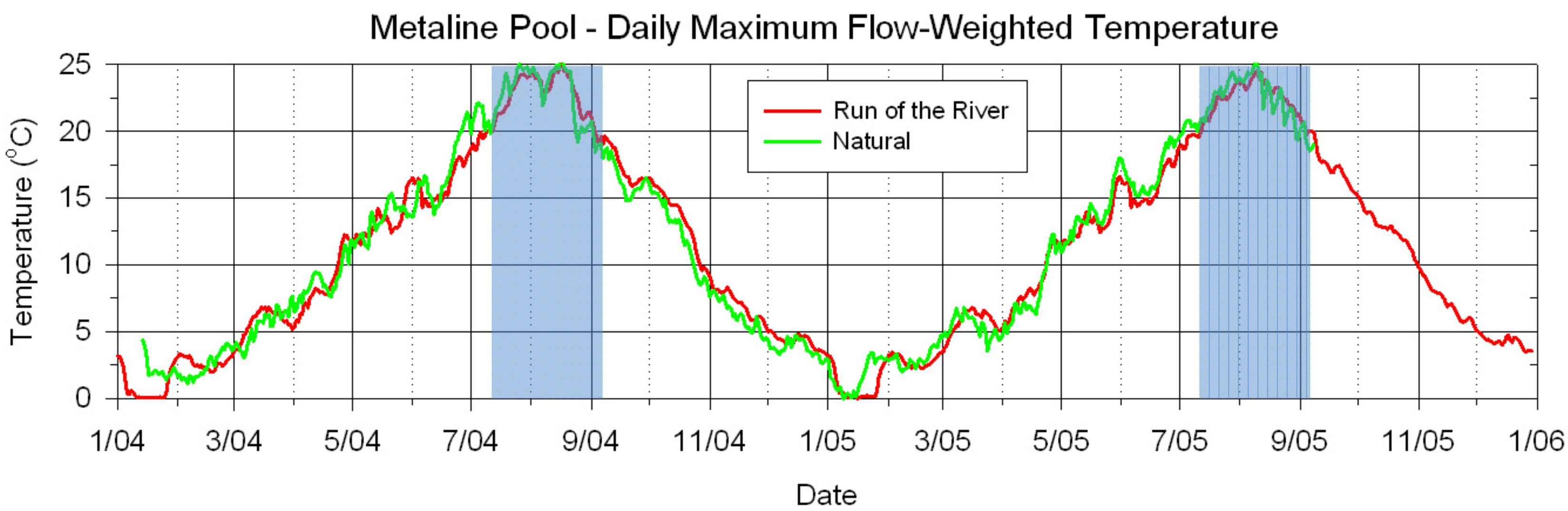
**b. Boundary Forebay**

| Case | Maximum ΔT relative to the Natural Condition using Surface Temperature from Frequency Analysis (Case-Natural) | Maximum ΔT relative to Existing Conditions using Surface Temperature from Frequency Analysis (Existing-Case) |
|---|---|---|
| **Existing** | 0.76ºC[1] | 0.0ºC |
| **Run-of-river, 1974 Elevation operation** | 0.94ºC[2] | -0.07ºC[3] |

**c. Boundary Tailrace**

| Case | Maximum ΔT relative to the Natural Condition using Surface Temperature from Frequency Analysis (Case-Natural) | Maximum ΔT relative to Existing Conditions using Surface Temperature from Frequency Analysis (Existing-Case) |
|---|---|---|
| **Existing** | 0.19ºC[1] | 0.0ºC |
| **Run-of-river, 1974 Elevation operation** | 0.16ºC[2] | 0.19ºC[3] |

Notes:
The period covered is July 9, 2004 to September 4, 2004 & July 8, 2005 to September 8, 2005. Existing = all dams are present, Natural = no dams are present, Run-of-river, 1974 Elevation operation = as stated with all dams present
[1] This represents the largest difference between the maximum flow-weighted temperature cumulative frequency distributions for the Existing Condition (with all dams in place) and Natural Condition.
[2] This represents the largest difference between the maximum flow-weighted temperature cumulative frequency distributions for the Run-of-river, 1974 elevation. and the Natural Condition.
[3] This represents the largest difference between the maximum flow-weighted temperature cumulative frequency distributions for the Run-of-river, 1974 elevation. and the Existing Condition. This shows the potential temperature difference associated with the Run-of-river, 1974 elevation alternative operations scenario compared to Existing Conditions




Notes:

1. Run of the River = run of river operation during the summer at 1974 ft elevation.
2. Daily maximum flow-weighted temperature is

$$T_W = \sum_{l=1}^{n} (T_l \times Q_l) / Q_T$$

   where $l$ is a layer of water column ($l$=1, 2,.., n), $T_W$ is the flow-weighted temperature, $T_l$ is the temperature at the layer, $Q_l$ is the flow rate at the layer, and $Q_T$ is the total flow.
3. The period when the Run of the River temperature is over 20ºC is indicated by the shading.

**Figure 6-1**a

Daily Maximum Flow-Weighted Temperatures for the Run of the River and the Natural Condition at Metaline Pool

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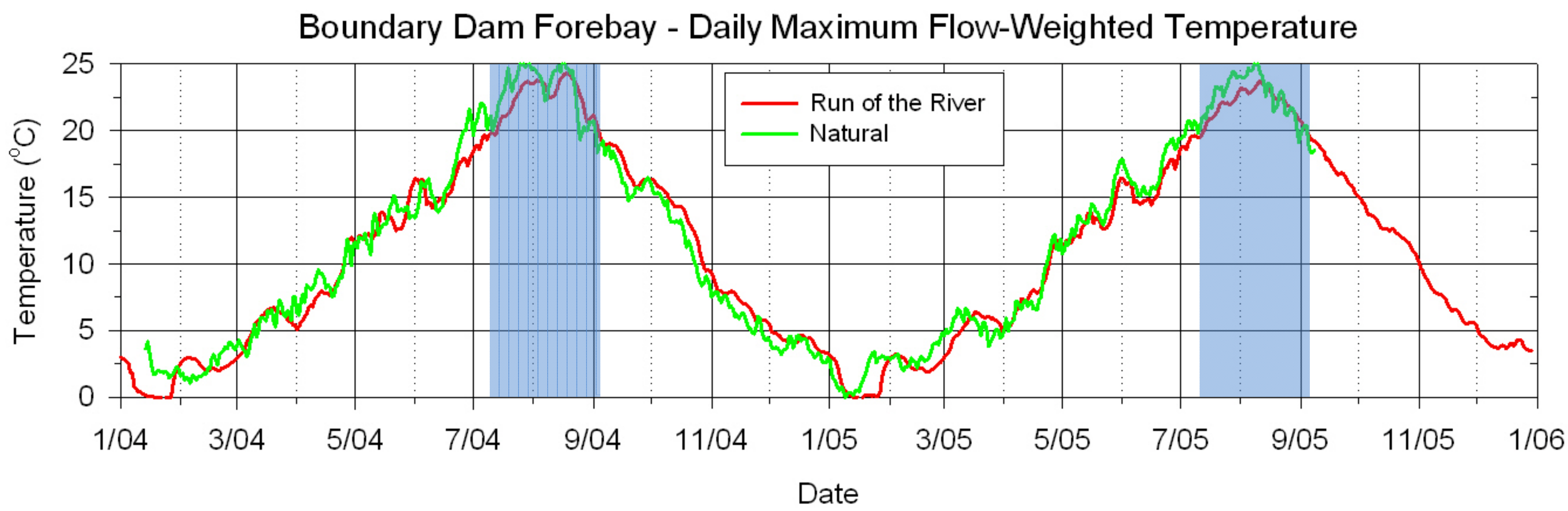



Notes:

1. Run of the River = run of river operation during the summer at 1974 ft elevation
2. Daily maximum flow-weighted temperature is

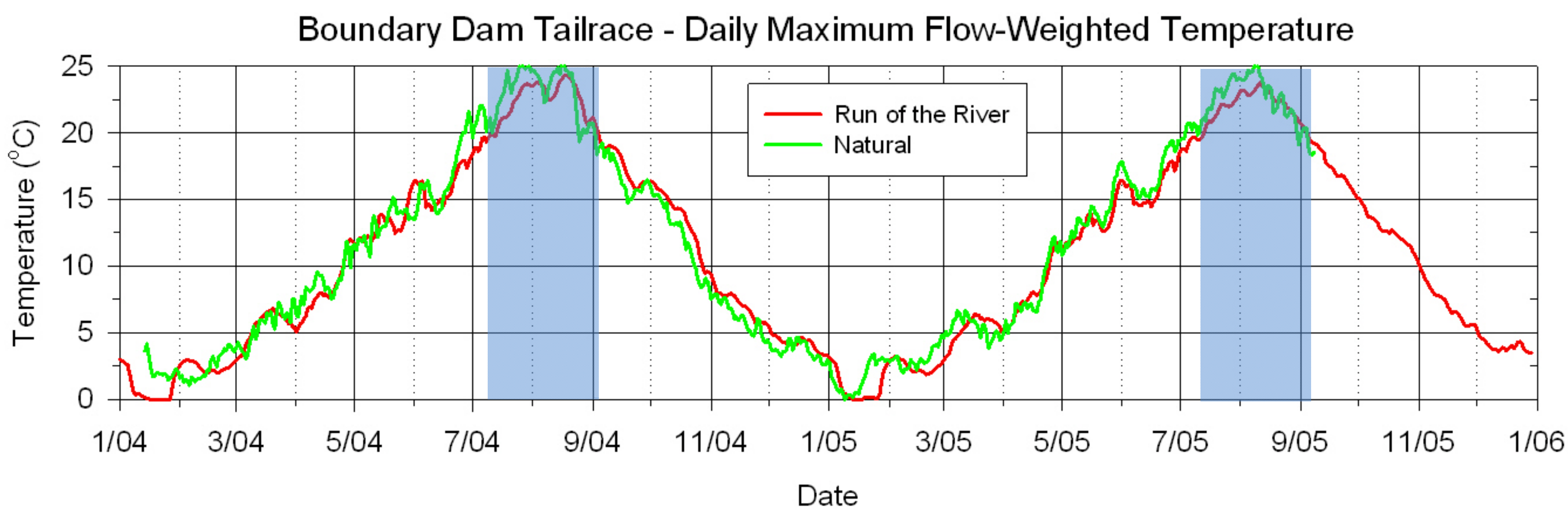
$$T_W = \sum_{l=1}^{n} (T_l \times Q_l) / Q_T$$

   where $l$ is a layer of water column ($l$=1, 2,.., n), $T_W$ is the flow-weighted temperature, $T_l$ is the temperature at the layer, $Q_l$ is the flow rate at the layer, and $Q_T$ is the total flow.
3. The period when the Run of the River temperature is over 20ºC is indicated by the shading.

**Figure 6-1**b

Daily Maximum Flow-Weighted Temperatures for the Run of the River and the Natural Condition at Boundary Dam Forebay

Seattle City Light
Seattle, WA




Notes:

1. Run of the River = run of river operation during the summer at 1974 ft elevation
2. Daily maximum flow-weighted temperature is

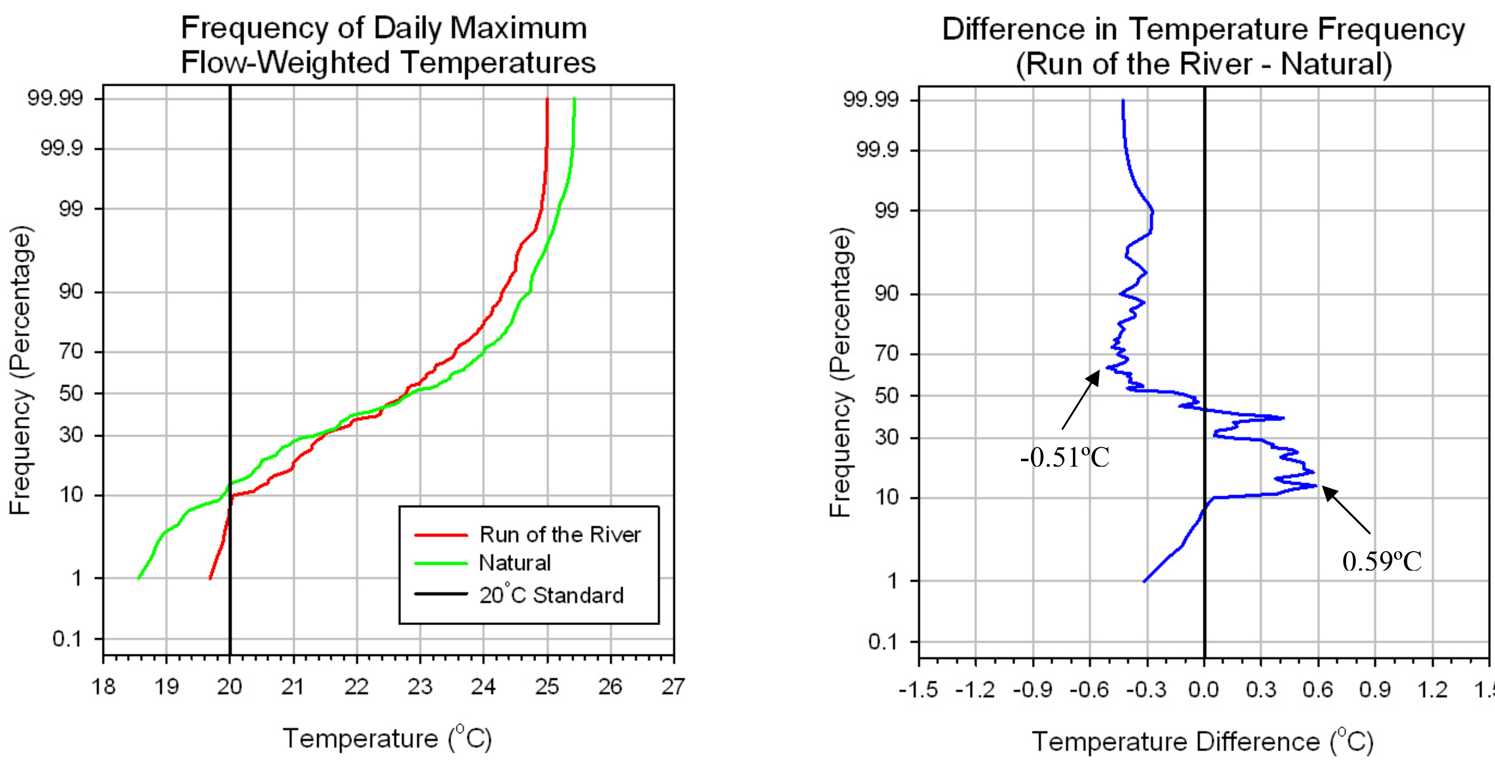
$$T_W = \sum_{l=1}^{n} (T_l \times Q_l) / Q_T$$

   where $l$ is a layer of water column ($l$=1, 2,.., n), $T_W$ is the flow-weighted temperature, $T_l$ is the temperature at the layer, $Q_l$ is the flow rate at the layer, and $Q_T$ is the total flow.
3. The period when the Run of the River temperature is over 20ºC is indicated by the shading.

**Figure 6-1**c

Daily Maximum Flow-Weighted Temperatures for the Run of the River and the Natural Condition at Boundary Dam Tailrace

Seattle City Light
Seattle, WA




Notes:

1. Run of the River = run of river operation during the summer at 1974 ft elevation.
2. The difference in temperature at each frequency is obtained by subtracting the Natural Condition values from the Run of the River values. (When Natural Condition is < 20ºC, the Natural temperature is replaced by the value 20ºC.)
3. The period covered by the frequency analysis was July 9, 2004 to September 4, 2004 and July 8, 2005 to September 8, 2005.
4. Flow-weighted temperature differences are between -0.51 ºC and +0.59 ºC due to the Run of the River operational scenario.

**Figure 6-2a**

Frequency Distribution of the Daily Maximum Flow-Weighted Temperatures for the Run of the River and the Natural Condition at Metaline Pool

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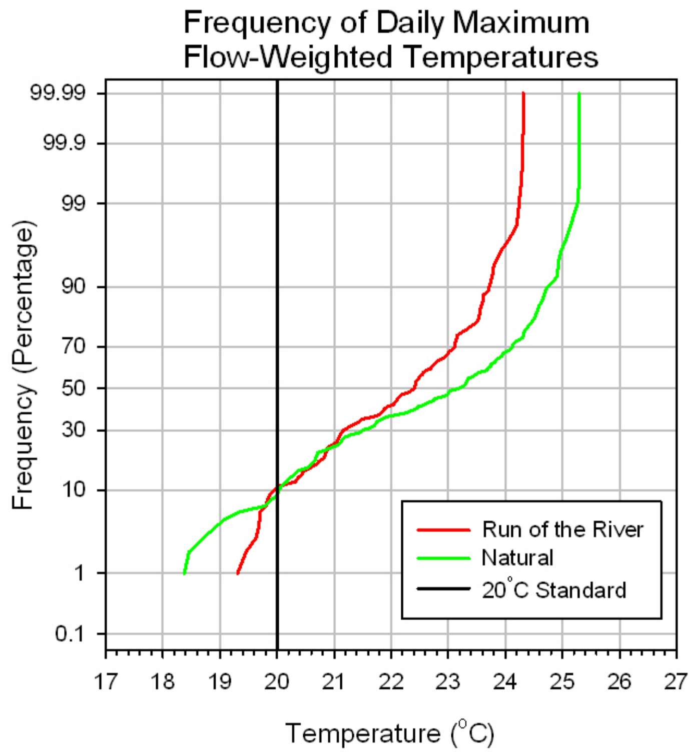
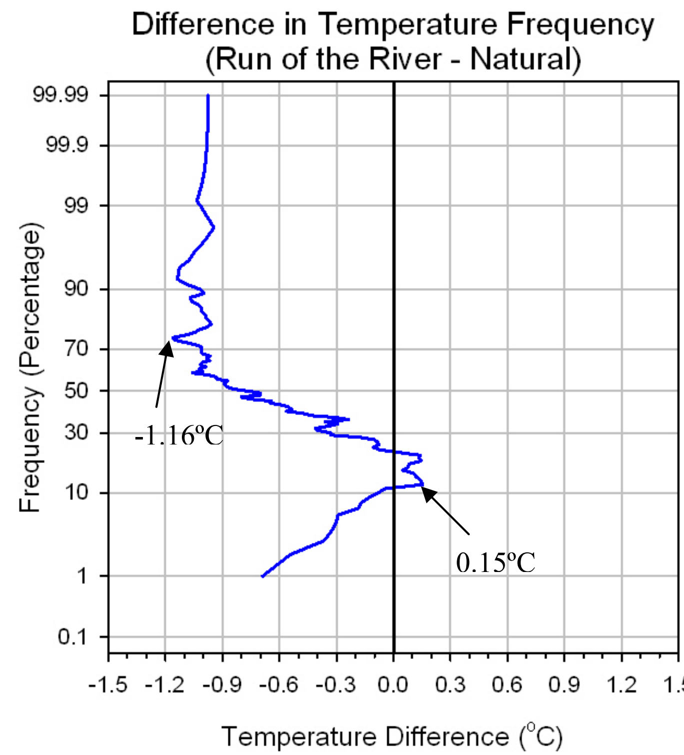
Seattle, WA




Notes:

1. Run of the River = run of river operation during the summer at 1974 ft elevation.
2. The difference in temperature at each frequency is obtained by subtracting the Natural Condition values from the Run of the River values. (When Natural Condition is < 20ºC, the Natural temperature is replaced by the value 20ºC.)
3. The period covered by the frequency analysis was July 9, 2004 to September 4, 2004 and July 8, 2005 to September 8, 2005.
4. Flow-weighted temperature differences are between -1.16 ºC and +0.15 ºC due to the Run of the River operational scenario.

**Figure 6-2**b

Frequency Distribution of the Daily Maximum Flow-Weighted Temperatures for the Run of the River and the Natural Condition at Boundary Dam Forebay

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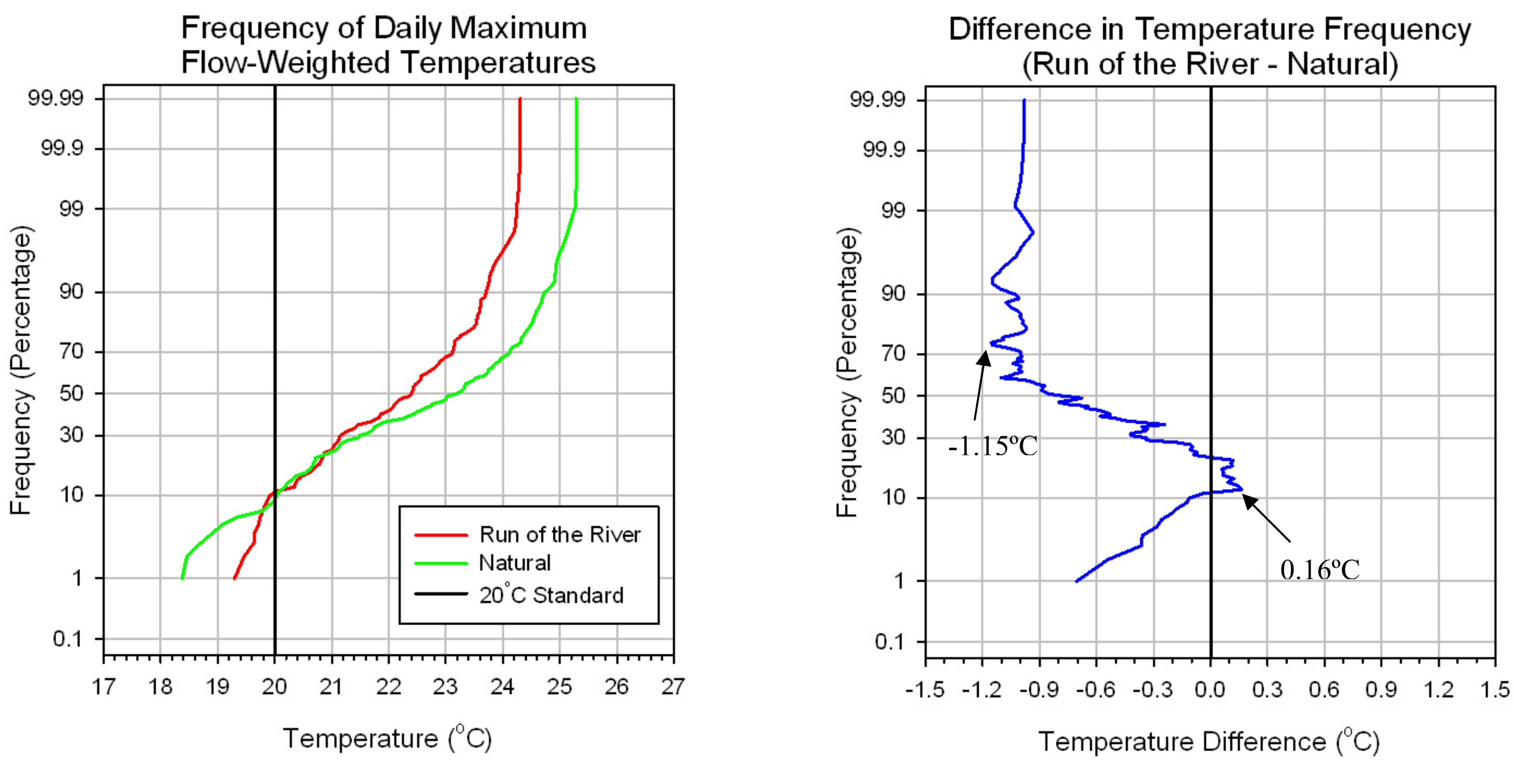
Seattle, WA



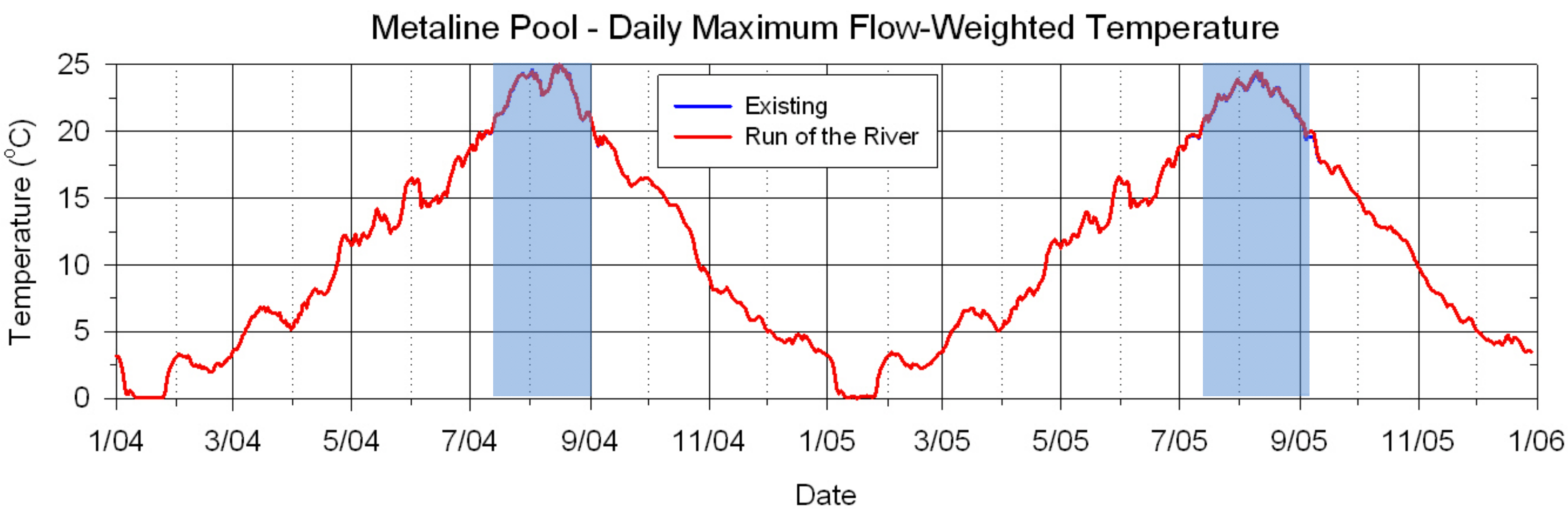

Notes:

1. Run of the River = run of river operation during the summer at 1974 ft elevation.
2. The difference in temperature at each frequency is obtained by subtracting the Natural Condition values from the Run of the River values. (When Natural Condition is < 20ºC, the Natural temperature is replaced by the value 20ºC.)
3. The period covered by the frequency analysis was July 9, 2004 to September 4, 2004 and July 8, 2005 to September 8, 2005.
4. Flow-weighted temperature differences are between -1.15ºC and +0.16ºC due to the Run of the River operational scenario.

**Figure 6-2c**

Frequency Distribution of the Daily Maximum Flow-Weighted Temperatures for the Run of the River and the Natural Condition at Boundary Dam Tailrace

Seattle City Light
Seattle, WA




Notes:

1. Run of the River = run of river operation during the summer at 1974 ft elevation
2. Daily maximum flow-weighted temperature is

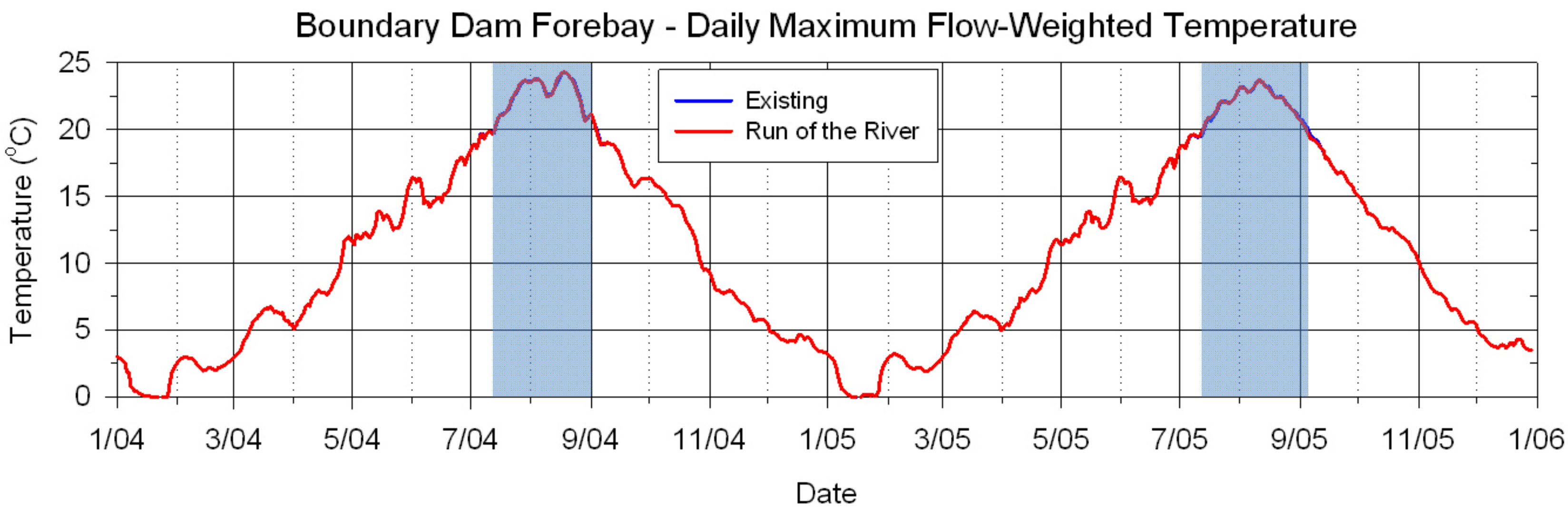
$$T_W = \sum_{l=1}^{n} (T_l \times Q_l) / Q_T$$

   where $l$ is a layer of water column ($l$=1, 2,.., n), $T_W$ is the flow-weighted temperature, $T_l$ is the temperature at the layer, $Q_l$ is the flow rate at the layer, and $Q_T$ is the total flow.
3. The period when the Run of the River temperature is over 20ºC is indicated by the shading.

**Figure 6-3**a

Daily Maximum Flow-Weighted Temperatures for the Existing Condition and the Run of the River at Metaline Pool

Seattle City Light
Seattle, WA




Notes:

1. Run of the River = run of river operation during the summer at 1974 ft elevation.
2. Daily maximum flow-weighted temperature is

$$T_W = \sum_{l=1}^{n} (T_l \times Q_l) / Q_T$$

where $l$ is a layer of water column ($l$=1, 2,.., n), $T_W$ is the flow-weighted temperature, $T_l$ is the temperature at the layer, $Q_l$ is the flow rate at the layer, and $Q_T$ is the total flow.

3. The period when the Run of the River temperature is over 20ºC is indicated by the shading.

**Figure 6-3b**

Daily Maximum Flow-Weighted Temperatures for the Existing Condition and the Run of the River at Boundary Dam Forebay

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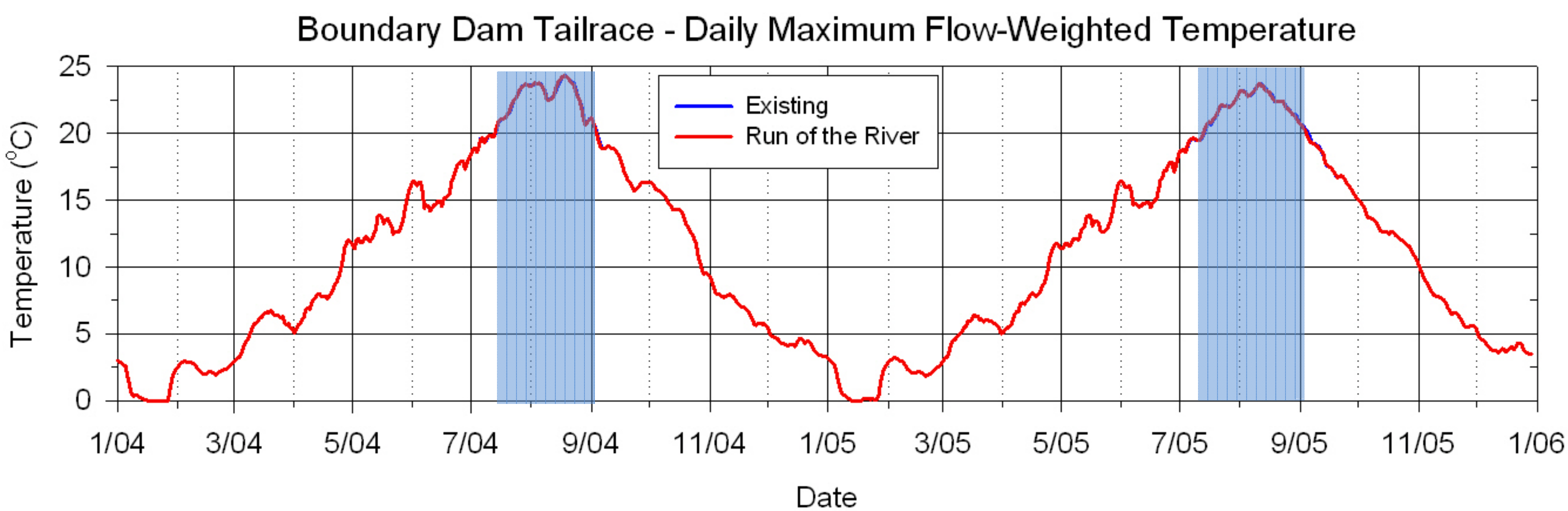



Notes:

1. Run of the River = run of river operation during the summer at 1974 ft elevation.
2. Daily maximum flow-weighted temperature is

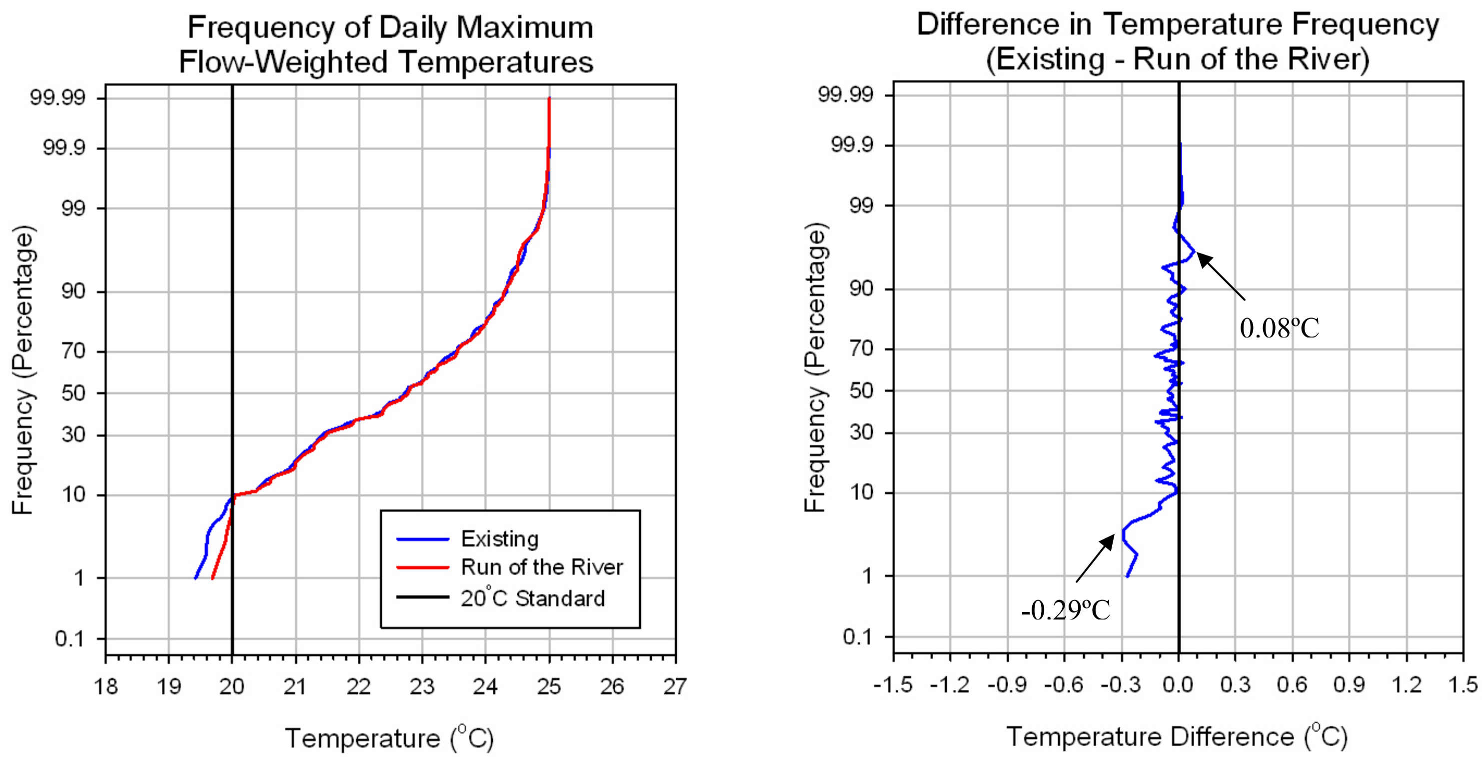
$$T_W = \sum_{l=1}^{n} (T_l \times Q_l) / Q_T$$

where $l$ is a layer of water column ($l$=1, 2,.., n), $T_W$ is the flow-weighted temperature, $T_l$ is the temperature at the layer, $Q_l$ is the flow rate at the layer, and $Q_T$ is the total flow.
3. The period when the Run of the River temperature is over 20ºC is indicated by the shading.

**Figure 6-3c**

Daily Maximum Flow-Weighted Temperatures for the Existing Condition and the Run of the River at Boundary Dam Tailrace

Seattle City Light
Seattle, WA



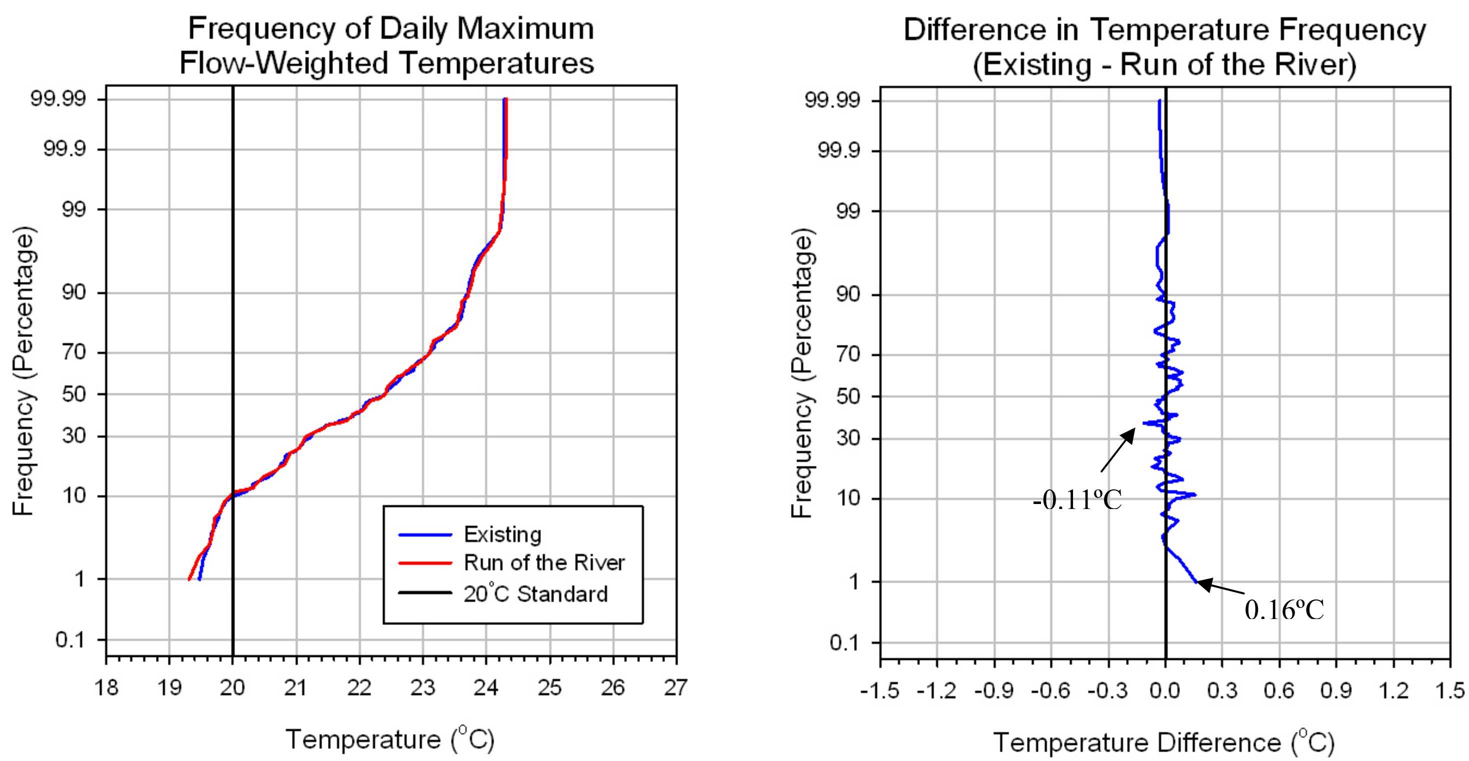

Notes:

1. Run of the River = run of river operation during the summer at 1974 ft elevation.
2. The difference in temperature at each frequency is obtained by subtracting the Run of the River values from the Existing Condition values.
3. The period covered by the frequency analysis was July 9, 2004 to September 4, 2004 and July 8, 2005 to September 8, 2005.
4. Existing Condition flow-weighted temperature differences are between -0.29ºC and +0.08ºC relative to the Run of the River operational scenario.

**Figure 6-4**a

Frequency Distribution of the Daily Maximum Flow-Weighted Temperatures for the Run of the River and the Existing Condition at Metaline Pool

Seattle City Light
Seattle, WA




Notes:

1. Run of the River = run of river operation during the summer at 1974 ft elevation.
2. The difference in temperature at each frequency is obtained by subtracting the Run of the River values from the Existing Condition values.
3. The period covered by the frequency analysis was July 9, 2004 to September 4, 2004 and July 8, 2005 to September 8, 2005.
4. Existing Condition flow-weighted temperature differences are between -0.11ºC and +0.16ºC relative to the Run of the River operational scenario.

**Figure 6-4**b

Frequency Distribution of the Daily Maximum Flow-Weighted Temperatures for the Run of the River and the Existing Condition at Boundary Dam Forebay

Seattle City Light
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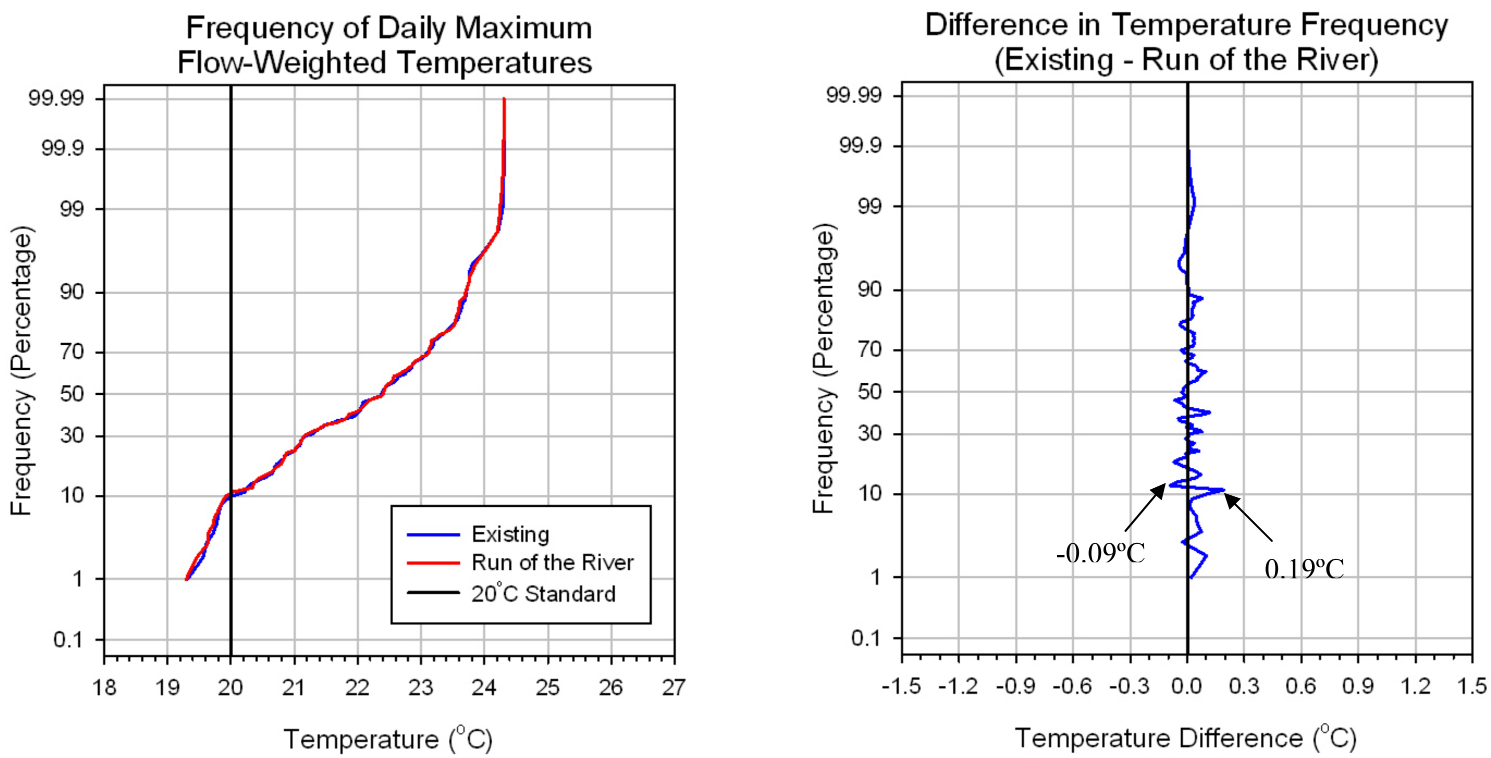


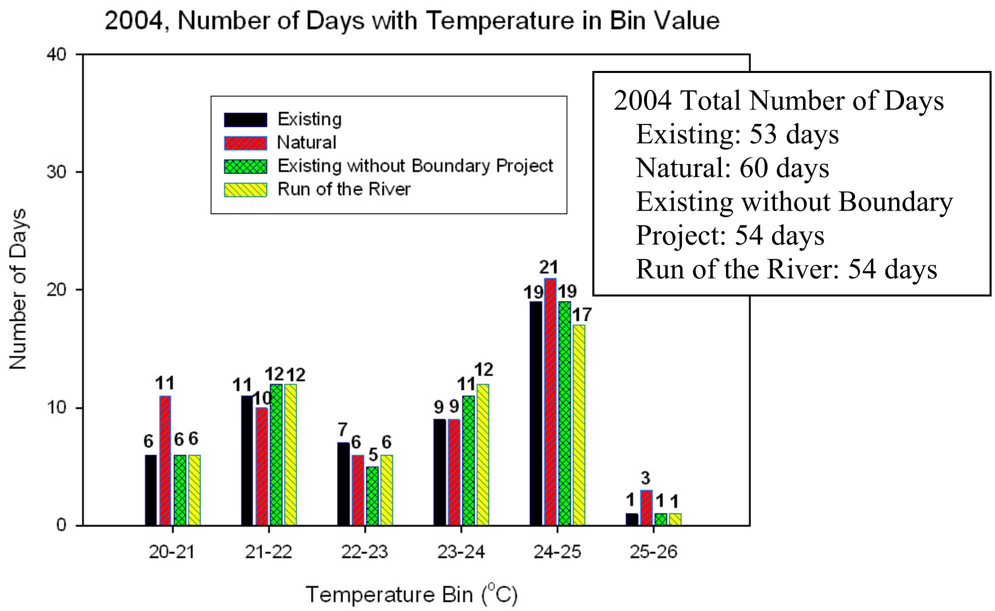

Notes:

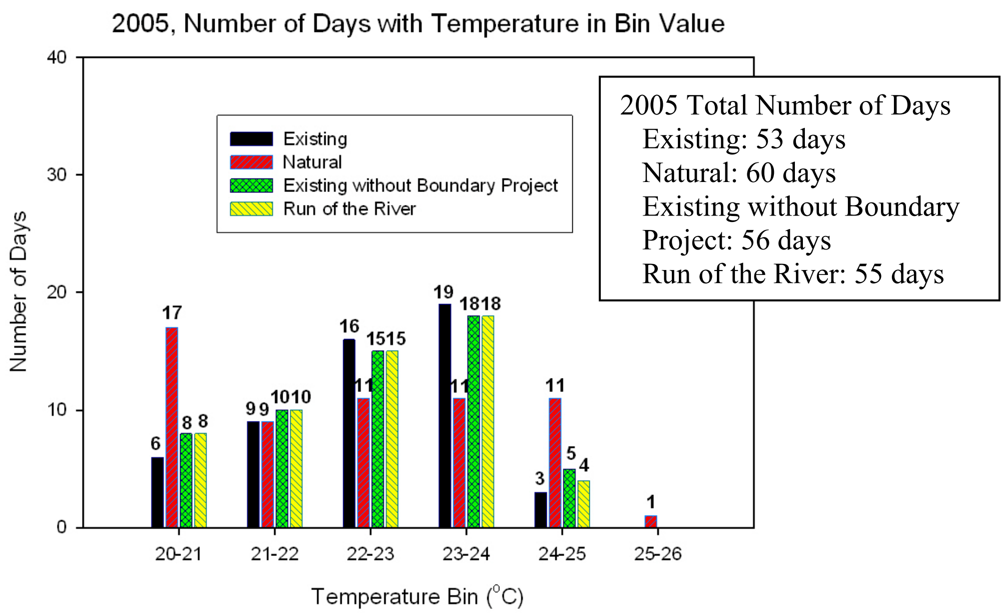
1. Run of the River = run of river operation during the summer at 1974 ft elevation.
2. The difference in temperature at each frequency is obtained by subtracting the Run of the River values from the Existing Condition values.
3. The period covered by the frequency analysis was July 9, 2004 to September 4, 2004 and July 8, 2005 to September 8, 2005.
4. Existing Condition flow-weighted temperature differences are between -0.09ºC and +0.19ºC relative to the Run of the River operational scenario.

**Figure 6-4**c

Frequency Distribution of the Daily Maximum Flow-Weighted Temperatures for the Run of the River and the Existing Condition at Boundary Dam Tailrace

Seattle City Light
Seattle, WA



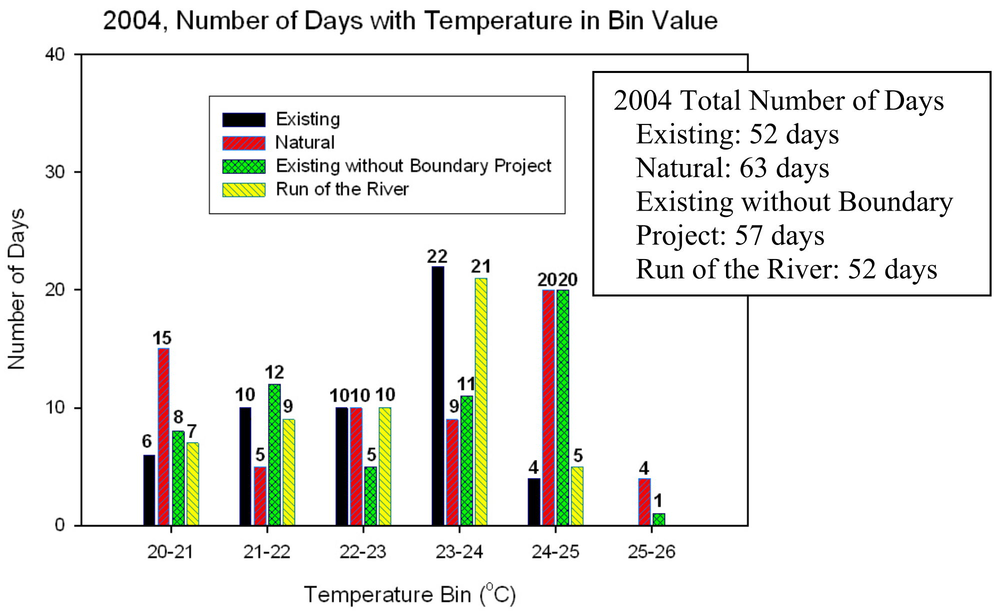

Notes:

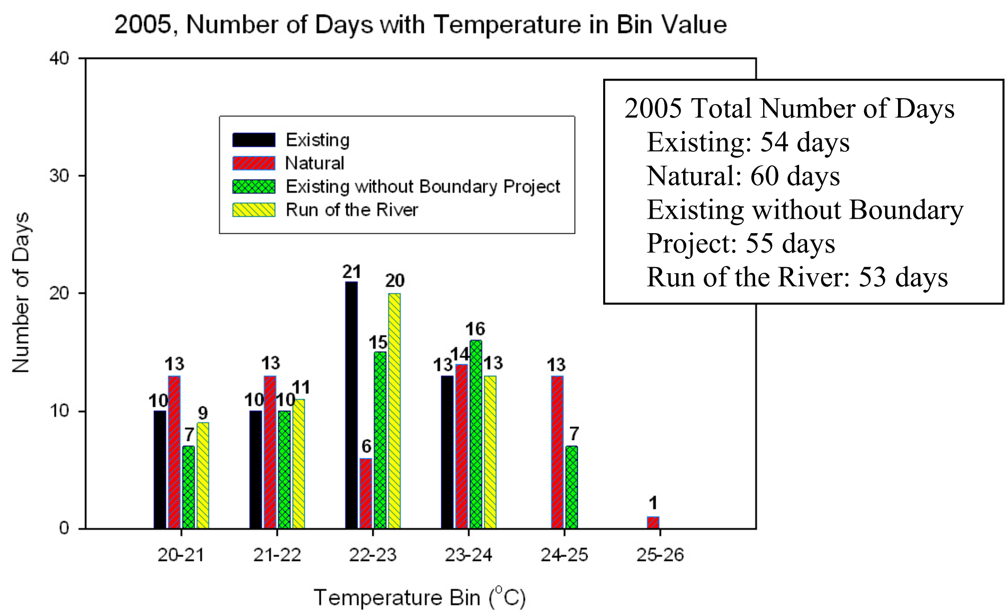
1. The total number of days for 2004 and 2005 was
   Existing – 106 days, Natural – 120 days,
   Existing without Boundary Project – 110 days
   Run of the River – 109 days
2. Peak annual flow-weighted temperatures at the Metaline Pool
   Existing – 2004: 25.01ºC & 2005: 24.40ºC
   Natural – 2004: 25.43ºC & 2005: 25.14ºC
   Existing without Boundary Project
   – 2004: 25.04ºC & 2005: 24.61ºC
   Run of the River
   - 2004: 25.00ºC & 2005: 24.51ºC

**Figure 6-5a**

Number of Days the Daily Maximum Flow-Weighted Temperatures Exceeded 20ºC at the Metaline Pool for 2004 and 2005

Seattle City Light
Seattle. WA



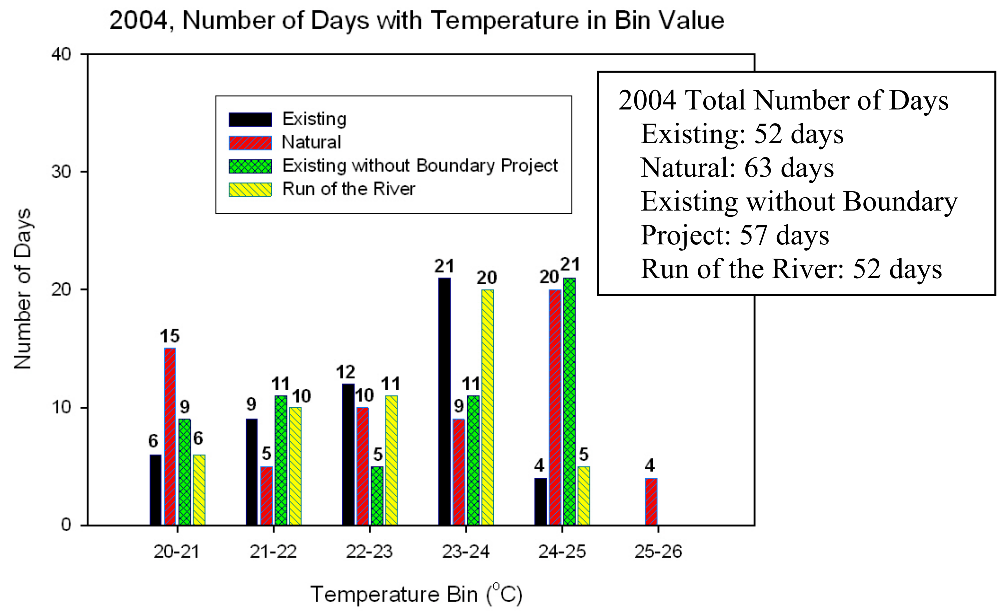

Notes:

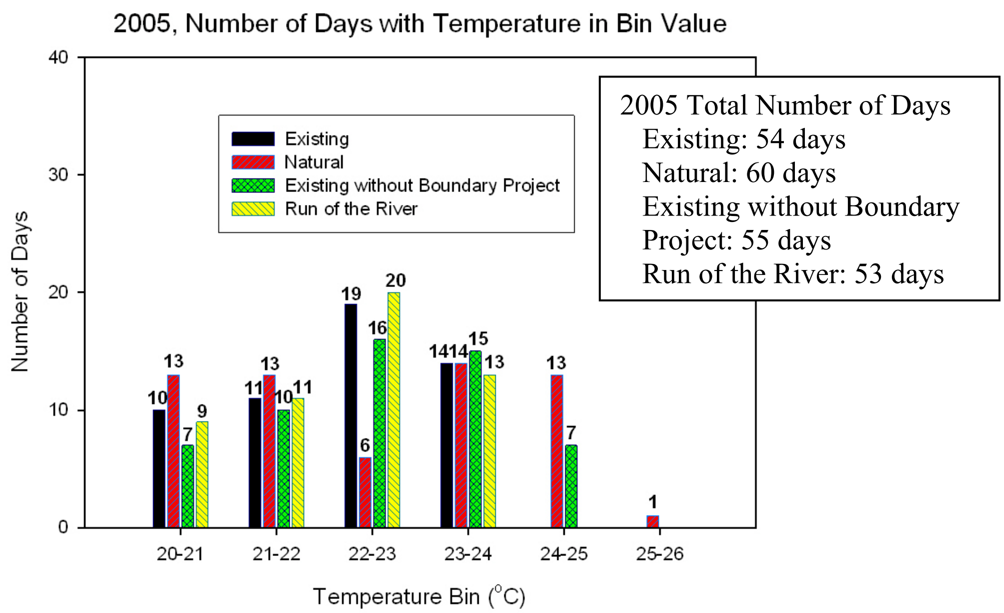
1. The total number of days for 2004 and 2005 was
   Existing – 106 days, Natural – 123 days,
   Existing without Boundary Project – 112 days,
   Run of the River – 105 days
2. Peak annual flow-weighted temperatures at the Boundary Dam Forebay Pool
   Existing – 2004: 24.29ºC & 2005: 23.72ºC
   Natural – 2004: 25.29ºC & 2005: 25.15ºC
   Existing without Boundary Project
   – 2004: 25.07ºC & 2005: 24.68ºC
   Run of the River
   - 2004: 24.32ºC & 2005: 23.76ºC

**Figure 6-5b**

Number of Days the Daily Maximum Flow-Weighted Temperatures Exceeded 20ºC at the Boundary Dam Forebay for 2004 and 2005

Seattle City Light
Seattle. WA




Notes:

1. The total number of days for 2004 and 2005 was
   Existing – 106 days, Natural – 123 days,
   Existing without Boundary Project – 112 days,
   Run of the River – 105 days
2. Peak annual flow-weighted temperatures at the Boundary Dam Tailrace Pool
   Existing – 2004: 24.31ºC & 2005: 23.71ºC
   Natural – 2004: 25.29ºC & 2005: 25.15ºC
   Existing without Boundary Project
   – 2004: 24.87ºC & 2005: 24.34ºC
   Run of the River
   - 2004: 24.31ºC & 2005: 23.75ºC

**Figure 6-5c**

Number of Days the Daily Maximum Flow-Weighted Temperatures Exceeded 20ºC at the Boundary Dam Tailrace for 2004 and 2005

Seattle City Light
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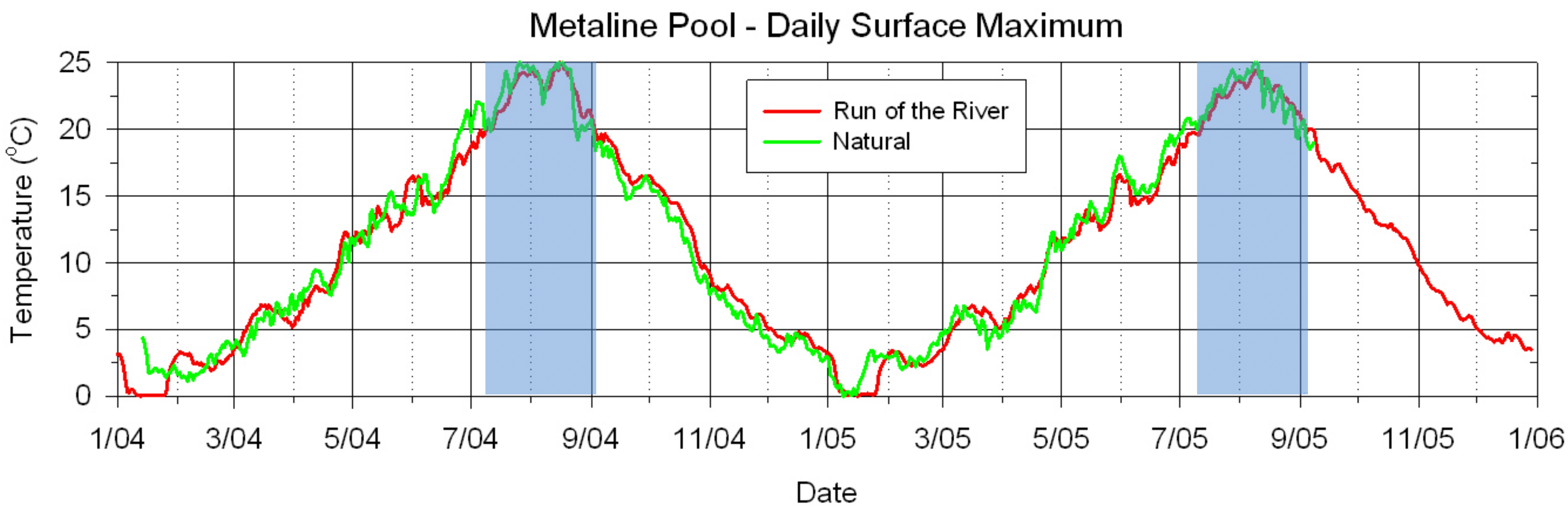


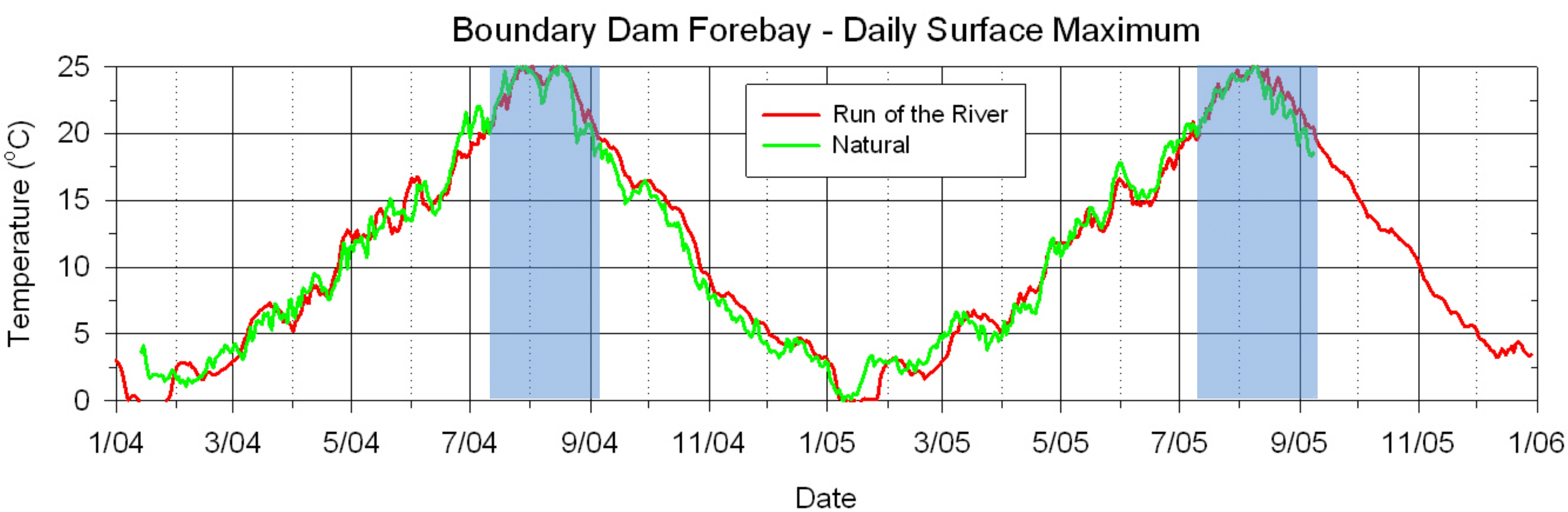

Notes:

1. Run of the River = run of river operation during the summer at 1974 ft elevation
2. Daily maximum temperatures are from the surface layer of the models.
3. The period in which the Run of the River temperature is over 20ºC is indicated by the shading.

**Figure 6-6**a

Daily Maximum Surface Temperatures for the Run of the River and the Natural Condition at Metaline Pool

Seattle City Light
Seattle, WA



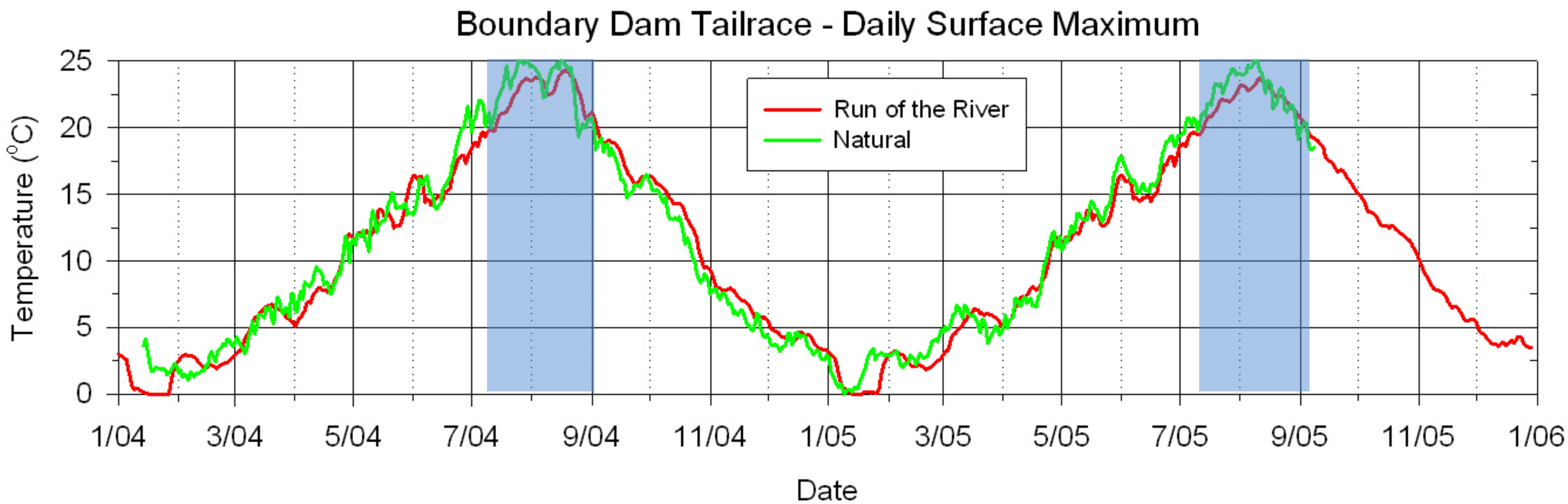

Notes:

1. Run of the River = run of river operation during the summer at 1974 ft elevation.
2. Daily maximum temperatures are from the surface layer of the models.
3. The period in which the Run of the River temperature is over 20ºC is indicated by the shading.

**Figure 6-6**b

Daily Maximum Surface Temperatures for the Run of the River and the Natural Condition at Boundary Dam Forebay

Seattle City Light
Seattle, WA



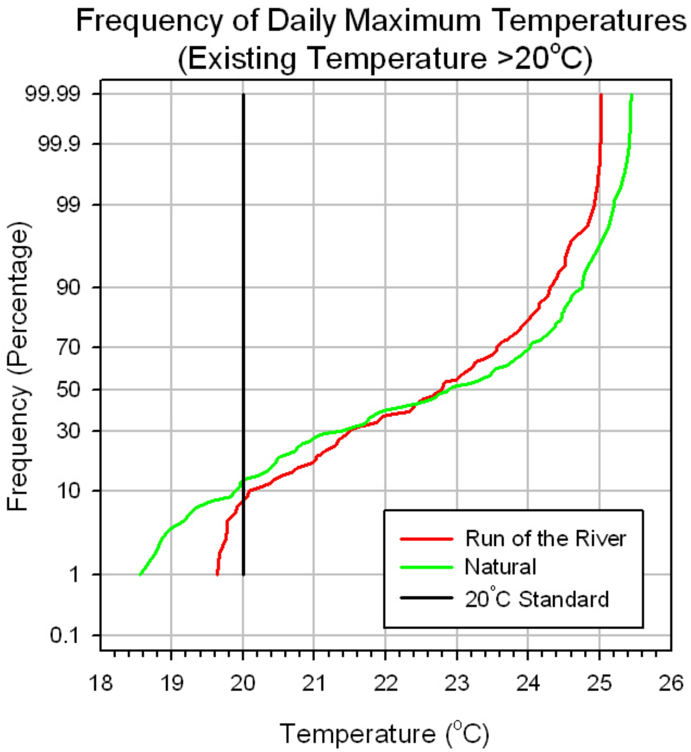

Notes:

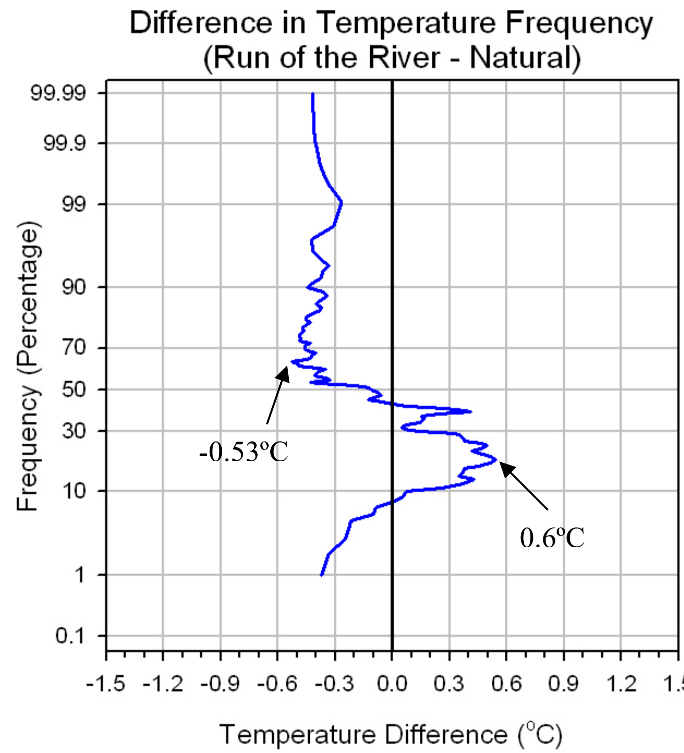
1. Run of the River = run of river operation during the summer at 1974 ft elevation .
2. Daily maximum temperatures are from the surface layer of the models.
3. The period in which the Run of the River temperature is over 20ºC is indicated by the shading.

**Figure 6-6c**

Daily Maximum Surface Temperatures for the Run of the River and the Natural Condition at Boundary Dam Tailrace

Seattle City Light
Seattle, WA



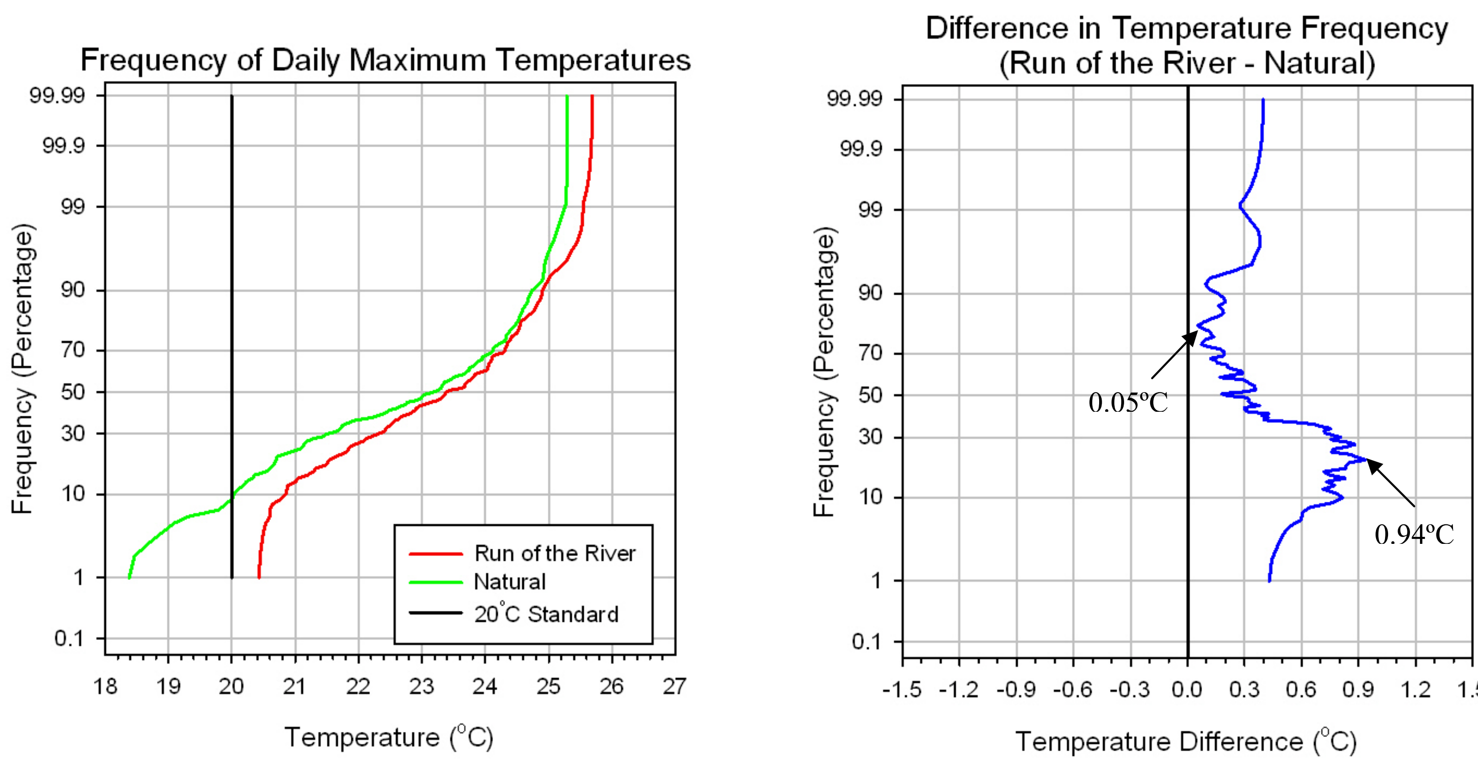




Notes:
1. Run of the River = run of river operation during the summer at 1974 ft elevation.
2. The difference in temperature at each frequency is obtained by subtracting the Natural Condition values from the Run of the River values. (When Natural Condition is < 20ºC, the Natural temperature is replaced by the value 20ºC.)
3. The period covered by the frequency analysis was July 9, 2004 to September 4, 2004 and July 8, 2005 to September 8, 2005.
4. Surface temperature differences are between -0.53ºC and +0.60ºC due to the Run of the River operational scenario.

**Figure 6-7**a

Frequency Distribution of Daily Maximum Surface Temperatures for the Run of the River and the Natural Condition at Metaline Pool

Seattle City Light
Seattle, WA

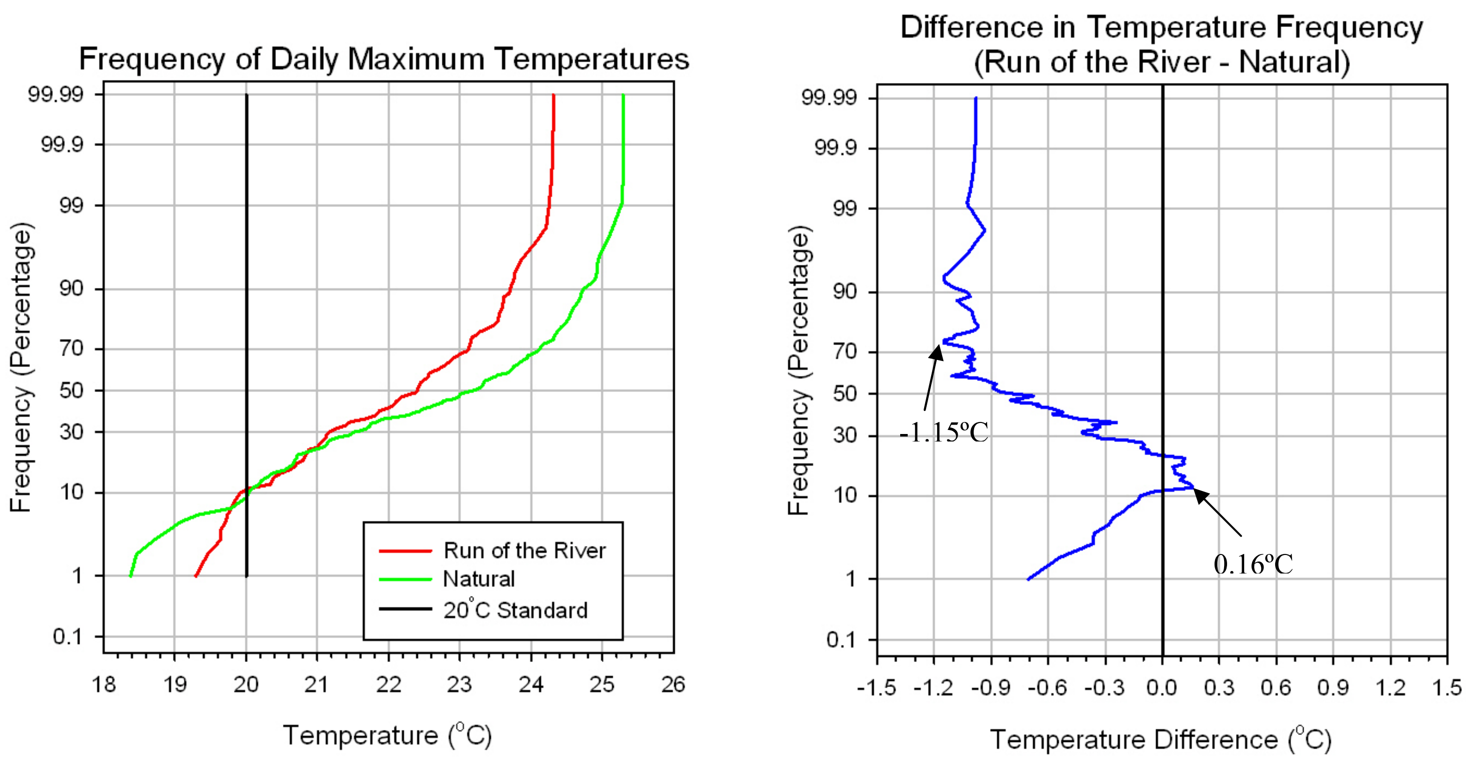



Notes:
1. Run of the River = run of river operation during the summer at 1974 ft elevation.
2. The difference in temperature at each frequency is obtained by subtracting the Natural Condition values from the Run of the River values. (When Natural Condition is < 20ºC, the Natural temperature is replaced by the value 20ºC.)
3. The period covered by the frequency analysis was July 9, 2004 to September 4, 2004 and July 8, 2005 to September 8, 2005.
4. Surface temperatures are between 0.05ºC and 0.94ºC higher due to the Run of the River operational scenario.

**Figure 6-7**b

Frequency Distribution of Daily Maximum Surface Temperatures for the Run of the River and the Natural Condition at Boundary Dam Forebay

Seattle City Light
Seattle, WA



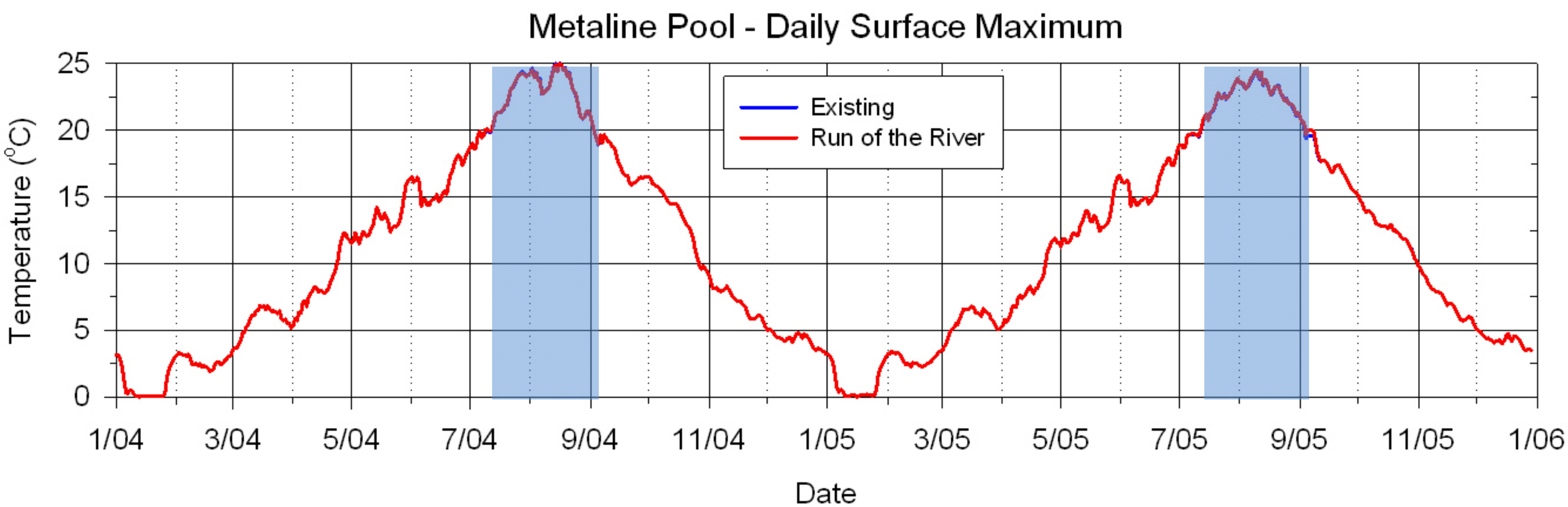

Notes:

1. Run of the River = run of river operation during the summer at 1974 ft elevation.
2. The difference in temperature at each frequency is obtained by subtracting the Natural Condition values from the Run of the River values. (When Natural Condition is < 20ºC, the Natural temperature is replaced by the value 20ºC.)
3. The period covered by the frequency analysis was July 9, 2004 to September 4, 2004 and July 8, 2005 to September 8, 2005.
4. Surface temperatures are between -1.15ºC and +0.16ºC due to the Run of the River operational scenario.

**Figure 6-7c**

Frequency Distribution of Daily Maximum Surface Temperatures for the Run of the River and the Natural Condition at Boundary Dam Tailrace

Seattle City Light
Seattle, WA

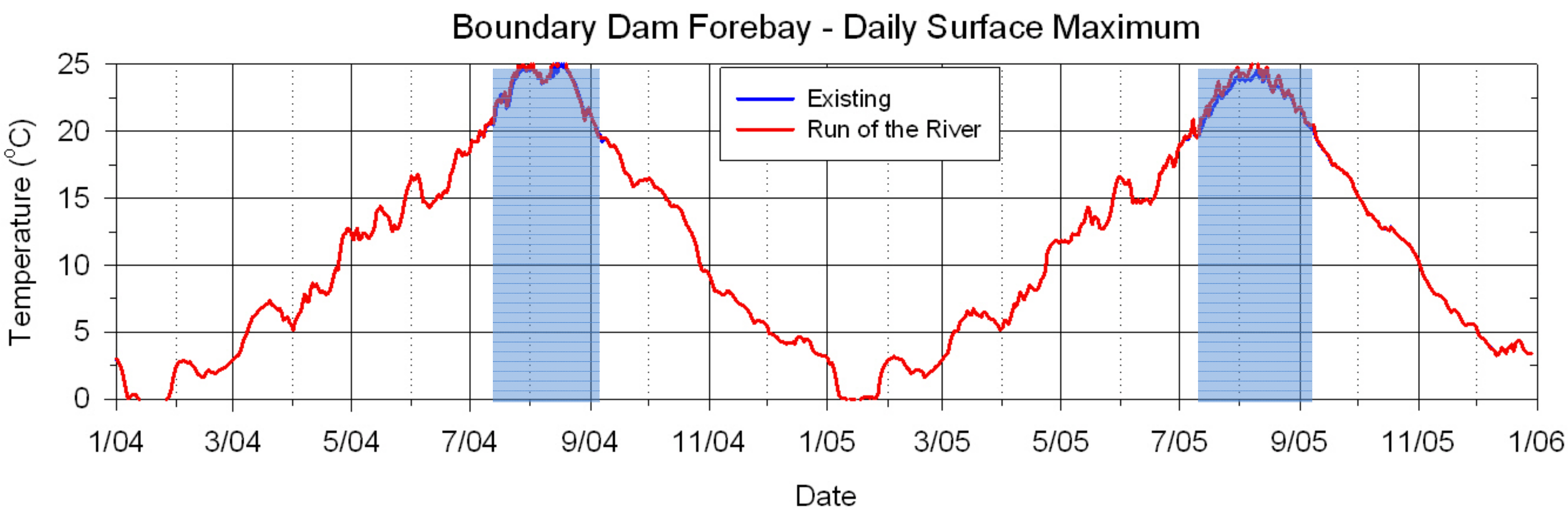



Notes:
1. Run of the River = run of river operation during the summer at 1974 ft elevation.
2. Daily maximum temperatures are from the surface layer of the models.
3. The period when the Run of the River temperature is over 20ºC is indicated by the shading.

**Figure 6-8**a

Daily Maximum Surface Temperatures for the Existing Condition and the Run of the River at Metaline Pool

Seattle City Light
Seattle, WA



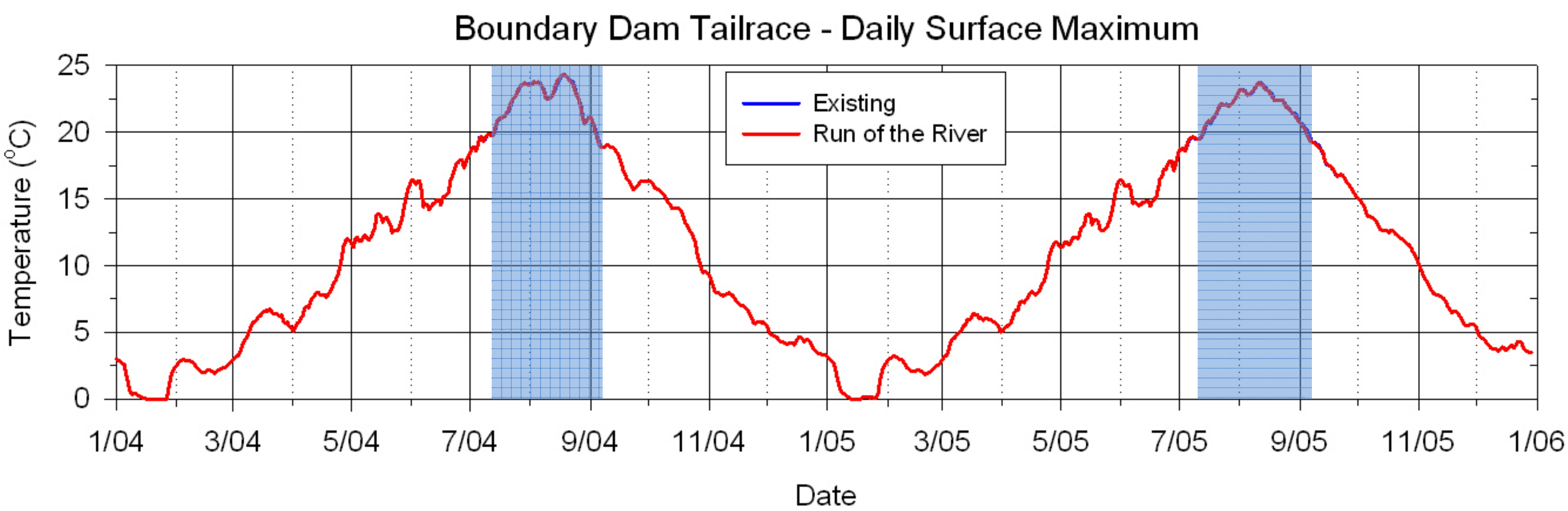

Notes:

1. Run of the River = run of river operation during the summer at 1974 ft elevation
2. Daily maximum temperatures are from the surface layer of the models.
3. The period when the Run of the River temperature is over 20ºC is indicated by the shading.

**Figure 6-8**b

Daily Maximum Surface Temperatures for the Existing Condition and the Run of the River at Boundary Dam Forebay

Seattle City Light
Seattle, WA



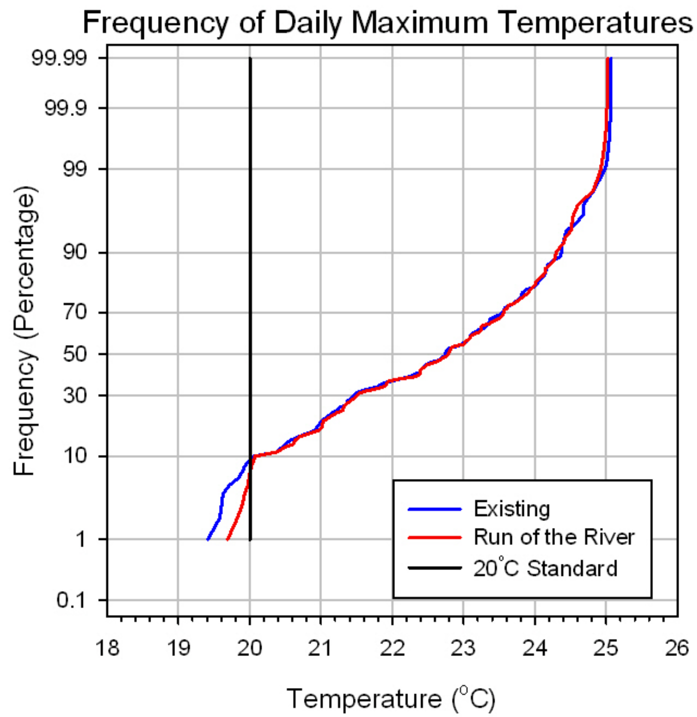

Notes:

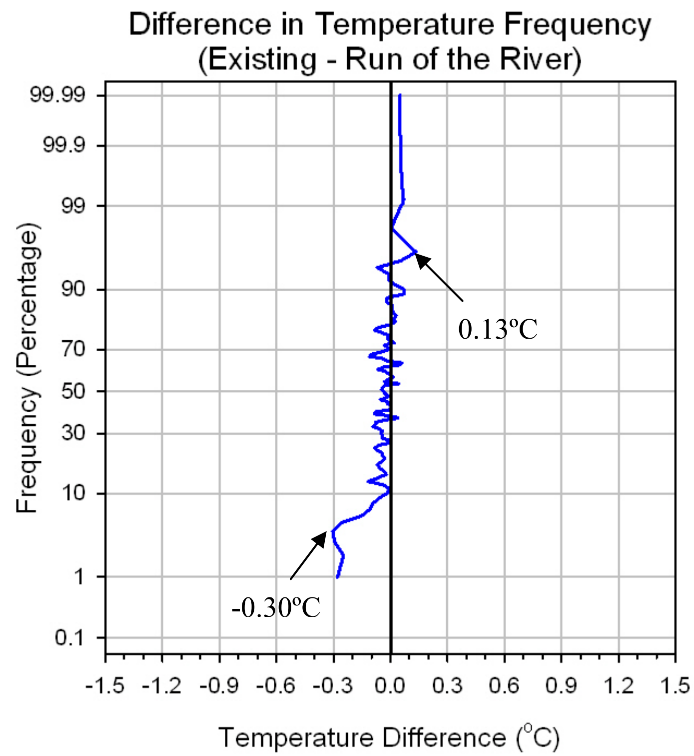
1. Run of the River = run of river operation during the summer at 1974 ft elevation
2. Daily maximum temperatures are from the surface layer of the models.
3. The period when the Run of the River temperature is over 20ºC is indicated by the shading.

**Figure 6-8c**

Daily Maximum Surface Temperatures for the Existing Condition and the Run of the River at Boundary Dam Tailrace

Seattle City Light
Seattle, WA



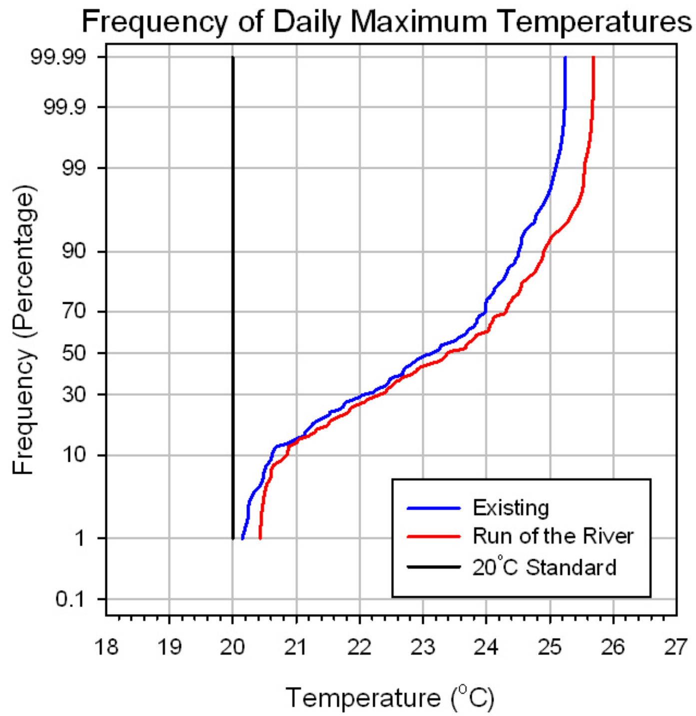

Notes:

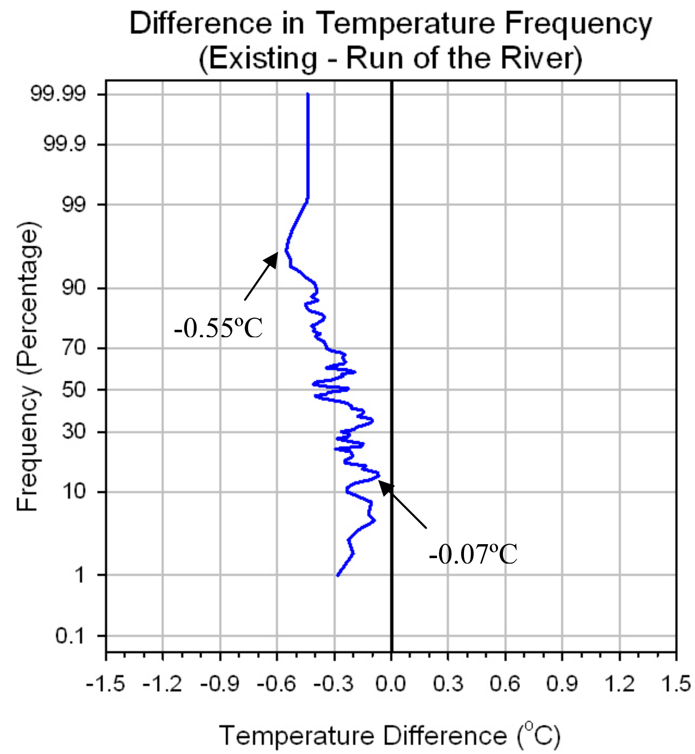
1. Run of the River = run of river operation during the summer at 1974 ft elevation.
2. The difference in temperature at each frequency is obtained by subtracting the Run of the River values from the Existing Condition values.
3. The period covered by the frequency analysis was July 9, 2004 to September 4, 2004 and July 8, 2005 to September 8, 2005 when Existing Condition > 20ºC
4. Existing Condition surface temperature differences are between -0.30ºC and 0.13ºC relative to the Run of the River operational scenario.

**Figure 6-9**a

Frequency Distributions of the Daily Maximum Surface Temperatures for the Existing Condition and the Run of the River at Metaline Pool

Seattle City Light
Seattle, WA



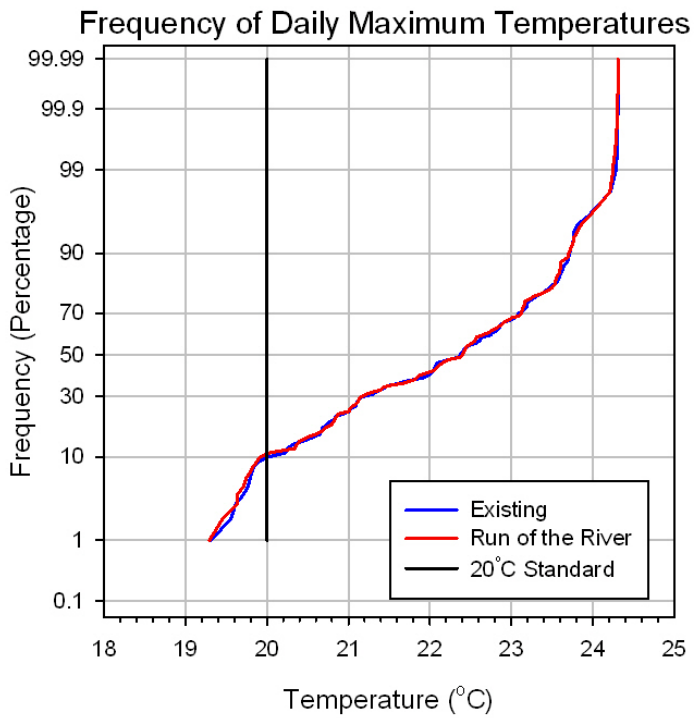

Notes:

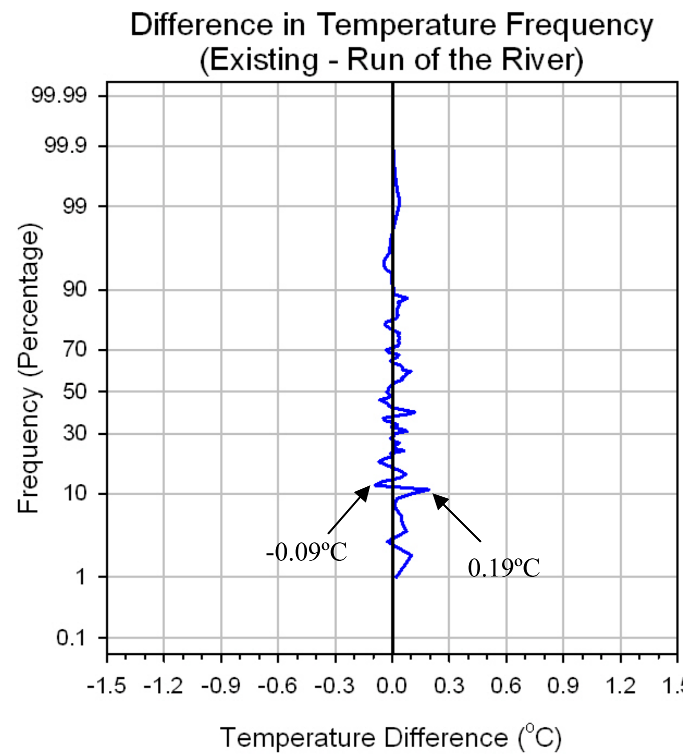
1. Run of the River = run of river operation during the summer at 1974 ft elevation.
2. The difference in temperature at each frequency is obtained by subtracting the Run of the River values from the Existing Condition values.
3. The period covered by the frequency analysis was July 9, 2004 to September 4, 2004 and July 8, 2005 to September 8, 2005 when Existing Condition > 20ºC.
4. Existing Condition surface temperatures are between 0.07ºC and 0.55ºC lower relative to the Run of the River operational scenario.

**Figure 6-9**b

Frequency Distributions of the Daily Maximum Surface Temperatures for the Existing Condition and the Run of the River at Boundary Dam Forebay

Seattle City Light
Seattle, WA



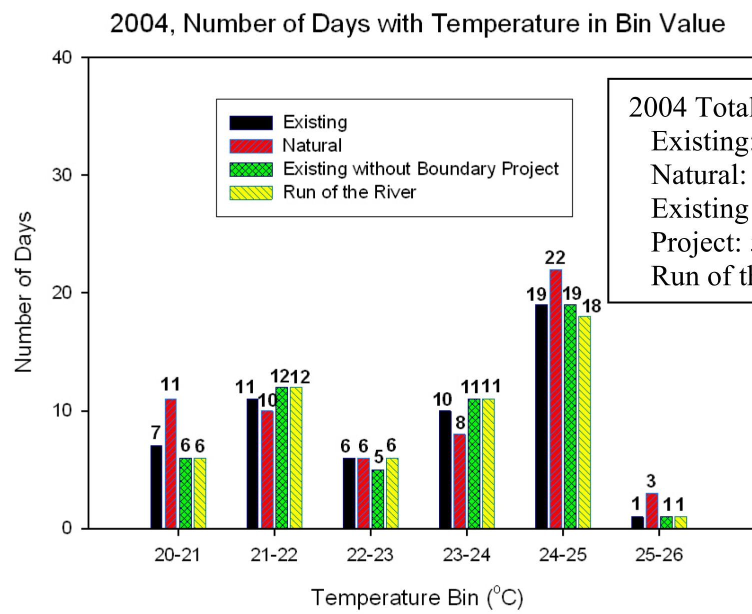

Notes:

1. Run of the River = run of river operation during the summer at 1974 ft elevation.
2. The difference in temperature at each frequency is obtained by subtracting the Run of the River values from the Existing Condition values.
3. The period covered by the frequency analysis was July 9, 2004 to September 4, 2004 and July 8, 2005 to September 8, 2005 when Existing Condition > 20ºC.
4. Existing Condition surface temperature differences are between -0.09ºC and +0.19ºC relative to the Run of the River operational scenario.

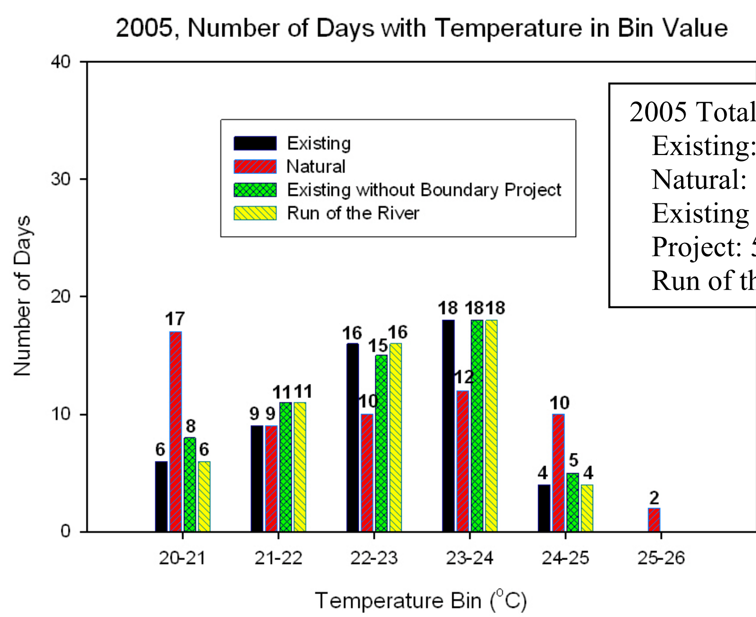
**Figure 6-9**c

Frequency Distributions of the Daily Maximum Surface Temperatures for the Existing Condition and the Run of the River at Boundary Dam Tailrace

Seattle City Light
Seattle, WA




2004 Total Number of Days
Existing: 54 days
Natural: 60 days
Existing without Boundary Project: 54 days
Run of the River: 54 days




2005 Total Number of Days
Existing: 53 days
Natural: 60 days
Existing without Boundary Project: 57 days
Run of the River: 55 days

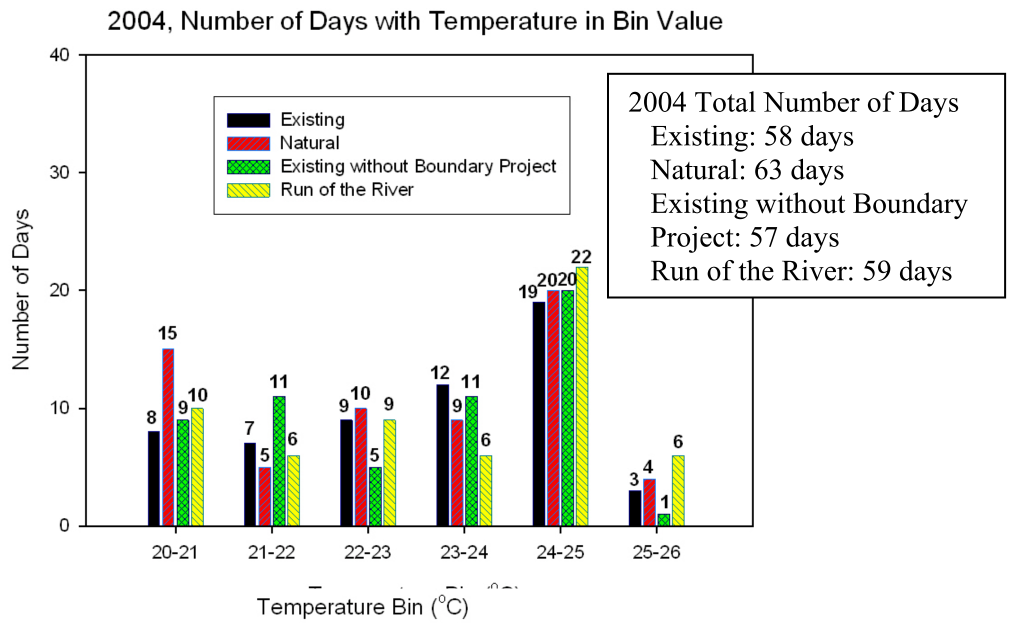
Notes:

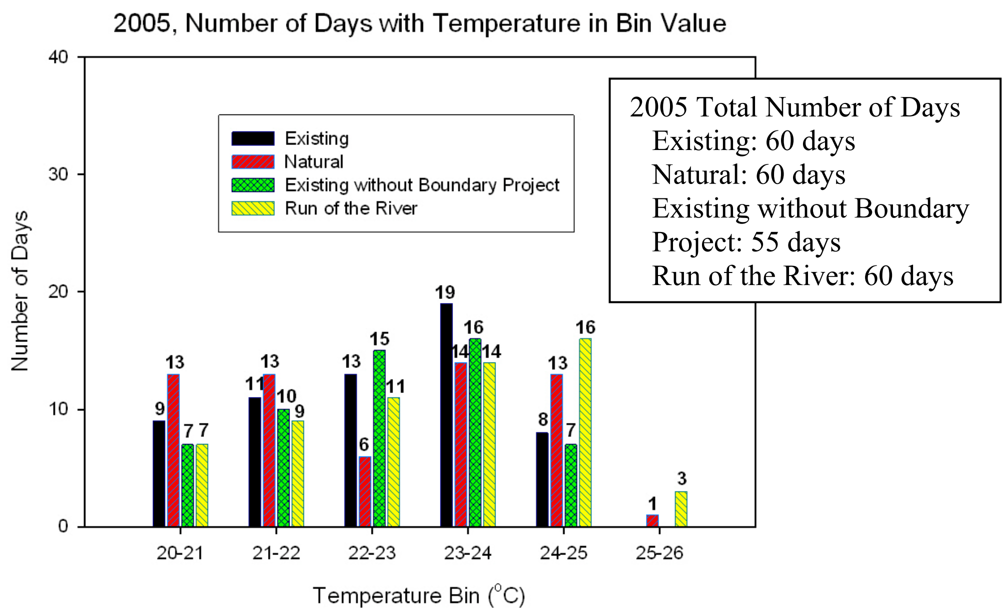
1. The total number of days for 2004 and 2005 was
   Existing – 107 days, Natural – 120 days,
   Existing without Boundary Project – 111 days
   Run of the River – 109 days
2. Peak annual surface temperatures at the Metaline Pool
   Existing – 2004: 25.07ºC & 2005: 24.41ºC
   Natural – 2004: 25.44ºC & 2005: 25.17ºC
   Existing without Boundary Project – 2004: 25.04ºC & 2005: 24.62ºC
   Run of the River – 2004: 25.02ºC & 2005: 24.52ºC

**Figure 6-10a**

Number of Days the Daily Maximum Surface Temperatures Exceeded 20ºC at the Metaline Pool for 2004 and 2005

Seattle City Light
Seattle, WA



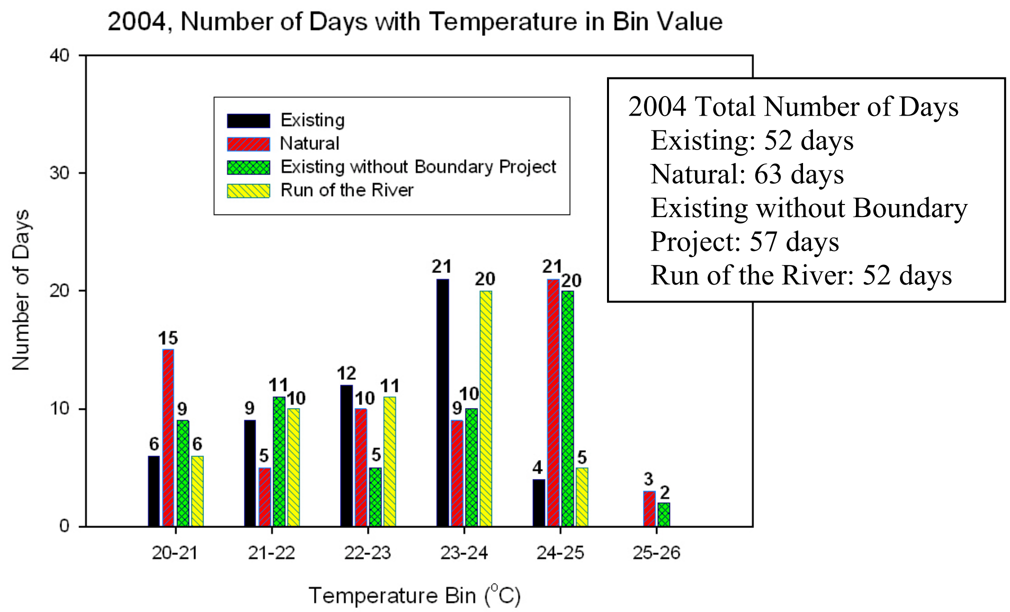

Notes:

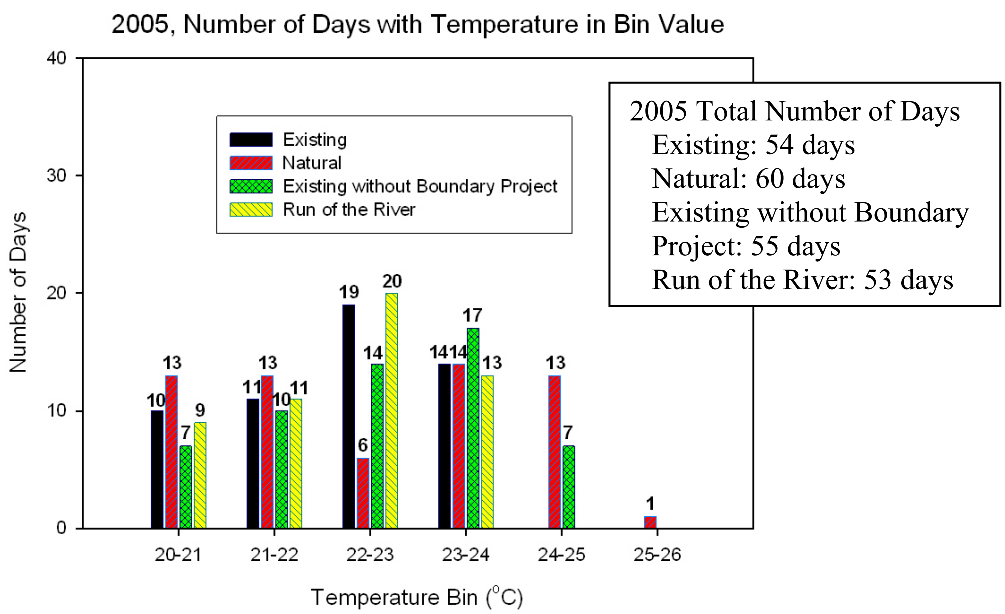
1. The total number of days for 2004 and 2005 was
   Existing – 118 days, Natural – 123 days,
   Existing without Boundary Project – 112 days,
   Run of the River – 119 days
2. Peak annual surface temperatures at the Boundary Dam Forebay
   Existing – 2004: 25.25ºC & 2005: 24.55ºC
   Natural – 2004: 25.29ºC & 2005: 25.15ºC
   Existing without Boundary Project – 2004: 25.07ºC & 2005: 24.68ºC
   Run of the River – 2004: 25.69ºC & 2005: 25.55ºC

**Figure 6-10b**

Number of Days the Daily Maximum Surface Temperatures Exceeded 20ºC at the Boundary Dam Forebay for 2004 and 2005

Seattle City Light
Seattle, WA




Notes:

1. The total number of days for 2004 and 2005 was
   Existing – 106 days, Natural – 123 days,
   Existing without Boundary Project – 112 days,
   Run of the River – 105 days
2. Peak annual surface temperatures at the Boundary Dam Tailrace
   Existing – 2004: 24.31ºC & 2005: 23.71ºC
   Natural – 2004: 25.29ºC & 2005: 25.15ºC
   Existing without Boundary Project – 2004: 25.14ºC & 2005: 24.77ºC
   Run of the River – 2004: 24.31ºC & 2005: 23.75ºC

**Figure 6-10c**

Number of Days the Daily Maximum Surface Temperatures Exceeded 20ºC at the Boundary Dam Tailrace for 2004 and 2005

Seattle City Light
Seattle, WA

# 7.0 Conclusion

Temperatures in the Pend Oreille River are influenced by many environmental factors but are most sensitive to the meteorological conditions and the hydraulic characteristics. Model simulations prepared by Ecology indicate that, in the Boundary Reach, temperatures under Natural Conditions would exceed the numeric state water quality criteria during many days in the summer months. The presence of reservoirs for hydroelectric power generation alters the distribution of heat load from solar radiation and also affects the hydrologic and hydraulic behavior of the river resulting in modification of the timing and distribution of temperature conditions.

This memorandum presents the results of a modeling-based assessment of the effect of Boundary Reservoir on the temperatures in the Pend Oreille River. As part of this evaluation, several items were examined including: (1) the method for accurately assessing temperature effect where lag time is present (via frequency analysis and flow-weighted temperature), (2) the total temperature difference at the Boundary Project due the presence of all dams on the Pend Oreille River (through comparisons between the Existing and Natural Conditions), (3) the apparent contribution of the Boundary Project to the total temperature difference, and (4) analysis of alternative operations including modeling of an alternative operations scenario consisting of run-of-river operations with a drawdown to 1974 feet NAVD 88 elevation during the summer. The analyses presented include the assessment of the flow-weighted daily maximum temperatures as well as the surface daily maximum temperatures, and provide results at three locations: Metaline Pool, Boundary forebay, and Boundary tailrace.

*Cumulative Frequency Analysis and Flow-Weighted Temperatures*

The use of cumulative frequency analyses is the appropriate method for assessment of temperature conditions in rivers whose hydrologic and hydraulic characteristics have been modified relative to the natural conditions (Section 2). Our analysis shows that the hydraulic characteristics in reservoirs, affected by the dam operations, induce a lag in the timing of the peak temperatures. This results in the temperatures in the Natural Condition being higher than in the Existing Condition during some periods (early summer) and vice versa in other periods (late summer). Closer examination also shows that maximum temperature differences (described in Sections 4, 5, and 6) occur mostly at the start of the warming period in July, and at the start of the cooling period in late August. At these times of year, the temperatures in the Natural Condition rise and fall more quickly than the temperatures in the Existing Condition. This is primarily due to the differences in travel time and thermal inertia between the two conditions. The Natural Condition responds faster to changes in atmospheric heating or cooling than does the Existing Condition. This delayed rise and fall in temperature does not reflect an addition of heat to the system, but rather the slower response time of Boundary Reservoir under Existing Conditions to rapid variation in atmospheric loading. Any comparison on one day therefore, is not an accurate reflection of relative temperature conditions. To make the comparisons in a manner inclusive of all relevant data points, an approach has been used that pools the data for the period during the critical summer months when temperatures exceed the 20˚C criterion. This method, referred to as the Frequency Analysis Approach, uses a cumulative frequency distribution of temperatures for each condition and makes the comparison by identifying the maximum temperature differences between the cumulative frequency curves. This approach eliminates the apparent temperature differences registered due to the effects of the travel time and thermal inertia differences between the Natural and Existing Conditions.

Similarly, analysis of flow-weighted temperatures best reflects temperature conditions in systems like the Boundary Reservoir that are deep but well-mixed, with a small temperature gradient (Section 3). This is especially relevant where examination of the data shows that maximum flow-weighted temperatures are the same or less under the Existing Condition (with Boundary Dam) than for the Existing Condition without Boundary Project (Table 5-2). As shown in Figures 5-5 a, b, and c, peak annual temperatures are similar (≈25˚C) with and without the Boundary Dam, but the presence of the dam results in a slight overall reduction in the peak annual temperature relative to the Existing Condition without Boundary Project. As shown in Figures 5-10 a, b, and c, when focusing exclusively on surface temperatures, the presence of the dam does not appear to cause peak temperatures to be consistently higher than they would be without the dam.

*Effect of all Dams on Boundary Project Temperatures*

Using the frequency analysis approach, at the Boundary forebay, the largest difference (that is, the increase in temperature above the Natural Condition) under the Existing Condition is 0.20ºC for the flow-weighted temperatures and 0.76ºC for the surface temperatures. These numbers include the effects of all the upstream influences including Box Canyon Dam and Albeni Falls Dam, as well as Boundary Dam. The contribution of dams other than Boundary to the total temperature difference was evaluated by simulating the Existing Condition without Boundary Project, but leaving the upstream dams in place. At the Boundary forebay, the maximum difference relative to the Natural Condition was found to be 0.40ºC for both the flow-weighted and surface temperatures. These temperatures are the same, because in the Existing Condition without Boundary Project, the reach downstream of Box Canyon Dam is an unimpounded river system and is completely mixed.

*Effect of Boundary Project Operations on Boundary Project Temperatures*

The above flow-weighted results could be interpreted to indicate that the potential effect of the upstream impoundments at the Boundary Dam forebay station is 0.40˚C (Existing Condition without Boundary Project) and -0.20˚C (0.20˚C – 0.40˚C) is attributed to the effect on temperature produced by Boundary Reservoir. Accordingly, the effect of Boundary Reservoir is actually to reduce the flow-weighted temperature at the Boundary forebay. Similar results were obtained at the Metaline Pool and Boundary tailrace stations, indicating that **the Boundary Project does not contribute to increased flow-weighted daily maximum temperatures at any of the locations within the Project area (Section 5.1 and Table 5-2).**

In Section 5.0, a comparison between the Existing Condition and the Existing Condition without Boundary Project was also provided as another means of estimating the relative contribution of Boundary project operations to temperature conditions. The fact that Boundary Reservoir does not contribute to, and may actually reduce flow-weighted temperatures is corroborated in this assessment by showing a decline in maximum flow-weighted temperatures of 0.15˚C at the Boundary forebay due to Boundary Dam (Section 5.1, Table 5-2 and Figure 5-4 b). Similar results were obtained at the Metaline Pool and Boundary tailrace stations, indicating that the Boundary Project does not contribute to increased flow-weighted daily maximum temperatures at any of the locations within the Project area (Section 5.1, Table 5-2 and Figures 5-4 a and c).

The surface temperature results could be interpreted to indicate that the potential effect of the upstream impoundments at the Boundary Dam forebay station is 0.4˚C (Existing Condition without Boundary Project), and 0.36˚C (0.76˚C − 0.40˚C) could then be attributed to the effect on temperature produced by Boundary Reservoir (Table 5-3). However, a comparison between the Existing Condition and the Existing Condition without Boundary Project shows that a maximum surface temperature difference of 0.58˚C may be attributable to Boundary Dam. Similar comparisons at Metaline Pool and Boundary tailrace indicate that, **while the Project may contribute to increased surface daily maximum temperatures at the Boundary forebay, the Boundary Project does not contribute to significant increases in surface daily maximum temperatures at Metaline Pool or Boundary tailrace, and may actually contribute to reductions compared to conditions without the Project (Section 5.2, Table 5-3 and Figures 5-9 a, b, and c).**

*Number of Days above 20°C and Peak Annual Temperatures*

In addition to the Frequency Analysis Approach, the number of days during which the flow-weighted temperature were above 20°C were determined for each case (Section 5.1, Table 5-3). This analysis demonstrated that, at all locations, the Existing Condition actually resulted in fewer days with flow-weighted temperatures above 20°C than did the Natural Condition and fewer even than the Existing Condition without Boundary Project. Similarly, at all locations, peak annual flow-weighted temperatures in both years were lowest under the Existing Condition and higher in the Existing Condition without Boundary Project and in the Natural Condition. **Accordingly, at all locations, the Boundary Project does not increase the number of days with flow-weighted temperatures above 20°C or increase the peak annual flow-weighted daily maximum temperatures.**

The number of days during which the surface temperatures were above 20°C were also determined for each case (Section 5.2, Table 5-5). They indicate that, at all locations, both the Existing Condition and the Existing Condition without Boundary Project had fewer days with surface temperatures above 20ºC, and had lower peak annual surface temperatures, than did the Natural Condition. Relative to the Existing Condition, it appears that some improvement in the number of days with surface temperatures above 20ºC could be achieved at the Boundary forebay station by removing Boundary Dam. However, doing so would not improve surface temperature conditions at the Metaline Pool station, and would actually worsen surface temperature conditions at the Boundary tailrace station. **Accordingly, while the Boundary Project may increase the number of days with surface temperatures above 20°C at the Boundary forebay, the Boundary Project either has no effect on or actually improves this parameter, as well as peak annual surface temperatures, at the Metaline Pool and Boundary tailrace stations.**

*Alternative Operations Analysis - Run-of-river Scenario at 1974 ft*

SCL conducted an alternative operations analysis to evaluate whether there were operational changes that could lower surface daily maximum temperatures at the forebay of Boundary Dam (Section 6). To do so, SCL evaluated the temperature effects of the most extreme operational modification possible consistent with operational constraints in order to provide an outer bound on possible alternative operational scenarios relative to current operations. Results presented in Section 6.0 show that the Run-of-river scenario at 1974 ft (NAVD88) during the summer would have insignificant effects on flow-weighted temperatures at all stations (Figures 6-4 a, b and c) and on surface temperatures at the Metaline Pool and Boundary tailrace stations (Figures 6-9 a and c). However, the alternative operations scenario would actually result in an increase in daily maximum surface temperatures at the Boundary forebay station throughout the entire critical summer month time period (Figure 6-9 b).

It is noted that this result is counterintuitive as one would expect the run-of-river at a lower pool elevation operation to improve temperatures by reducing the storage of warm water, reducing depth, and reducing heating due to reduced water surface area. However, a closer examination showed that the area affected by the drawdown is mostly canyon, and accordingly the reduction in surface area with reduced elevation is relatively small. Further, in the current and proposed peaking mode operation, during the night, the flow rate is near zero, whereas during the day flow rate is double the daily average flow rate. In contrast, for the run-of-river operation, because outflow equals inflow, the flow rate during the day is only half of what it is in the Existing Condition which effectively slows down the river speed during the day relative to existing current peaking mode operation, i.e., water velocity during the day in the Existing Condition is nearly twice as high as in the Run-of-river condition. Finally, the reduced water depth in the Run-of-river, Elevation 1974 alternative operations scenario increases temperature amplitude in the Boundary forebay. This, coupled with slower travel time, causes surface temperatures to be warmer than under current operations.

These results of the alternative operations analysis indicate that, rather than reducing or eliminating the surface maximum temperature effect observed at the Boundary forebay, the most extreme change in operations possible consistent with physical Project constraints would instead worsen surface temperature conditions at the forebay. **Accordingly, there do not appear to be operational changes that could lower surface daily maximum temperatures at the forebay of Boundary Dam.**