MARTIN RIVER TEMPERATURE IMPACT ASSESSMENT

BRADLEY LAKE HYDROELECTRIC PROJECT

BRADLEY LAKE EXPANSION

FERC NO. 8221

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ACRONYMS AND ABBREVIATIONS

°C	degrees Celsius
7DADM	7-day average of the daily maximum
A	
AEA	Alaska Energy Authority
B	
Bradley Lake Project	Bradley Lake Hydroelectric Project (Federal Energy Regulatory Commission Project No. 8221)
C	
cfs	cubic feet per second
D	
DO	dissolved oxygen
E	
EFMR	East Fork Martin River
K	
Kleinschmidt	Kleinschmidt Associates
M	
mg/L	milligram(s) per liter
N	
NA	not available
NTU	nephelometric turbidity unit
O	
OCH	off-channel habitat
P	
Project	Bradley Lake Expansion Project
R	
RM	River Mile

U

USGS	U.S. Geological Survey

W

WFMR	West Fork Martin River

1.0 INTRODUCTION

1.1 Background

The Alaska Energy Authority (AEA), Licensee and owner of the 120-megawatt Bradley Lake Hydroelectric Project (Bradley Lake Project; Federal Energy Regulatory Commission Project No. 8221), is pursuing a license amendment for the proposed Bradley Lake Expansion Project (Project). The Project would divert water from the Dixon Glacier outflow from May through November (AEA 2022a) to Bradley Lake, potentially impacting water quality in the mainstem Martin River including water temperature. The Water Quality Monitoring Study provided baseline data to support the evaluation of the potential effects of the Project on water quality in the Martin River with respect to state standards (Table 1-1) and habitat for fish and aquatic life by measuring water quality parameters that have the potential to be impacted by the proposed Project. The mainstem Martin River is used by salmonids as a migration corridor, therefore the 15 degrees Celsius (°C) (59 degrees Fahrenheit) temperature standard for migration routes is applicable (Table 1-1).

AEA began implementing the Water Quality Monitoring Study in 2023 as described in the Draft Study Plan (AEA 2022b). The 2023 monitoring effort and results were summarized in a February 2024 report (Kleinschmidt Associates [Kleinschmidt] 2024). The 2024 monitoring effort and results were summarized in a May 2025 report (Kleinschmidt 2025a). In 2025, AEA added temperature and discharge monitoring sites (Figure 1-1) to estimate the potential impacts of the proposed Project on water temperature in the Martin River. This report describes the methods and results of the analysis.

Table 1-1 Water quality standards for Alaska freshwater uses.

Pollutant	Criteria
Dissolved Gas	Dissolved oxygen (DO) must be greater than 7 milligrams per liter (mg/L) in waters used by anadromous or resident fish. In no case may DO be less than 5 mg/L to a depth of 20 centimeters in the interstitial waters of gravel used by anadromous or resident fish for spawning. For waters not used by anadromous or resident fish, DO must be greater than or equal to 5 mg/L. In no case may DO be greater than 17 mg/L. The concentration of total dissolved gas may not exceed 110 percent of saturation at any point of sample collection.

Pollutant	Criteria
pH	May not be less than 6.5 or greater than 8.5. May not vary more than 0.5 pH unit from natural conditions.
Temperature	May not exceed 20°C at any time. The following maximum temperatures may not be exceeded where applicable: Migration routes 15°C Spawning areas 13°C Rearing areas 15°C Egg and fry incubation 13°C For all other waters, the weekly average temperature may not exceed site-specific requirements needed to preserve normal species diversity or to prevent the appearance of nuisance organisms.
Turbidity	May not exceed 25 nephelometric turbidity units (NTUs) above natural conditions. For all lake waters, may not exceed 5 NTUs above natural conditions.

Source: Alaska Department of Environmental Conservation (2020).
Note. The water quality standards listed in this table include the criteria for the growth and propagation of fish, shellfish, other aquatic life, and wildlife.

1.2 Goals and Objectives

The goal of the Temperature Impact Assessment is to quantify the potential impacts of the Project on water temperature in the mainstem Martin River. Waters potentially affected by the proposed Project are identified as Class C waters by the State of Alaska, intended to protect the designated use of growth and propagation of fish, shellfish, other aquatic life, and wildlife. As part of the overall effort, data were collected under the Water Quality Monitoring Study to characterize water quality in the Martin River basin. The purpose of the data collection and the temperature assessment is to evaluate the compliance with water quality criteria as well as summarize the potential temperature changes from current conditions to operations with the Project.

1.3 Study Area

The study area included the mainstem Martin River and associated off-channel habitat (OCH) from the constriction near River Mile (RM) 1.9 upstream to the confluence of the East Fork Martin River (EFMR) and West Fork Martin River (WFMR), the mouth of EFMR, and WFMR downstream from the outlet of Red Lake. Water quality monitoring locations are shown in Figure 1-1.

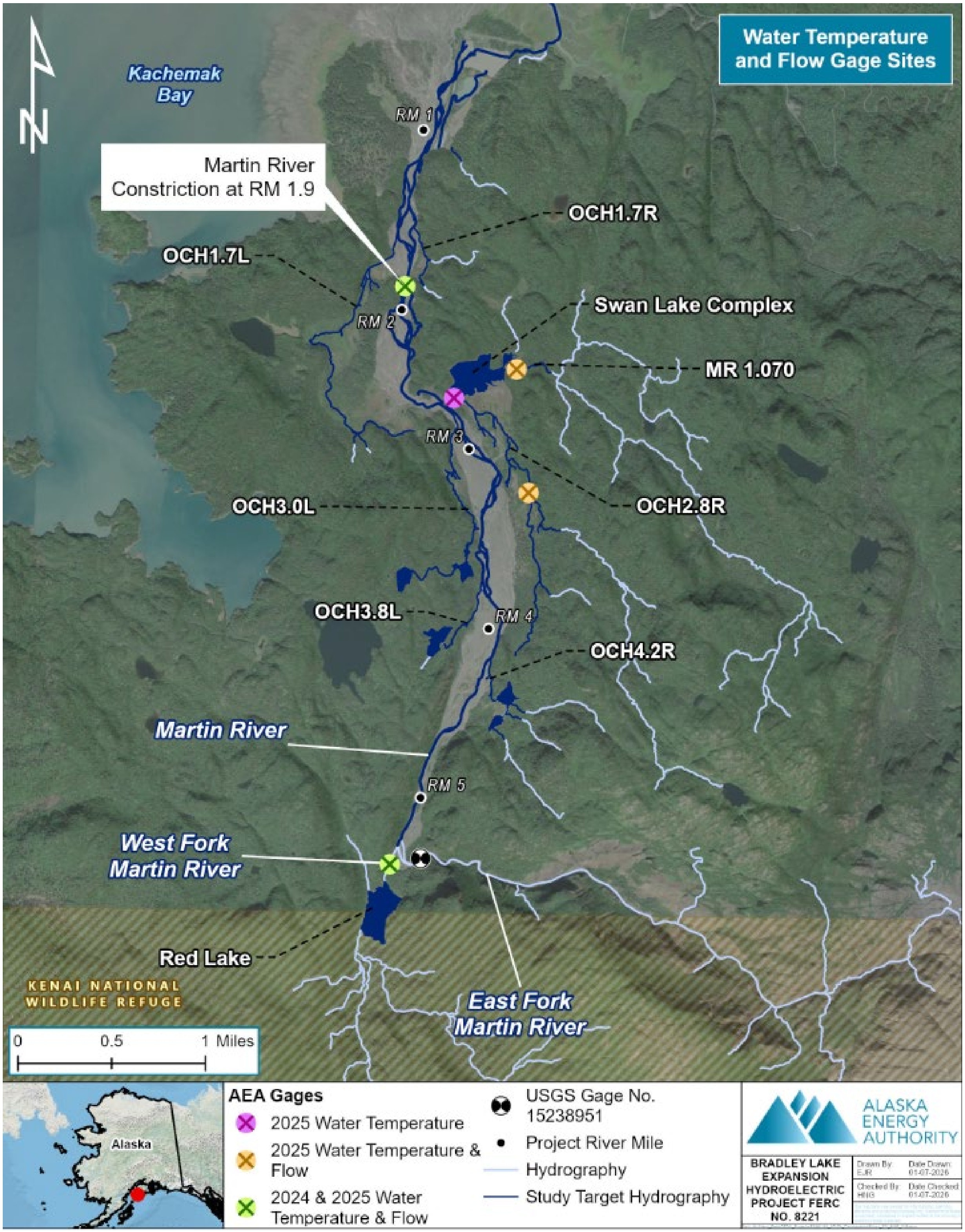

Figure 1-1 Martin River water quality monitoring sites.

2.0 SUMMARY OF FLOW AND TEMPERATURE DATA COLLECTED

Data collected in 2024 and 2025 that were used in the Martin River Temperature Impact Assessment are summarized in the sections below. All data were collected in 15-minute increments.

2.1 2024

Water temperatures measured in 2024 are shown in Figure 2-1. Unfortunately, a gap in data is present between July 23, 2024, through August 30, 2024, for WFMR when the logger was buried under sediment from the August 7, 2024 high flow event. Measured temperatures in 2024 were significantly lower than the ADEC temperature standard at the EFMR site, but they came close to the standard in June at the WFMR site and exceeded it for several hours on June 24, 2024. Measured streamflow for WFMR is provided in Figure 2-2 for 2024.

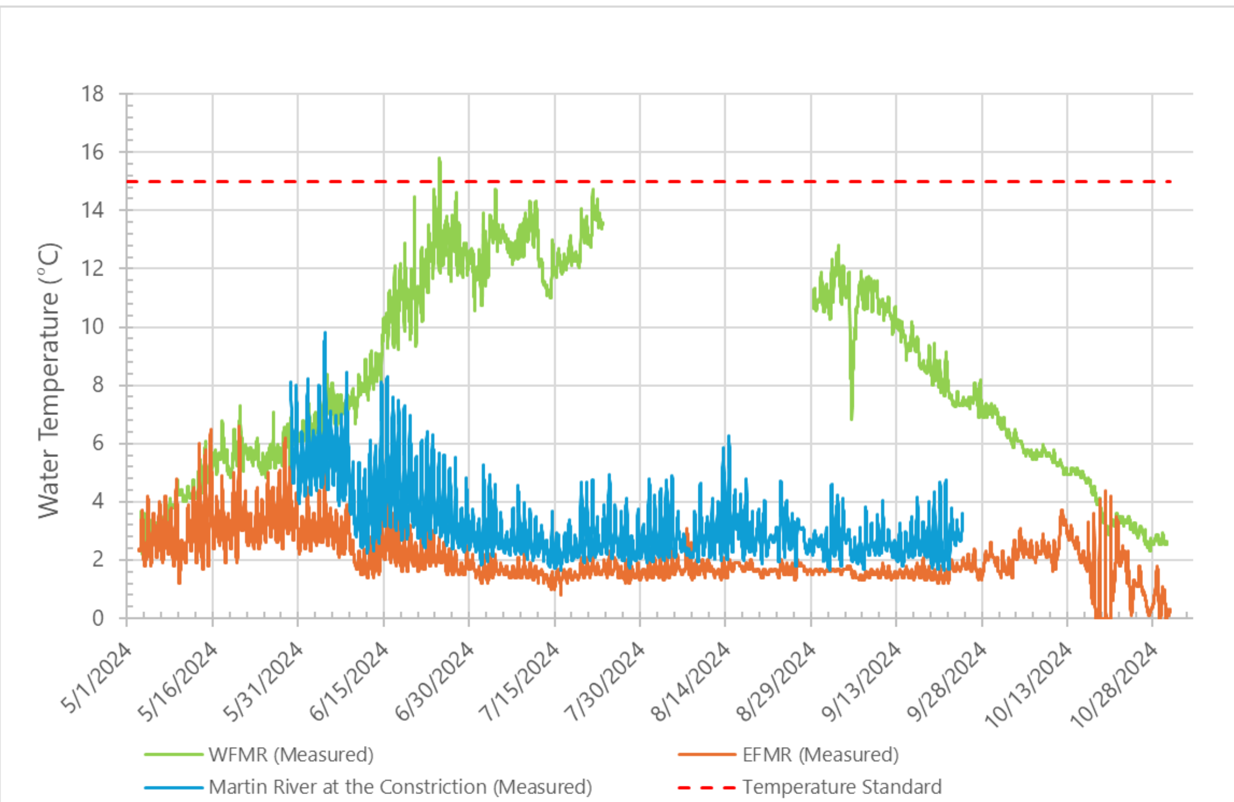

Figure 2-1 Measured water temperature in the Martin River, 2024.

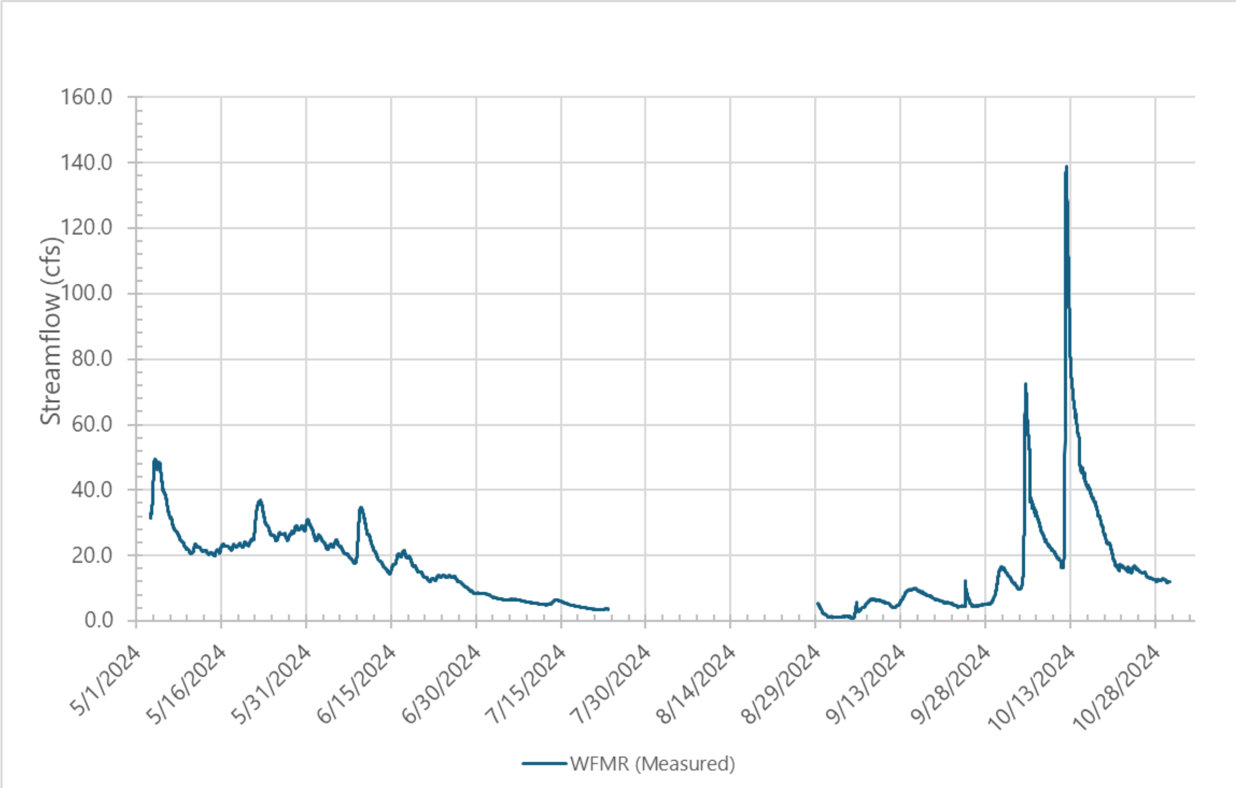

Figure 2-2 Measured streamflow for WFMR, 2024.

2.2 2025

Water temperatures measured in the Martin River and tributaries during 2025 are shown in Figure 2-3. Temperature monitoring at the Swan Lake Outlet site was added in 2025. Measured temperatures in 2025 were significantly lower than the ADEC water temperature standard at both EFMR and Martin River at the constriction, but they came close to the standard and exceeded the standard on several days in July and August at the WFMR site. Measured water temperature for three locations near Swan Lake (OCH2.8R, MR1.070, and Swan Lake Outlet) are provided in Figure 2-4. Between June 21 and September 5, 2025, the mainstem Martin River flow was high and flowed into the OCH2.8R complex at its upstream end and into Swan Lake through the new channels that were developed during the August 2024 high flow event (Dowl, personal communication November 20, 2025). Data for this period for the Swan Lake Outlet and OCH2.8R sites were not used for this mainstem Martin River temperature assessment, as the data are not representative of incoming temperatures from the off-channel/tributary complexes. During high flow or backwater periods, the mainstem river pushes water into to the OCH2.8R and Swan Lake Outlet sites such that the incoming temperature from these inflows occur somewhere upstream. As a result, the measured temperatures are indicative of the mainstem or a mix of the two and are not representative of incoming conditions. Measured streamflow for the Martin River and its tributaries is provided in Figure 2-5 for 2025. Similar to the temperature data, streamflow data for OCH2.8R were not reported for the same period due to backwatered conditions.

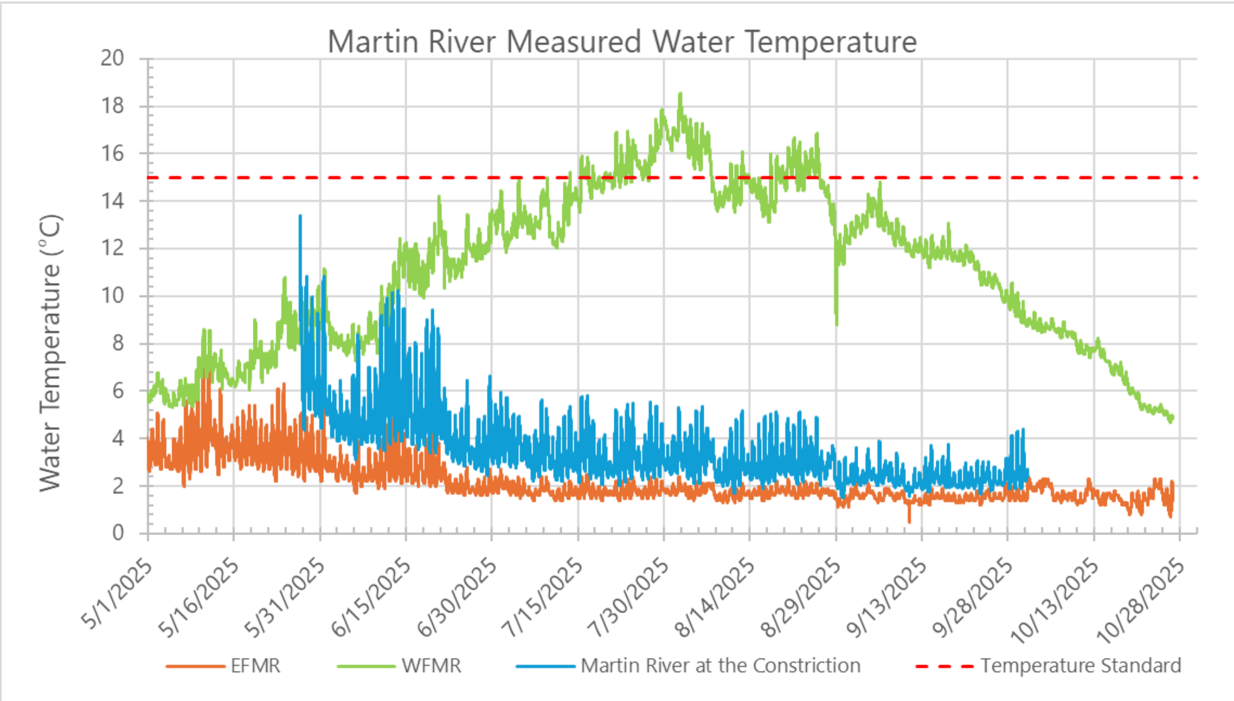

Figure 2-3 Measured water temperature for select locations in the Martin River, 2025.

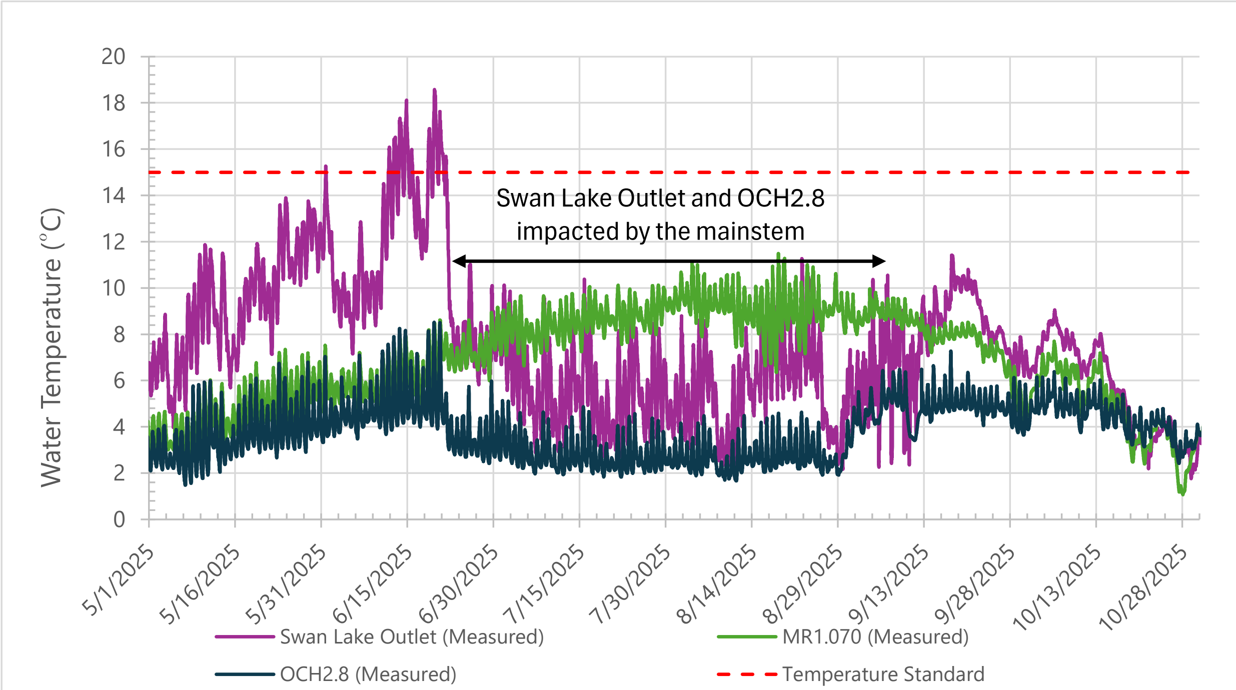

Figure 2-4 Measured water temperature for monitoring locations near Swan Lake, 2025.

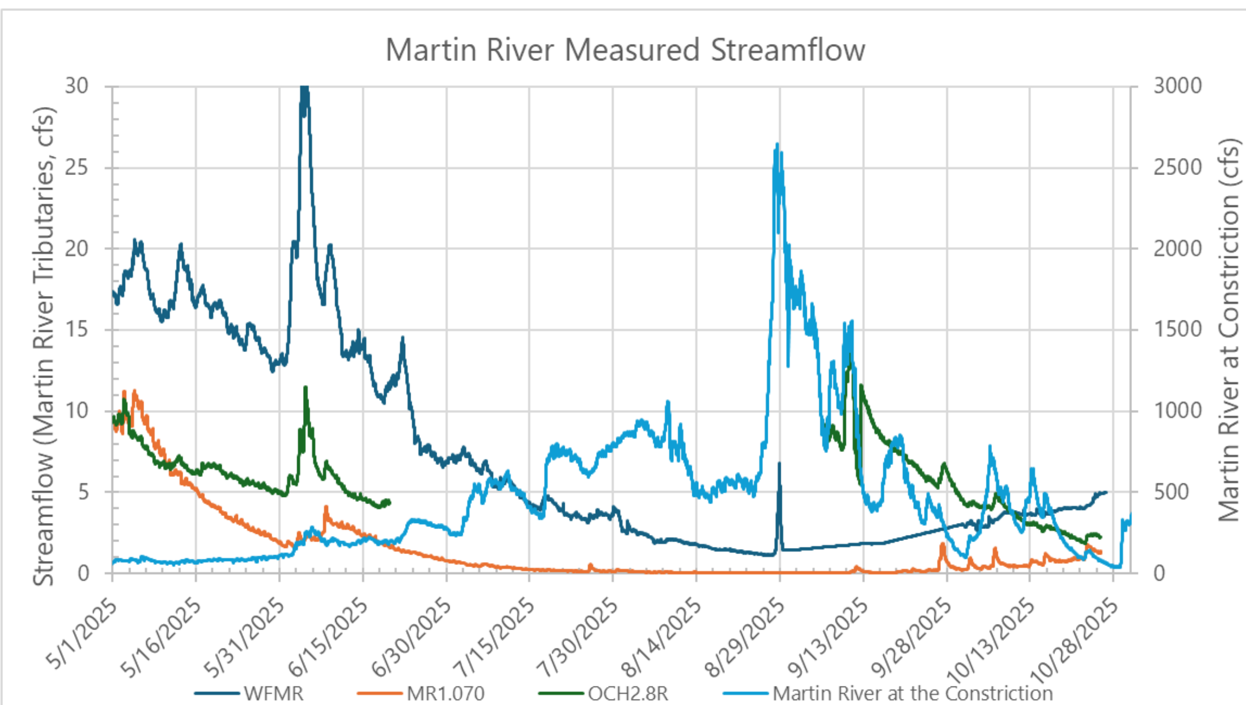

Figure 2-5 Measured streamflow for the Martin River and tributaries, 2025.

3.0 ASSESSMENT METHODS

3.1 With-Project Temperature Assessment Calculations

Water temperature impacts under Project operations were assessed using a mass balance approach and computations of solar radiation were used to estimate temperature conditions of the Martin River at the constriction in comparison to baseline conditions.

Four key steps were used for the assessment:

1) Estimate temperature in the mainstem Martin River below the EFMR/WFMR confluence. This step relied on measured temperature and flow from EFMR and WFMR and assumed waters were fully mixed immediately below the confluence. Water temperature can be estimated from the mass balance equation:

   $T_{Below\ Confluence} = (Q_{WFMartin}T_{WFMartin} + Q_{EFMartin}T_{EFMartin})/(Q_{WFMartin}+Q_{EFMartin})$

   Where:

   $T_{Below\ Confluence}$ = Estimated temperature in the Martin River just downstream of the EFMR/WFMR confluence
   $Q_{WFMartin}$ = Measured discharge for WFMR (i.e., Red Lake Outlet)
   $T_{WFMartin}$ = Measured temperature in WFMR (i.e., Red Lake Outlet)
   $Q_{EF\ Martin}$ = Discharge from EFMR
   $T_{EFMartin}$ = Measured Temperature in EFMR

2) Using the above algorithm, water temperature in the Martin River was estimated for a minimum instream flow in EFMR of 100 cubic feet per second (cfs). This calculation assumed water temperature in EFMR can be adequately represented by the water temperature at the U.S. Geological Survey (USGS) gage despite the reduction in flow due to the diversion to Bradley Lake. This assumption is reasonable given the relatively short travel time through steep canyon terrain with limited solar inputs. At a velocity of 5 feet per second, which is the maximum velocity for a flow of 100 cfs predicted from the hydraulic model at the downstream end of the EFMR, it would take just over 1 hour for water to travel the 3.7 miles from the Dixon Diversion to the EFMR/WFMR confluence.

3) This analysis used direct solar radiation to estimate the increase in water temperature from the EFMR/WFMR confluence to above the Swan Lake Outlet. Direct solar radiation is the solar energy reaching the top of the atmosphere without being filtered by any atmospheric factors, such as air, cloud, wind, shade, and moisture, and it represents the maximum possible energy the earth's surface could receive. Direct solar radiation was used for this analysis because meteorology (i.e., wind speed, cloud cover, dew point temperature, etc.) or atmospheric

conditions (i.e., dust coefficient, refraction coefficient, etc.) were not readily available at the Project site. However, the water temperature increase estimated with direct solar radiation in the absence of meteorological or atmospheric conditions results in the maximum possible temperature increase. The increase in water temperature based on the direct solar radiation was calculated as 4.2°C in the 2.3-mile reach between the EFMR/WFMR confluence and Swan Lake as shown in Appendix A. Tributary flow inputs between the EFMR/WFMR confluence and Swan Lake were not included in the analysis because their contributions were relatively small. Spot flow measurements were collected at three small tributaries (OCH3.0L, OCH3.8L, and OCH4.2R) in this reach during the 2025 field season to confirm this assumption. Measured flows were collected on three dates and ranged from 0.78 to 2.62 cfs, with the total flow from all three ranging from 3.9 to 4.8 cfs. Water temperature collected at OCH3.0L and OCH3.8L were all less than 10°C, while water temperature at OCH4.2R ranged from 7 to 15°C, but this off channel-tributary complex had the smallest contribution of flow ranging from only 0.4 to 0.7 cfs. The maximum total flow of 4.8 cfs accounts for less than 4.5 percent of the flow in the mainstem with the project assuming 11.3 cfs for WFMR (i.e., spring flow as determined from the hydraulic model [Kleinschmidt 2025b]) and a minimum instream flow of 100 cfs from EFMR. Given the measured flows and water temperatures, these tributaries are not expected to have an appreciable impact on the mainstem Martin River temperature.

4) Estimate temperature downstream of Swan Lake using a mass balance approach assuming full mixing between the mainstem Martin River and water from Swan Lake:

$$T_{BelowSL} = (Q_{SwanLake}T_{SwanLake} + Q_{Martin}T_{Martin})/(Q_{SwanLake}+Q_{Martin})$$

Where:

TBelowSL = Temperature in the Martin River just downstream of Swan Lake

QSwanLake = Measured discharge out of Swan Lake (estimated as the sum of OCH2.8R and Tributary MR1.070)

TSwanLake = Temperature at Swan Lake Outlet

QMartin = Discharge for the Martin River above Swan Lake estimated as QWFMartin + QEFMartin

T_{Martin} = Temperature in the Martin River above Swan Lake (estimated from Step 2)

This step relied on water temperature and flow from the previous step and Swan Lake Outlet. Swan Lake Outlet flow (i.e., $Q_{SwanLake}$) was approximated from the measured discharge into the lake from OCH2.8R and MR1.070. Accretion in the Martin River between EFMR and the Swan Lake Outlet was assumed to be negligible, such that the flow in the Martin River above Swan Lake (i.e., Q_{Martin}) was assumed to be the sum of Red Lake Outlet and EFMR.

5) Use direct solar radiation to estimate the increase in water temperature from the Martin River below the Swan Lake Outlet to the constriction at RM 1.9. This calculation used the same algorithm detailed in Step 2. The maximum increase in water temperature was calculated as 1.6°C as shown in Appendix A. Tributary flow inputs in this reach were assumed to be negligible. OCH1.7L is the largest tributary contributing flow in this reach and had two measurements in 2025 of 1.6 cfs and 2.2 cfs. Assuming a WFMR flow of 11.3 cfs (i.e., spring flow as determined from the hydraulic model [Kleinschmidt 2025b]) and a minimum instream flow of 100 cfs in EFMR, this tributary flow represents less than 2 percent of the total flow in the Martin River under the with project scenario.

These calculations were performed for available data in 2024 and 2025. No flow or temperature records were available for Swan Lake Outlet in 2024, so the analysis stopped after Step 2 in 2024. Data were available for all necessary locations in 2025, so all steps were completed. However, a data gap for Swan Lake Outlet in 2025 required synthesis of estimated data for this period as described in the section below.

3.2 Synthesized Temperature and Flow for Swan Lake Missing Periods

Calculations as described in Section 3.1 cannot be performed for periods with missing data, which severely limits the analysis period, as a data gap existed for Swan Lake Outlet from June 19 through September 5, 2025 when the monitoring site was influenced by the mainstem Martin River flow. To extend the period of analysis, worst-case conditions were assumed for Swan Lake Outlet temperature and flow.

Estimated Swan Lake Outlet temperatures are provided in Figure 3-1. Measured Swan Lake temperature in the beginning of summer follows a similar pattern to measured Red Lake temperature as can be seen from the overlapping period of record for May 1 through June 19, 2025, in Figure 3-1. On average, the Swan Lake Outlet temperature was 2.2°C higher than the Red Lake Outlet temperature, but the difference was as large as 4.5°C. The largest temperature difference was confirmed by reviewing available temperature data at the two locations in 2024. The Swan Lake Outlet temperature during the missing period was estimated by adding 4.5°C to the Red Lake Outlet temperature. By fall (i.e., September/October period), the measured Swan Lake Outlet temperature was several degrees cooler than WFMR, and therefore the assumption used to synthesize the Swan Lake Outlet temperature was a conservative one.

Streamflow measurements for the same period were also not representative of the tributary inflows from Swan Lake and OCH2.8R and were therefore excluded from the analysis. The last streamflow reading on June 19, 2025, was 4.4 cfs, and the next reading on September 5, 2025, was 9.2 cfs, as shown in Figure 2-5. The actual streamflow was likely somewhere between 4 to 9 cfs. For the temperature analysis, the flow for June 19 through September 5 was assumed to be 8.4 cfs, the same as the average of the measured streamflow readings on September 6, 2025, the first full day of measured flows once the backwater receded. In all, these two assumptions likely slightly overestimated both the temperature and flow out of Swan Lake, which would, in turn, overestimate the potential impact of the Project on the mainstem water temperatures and therefore be a conservative approach to evaluate the Project.

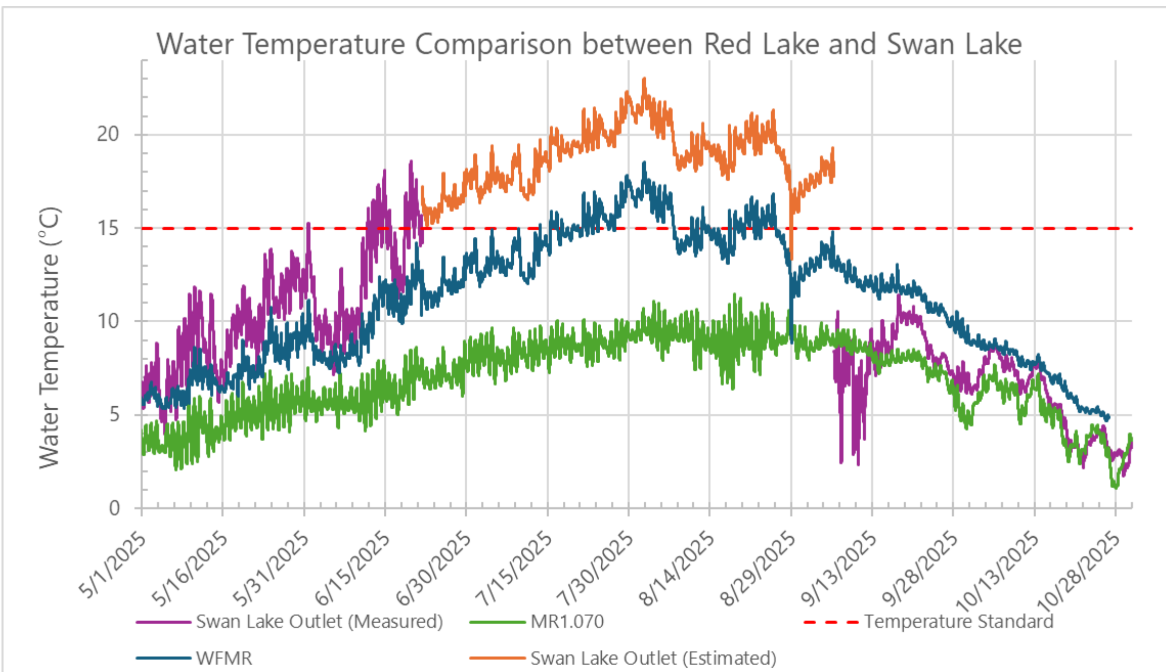

Figure 3-1 Measured and estimated temperature for Swan Lake Outlet, 2025.

3.3 Project Operations

Project operations are projected to occur from May 1 through November 30. During this time, proposed minimum instream flows in EFMR would be 100 cfs. The proposed Dixon Diversion tunnel capacity is 1,650 cfs. When flow in EFMR exceeds the tunnel capacity plus the 100 cfs EFMR minimum instream flow, the excess flow would remain in the river. However, for the purposes of this analysis, it was assumed that flow in EFMR would be limited to 100 cfs providing a worst-case condition for flows.

4.0 RESULTS

Results for the 2 years with available data are presented in the sections below.

4.1 2024

The calculated temperatures for the Martin River below the EFMR/WFMR confluence and for the Martin River above Swan Lake are shown in Figure 4-1. As can be seen from this figure, temperatures in the Martin River at both locations below the EFMR/WFMR confluence were well below the 15°C ADEC standard. No baseline temperature data were available for comparison. Temperatures in the WFMR come close to the standard and in some cases exceed it but the project is located outside of the WFMR basin and will not impact either the flow or temperature in the WFMR.

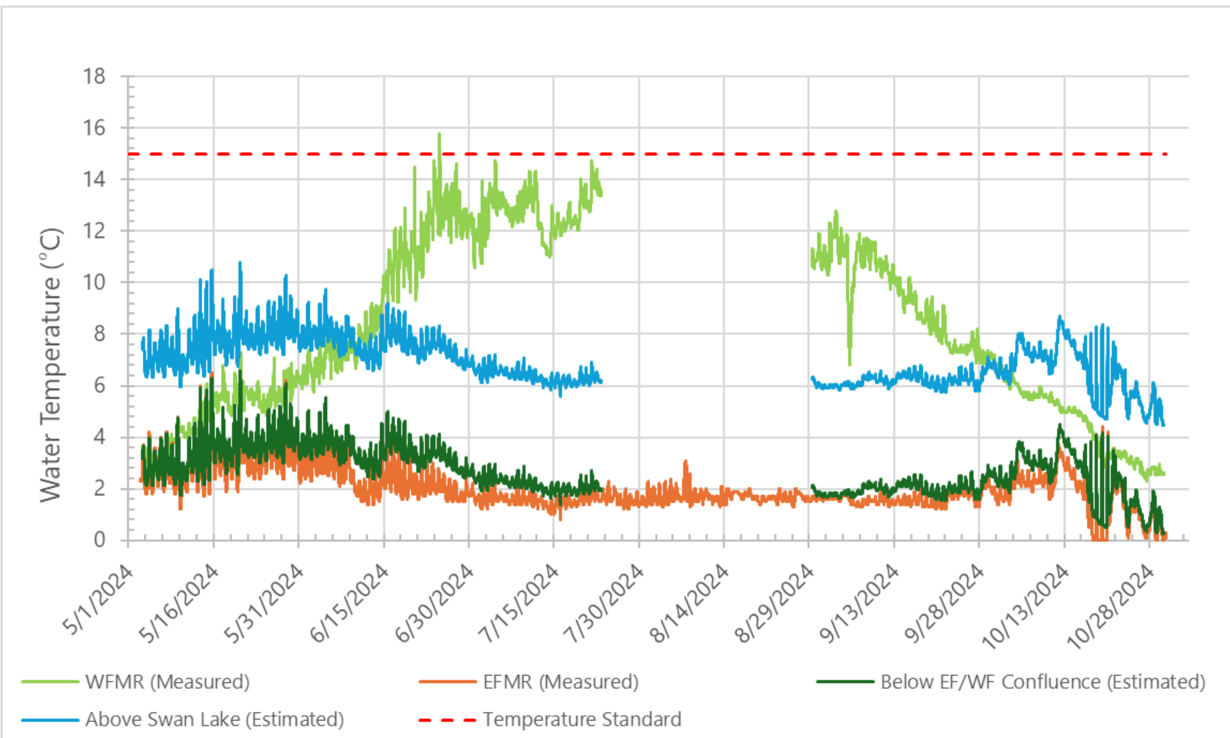

Figure 4-1 Calculated Martin River temperature with proposed Project operations, 2024.

4.2 2025

The calculated temperature for the Martin River at various locations is shown in Figure 4-2. As can be seen from this figure, temperatures in the Martin River at the three locations below the EFMR/WFMR confluence were well below the 15°C standard. Temperatures in the WFMR exceed the standard in July and August but the project is located outside of the WFMR basin and will not impact either the flow or temperature in the WFMR.

A comparison of the temperature for Martin River at the constriction under baseline and with-Project conditions is provided in Figure 4-3 which shows that the temperature in the Martin River at the constriction was as much as 6°C warmer under the with-Project condition than under baseline based on worst case assumptions as previously described. However, the maximum temperature in the Martin River at the constriction was modeled as 13°C on several dates in May, which is well below the 15°C ADEC standard. Comparison of the monthly average temperature under baseline and with Project is provided in Table 4-1. Average differences ranged from 3.8°C to 5.9°C. Comparison of the monthly maximum of the 7-day average of the daily maximum (7DADM) is provided in Table 4-2. The 7DADM represents the arithmetic average of seven consecutive measures of daily maximum temperatures and is recommended by recent U.S. Environmental Protection Agency guidance (ADEC 2021-2204 Triennial Review Factsheet Undated). The 7DADM reflects an average of maximum temperatures that fish are exposed to over a week-long period but is not overly influenced by the maximum temperature of a single day. Average differences of the maximum 7DADM ranged from 4.2°C to 5.4°C.

Keep in mind, the estimated temperatures in the Martin River as shown in Figure 4-2 and Figure 4-3 and summarized in Table 4-1 and Table 4-2 represent worst-case conditions for 2025 because flows in EFMR were assumed to be 100 cfs at all times, the maximum solar radiation inputs were used, and higher temperature and flow conditions than expected for Swan Lake Outlet were assumed during the June 19 to September 5, 2025 period. The maximum solar radiation inputs do not mimic natural temperature diurnal fluctuations but estimate a worst-case condition, which is not environmentally realistic. Given the modeling approach and these assumptions, the estimates of temperature in the Martin River at the constriction are likely over predicted and yet indicated the temperatures would remain below ADEC's water temperature standard for both salmonid migration routes and spawning areas (15°C).

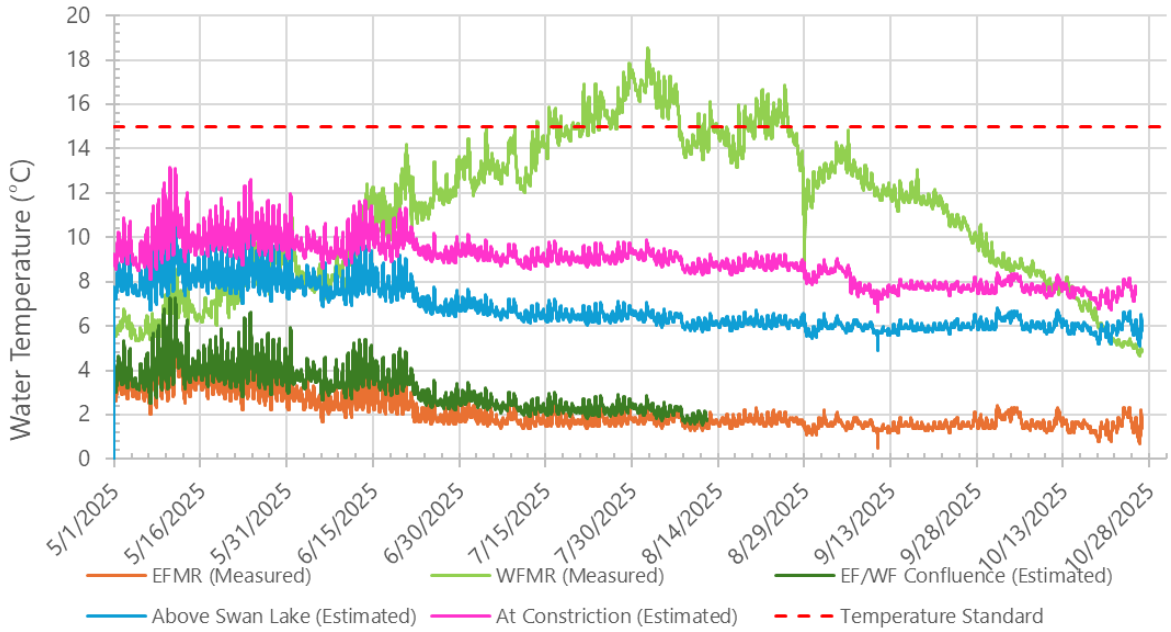

Figure 4-2 Calculated Martin River temperature with Project operations, 2025.

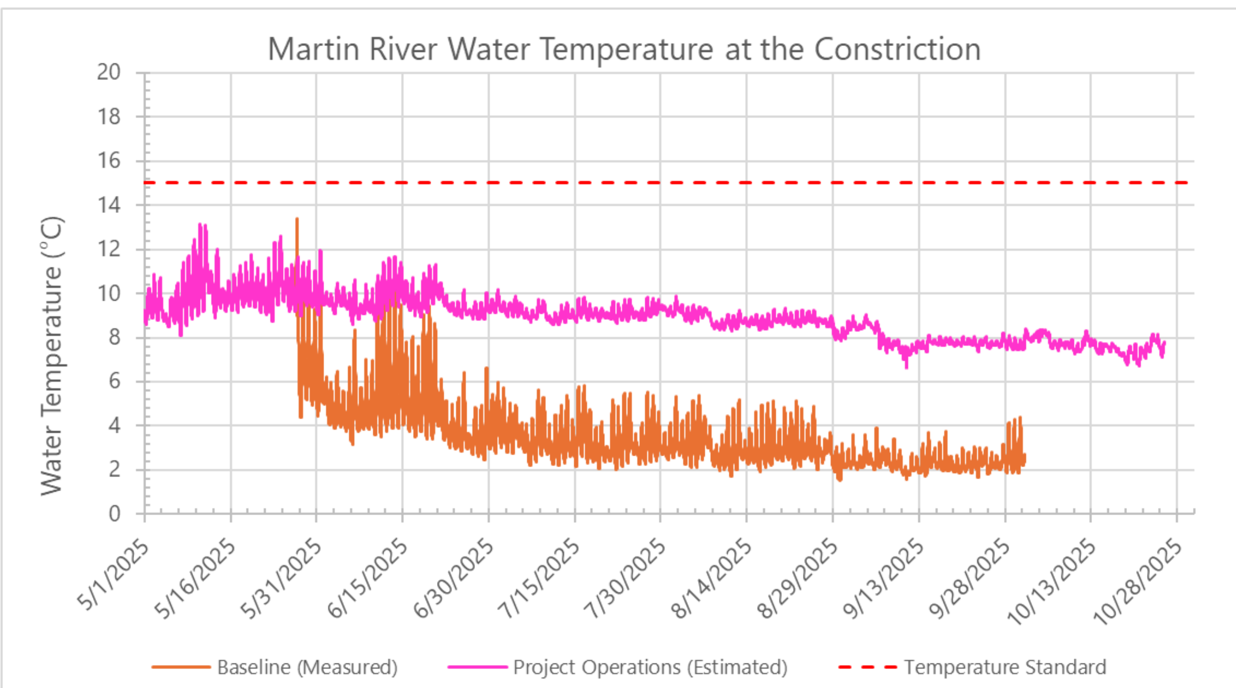

Figure 4-3 Comparison of Martin River at the constriction under baseline and Project operations, 2025.

Table 4-1 Monthly average water temperature for the Martin River at the constriction under baseline and proposed with-Project conditions.

Month	Baseline	With Project	Difference
May	NA	10.0	NA
June	3.8*	9.7	5.9
July	3.3	9.1	5.8
August	2.9	8.8	5.9
September	2.3	7.8	5.5
October	2.3	6.1	3.8

NA = not available

*Average is based on only 7 days of data.

Table 4-2 Monthly maximum of the 7-day average of the daily maximum for the Martin River at the constriction under baseline and proposed with-Project conditions.

Month	Baseline	With Project	Difference
May	NA	12.1	NA
June	NA	11.3	NA
July	5.6	9.8	4.2
August	4.7	9.7	5.0
September	3.4	8.8	5.4
October	4.0	8.2	4.2

NA = not available

5.0 TEMPERATURE DISCUSSION

Temperatures in the Martin River are predicted to increase with proposed Project operations. The magnitude of the temperature increase, under assumed worst-case conditions, varied by 4-6°C, but all temperatures in the Martin River remained well below the 15°C ADEC temperature standard. During August and September when measured flows at the constriction can be high with high variability (i.e., between 500 to 2,500 cfs), measured water temperatures under the baseline condition are on average 3°C with a range between 2°C to 4.5°C as shown in Figure 4-3 and Table 4-1. Measured temperatures appeared to be minimally increased by solar radiation in the reach from the EFMR/WFMR confluence to the constriction at RM 1.9. In contrast, a minimum instream flow of 100 cfs in the EFMR plus tributary inflows will produce lower velocities. The longer travel time provides conditions necessary to estimate temperature increases by direct solar radiation. In the downstream reach the estimated average water temperature would be 7.8-8.8°C as shown in Figure 4-3 and Table 4-1. This increase can be attributed to the combined increase of 4.2°C from the EFMR/WFMR confluence to Swan Lake and 1.6°C from Swan Lake to the constriction suggesting that the solar radiation impacts are driving the temperature increases rather than the tributary inputs from OCH2.8R and MR1.070. Since the temperatures under baseline are less than 4.5°C, the theoretical maximum increase from solar radiation would not increase the temperature above the 15°C standard.

Temperature comparison results were only available for 2025, and a large data gap required synthesis of estimated temperature and flow out of Swan Lake for an extended period. However, despite this limitation, it is not expected that conditions under warmer or wetter years would generate a significantly different outcome. Besides solar radiation, the main source of potential warming in the Martin River comes from outflows from Red Lake and Swan Lake. The flows from WFMR (i.e., Red Lake outflows) are typically highest during May and June. However, the temperatures during this time are much cooler (i.e., less than 10°C), so these inflows are not expected to significantly increase the Martin River temperature. Despite the increase in temperature from Red Lake over the summer, the outflows are decreasing, thereby reducing the potential for exceedances above the ADEC water temperature standard.

While temperatures at Swan Lake Outlet were measured above the 15°C standard, the volume of flow coming from Swan Lake is small compared to the overall flow in the Martin River even under the reduced minimum instream flow conditions of 100 cfs from EFMR.

During periods when temperatures are high at the Swan Lake Outlet, the outflows can be as much as 14 cfs, which is still less than 15 percent of a predicted Martin River flow of 111.3 cfs (i.e., 100 cfs from EFMR and 11.3 cfs from WFMR in spring). During glacier melt, the EFMR temperature is approximately 2°C, which when coupled with the 100 cfs minimum instream flow, makes it very difficult to increase the temperature past the 15°C standard when inputs from WFMR, OCH2.8R, and MR1.070 may be high. For example, using the following assumptions:

- EFMR discharge of 100 cfs (minimum instream flow);
- EFMR temperature of 2°C (observed temperatures during glacial melting periods);
- A general tributary input temperature of 18°C (highest measured tributary temperature);
- Solar radiation warming of 4.2°C between the EFMR/WFMR confluence and Swan Lake; and
- Solar radiation warming of 1.6°C between Swan Lake and the constriction,

the total tributary inputs would have to be 156.5 cfs for the mainstem temperature to reach 15°C at the constriction, which is significantly higher than any of the total measurements for WFMR, OCH2.8R, or MR1.070.

As mentioned, the solar radiation warming of 4.2°C between the EFMR/WFMR confluence and Swan Lake and 1.6°C between Swan Lake and the constriction represents a worst case condition as it does not include other atmospheric factors such as wind, cloud cover, and shade. Each of these factors would work to decrease the warming within these two reaches such that temperature increases would be lower than those presented herein.

6.0 IMPLICATIONS FOR DISSOLVED OXYGEN SATURATION

Dissolved oxygen (DO) saturation is a function of temperature. The warmer the temperature, the lower the DO saturation (i.e., warmer water cannot hold as much DO as colder water). As such, if the temperature in the Martin River is affected by Project operations, the DO may also be affected. The DO standard for waters used by anadromous fish is 7 milligrams per liter (mg/L). DO saturation as a function of temperature is provided in Table 6-1 (taken from USGS 2022). Temperatures in the Martin River with Project operations are expected to range from 6°C to 14°C, which have a much higher DO saturation limit than the 7 mg/L standard.

Table 6-1 Dissolved oxygen saturation as a function of temperature.

Temperature (°C)	DO Saturation (mg/L)
6	12.45
10	10.78
15	10.08
18	9.47
20	9.09
24	8.42

Source: Extracted from USGS (2022).

7.0 REFERENCES

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Appendix A
Maximum Solar Radiation for the EFMR/WFMR Confluence to Swan Lake

A-1.0 INTRODUCTION

Water temperature in a river system is commonly simulated using numerical models such as SSTEMP (Bartholow 2010), SNTEMP (Bartholow 1989), CEQUAL-W2 (Cole and Wells 2010), and HEC-RAS (USACE 2025), all of which are capable of modeling spatial and temporal temperature variations between upstream and downstream locations. These models typically rely on energy-balance framework to estimate water temperature. However, some of the models—such as SSTEMP and SNTEMP—produce only daily average temperatures, which may not provide the level of temporal resolution required for the current study.

Running any of these temperature models requires an extensive set of input parameters spanning hydraulics, hydrology, atmospheric conditions, channel geometry, groundwater interactions, climatology, riparian vegetation, solar exposure, and more. Each parameter can significantly influence the simulated water temperatures. Because of the complexity and volume of required data, these models are typically applied only to larger-scale projects. A few notable examples are the United States Geological Survey's (USGS) applications to the North Santiam River study (Stonewall and Buccol 2015) using HEC-RAS and CE-QUAL-W2, and the Yakima River study (Voss, Curran, and Mastin 2008) using SNTEMP. However, even when most input data exist, uncertainties or errors in those inputs can reduce the accuracy of modeled temperature results.

After considering all temperature-related factors, including input data availability, stream length, types of model output (daily versus instantaneous), and the required accuracy of simulated temperature results (exact values versus ranges), a simplified approximation approach was determined to be the most practical method for meeting the study's objective which was to assess whether water temperatures would exceed water quality standards under particular diversion operations. This simplified approach relied solely on direct solar radiation as the energy source input, rather than incorporating the full suite of model parameters.

Direct solar radiation is the portion of sunlight that travels in a straight line from the Sun to the Earth's surface without being scattered or diffused by the atmosphere. It represents the maximum possible solar energy reaching the ground and, by extension, the maximum potential energy input to a stream. As a result, estimating water-temperature change based solely on direct solar radiation provides a theoretical upper bound on the temperature increase that could occur within the study reach. In practical terms, the temperature increase produced by this simplified approach will be greater than the increase predicted by the more comprehensive numerical models described above or what will be observed naturally in the environment. This approach was applied to determining water temperature rise in the stream reach extending from the confluence of the EFMR and WFMR at approximately RM 5.2 to the Swan Lake at approximately RM 2.7 and from Swan Lake to the Martin River Constriction at RM 1.9.

A-1.1 Solar Radiation

This section describes solar radiation and the calculation used to estimate the energy received by the Martin River. To produce the most conservative (i.e., maximum) estimate of potential temperature increase, the solar radiation at solar noon on the summer solstice was assumed as the sole energy input to the stream reach during the entire period when fish are present, regardless of the specific day or time within the period.

A-1.1.1 Director Solar Radiation

Solar radiation that reaches the outer boundaries of the Earth's atmosphere is known as direct solar radiation or beam radiation (USDOE 2025) as illustrated in Figure 1 (Salameh 2014).

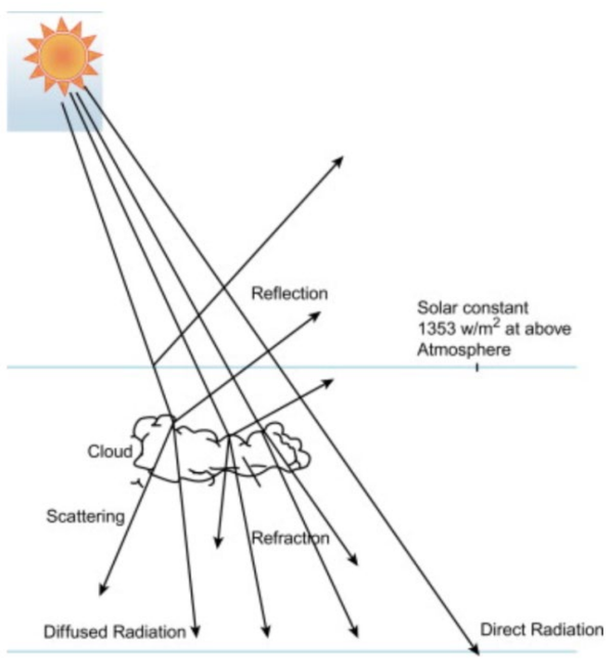

Figure A-1 Illustration of solar radiation. Only direct solar radiation was considered for temperature increase between tributaries.

The direct solar radiation on flat surface S_o, also referred to as instantaneous potential radiation, is given by:

$$S_o = I_o[\cos\varphi \cos H \cos\delta + \sin\varphi \sin\delta]$$

where I_o is the solar constant = 1,370 Watts/m^2 or 1.37kW/m^2, φ is latitude of the location of interest, H is hour angle measured from solar noon, δ is the Sun's declination angle, β is the solar elevation angle or, interchangeably, altitude angle, defined as:

$$\beta = 90^o + \varphi - \delta.$$

Solar noon is when the Sun reaches its apparent highest point in the sky and H=0 at solar noon such that:

$$S_o = I_o \sin\beta$$

The sun's declination angle δ is defined as

$$\delta = 23.45^o \sin\left[\frac{360}{365}\langle n + 284\rangle\right],$$

where n is the calendar day of the year starting from January 1.

Note that all angles are in degrees.

A-1.2.1 Application to the Martin River

Direct solar radiation on the Martin River was estimated at solar noon on the longest day of the year, i.e., the summer solstice on June 21 (i.e., Day 172 from January 1). The Sun's declination angle is defined as:

$$\delta = 23.45^o \sin\left[\frac{360}{365}\langle 172 + 284\rangle\right] = 23.45^o$$

At Swan Lake outlet to the Martin River, the latitude φ = 59.74^o (from Google Earth). At solar noon, the direct solar radiation, denoted as S_o, is therefore:

$$S_o = I_o[\cos\varphi \cos H \cos\delta + \sin\varphi \sin\delta]$$
$$= I_o[\cos 59.74^o \cos 0^o \cos 23.45^o + \sin 59.74^o \sin 23.45^o]$$

or

$$S_o = 1{,}104\ Watts/m^2 = 1.1\ kW/m^2$$

Figure 2 illustrates direct solar radiation at solar noon throughout the year calculated from this equation and shows S_o to be 1.1 kW/m^2 on Day 172 (i.e., the summer solstice).

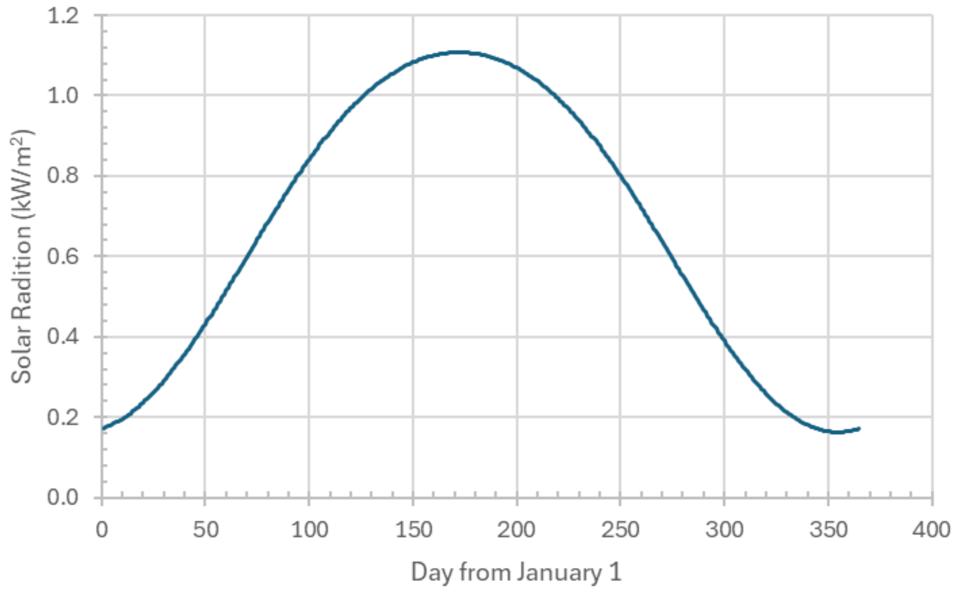

Figure 2 Daily direct radiation at solar noon throughout the year. The maximum direct soler radiation is approximately1.1 KW per square meter of surface area on the summer solstice.

A-2.0 HYDRAULICS

The two-dimensional hydraulic model presented in the Hydraulic Modeling and Aquatic Habitat Connectivity Study Report (AEA 2025b) was used to estimate the average velocity and depth for the WFMR/EFMR Confluence to the Swan Lake Outlet and for the Swan Lake Outlet to the Martin River at the Constriction. A combined flow of 111.3 cfs was selected as the representative hydraulic condition for the flow between the WFMR/EFMR Confluence to the Swan lake Outlet. study. This flow rate includes 100 cfs from the EFMR (i.e., the minimum instream flow for the EFMR) and the springtime flow of 11.3 cfs for the WFMR (AEA 2025). In spring 2024 an additional flow of 9.3 cfs may enter the reach between EFMR/WFMR confluence and Swan Lake during as tributaries (AEA 2025). This incremental flow was excluded from the solar radiation analysis. Omitting the additional flow yields a more conservative assessment by producing higher predicted water temperature increases under lower channel flow. A combined flow of 116.4 cfs was selected as the representative hydraulic condition for the flow between the Swan Lake Outlet and the Constriction. This flow rate includes 100 cfs from the East Fork Martin River, the springtime flows of 11.3 cfs from the West Fork Martin River, 0.1 cfs from OCH2.8R, and 5.1 cfs from MR1.070 (AEA 2025). Table 1 summarizes relevant information extracted from the hydraulic model used to estimate solar radiation.

Table 1 Reach-average hydraulics and channel width from the EF/WF Martin River confluence to the Swan Lake outlet and from the Swan Lake outlet to the Constriction.

Hydraulics	WF/EF Confluence to Swan Lake	Swan Lake to Constriction
Distance (ft)	14,100	4,900
Centerline Reach-Average Velocity (ft/s)	2.67	2.46
Centerline Reach-Average Depth (ft)	1.56	1.38
Ratio of Reach-Average Depth to Centerline Depth	0.69	0.77
Average Channel Depth (ft)	1.08	1.07
Reach-Average Channel Width (ft)	38.53	44.2

A-3.0 TEMPERATURE ESTIMATE

A-3.1 WFMR/EFMR Confluence to Swan Lake

The steps used to estimate water temperature increase from the WFMR/EFMR confluence to the Swan Lake outlet are summarized below:

1. Calculate the volume of water assuming a 1-meter-long parcel of water traveling from the WF/EF Martin River confluence to the Swan Lake outlet.

   The volume of the 1-m water parcel (V_{parcel}) = W * D * 1

   = (38.53 ft * 0.3048 ft/m) * (1.08 ft * 0.3048 ft/m) * 1 m = 3.866 m^3

   Where width (W) = 38.53 ft and depth (D) = 1.08 ft are obtained from Table 2.

2. Calculate the energy required to raise the volume of the parcel by 1°C.

   $E = V_{parcel} * c * \rho$

   Where:

   V_{parcel} is calculated from Step 1 above.

   c = specific heat capacity of water = 4.184 J/g°C.

   ρ = density of water = 1 g/cm^2 or 10^6 g/m^3

E = 3.866 m^3 * 4.184 J/ g°C * 10^6 g/m^3 = 16.17x10^6J per 1°C.

3. Calculate the temperature increase to the parcel of water from the EFMR/WFMR confluence to Swan Lake Outlet.

   $T_{raised} = S_t / E$

   Where:

   S_t = Total direct radiation on the surface area of the water parcel = $A * S_o * T_{Travel}$

      Where:

      A = Surface Area of a 1 m long water parcel = W * 1 = (38.53 ft *0.3048 m/ft) *1 m =11.7 m^2.

      S_o = Direct Solar Radiation = 1.1 kW/m^2 on Day 172 (Calculated in Section 9.2)

      T_{Travel} = 1.47 hours and is calculated as the travel time from the EFMR/WFMR confluence to the Swan Lake Outlet (14,100 ft travel distance and 2.67 ft/s velocity obtained from Table 1).

   S_t = 11.7 m^2 * 1.1 KW/m^2 * 1.47 hr * 3,600 s/hr

   = 68,108 *10^3 W-s

   = 68.1 * 10^6 W-s

   = 68.1 * 10^6 J

   Water temperature raised by direct radiation is therefore:

   $T_{raised} = S_t / E$

   = (68.1 * 10^6 J) / (16.17*10^6 J/°C) = 4.2 °C

A-3.2 Swan Lake to Martin River at the Constriction

The steps used to estimate the water temperature increase from the Swan Lake outlet to the Constriction are summarized below:

1. Calculate the volume of water assuming a 1-meter-long parcel of water traveling from the Swan Lake outlet to the Constriction.

   The volume of the 1-m water parcel (V_{parcel}) = W * D * 1

   = (44.2 ft * 0.3048 ft/m) * (1.07 ft * 0.3048 ft/m) * 1 m = 4.394 m^3

   Where width (W) = 44.2 ft and depth (D) = 1.07 ft are obtained from Table 2.

2. Calculate the energy required to raise the volume of the parcel by 1°C.

   $E = V_{parcel} * c * \rho$

   Where:

   V_{parcel} is calculated from Step 1 above.

c = specific heat capacity of water = 4.184 J/g°C.

ρ = density of water = 1 g/cm^2 or 10^6 g/m^3

E = 4.394 m^3 * 4.184 J/ g°C * 10^6 g/m^3 = 18.38x10^6J per 1°C.

3. Calculate the temperature increase to the parcel of water from the Swan Lake Outlet to the Constriction.

$T_{raised} = S_t / E$

Where:

S_t = Total direct radiation on the surface area of the water parcel = A * S_o *T_{Travel}

Where:

A = Surface Area of a 1 m long water parcel = W * 1 = (44.2 ft *0.3048 m/ft) *1 m =13.47 m^2.

S_o = Direct Solar Radiation = 1.1 kW/m^2 on Day 172 (Calculated in Section 9.2)

T_{Travel} = 0.55 hours and is calculated as the travel time from the Swan Lake Outlet to the Constriction (4,900 ft travel distance and 2.46 ft/s velocity obtained from Table 1).

S_t = 13.47 m^2 * 1.1 KW/m^2 * 0.55 hr * 3,600 s/hr

= 29,337 *10^3 W-s

= 29.3 * 10^6 W-s

= 29.3 * 10^6 J

Water temperature raised by direct radiation is therefore:

$T_{raised} = S_t / E$

= (29.3 * 10^6 J) / (18.38*10^6 J/^{o}C) = 1.6 ^{o}C

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