Total Maximum Daily Loads for the Lower Columbia-Sandy Subbasin

Technical Support Document

Appendix E: Bull Run River Surrogate Measure Approach

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State of Oregon
DEQ Department of Environmental Quality

The purpose of this appendix is to document the surrogate measure model scenario and the method used to develop the regression equation (**Equation 2**) DEQ used to predict the “no dam” scenario temperatures for the Bull Run River model extent in the 2024 temperature TMDL for the Lower Columbia-Sandy Subbasin.

The City of Portland Bull Run drinking water and hydroelectric project has been assigned 0.30°C of the human use allowance (HUA) and the equivalent load allocation on the Bull Run River. In the Sandy River, warming from the Bull Run dam and reservoirs has been assigned 0.02°C of the HUA for the Sandy River assessment unit OR_SR_1708000107_02_103616, which extends from the confluence of the Sandy River and Bull Run River downstream to the Sandy River mouth.

As outlined in the TMDL section 9.1.4.2, the surrogate measure temperature target at the lamprey barrier just downstream of Reservoir #2 is:

a) The estimated free flowing (no dam) 7DADM temperatures at the lamprey barrier; or
b) On days the surrogate measure calculated under item a) is cooler than the values in I and II, the surrogate 7DADM temperature may be no warmer than values in I and II.
    I. 16.3°C from June 16 to August 14
    II. 13.3°C from May 1 to June 15 and August 15 to November 15.

DEQ developed a regression equation (**Equation 2**) to predict the free flowing (no dam) daily maximum temperatures at the lamprey barrier downstream of Reservoir #2.

Two different regression approaches were evaluated. The first was to develop a regression to predict the daily maximum directly. The second regression approach is based on the concept that the daily maximum temperature can be calculated from the daily mean plus half the daily diel range as shown in **Equation 1.**

$$Daily\ Maximum = \ Daily\ Mean + \frac{Daily\ Diel\ Range}{2} \qquad \textbf{Equation 1}$$

Using this framework, two separate regressions were developed to predict the two components of **Equation 1**: (i) a regression to predict the daily mean no dam temperatures, and (ii) a regression to predict the daily no dam temperature diel range. Rounds (2010) used a similar approach to estimate no dam temperatures in the Willamette Basin.

To develop regressions, the response variables were derived from segment 7 of the Lower Bull Run No Dam (Background) CE-QUAL-W2 model scenario for the period of 2014 to 2018. The City of Portland developed the 2014 to 2018 CE-QUAL-W2 models, and based the scenarios in this TMDL on the 2016 calibrated model and 2016 background scenario model. The City of Portland provided the model outputs to DEQ to process.

The upstream boundary condition input into Lower Bull Run No Dam (Background) model is from the Middle Bull River No Dam (Background) scenario that includes restored vegetation conditions and an estimated natural channel. DEQ also considered using the No Dam scenario for regression development. The only difference between the No Dam and No Dam (Background) models is that in the No Dam (Background) model, vegetation outside of the reservoir footprint was set to restored conditions, whereas in the No Dam model, vegetation outside of the reservoir footprint was set to current conditions. The resulting temperature differences between the models were very small; nevertheless, the No Dam (Background) version was used to develop regressions as a margin of safety because it resulted in slightly cooler (more protective) temperatures.

The explanatory variables used in the regressions included:

- daily maximum temperature (t_max)
- daily mean temperature (t_mean)
- daily temperature diel range calculated as the daily maximum minus daily minimum (t_range)
- daily mean flow rate (q_mean)

Data for the explanatory variables were obtained from the following USGS gages near the Bull Run Project:

- 14138850 Bull Run River Near Multnomah Falls OR
- 14138900 North Fork Bull Run River Near Multnomah Falls OR
- 14138870 Fir Creek Near Brightwood, OR
- 14139800 South Fork Bull Run River Near Bull Run, OR
- 14141500 Little Sandy River Near Bull Run, OR

Only data between May 1 and November 30 were used to develop regressions. This period corresponds to the TMDL critical period and when the TMDL allocation applies on the Bull Run River. The daily mean flow rates were transformed by taking the log of each value prior to regression development. Days with missing values were removed. There were 1070 total observations available for the five-year period.

The full set of models is described in **Table 1**. The daily mean flow for models 1, model 8, and model 13 is the log of the summed daily mean flows from all USGS gages monitoring streams upstream of the reservoirs (**Equation 2**). The sum of these gages approximates the unregulated flow through the reservoir reaches. Model 1 and model 13 use the flow-weighted daily mean temperatures (**Equation 3**) or flow-weighted daily max. temperatures (**Equation 4**) from all USGS gages upstream of the reservoirs.

$$q\_mean\_log = \log\left(\begin{matrix} q_{mean\_14138850} + \\ q_{mean\_14138870} + q_{mean\_14138900} + \\ q_{mean\_14139800} \end{matrix}\right)$$

Equation 2

$$t_{\_mean} = \frac{\left(\begin{matrix} \left(t_{mean\_14138850} * \ q_{mean\_14138850}\right) + \\ \left(t_{mean\_14138870} * q_{mean\_14138870}\right) + \\ \left(t_{mean\_14138900} * q_{mean\_14138900}\right) + \\ \left(t_{mean\_14139800} * q_{mean\_14139800}\right) \end{matrix}\right)}{\left(\begin{matrix} q_{mean\_14138850} + \\ q_{mean\_14138870} + q_{mean\_14138900} + \\ q_{mean\_14139800} \end{matrix}\right)}$$

Equation 3

$$t_{\_max} = \frac{\begin{pmatrix} (t_{max\_14138850} * \ q_{mean\_14138850}) + \\ (t_{max\_14138870} * q_{mean\_14138870}) + \\ (t_{max\_14138900} * q_{mean\_14138900}) + \\ (t_{max\_14139800} * q_{mean\_14139800}) \end{pmatrix}}{\begin{pmatrix} q_{mean\_14138850} + \\ q_{mean\_14138870} + q_{mean\_14138900} + \\ q_{mean\_14139800} \end{pmatrix}} \qquad \textbf{Equation 4}$$

Table 1: Summary of regression models.

Model #	Response variable	Explanatory variables
1	Daily Mean	t_mean + q_mean_log
2	Daily Mean	t_mean_14138850 + q_mean_14138850_log
3	Daily Mean	t_mean_14138870 + q_mean_14138870_log
4	Daily Mean	t_mean_14138900 + q_mean_14138900_log
5	Daily Mean	t_mean_14139800 + q_mean_14139800_log
6	Daily Mean	t_mean_14141500 + q_mean_14141500_log
7	Daily Range	t_range_14138850 + q_mean_14138850_log
8	Daily Range	t_range_14138870 + q_mean_log
9	Daily Range	t_range_14138870 + q_mean_14138870_log
10	Daily Range	t_range_14138900 + q_mean_14138900_log
11	Daily Range	t_range_14139800 + q_mean_14139800_log
12	Daily Range	t_range_14141500 + q_mean_14141500_log
13	Daily Maximum	t_max + q_mean_log
14	Daily Maximum	t_max_14138850 + q_mean_14138850_log
15	Daily Maximum	t_max_14138870 + q_mean_14138870_log
16	Daily Maximum	t_max_14138900 + q_mean_14138900_log
17	Daily Maximum	t_max_14139800 + q_mean_14139800_log
18	Daily Maximum	t_max_14141500 + q_mean_14141500_log

Each set of models was evaluated using the second-order Akaike information criterion (AICc) (Sugiura, 1978; Hurvich and Tsai, 1989, 1991) and the coefficient of determination (R-squared).

Table 2: Ranking models fitted to the daily mean temperature.

Model #	AICc	Delta_AICc	log-likelihood
6	1930.02	0	-960.99
1	2358.4	428.38	-1175.18
2	2472.3	542.27	-1232.13
5	2606.86	676.84	-1299.41
3	3081.72	1151.69	-1536.84
4	3628.93	1698.91	-1810.45

Table 3: Ranking models fitted to the daily diel temperature range.

Model #	AICc	Delta_AICc	log-likelihood
12	2684.02	0	-1337.99
8	2865.53	181.51	-1428.75
9	2900.73	216.71	-1446.34
10	3004.85	320.83	-1498.41
7	3015.47	331.44	-1503.71
11	3237.33	553.31	-1614.64

Table 4: Ranking models fitted to the daily maximum temperature.

Model #	AICc	Delta_AICc	log-likelihood
18	2834.19	0	-1413.08
13	3096.87	262.68	-1544.41
14	3254.42	420.23	-1623.19
17	3464.56	630.37	-1728.26
15	3828.7	994.51	-1910.33
16	3919.5	1085.31	-1955.73

The AICc results show the regression model 6 (daily mean), model 12 (daily range), and model 18 (daily max), all of which utilized data from the Little Sandy River gage 14141500, had the best fit based on AICc. After combining models 6 and 12 using the framework from **Equation 2**, the overall R-squared was 0.97 and the residual standard error was 0.91. The R-squared for the daily maximum model (model 18) was also 0.97 and residual standard error was 0.91. Based on these metrics, both models had the same goodness-of-fit.

Reviewing the residuals, the range between the 1st and 3rd quartile residuals for the combined models 6 and 12 was slightly smaller (1.1541) than the range for model 18 (1.2093), implying combined models 6 and 12 had a marginally better fit for at least 50% of the data points. The median residual for combined models 6 and 12 was slightly positive (0.1630), whereas model 18 had a slightly negative residual (-0.0767), implying that the combination of models 6 and 12 slightly under-predicted the daily maximum temperatures. While small, this under-prediction represents a margin of safety; thus, DEQ opted to utilize the combination of models 6 and 12, which respectively used the Little Sandy River daily mean and daily range as explanatory variables (predictors), as the final model to predict the no dam temperatures. **Equation 5** represents the combined final form.

Equation 5

$$T_{Max} = 0.1405173 + 1.1572642\overline{T_{LS}} + \; -0.3588068 \log \overline{Q_{LS}} + \left(\frac{3.7557135 + 1.1668769 T_{dLS} + -0.5969993 \log \overline{Q_{LS}}}{2} \right)$$

Where,

$T_{Max} =$ The no dam daily maximum stream temperature at the lamprey barrier downstream of Reservoir #2. (Lower Bull Run River model segment 7)

$\overline{T_{LS}} =$ The daily mean temperature (°C) at USGS Gage 14141500 Little Sandy River Near Bull Run.

$\overline{Q_{LS}} =$ The mean daily discharge (cfs) at USGS Gage 14141500 Little Sandy River Near Bull Run.

$T_{dLS} =$ The daily temperature range (°C) calculated as the daily maximum minus the daily minimum at USGS Gage 14141500 Little Sandy River Near Bull Run.

Figure 1 presents a plot of the predicted daily maximum at the lamprey barrier compared to the daily maximum derived from the CE-QUAL-W2 model for years 2014 to 2018.

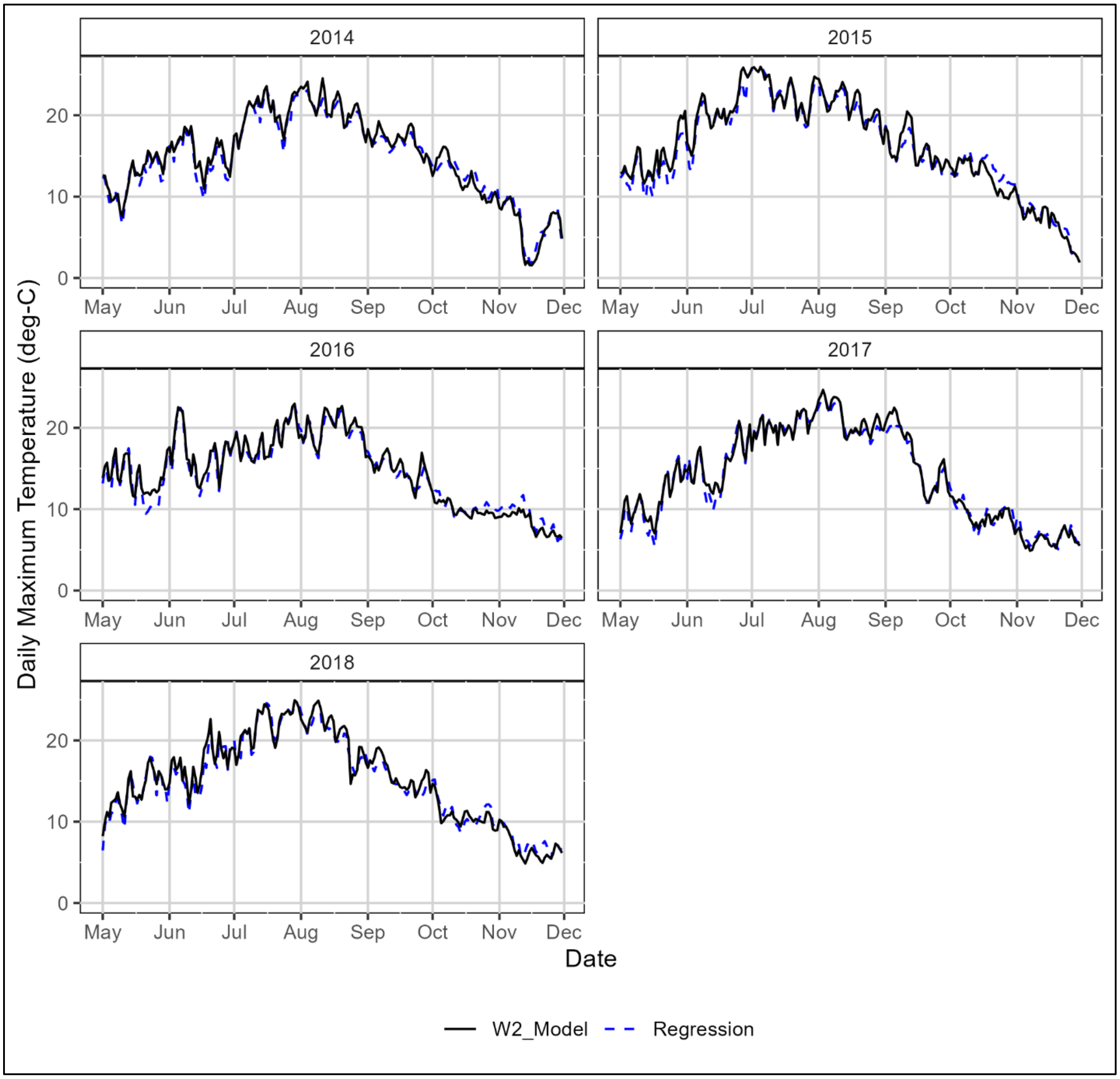

Figure 1: Comparison of daily maximum stream temperatures at the lamprey barrier calculated using Equation 2 and from the CE-QUAL-W2 No dam (background) model for years 2014 to 2018.

A model scenario was developed to estimate the Bull Run temperatures with the dam and reservoir release temperatures set at the surrogate measure temperature target. The surrogate measure scenario is the same as the 2016 calibrated model except the boundary condition dam release temperatures (Tin_BR2.npt) and flow (Qin_BR2.npt) at segment 7 were modified. The boundary condition temperatures for Tin_BR2.npt were set to the surrogate measure target temperatures. To translate the surrogate measure target, which is expressed as a 7DADM, to hourly temperatures, the hourly no dam temperatures were increased by the same amount each day such that the daily maximum temperature for that day equaled the minimum of the surrogate measure target in the previous seven days. This approach was used to ensure the target temperatures used in the model were attained as a 7DADM.

The boundary condition flow for Qin_BR2.npt was set identical to the no dam scenario flows. This allowed direct comparison of temperatures between the (baseline) no dam scenario and surrogate measure scenario. **Figure 2** shows the maximum longitudinal 7DADM differences between the no dam scenario and the surrogate measure scenario for days when temperatures exceeded applicable criteria. The difference represents the warming attributable to the Bull Run dam and reservoir operations with dam release temperatures that attain the surrogate temperature target. The point of maximum impact is located at the lamprey barrier (segment 7) with a maximum 7DADM temperature increase of 0.30°C. The maximum temperature impact decreases moving downstream. At the mouth of the Bull Run River (segment 99), the maximum 7DADM temperature impact is 0.07°C. These model results demonstrate that the temperature surrogate measure will attain the human use allowance assigned to the Bull Run project.

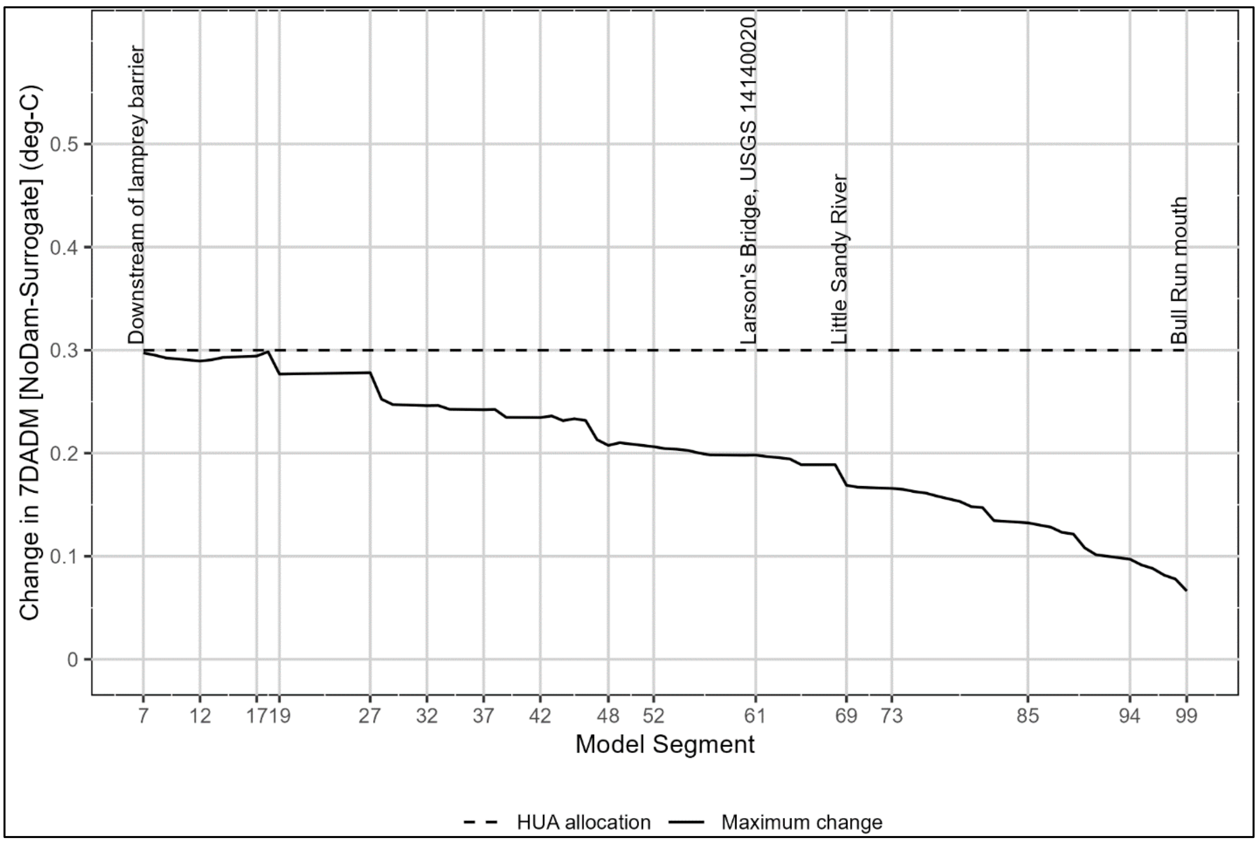

Figure 2: Bull Run River maximum 7DADM temperature change above the applicable criteria due to Bull Run River dams and reservoirs with discharges attaining the surrogate measure.

References

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