APPENDIX H TEMPERATURE METRIC ANALYSIS

Comparing Daily Maximum, Daily Average and 7-Day Average of the Daily Maximum Temperature Averaging Periods on the Columbia and Snake Rivers

To: Columbia and Snake River Temperature TMDL Technical Team

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Introduction

The patchwork of numeric temperature Water Quality Criteria (WQC) on the Columbia and Snake Rivers all have one of two averaging periods associated with them: the daily maximum (DM) temperature or the 7-day average of the daily maximum (7-DADM) temperature. Further, the model being utilized for the development of the Columbia and Snake River Temperature TMDL operates using daily average (DA) temperatures. The relative stringency of the two WQC averaging periods is not mathematically clear cut, and the magnitude difference between DM temperature calculations and DA temperature calculations is dynamic and may change throughout the year. In a number of instances during the development of the Columbia and Snake River Temperature TMDL, EPA may need to identify which of two WQC with different averaging periods is more stringent or may need to compare daily average model results with measured daily maximum temperatures. This memo aims to identify the relationship between these different averaging periods in the context of the Columbia and Snake Rivers.

Daily Maximum (DM) versus 7-Day Average of the Daily Maximum (7-DADM) Temperature

The data utilized to evaluate current river conditions and calculate WQC exceedances were downloaded from Columbia River DART website (http://www.cbr.washington.edu/dart/query/wqm_hourly) as hourly measurements for the years 2011-2016. The hourly temperature data were translated into the averaging period(s) corresponding to the numeric temperature WQC, either DM or 7-DADM (EPA 2018; Figure 2). DM values were calculated by taking the maximum of the 24 hourly measurements for each given day. The 7-DADM temperatures were calculated by averaging the daily maximum temperature for a given day with the daily maximum temperature values of the previous three days and the following three days, as specified in the Washington Water Quality Standards.

Picture an example situation where two numeric WQC apply to the same reach of river: one WQC is 20C with a DM averaging period and the other is 20C with a 7-DADM averaging period. This is the case along the Lower Columbia River where WA and OR both have applicable WQC. Which is more stringent? For a given day, it is possible that the 7-DADM temperature will be higher than the DM, where perhaps the maximum temperature from that particular day is 19.5C, but the surrounding days on either side were much higher, say 22C. If the 20C 7-DADM WQC were utilized, that day would register as an exceedance (Figure 1). On another given day, the DM may be more stringent, where perhaps the temperature on a given day is 22C, but the surrounding days on either side are much cooler, say 19.5C (Figure 2).

DAY	DM Temperature	7-DADM Temperature
1	22	
2	22	
3	22	
4	22	
5	22	
6	19.5	21.64
7	22	
8	22	
9	22	
10	22	

Figure 1: Example river temperature scenario where 7-DADM is a more stringent averaging period than DM.

DAY	DM Temperature	7-DADM Temperature
1	19.5	
2	19.5	
3	19.5	
4	19.5	
5	19.5	
6	22	19.86
7	19.5	
8	19.5	
9	19.5	
10	19.5	

Figure 2: Example river temperature scenario where DM is a more stringent averaging period than 7-DADM.

Given the above examples, it is clear that the more stringent WQC is dictated in large part by the temperature regime of the river. To understand the relationship between DM and 7-DADM in the context of the Columbia and Snake River temperature regime, the delta between the DM and 7-DADM calculations is examined at two example locations: John Day Dam Tailrace on the Columbia River and Ice Harbor Dam Tailrace on the Snake River.

Figure 3 illustrates the delta between DM and 7-DADM (DM minus 7-DADM) at John Day Dam for the year 2016. When the data point is positive, it means the DM was higher on that given day in 2016. If the data point is negative, it means the 7-DADM value was higher on that given day in 2016. The figure indicates that the delta between DM and 7-DADM is generally just as likely to be positive as negative at John Day Dam in 2016.

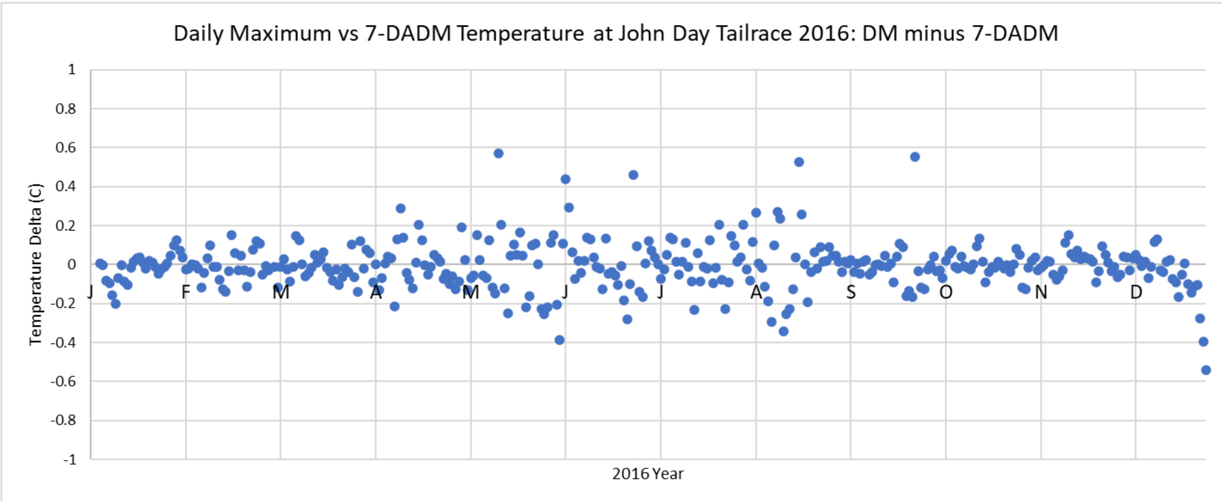

Figure 3: Delta between DM and 7-DADM (DM minus 7-DADM) at John Day Dam on the Columbia River for the year 2016.

Figure 4 illustrates the delta between DM and 7-DADM (DM minus 7-DADM) at Ice Harbor Dam for the year 2015. When the data point is positive, it means the DM was higher on that given day in 2015. If the data point is negative, it means the 7-DADM value was higher on that given day in 2015. The figure indicates that the delta between DM and 7-DADM is generally just as likely to be positive as negative at Ice Harbor Dam in 2015.

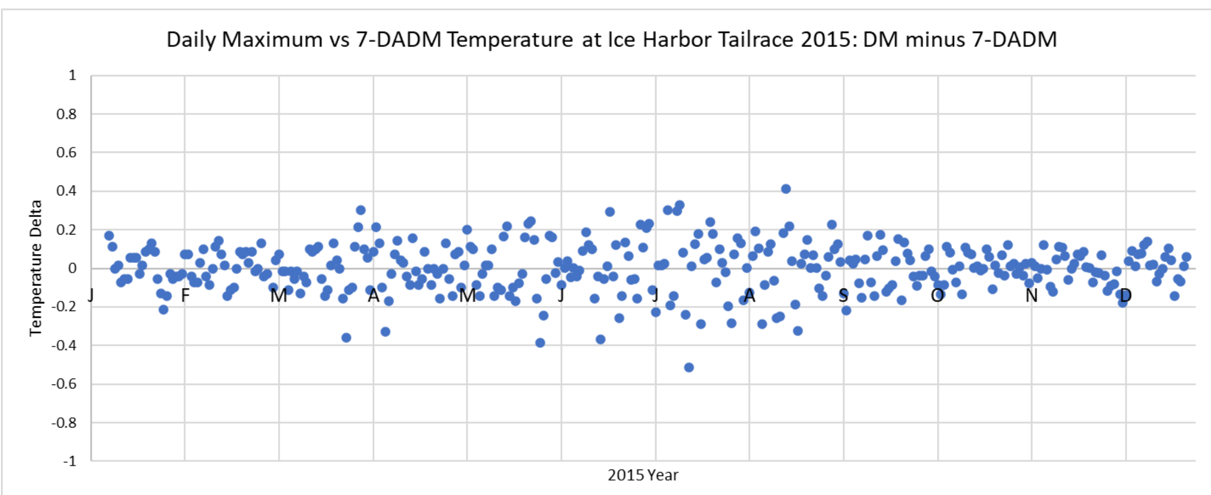

Figure 4: Delta between DM and 7-DADM (DM minus 7-DADM) at Ice Harbor Dam on the Snake River for the year 2015.

Given the above analysis, it is clear that there is no mathematically clear answer to the question of which averaging period is more stringent – in all cases where EPA was faced with choosing between two equivalent WQC with different averaging periods, we utilized the DM averaging period. However, there is one instance where EPA must decide whether a 17.5C 7-DADM criteria is more stringent than an 18C DM WQC. Figure 3 serves as a useful illustration of EPA's decision to utilize the 17.5C 7-DADM criteria. In principal, in order for 18C DM to be the more stringent WQC in the context of the Columbia-Snake temperature regime, the delta in Figure 3 would need to show a tendency to be positive more often than negative, indicating that DM values are higher than 7-DADM values. Further, the average magnitude of these positive values would need to exceed 0.5C, to make up for the numeric difference between the 17.5 and 18C standards. The plot shows no clear trend in the delta, supporting the decision to utilize the 17.5C 7-DADM standard in this instance.

Daily Maximum (DM) versus Daily Average (DA) Temperature

Unlike with the two WQC averaging periods, it is mathematically clear that the DM will be higher than the DA, unless you picture a system with a completely constant temperature, in which case the DM and DA would be equal. Since EPA will need to at least conceptually compare DA values with DM values, an understanding of the magnitude difference between the DM and DA is important. In a small creek that exhibits very warm temperatures during the day and very cold temperatures at night, you would expect the DM to be substantially higher than the DA. Conversely, for large rivers like the Columbia and Snake, which exhibit less diel temperature variation, the DM would not be expected to be very much warmer than the DA.

Figure 5 illustrates the delta between DM and DA (DM minus DA) at the John Day Dam Tailrace on the Columbia River in 2016. On average the DM is 0.1C greater than the DA in the context of the Columbia River temperature regime. The summer months seem to involve a higher likelihood of a larger delta. This could be explained by the lower flows in the Columbia during the summer, which are more responsive to daily heat fluctuations, which can expand the delta between the DM and DA.

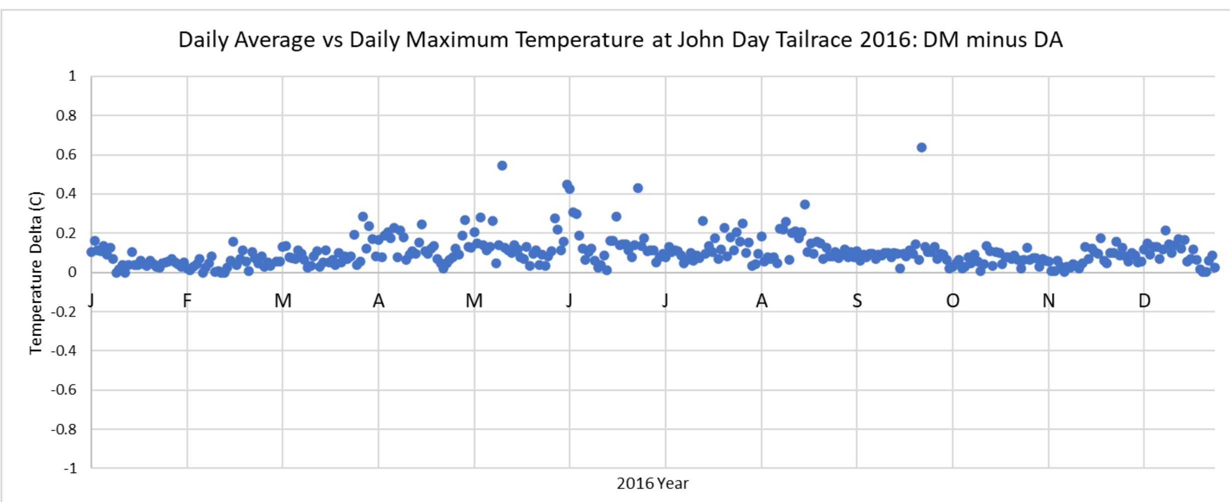

Figure 5: Delta between DM and DA (DM minus DA) at the John Day Dam Tailrace on the Columbia River in 2016.

Figure 6 illustrates delta between DM and DA (DM minus DA) at the Ice Harbor Dam Tailrace on the Snake River in 2015. On average the DM is 0.2C greater than the DA in the context of the Snake River temperature regime. This greater delta is partially explained by the smaller Snake River flow compared to the Columbia River, which likely causes the diel temperature cycle on the Snake to be more pronounced. The summer months also show a higher likelihood of a larger delta, likely also explained by the lower flows in the Snake during the summer.

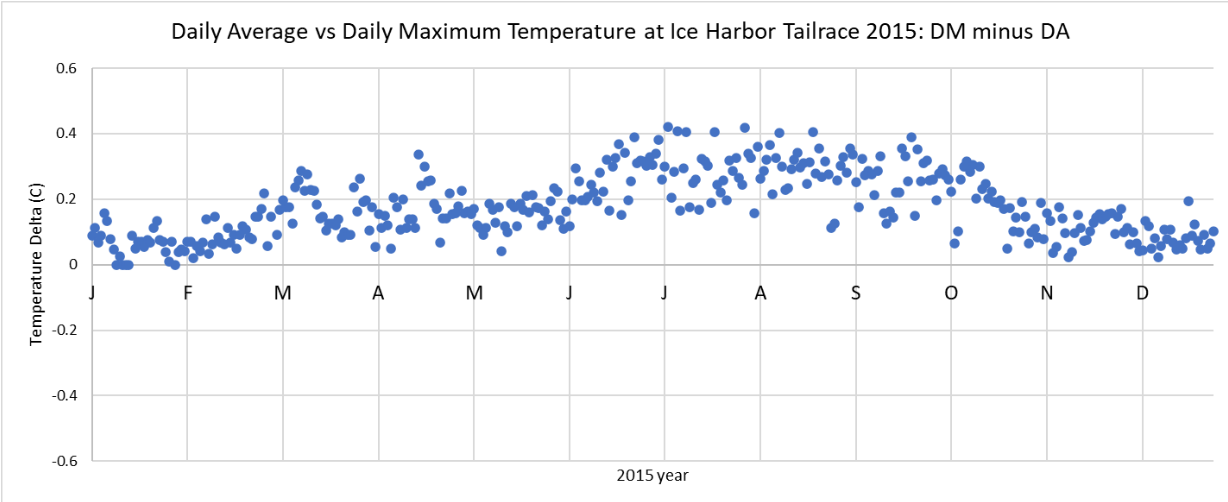

Figure 6: Delta between DM and DA (DM minus DA) at the Ice Harbor Dam Tailrace on the Snake River in 2016.

Daily Maximum (DM) versus Daily Average (DA) Temperature as a Metric for Analyzing Dam Impacts with RBM10

The model used in the development of this TMDL (RBM10) utilizes a daily time step, and therefore, does not allow for the derivation of DM temperature values – it only yields DA values. Given that the relevant WQC are based on DM values, it is important to explain why it is valid to use DA values in the dam impacts analysis in the TMDL.

As discussed in Section 6.5.1 of the TMDL, dams can have a cooling or warming effect on the river, depending on the season. For the purposes of calculating load allocations in this TMDL, the relevant impact is the warming effect of the dams. The warming effect (i.e., the impact) of the dams is quantified in the TMDL using the difference between the DA with dams and the DA without dams. The TMDL notes that calculating dam impacts using the difference between DAs is more conservative than using the difference between DMs. The following figures and discussion support that this is true.

Because the RBM10 model does not yield DMs, EPA does not have RBM10-generated data to directly demonstrate this principle. In lieu of such data, Figure 7 is presented as a conceptual visualization tool. In this figure, the three red lines represent three different metrics for a hypothetical temperature time series for a river *with* dams. The blue lines show the same metrics for the same hypothetical river *without* dams.

The three metrics represented by the three lines are the hourly time series, the average of the DAs for the full time series, and the average of the DMs for the full time series. A key factor in this comparison is the effect of dams in dampening the diel fluctuation of a river. This figure demonstrates that when dams have a warming effect on the average temperature, the difference between DAs *with* and *without* dams is greater than the difference between DMs *with* and *without* dams. In other words, the impact on DA is greater than the impact on DM.

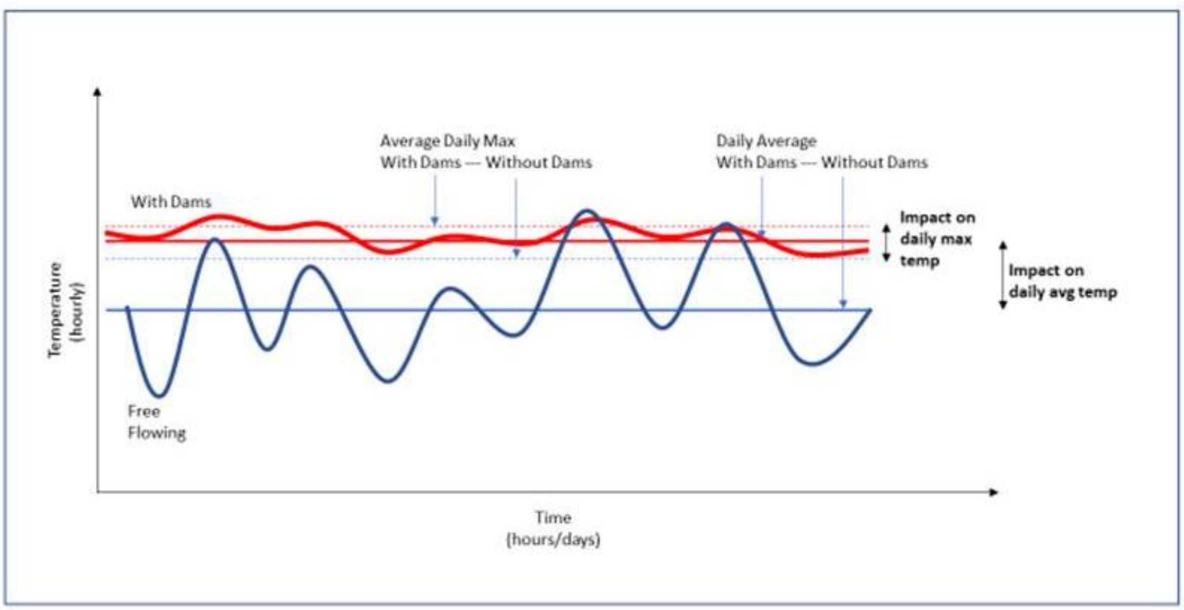

Figure 7: Schematic representation of a hypothetical multi-day time series of river temperature with and without dams.

As a further illustration of this principle, Figure 8 displays model results from the USACE's Snake River temperature modeling, performed as part of the CRSO EIS (2020). We present these model results because they used an hourly timestep, and therefore yield both DM values and DA values, allowing for a more direct comparison.

The solid lines represent the DA values and the shaded bands show the range from the highest daily maximum to the lowest daily minimum from a 5-year modeling period (2011 to 2015). Yellow represents the without-dams scenario and black shows the with-dams scenario. This figure is not a perfect comparison of difference in DMs vs. difference in DAs, because it uses the single highest DM from the 5-year series. A more appropriate metric for a tighter comparison would be the average of the 5 DMs. Nonetheless, that discrepancy does not preclude an evaluation of which metric (difference in DAs or difference in DMs) leads to a higher estimate of dam impacts. As in Figure 7, when the dams have a warming effect, the difference in DA with dams and DA without dams is generally greater than the difference in DMs.

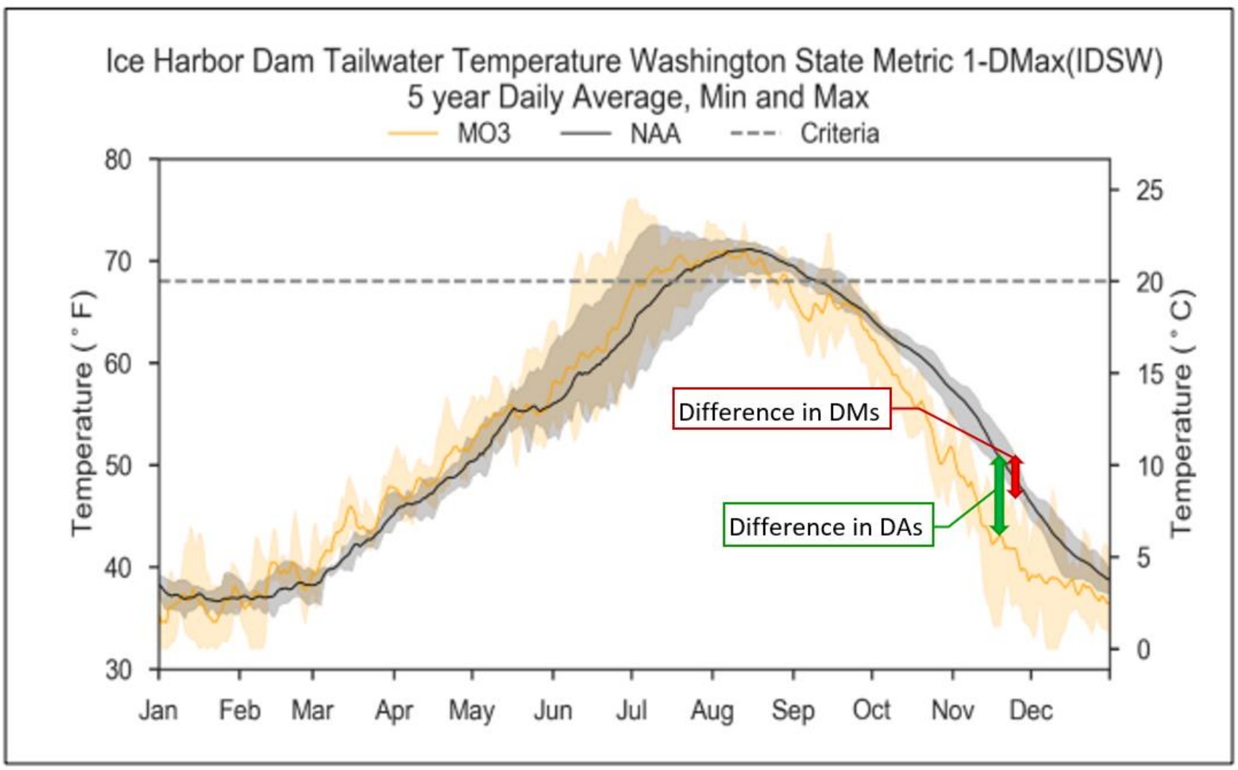

Figure 8: Model results from USACE Snake River temperature modeling at Ice Harbor Dam tailrace. Adapted from Appendix D, Figure 6-25 of CRSO EIS (2020).