Draft Technical Memorandum
Date: August 19, 2019
To: Cold Water Refuges Team
From: Martin Merz, John Palmer, and Alex Clayton
Subject: Characterization of Columbia River Temperature Variability

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This memorandum discribes the lognitundinal, seasonal, interannual, vertical, and daily temperature variation in the Lower Columbia River from the confluence with the Snake River to the ocean.

Longitudinal Temperature Variability in the Lower Columbia River

The Columbia River is a large low-lying river, which enters the State of Washington from Canada and warms as it moves through Washington towards the Pacific Ocean. ***Figure 1***, assembled with NorWeST data, illustrates this longitudinal warming in the summer month of August when river temperatures are at their seasonal peak. When the river enters Washington, average August river temperatures generally fluctuate between 17-18°C from year to year. Throughout the Lower Columbia River, where the river serves as the border between Washington and Oregon, the river fluctuates between 21-22°C. The lower section of the river is the corridor through which all Columbia Basin salmon migration must begin and is the focus of EPA's Cold Water Refuges project.

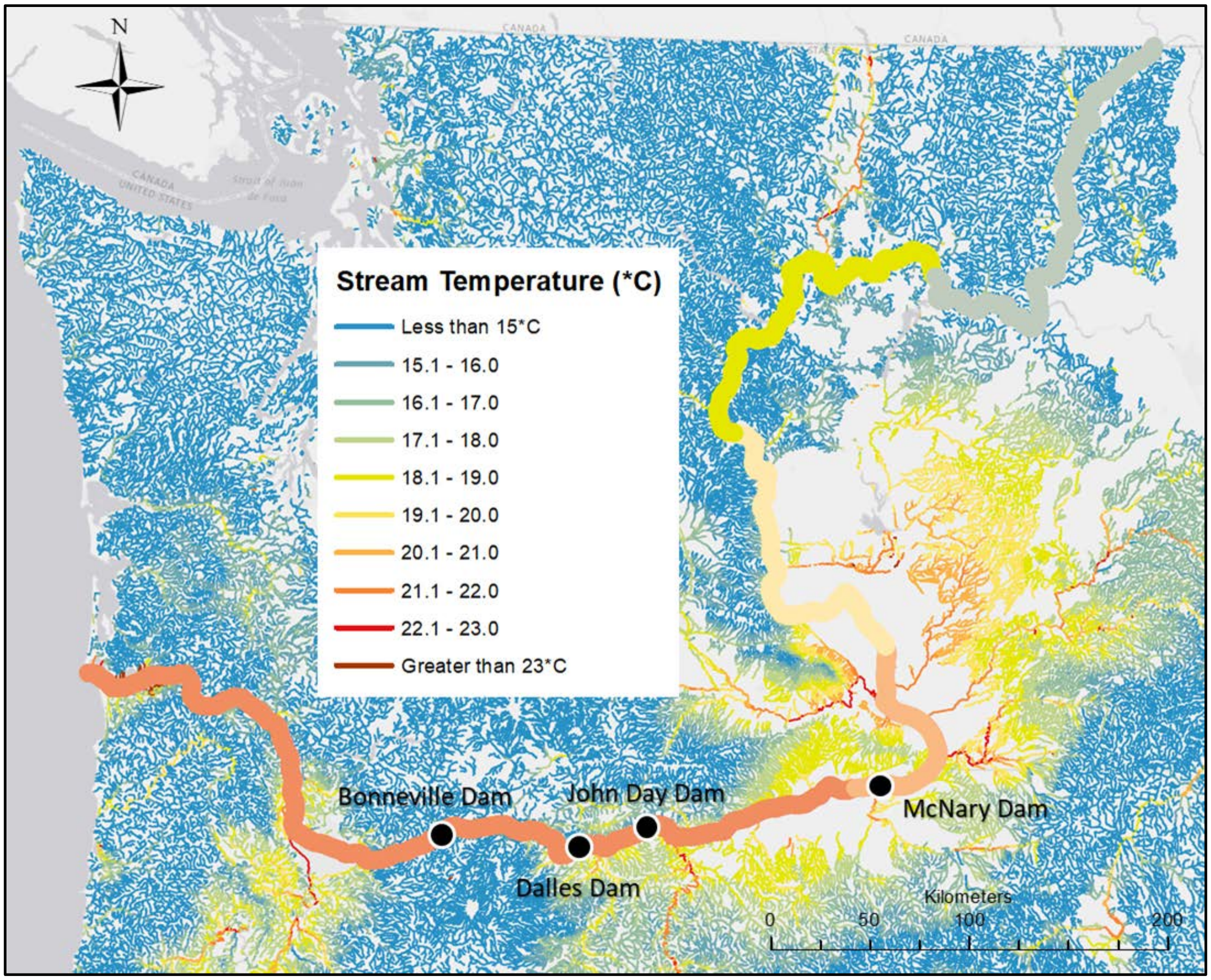

Figure 1 Current August Mean Water Temperature in the Columbia River and tributaries (2011-2016)

Columbia River DART data from the forebay (upstream) and tailrace (downstream) of each Lower Columbia River Dam was utilized to provide a closer look at the longitudinal temperature regime in the Lower Columbia River (***Figure 2***). The August data was averaged for the years 2011-2016. The forebay and tailrace data were already similar at any given dam but was averaged for this analysis. Thirty-five river miles upstream of McNary Dam, the Columbia River mixes with its largest tributary, the Snake River, which is warmer albeit smaller than the Columbia. By the time the Columbia River reaches McNary Dam, the most upstream of the four Lower Columbia River dams, the average August temperature is 21°C. The Columbia River then warms by 0.5°C on average in the 80-mile pool between McNary Dam and John Day Dam. The highest average August temperatures in the Lower Columbia River, and the whole Columbia River for that matter, occur near the John Day Dam, reaching 21.5°C on average in August. Temperatures then decrease slightly at The Dalles Dam and Bonneville Dam from the high temperatures at John Day Dam (***Figure 2***).

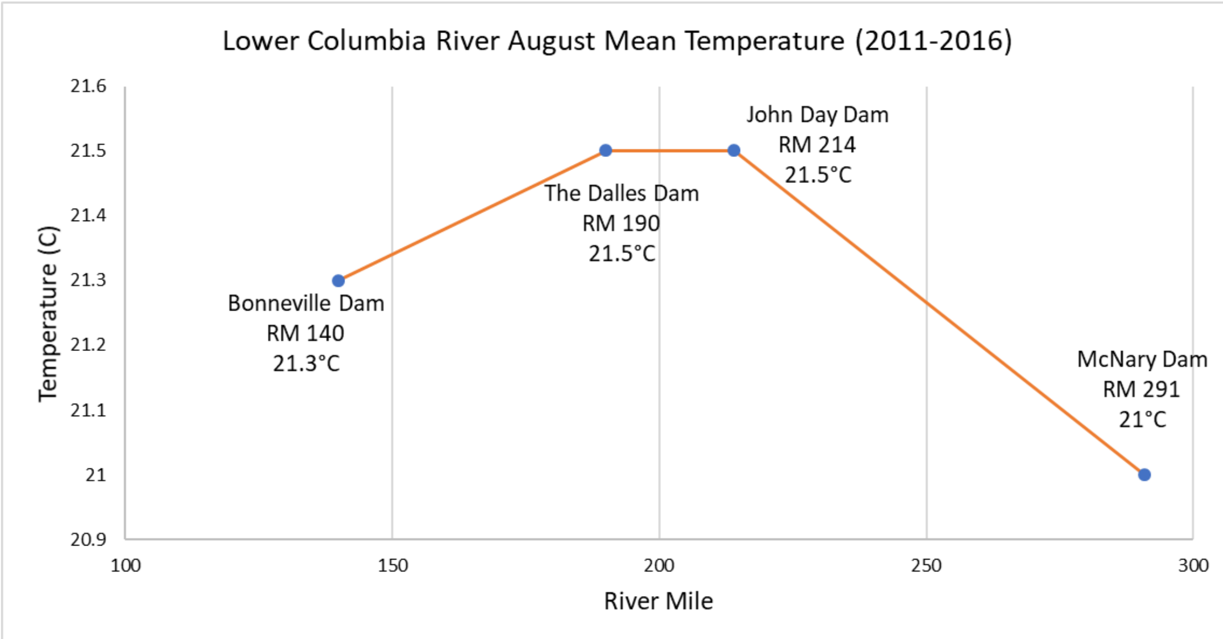

Figure 2 Longitudinal profile of the August Mean Columbia River Temperature from McNary Dam to the Bonneville Dam (2011-2016)

Figure 3 illustrates the six-year (2011-2016) observed daily average temperatures at the tailrace (downstream side) of the same four Columbia River dams, McNary (MCPW), John Day (JHAW), The Dalles (TDDO) and Bonneville (WRNO). Also illustrated in ***Figure 3*** is the 20°C water quality standard for the whole Lower Columbia River, developed by both Washington and Oregon to be protective of migrating salmon. Daily average temperatures typically exceed 20°C for 2 months in a given summer on average throughout the Lower Columbia River, from the middle of July to the middle of September. Further, temperatures exceed 21°C for one month on average, generally the month of August, and peak close to 22°C during this time. Average temperatures are slightly cooler at McNary Dam, due to the longitudinal warming pattern in the Lower Columbia River visible in ***Figure 2***, which is also observable in ***Figure*** 3.

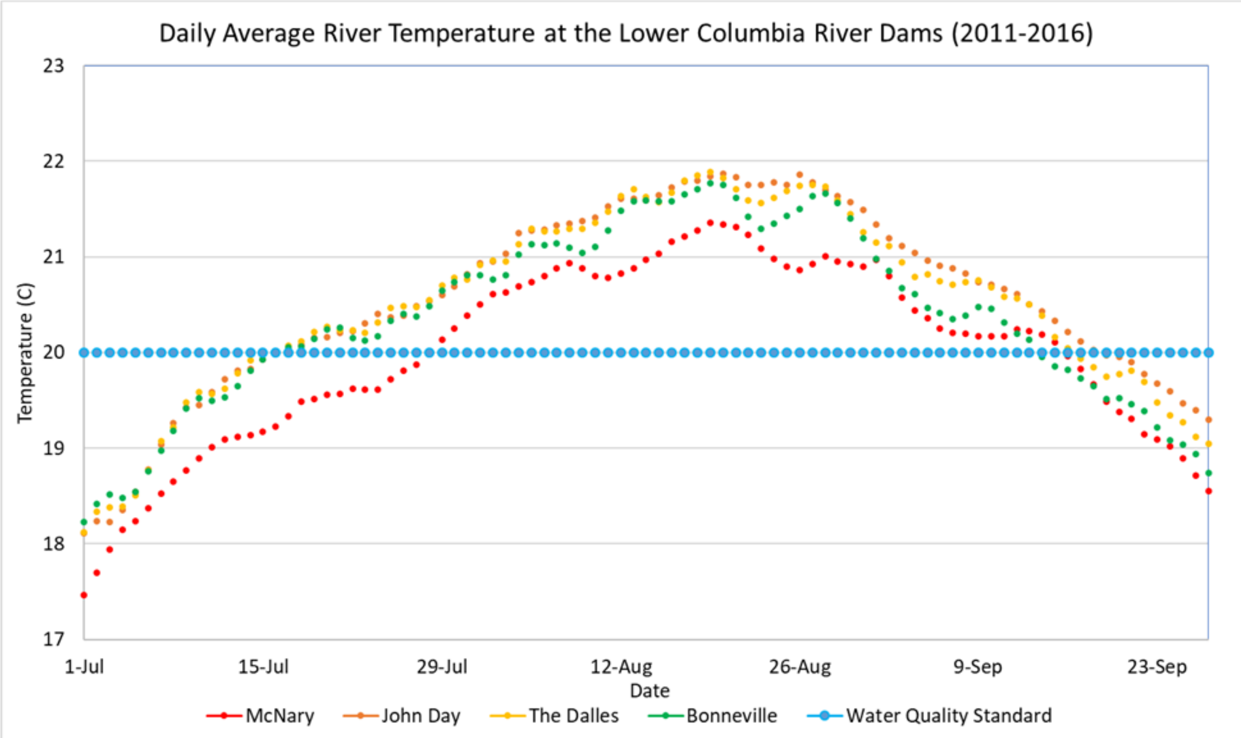

Figure 3 Lower Columbia River Temperature from early July to mid-September, 6-year average 2011-2016.

Upstream of McNary Dam (RM 291) is the Snake River confluence with the Columbia River (RM 325). The six-year daily average temperatures at McNary Dam (MCPW) are a function of the Columbia River temperature in Pasco (PAQW; just upstream of the Snake confluence) and the temperature of the smaller Snake River at Ice Harbor (IDSW; just upstream of the confluence), in addition to any longitudinal warming between the confluence and McNary Dam. The Snake River flow is generally close to 20% that of the Columbia River in July and August, so the temperature of the Columbia River has a larger impact after mixing. ***Figure 4*** illustrates this blending, showing the Columbia River (yellow) mix with the smaller yet warmer Snake River (blue) leading to the temperature at McNary Dam (MCPW), along with longitudinal warming between the confluence and McNary Dam.

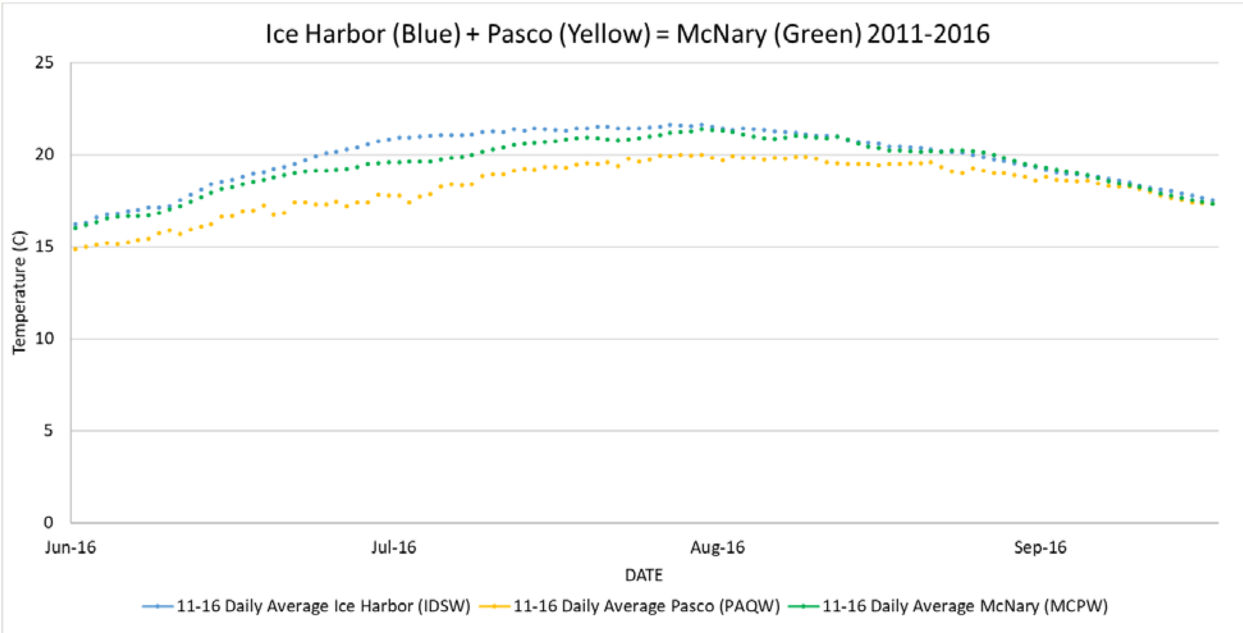

Figure 4 Influence of the Snake River (IDSW) and Columbia River as measured upstream of the Snake confluence in Pasco (PAQW) on the Lower Columbia River as measured at McNary Dam (MCPW)

Consistent temperature measurements are limited below Bonneville Dam. ***Figure 5*** illustrates that 10-year daily average temperatures below Bonneville dam at Cascade Island (CCIW) and Camas/Washougal (CWMW) are about the same as Bonneville forebay (BON) temperatures, suggesting very little change in river temperatures below Bonneville Dam.

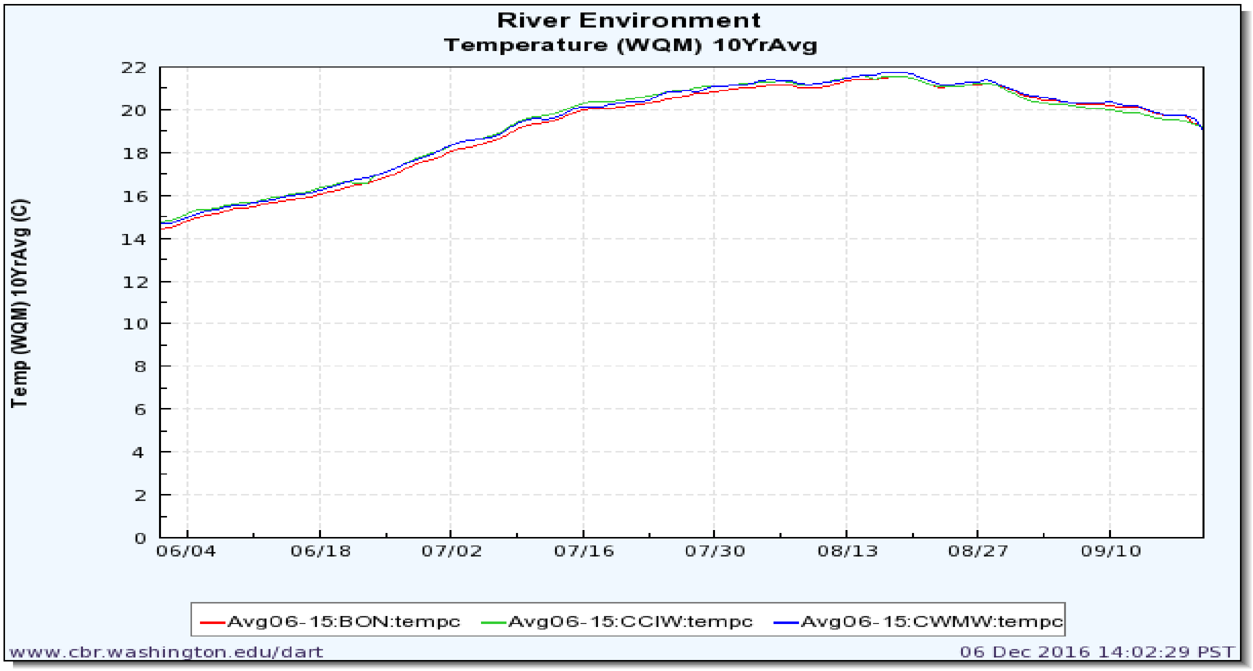

Figure 5 10 year average temperature at Bonneville Dam compared with temperatures slightly downstream at Cascade Island and Camas/Washougal

Daily average temperatures further downstream at Kalama (KLAW) compared to Bonneville forebay (BON) show very similar temperature profiles in 1996 – 1998, when temperatures were recorded at Kalama (see ***Figure 6***). This, along with ***Figure 5*** above, indicates that Bonneville forebay temperatures are representative of Columbia River temperatures downstream of Bonneville Dam.

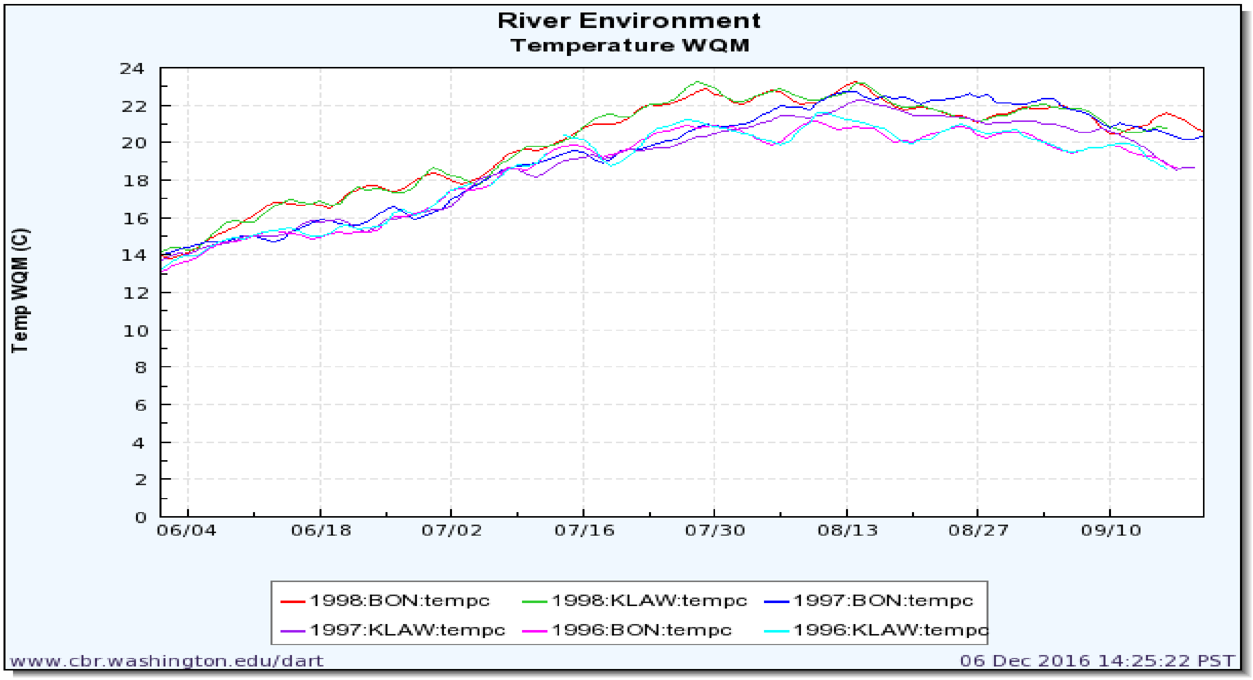

Figure 6 1996, 1997 and 1998 average temperature at Bonneville Dam compared with temperatures downstream at in Kalama

Seasonal and Interannual Temperature Variability in the Lower Columbia River

The figures above illustrates the temperature regime of the Columbia River averaged over multiple years, but it is important to note that this seasonal temperature profile can look very different between years due to different timing and magnitude of flows, different timing and intensity of warm weather and other factors. ***Figure 7*** shows the seasonal temperature profile downstream of Bonneville Dam (WRNO) for 10 individual years (2009-2018), illustrating the range that is observed in this seasonal temperature profile. These Bonneville daily average temperatures typically reach 20°C in mid July (thick black line), rise to 21-22°C in August, and fall below 20°C in early September.

The timing, duration and peak of warming can vary substantially year to year, and these characteristics relative to the timing of fish runs is very important in the context of cold water refuges. In mid-July, temperature ranged from about 17.5°C in 2011 (blue line) to 22.5°C in 2015 (red line) during this 10-year timeframe, a spread of 5°C (***Figure 7***). In mid-August when cold water refuge use is of particular importance, temperatures have less interannual variablity ranging from 20-22°C, more reliably exceeding the 20°C water quality standard. As an individual example year, 2015 (red line) warmed very early and peaked very early, but come the month of August when cold water refuge use is of particular importance, 2015 fits in with the average temperatures. The relatively cool summer of 2011 is an example of the river warming late, only exceeding 20°C for closer to a month and peaking at a much lower temperature than average.

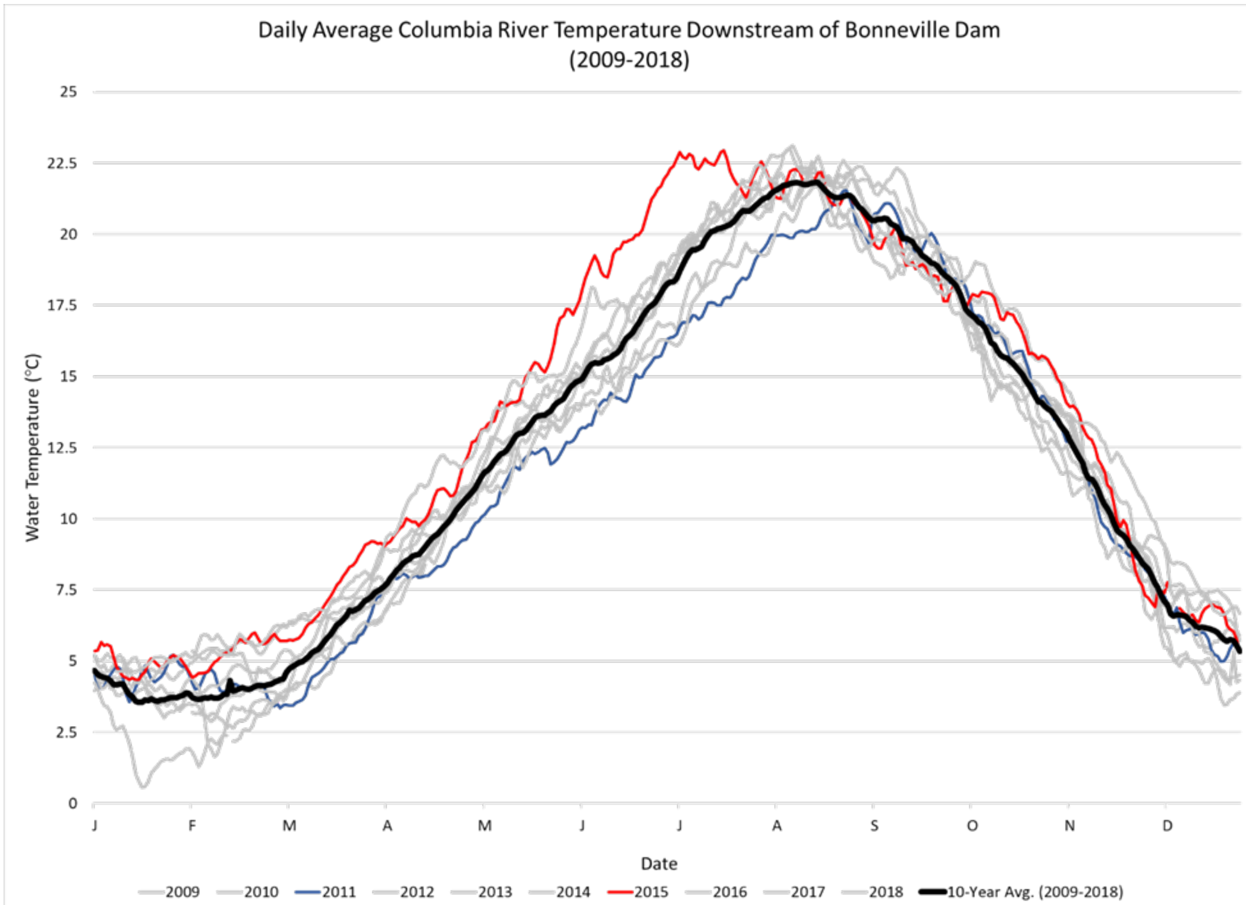

Figure 7 Seasonal temperature profiles downstream of Bonneville Dam, 10-year average 2009-2018

Vertical Temperature Variability in the Lower Columbia River

The following figures (***Figures 8-10***) are from the U.S. Army Corps of Engineers (USACE) (Dan Turner, personal communication, May 6, 2016). The Columbia River is not thermally stratified and has very little temperature variation at different depths. As shown by temperature profiles in the Bonneville (***Figure 8***) and The Dalles reservoirs (***Figure 9***), the temperatures at different depths (1 foot to 60/80 feet) are about the same. The John Day reservoir (***Figure 10***) heats up near the surface on warm days, causing the upper 20 feet of the reservoir to be slightly warmer (about 1°C) than the bottom 60/80 feet of the reservoir. Thus, there is no CWR from thermal stratification within Columbia River mainstem.

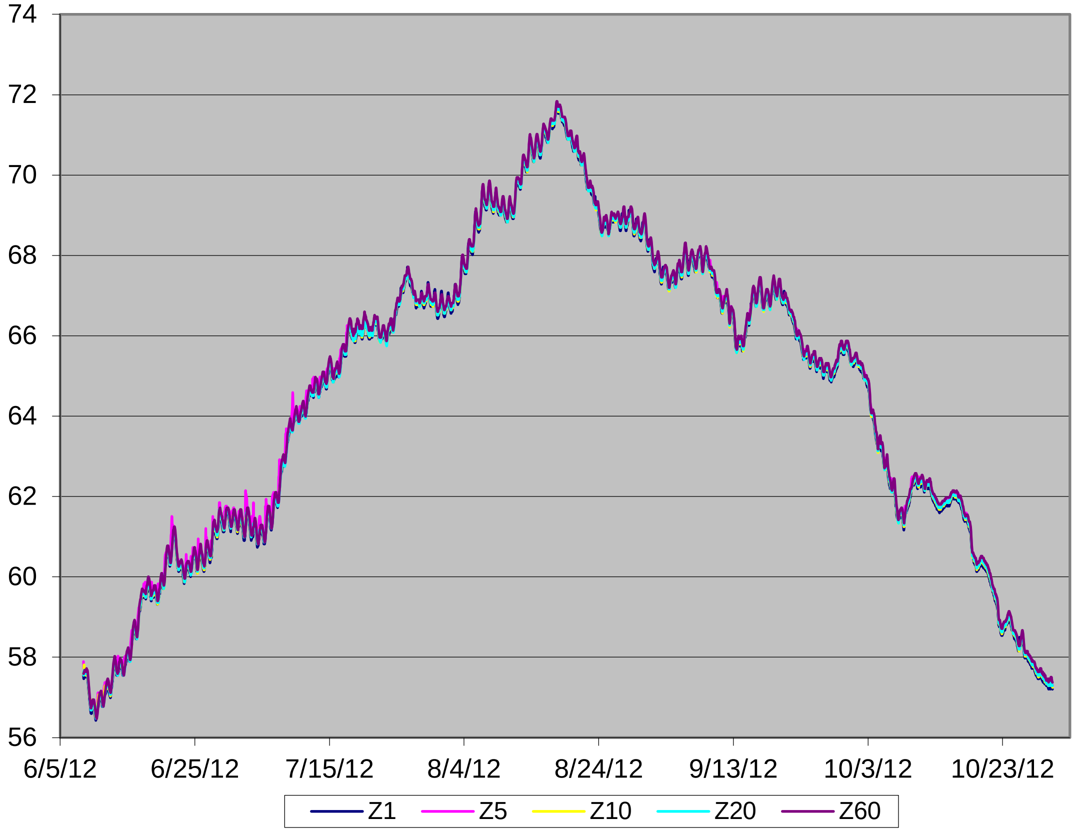

Figure 8 Bonneville Reservoir – Vertical Temperature Profile. (Z1 = 1 foot depth etc; y-axis in degrees F)

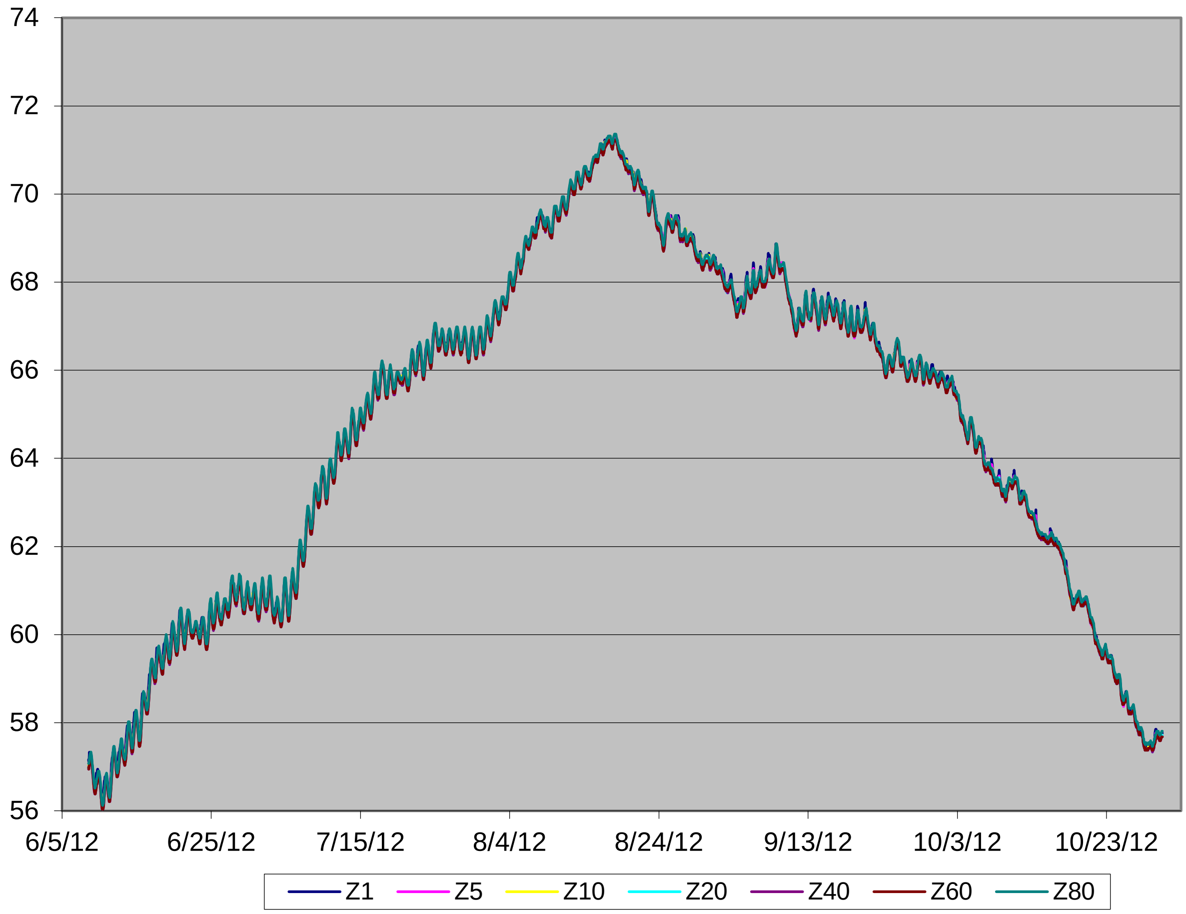

Figure 9 The Dalles Reservoir – Vertical Temperature Profile. (Z1 = 1 foot depth etc; y-axis in degrees F)

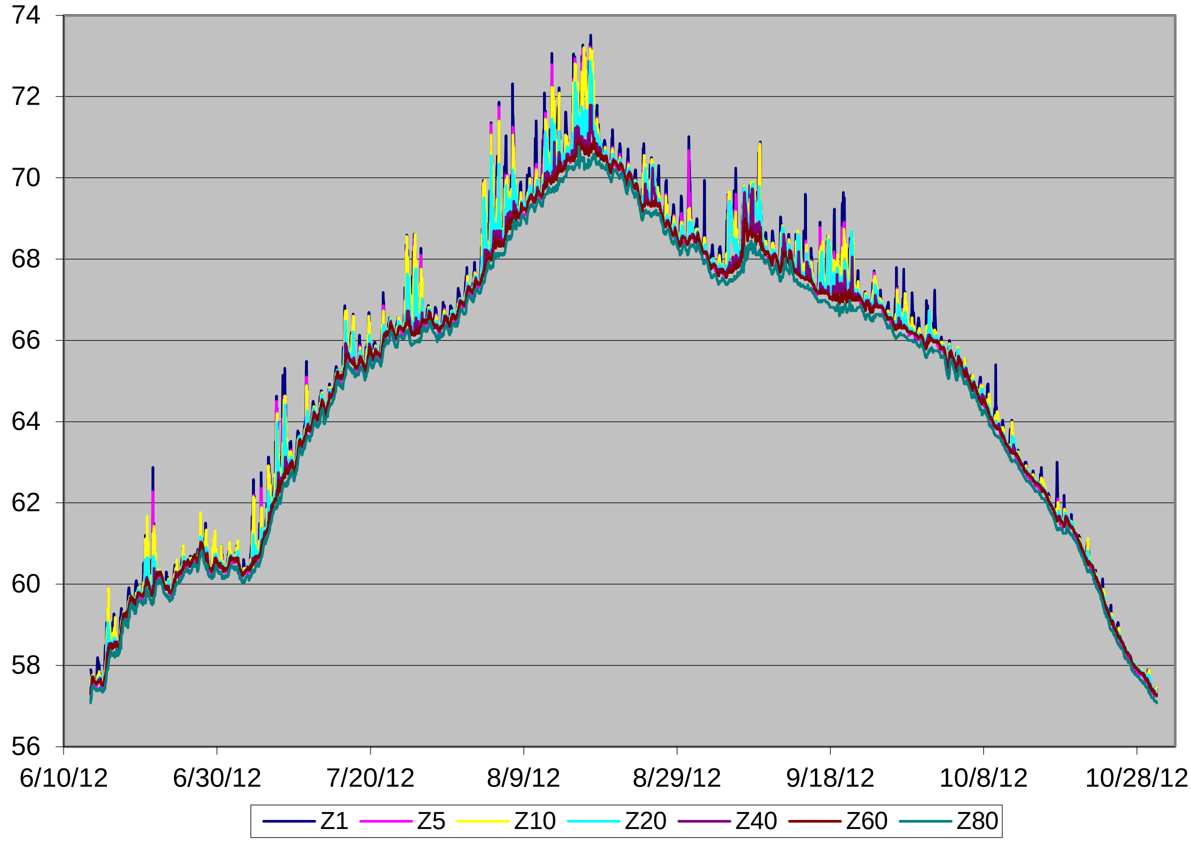

Figure 10 John Day Reservoir – Vertical Temperature Profile. (Z1 = 1 foot depth etc; y-axis in degrees F)

The vertical stratification behind McNary Dam is more complicated than that of other reservoirs in the Lower Columbia River. This is due to the influence of the Snake River on the Columbia River 35 miles upstream. Where the Snake River enters the Columbia River, the Columbia River is cooler than the Snake River during the summer. This difference is greatest in mid-to-late July (2-3°C) but is also substantial in August (1°C), as reflected by temperatures at Ice Harbor (Snake) and Pasco Dam (Columbia) (***Figure 4***). The merging of the cooler Columbia River and the warmer Snake River likely contributes to the more substantial vertical temperature gradient in the McNary reservoir, with the warmer Snake River water layering on top of the cooler Columbia River water. In addition, data indicates there is a lateral temperature gradient in the McNary Dam forebay, likely due to incomplete lateral mixing of the Snake River, with its warmer influence impacting the Oregon side of the Columbia River, and due to flow dynamics associated with the forebay curtain and flow through the dam creating surface pooling of warmer water on the Oregon side of the forebay. This vertical and lateral temperature variation in the McNary reservoir is illustrated in ***Figure 11***, with lateral sampling locations mapped in ***Figure 13***. In ***Figure 13***, the T4P5 sampling location, on the Washington side of the Columbia river, surface water temperature is cooler than the middle and the Oregon side of the river at sampling locations T4P1 and T4P3.

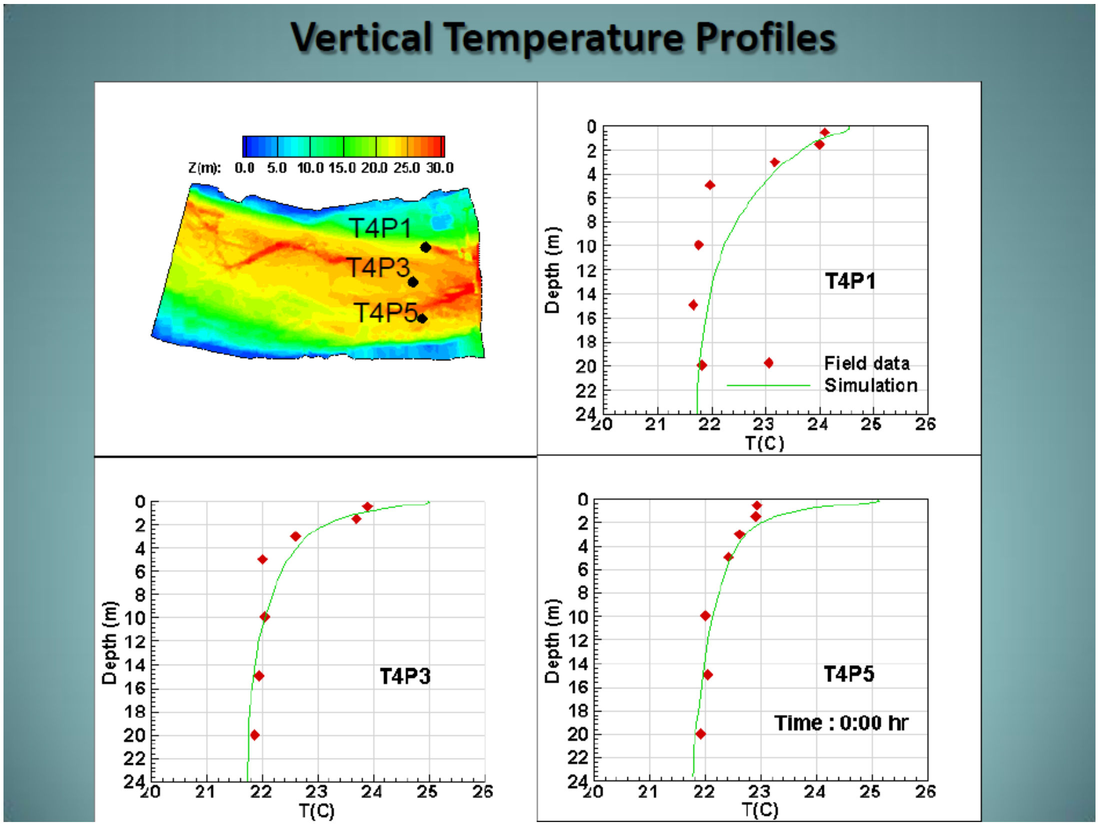

Figure 11 Lateral / vertical temperature variation in the McNary forebay. Lateral sampling locations in red in Figure 13 (M. Haque presentation of McNary Dam model)

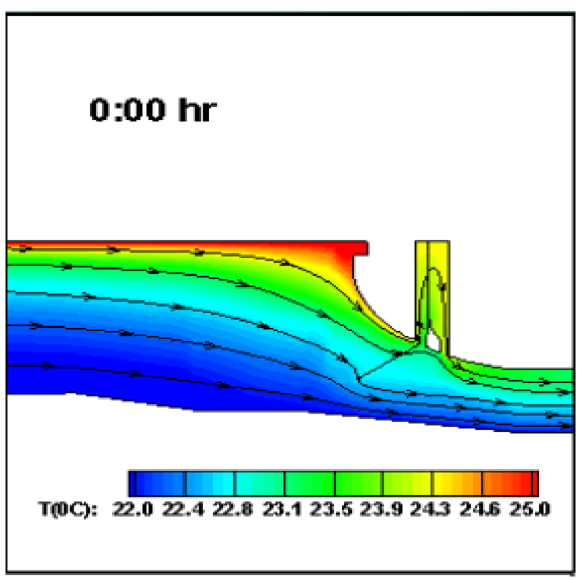

Figure 12 Dissection view of vertical temperature variability in the McNary Forebay (M. Haque presentation of McNary Dam model)

Figure 12 shows that the cooler Columbia mixing with the warmer Snake River causes vertical stratification in the water column. Because the cooler water from the Columbia lies underneath the warmer water from the Snake, the cool waters can actually act as a refuge for fish once they cross McNary Dam. Waters at a lower depth can be up to 2°C cooler than the surface of the forebay.

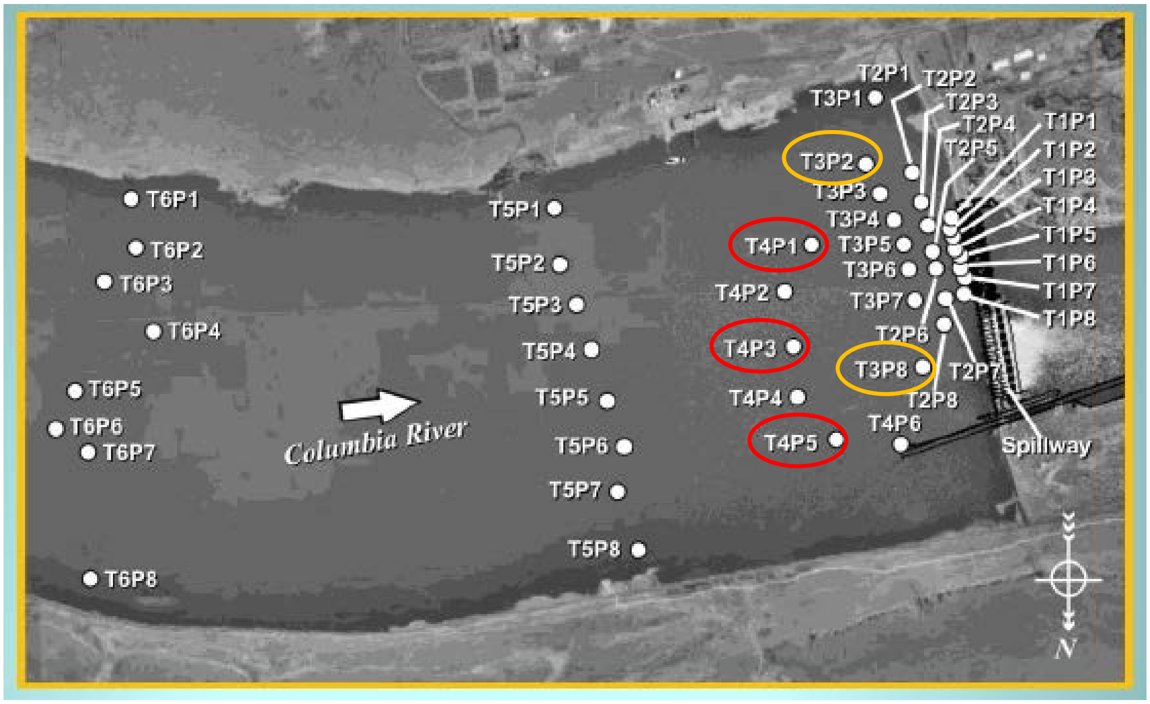

Figure 13 Lateral temperature sampling locations in the McNary Dam Forebay (M. Haque presentation of McNary Dam model)

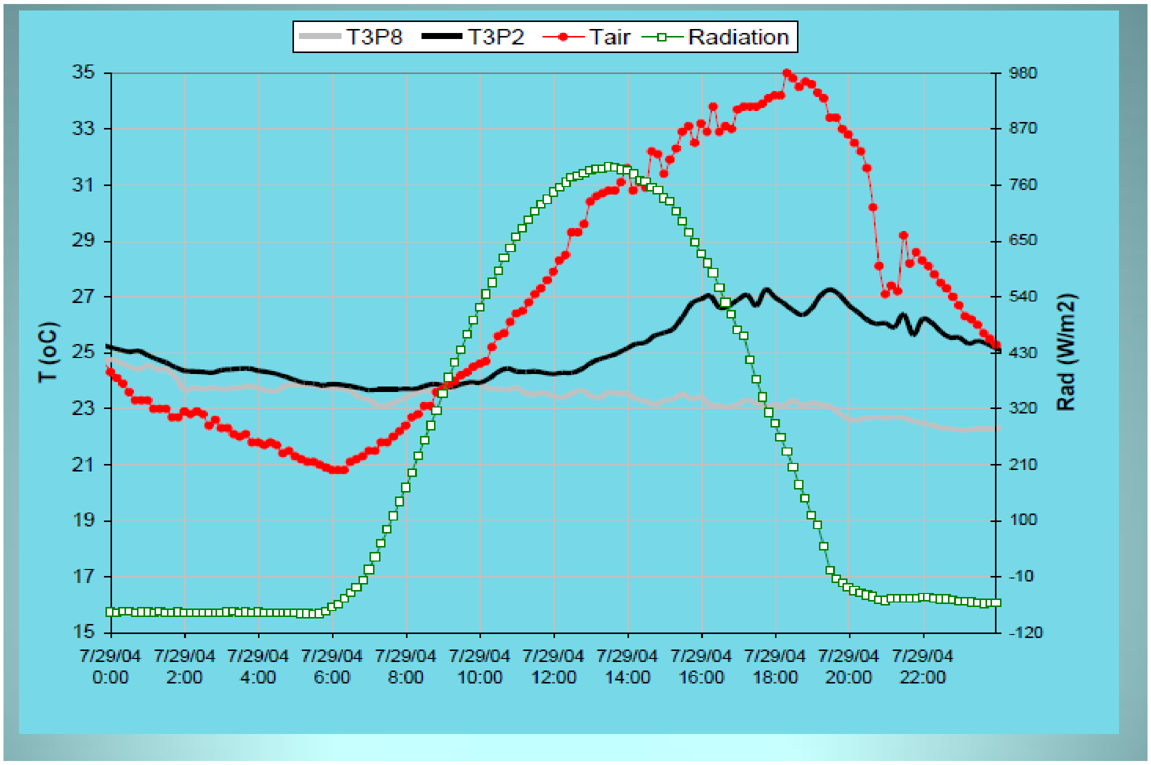

Figure 14 Vertical temperature variation in McNary forebay in response to solar radiation. See sampling locations in yellow in Figure 13 (M. Haque presentation of McNary Dam model)

Figure 14 demonstrates temperature variability in the McNary forebay. Location T3P2 (black line) experiences hotter temperatures than T3P8 (grey line) due to its location on the Oregon side of the McNary forebay, even though they both experience the same amount of solar radiation (yellow line) and air temperature (red line). The Oregon side of the Columbia in the McNary forebay experiences more pooling than the Washington side (T3P8) for reasons described earlier.

Diurnal Temperature Variability in the Lower Columbia River

The following figures (***Figure 15*** and ***Figure 16***) are from Columbia River DART (Columbia River DART, 2017). Due to the large volume of water, there is only a small amount of daily variation in the Columbia River temperatures. During warm periods, the difference between the maximum and minimum temperature is less than 1°C, and typically about 0.2 – 0.5°C. Thus, there is no CWR in the Columbia River mainstem due to cooler nighttime temperatures.

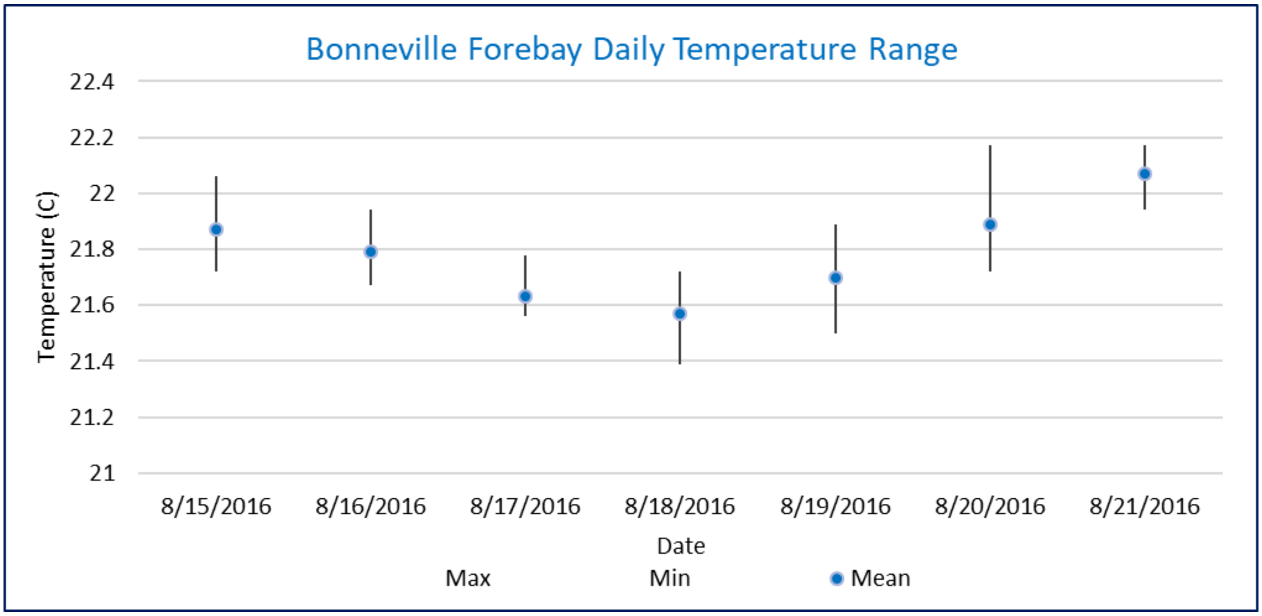

Figure 15 Bonneville Forebay Daily Temperature Range

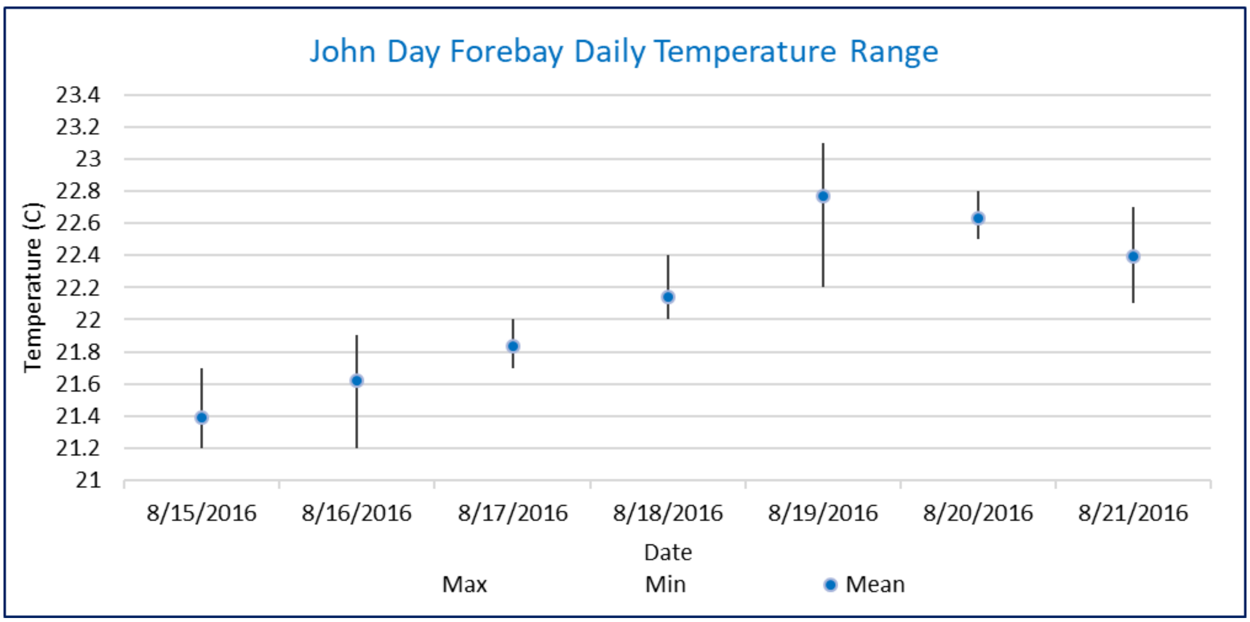

Figure 16 John Day Forebay Daily Temperature Range