North Clackamas Watersheds Temperature Study

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Executive Summary

Purpose
In 2019-20 the North Clackamas Watersheds Council (the Council) completed a Watershed Bio-Assessment. The Bio-Assessment determined that the absence of temperature data has made it difficult to prioritize projects that protect cold water refugia, or to track long term watershed conditions over time. Thanks to funding from the PGE Habitat Support Program and Oak Lodge Water Services, the North Clackamas Watersheds Council has begun to fill some of these stream temperature data gaps. Robust temperature monitoring information is critical to the management and restoration of our watersheds in four ways:

1. Determining the location of cold-water sources that create refugia for fish
2. Tracking on-going watershed trends
3. Informing decision-making by multiple agencies in project prioritization, land management, policy, and resource allocation
4. Educating landowners and land managers about watershed health

The methodology for this monitoring study was developed in cooperation with the Oregon Department of Environmental Quality (DEQ) Volunteer Monitoring Program. Temperature probes were launched in mid-May and were collected mid-October. The months of July and August were identified as the time period where temperatures were most critical for cold water species. We placed loggers at the confluences of the creeks in our service area to see how they function as potential cold water refugia (CWR) for fish migrating through the Lower Willamette.

Findings

1. *Willamette River confluences are potential cold water refugia*
Data from the mouth of Rinearson Creek was supposed to be collected by Columbia Restoration Group as a part of their mitigation requirements and at the time this report was written we were unable to acquire that data. Boardman Creek was identified as CWR. Both Kellogg Creek and River Forest Creek were warmer than the Lower Willamette River. However, loggers placed above Kellogg and River Forest Lakes showed that those impoundments significantly increased water temperatures. If Kellogg Dam and its associated impoundment could be removed then the mouth of Kellogg Creek would function as CWR habitat. And if River Forest Lake could be hydraulically disconnected from River Forest Creek, that confluence could also function as CWR habitat.

2. *Kellogg Creek, Dean Creek, the North Fork of Boardman Creek, and Minthorn Springs provide cold water*
We were able to identify several cold-water sources in the North Clackamas watersheds. The water flowing from Dean Creek and Kellogg Creek upstream of its confluence with Mt. Scott Creek was significantly cooler than Mt. Scott Creek. Phillips Creek was also slightly cooler than Mt. Scott Creek. The upper reaches of Mt. Scott also appears to be quite cool; however, our logger at that location stopped working early in the monitoring season which will require another year of monitoring to confirm this finding. The coldest water found was at Minthorn Springs, however, this water warmed significantly to become the warmest water studied as it travelled through Minthorn Springs Wetland. In Boardman Creek, the temperatures in the North Fork of Boardman Creek were significantly cooler and may function as a thermal refuge in the summer.

3. *Water heated up through the McLoughlin corridor, downstream of the upper reaches of Mt. Scott Creek along Sunnyside Road, and through water impoundments.*
   There were several areas where we recorded significant increases in water temperatures. Wide shallow impoundments of water allowed water to heat up, including Kellogg Lake, Minthorn Springs Wetland, River Forest Lake and the pond downstream of the diversion structure in 3-Creek Natural Area. We also saw increases in water temperatures along major urban arteries such as McLoughlin Boulevard and along Sunnyside Road.

Implications for Restoration, Protection and Management

1. *Fix heat-loading effects at impoundments*
   Water temperatures increased significantly through water impoundments. Potential treatments vary at each site:
   - When Kellogg Dam is removed, the associated impoundment will be dewatered and the channel will be restored to a sinuous flowing creek.
   - River Forest Lake could potentially be disconnected hydraulically from River Forest Creek, while maintaining the lake for its surrounding residents. Further study should be conducted to determine the feasibility of accomplishing this.
   - Minthorn Springs Wetland heats up considerably in the summer and restoration of that wetland should focus on controlling summer temperatures.
   - As Clackamas WES plans restoration of their 3-Creeks property, consideration should be given to the pool downstream of the water diversion structure to determine how best to mitigate the temperature impacts at that site.

2. *Target cold water areas for protection and fish access*
   The cold-water areas (Boardman/Willamette Confluence, Dean Creek, Upper Kellogg Creek, North Fork Boardman Creek) should be prioritized for protection and fish access. These areas will provide thermal refuge for fish in the summer, and the Council will focus on removing any barriers to fish accessing these reaches, especially during summer low flows.

3. *Identify solutions for reducing heat loading through urbanized corridors with large heat island effects*
   Significant temperature increases occur where streams pass through the McLoughlin (Highway 99E) corridor and the upper reaches of Mt. Scott Creek down to Mt. Talbert Nature Park. Projects should be explored that reduce the heating effect such as reducing impervious surface area, improving stormwater inputs, or preventing point-source inputs of warm water from businesses.

Further Study

Future monitoring years should study the following in more depth:

- Study temperature dynamics in Minthorn Creek to better understand both heat inputs in Minthorn Springs Wetland and water heating/cooling between the wetland and the confluence with Mt. Scott Creek.
- Study Kellogg Creek upstream of Mt. Scott to pinpoint sources of cold water and understand temperature dynamics up to the headwaters at Hearthwood Wetland.
- Conduct a year-round study of temperatures in areas that have potential spawning habitat in the Kellogg Creek watershed.
- Repeat temperature monitoring in the upper reaches of Mt. Scott Creek to verify potential cold-water sources and determine why it heats up so much as water flows down to Mt. Talbert.

- Continue long-term trend monitoring to track changes in watershed temperature impacts from climate change, development, and restoration actions.
- Compare the results of this study with the Council's fish passage barrier and eDNA studies to better understand fish utilization.

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Introduction

In 2019-20 the North Clackamas Watersheds Council (the Council) completed a Watershed Bio-Assessment and developed a list of high-priority restoration projects for ecological uplift of the Clackamas fish population (NCWC, 2020). The Bio-Assessment found there is little to no continuous temperature monitoring underway in these watersheds, the exceptions being one project on Lower Rinearson Creek and 3 stations maintained by the Clackamas Water Environment Services (WES) to calibrate flow meters. The absence of this fundamental information has made it difficult to prioritize projects that protect cold water refugia, or to track long term watershed conditions over time as we monitor impacts from restoration, climate change, and urbanization.

Water temperature affects the distribution, health, and survival of native salmonids and other aquatic organisms by influencing their physiology and behavior. Water that is too warm can cause direct mortality of fish. But while lethal high temperatures can be locally problematic, temperatures in the range that cause sublethal effects are much more widespread and may have the greatest effect on the overall wellbeing of our native fish populations. These sub-lethal effects resulting from abnormally high temperatures include impaired feeding, reduced growth, diminished resistance to disease, inability to compete, and poor predator avoidance (EPA, 2001). Evidence suggests that small increases in temperatures (2-3 °C) above biologically optimal ranges can begin to reduce salmonid fitness. Temperature related impacts to lamprey are more difficult to describe as there are few studies in nature to describe such impacts. Researchers investigating lamprey through laboratory experiments, field observations, and telemetry work concluded that water temperature in the Willamette Basin ≥ 20 °C is corelated with developmental abnormalities in larvae, expedition of sexual maturation, pre-spawning mortality, slowed or stopped upstream migration by adults, and gonadal tissue damage (Ben Clemens, ODFW Statewide Lamprey Coordinator, personal communication with Todd Alsbury, November 2020).

Water temperatures are influenced by solar radiation, stream shade, ambient air temperatures, channel morphology, groundwater inflows, and stream velocity, volume, and flow. Surface water temperatures may also be warmed by anthropogenic activities such as discharged heated water, changed stream width or depth, lowered stream complexity that decreases hyporheic exchange, reduced stream shading, and water withdrawals.

The Kellogg-Mt. Scott, Rinearson, River Forest, and Boardman watersheds provide rearing habitat and some migrating and spawning habitat to threatened and endangered salmonids and other priority species including winter steelhead, coho salmon, Pacific lamprey, cutthroat trout (resident, fluvial, and anadromous), and fall and spring Chinook salmon (Clackamas Partnership, 2018). Furthermore, they provide both potential off-channel cold-water refugia in a stretch of the Willamette where geological features largely prevent alcoves and significant side channel refugia in the Willamette mainstem (DEQ, 2020). This makes the availability of cold water refugia critical in lower Willamette tributaries and tributary junctions. However, the lack of information on cold-water refugia in these tributary systems of the Willamette floodplain is a key knowledge gap that has hindered strategic restoration.

Thanks to funding from the PGE Habitat Support Program and Oak Lodge Water Services, the North Clackamas Watersheds Council has begun to fill some of these stream temperature data gaps. This study is being undertaken in partnership and consultation with multiple jurisdictions and partners including the Oregon Department of Environmental Quality (DEQ), Oregon Department of Fish and

Wildlife (ODFW), Oak Lodge Water Services (OLWS), Clackamas Water Environment Services (WES), City of Gladstone, City of Milwaukie, and City of Happy Valley.

Project Goals

Robust temperature monitoring information will be critical to the management and restoration of these watersheds in four ways:

1. *Determine the location of cold-water sources that create refugia for fish:* This study helps address knowledge gaps regarding cold-water refuges in tributaries of the lower Willamette and North Clackamas watersheds. By closing information gaps on temperature, the Council will ensure that future projects are located to protect and maximize cold water refugia, and remove barriers that potentially prevent access to cold water refugia.

2. *Track ongoing watershed trends:* Ongoing continuous temperature monitoring is fundamental to a long-term understanding of watershed function and how it changes over time with impacts from climate change, urbanization, and ongoing restoration efforts. We will maintain these temperature stations in the same locations, creating a long-term trend analysis that will guide the Council's restoration and advocacy.

3. *Inform decision-making by multiple agencies:* The information gathered in this study will be shared with local and state jurisdictions, allowing them to utilize it to engage in informed planning when projects may impact these watersheds. It will also help to monitor the impact natural areas have on stream temperatures as local jurisdictions advocate to create, protect and manage natural areas, parks and public lands and take other steps to improve water quality and climate resilience in their jurisdictions. Finally, the data will provide baseline information to better understand how man-made impacts such as development and point-source discharges affect stream temperatures.

4. *Use for landowner education:* Projects such as these provide vital opportunities to engage the public in watershed science. Discussions with landowners and residents during the Bio-Assessment revealed a lack of understanding by well-meaning landowners of the role of large wood, side channels, wetlands, in-channel complexity, and temperature as a limiting factor for aquatic health. This field work opened the door to these conversations and informed the Council of a need for public education. This temperature monitoring information will be incorporated into these on-going landowner education efforts.

Methods

The Council developed the temperature monitoring methodology in cooperation with the Oregon Department of Environmental Quality (DEQ) Volunteer Monitoring Program. The Council developed a Sampling and Analysis Plan (SAP) which was approved by DEQ. During this study we collected Level A quality data, as defined by DEQ in the Quality Assurance Project Plan (QAPP): Volunteer Water Quality Monitoring, July 2021. The monitoring was intended to capture high water summer water temperatures, which predominantly occur during June, July, August, and September. Level A is the highest level of data quality. It can be used to assess compliance with water quality standards, permitting requirements, or other regulatory activities. It requires that the accuracy of every thermograph is checked with a NIST thermometer within an accuracy +/- 0.5°C and a precision of +/- 0.5°C. All temperature data was collected using Onset HOBO MX2203 Tidbit Data Loggers in Celsius. The Tidbits are durable and designed for data collection up to 400-foot depths. They are waterproof with a precision sensor with ±0.2°C accuracy, 0.01C resolution, and ranges between -20°C and 50°C (-4 to 122°F) in water. The accuracy of the thermographs were tested against a NIST certified temperature probe before and after field deployment to ensure that they operated within their designed range of accuracy (+/- 0.5°C), which they all did. These pre- and post-season logger calibrations can be seen in Appendix A and B.

Temperature monitoring occurred in Kellogg-Mt. Scott, Rinearson, River Forest, and Boardman watersheds and their confluences with the Willamette River. The Council selected some sites as reference sites to reflect baseline conditions within a specific stream. Other sites were chosen as study sites to answer specific questions about how water temperatures are impacted by water impoundments, nature areas, or instream temperatures. Temperatures were monitored May through October. The Council secured access permission from private landowners and obtained agreements from agency partners for publicly owned land.

Figure 1 - Locations of temperature monitoring stations for 2022.

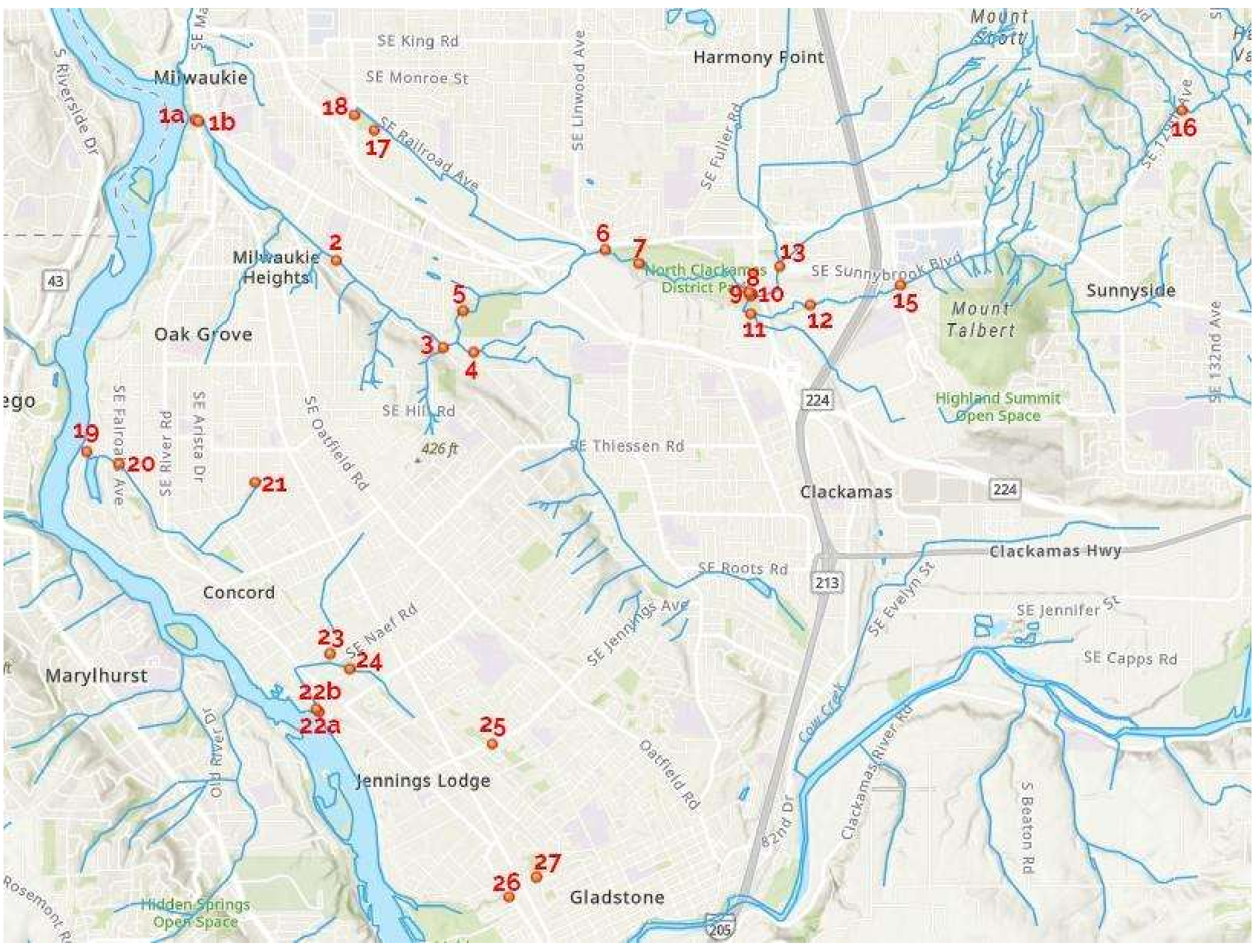


Table 1 - Station descriptions and research questions being asked at each location.

Site ID#	Station Description	Research Question
1a	Kellogg Dam fish ladder	What are the temps at the downstream end of the Kellogg Dam impoundment?
1b	Kellogg Dam impoundment	Duplicate of 1a in slightly different location in case one is stolen. Highly visible area.
2	Kellogg Creek upstream of impoundment (on private land)	What are the stream temps flowing into the Kellogg Dam impoundment?
3	Kellogg Creek near Kuehn Road	How does Mt. Scott affect water temps in Kellogg Creek?
4	Kellogg Creek at Amiguitos Preschool (private property)	What is the temperature of Kellogg before influence of Mt. Scott Creek?
5	Mt. Scott Creek mouth at North Clackamas Park	What is the temp of Mt. Scott Creek before it joins Kellogg Creek?
6	Mt. Scott Creek at downstream end of 3-Creeks Natural Area	What effect does the 3-Creeks pond have on temps as water passes through the natural area?
7	Mt. Scott Creek upstream of water control structure	What are the temps going into the pond downstream of the water control structure at 3 Creeks?
8	Mt. Scott downstream of Phillips confluence	How does Phillips Creek influence Mt. Scott Creek stream temps?
9	Mt. Scott Creek upstream of Phillips Creek confluence	What are the temps of Mt. Scott Creek before influence from Phillips Creek?
10	Phillips upstream of Mt. Scott confluence	What are the temps in Phillips Creek before entering Mt. Scott?
11	Mouth of Dean Creek behind PCC	What are the temps in Dean Creek before entering Mt. Scott?
12	Mt. Scott at SE 84th	What are the temps of Mt. Scott before being influence by Dean Creek?
13	Phillips on WEST 84th property	What are the stream temps at proposed site for vegetation management and downstream of Clackamas Town Center?

Site ID#	Station Description	Research Question
15	Mt. Scott downstream of Mt. Talbert east of 97th	What are the stream temps flowing out of Mt. Talbert Nature Park?
16	Mt. Scott end of anadromy	What are the temps at the uppermost limit of anadromy (as defined by ODFW)?
17	Leaving Minthorn Wetlands	What are the temps flowing out of Minthorn Wetlands compared to the springs?
18	Spring entering Minthorn Wetlands	What temperature is the spring feeding Minthorn Wetlands?
19	River Forest downstream of lake below culvert	How does the lake impact River Forest temps before it drains into the Willamette?
20	River Forest upstream of lake at SE Fairoaks	What are the temps of River Forest before it enters River Forest Lake?
21	River Forest headwaters at Woodland Way	What are the baseline temps in the headwaters of River Forest?
22a	Boardman at mouth	What are temps at the confluence of Boardman with consideration to the tidal influence from the Willamette?
22b	Boardman at OLWS lift station	What are Boardman's temperatures before draining into the Willamette?
23	NF Boardman (on private property)	What are the temps of the north fork before it joins with the south fork?
24	SF Boardman at Stringfield Park	What are the temps of the south fork before it joins with the north fork?
25	Boardman upstream of Jennings Road	What are the stream temps flowing into the series of wetlands along the south fork?
26	Rinearson downstream of River Road	What are the stream temps going into the restoration site after creek flows through Hwy99 corridor (to compare with data collected by Columbia Restoration Group in Rinearson Natural Area)?
27	Rinearson at Olson wetlands (end of Risley Ave)	How does the influence of Olson Wetlands affect stream temps?

At all sites except for Kellogg Dam (Site 1a and 1b), a three-foot piece of rebar was driven into the streambed and was used to secure each thermograph. This rebar was driven to a depth below the surface of the water level, keeping the installation relatively hidden (see Figure 2). At locations that were accessible to the public, the rebar was topped with a plastic cap to prevent people from injuring themselves on it. The probes were housed in a 2" ABS pipe that had 15-20 ¼ inch holes drilled out to allow water to through on a constant basis while preventing potential sediment accumulation around the probe. Stainless steel cable and clamps then attached the ABS pipe to the rebar to ensure probes were not lost during the sampling period. Once the rebar and pipe were installed, the probe was not noticeable from above the water to prevent tampering. For this reason, photos were taken at every installation location and the sample sites were geo-located utilizing the ArcGIS Field Maps phone app to ensure that the rebar could be found when collecting the probes at the end of the sample season.

Figure 2 - Consultant securing ABS pipes containing the temperature probes to underwater rebar.

Two temperature loggers were installed at the mouth of Kellogg Creek, one in the fish ladder (Site 1a) and one in the impoundment just upstream of the dam (Site 1b). The thermograph in the fish ladder was put in a ABS pipe and affixed to a 10-pound weight, and then sunk into the fish ladder. The logger in the impoundment was attached to an anchor that was sunk in the lake, which was all attached to a buoy for retrieval (see Figure 3). The reason for launching two loggers at this site is that staff from ODOT mentioned they have had several temperature loggers stolen from this area, due to the high use and visibility by the public. The logger in the impoundment that was attached to the buoy did indeed get stolen. Thankfully the probe in the fish ladder was recovered.

At the end of the sampling season, the thermographs were recovered and downloaded. The data was summarized based on a 7-day average maximum (7dAM), which is calculated by averaging the daily maximum instream water temperatures for 7 consecutive days. Because the criteria apply to every 7-day period, it is often referred to as the rolling 7dAM. For example, one 7-day period is July 1-7, and the next is July 2-8. The 7dAM value for each 7-day period is reported on 7th day of the period. All raw and analyzed data has been backed up in NCWC's Google Drive cloud storage.

Figure 3 - Two different methods were used to install loggers at Kellogg Dam. In the fish ladder (left photo) the unit was submerged using a 10-pound weight. In the impoundment (right photo), the logger was attached to an anchor that was marked with a buoy.

Temperature Standards

The Council is not a regulatory entity, and will not be using temperature data in a regulatory capacity. Temperature standards are simply a way that we can reflect on a waterbody's capacity to provide habitat for cold-water fish species. This data will predominately be used for the purpose of strategic watershed planning, with of goal of prioritizing cold-water areas for restoration and protection. The data will be provided to DEQ annually as per our Sampling and Analysis Plan (SAP) through DEQ's Volunteer Water Quality Monitoring Program.

Beneficial Uses

The objective of a water quality standard, as required by the Clean Water Act, is to protect the beneficial uses of the waters of the State. In the case of temperature, the most sensitive beneficial use is Oregon's native cold-water aquatic species such as salmon and trout. The DEQ established temperature standards for specific life history stages of salmon and steelhead (as seen below in Table 2). The standards are used in establishment for Total maximum Daily Load (TMDL) criteria for water quality limited streams in Oregon (DEQ, 2008), and are based on 7dAM.

Table 2 - List of designated beneficial uses and associated temperatures.

Beneficial use	7dAM
1. Salmon & steelhead spawning (during spawning use)	55.4 F / 13 C
2. Core coldwater habitat (year round)	60.8 F / 16 C
3. Salmon & trout rearing & migration (year round)	64.4 F / 18 C
4. Migration corridor for salmon & steelhead (year round)	68.0 F / 20.0 C

1. *Salmon & steelhead spawning* – Waters that are or could be used for salmon and steelhead spawning, egg incubation, and fry emergence
2. *Core coldwater habitat* – Waters that are expected to maintain temperatures within the range generally considered optimal for salmon and steelhead rearing
3. *Salmon & trout rearing & migration* – Waters that are thermally suitable rearing habitat for salmon, steelhead, rainbow trout, and cutthroat trout.
4. *Migration corridor for salmon & steelhead* – Waters that are predominantly used for salmon and steelhead migration during the summer and have little or no anadromous salmonid rearing in the months of July and August.

The creeks being studied here are primarily limited to rearing habitat since few spawners are able to access Kellogg Creek due to the existing dam, so the ideal 7dAM threshold would be 18°C. Once Kellogg Dam is removed, there is potential for the Kellogg-Mt. Scott watershed to be utilized by salmonids and Pacific lamprey for spawning in the future. For this reason, a future temperature study may want to target areas with spawning gravels in Kellogg-Mt. Scott Creek for year-round monitoring to consider temperatures during potential spawning seasons (fall through spring), as well as the summer months when thermal loading is a problem.

Cold-Water Refugia

DEQ also establishes standards for identifying cold-water refuge (CWR) along the Lower Willamette. The CWR provision supplements the migration criterion in the Lower Willamette of 20°C to protect migrating populations of salmon and steelhead. The criterion states that these water bodies must have sufficiently distributed CWR that allow salmon and steelhead migration without significant adverse effects from 7dAM temperatures up to 20°C (DEQ, 2020). Candidates as cold-water refuge from tributaries was defined as having at least a 2°C colder temperature than the daily maximum temperature of the adjacent well-mixed flow of the water body. Therefore, at creek confluences with the Willamette we will be assessing the differences between average daily maximum temperatures during the months of July and August, which is slightly different than the 7-day rolling average temperatures (7dAM) that we will be assessing outside of the Lower Willamette confluence CWR analysis.

Wetlands

Oregon has no unique temperature criteria for wetlands at this time. However, wetlands with direct connections to creeks and rivers have the potential to impact water temperatures. For example, in this study the Minthorn Springs wetland acts as the headwaters of Minthorn Creek and directly impacts water temperatures flowing into that system.

Results: Lower Willamette Confluences as CWR

Evaluating creek confluences that flow into migration corridors as potential CWR is important, particularly in the Lower Willamette where side channels and backwater habitats are limited by the area's geology. Migration corridors are often channels that are too large to be cooled by shading vegetation and groundwater inflow. Because of the importance of CWR in the Lower Willamette, NCWC has developed a confluence strategy to prioritize protecting and enhancing potential cold-water inputs into the Willamette River (see Figure 4). As part of that strategy, the need for confluence temperature monitoring was identified, and loggers were placed at the mouths of all confluences within NCWC's service area. In Rinearson Creek, the confluence thermograph was going to be installed by Columbia Restoration Group as a part of the monitoring of their mitigation bank site (personal communication, Evan Ocheltree). However, at the time of this report writing, NCWC was unable to acquire the data from Columbia Restoration Group.

Any identified CWR habitat may be enhanced and protected by:

1. maintaining or enhancing vegetation for shade,
2. protecting cold tributaries from development in riparian areas,
3. reducing heat impacts from stormwater,
4. protecting and creating channel features that create cold water flows through hyporheic exchange,
5. protecting sources of groundwater inflows,
6. reducing heat impacts from stormwater inputs through detention and treatment, and
7. removing physical and thermal barriers to fish accessing areas of cold water.

The USGS gaging station for the Willamette River at Portland (USGS 14211720) was used as the reference temperature for the main stem Lower Willamette. This same gage station was also used during the DEQ 2020 study. In 2022, the lower Willamette River exceeded the DEQ 20°C temperature standard for migration corridors from June 30, 2022 to September 11, 2022, as seen below in Figure 5. This is consistent with the EPA study that identified July and August as the temporal extents of quantifying CWR in the lower Willamette (EPA, 2012). For this reason, we will look at the July and August temperatures for identifying CWR at creek confluences.

Figure 4 - Potential CWR along the lower Willamette River located in creek confluences.

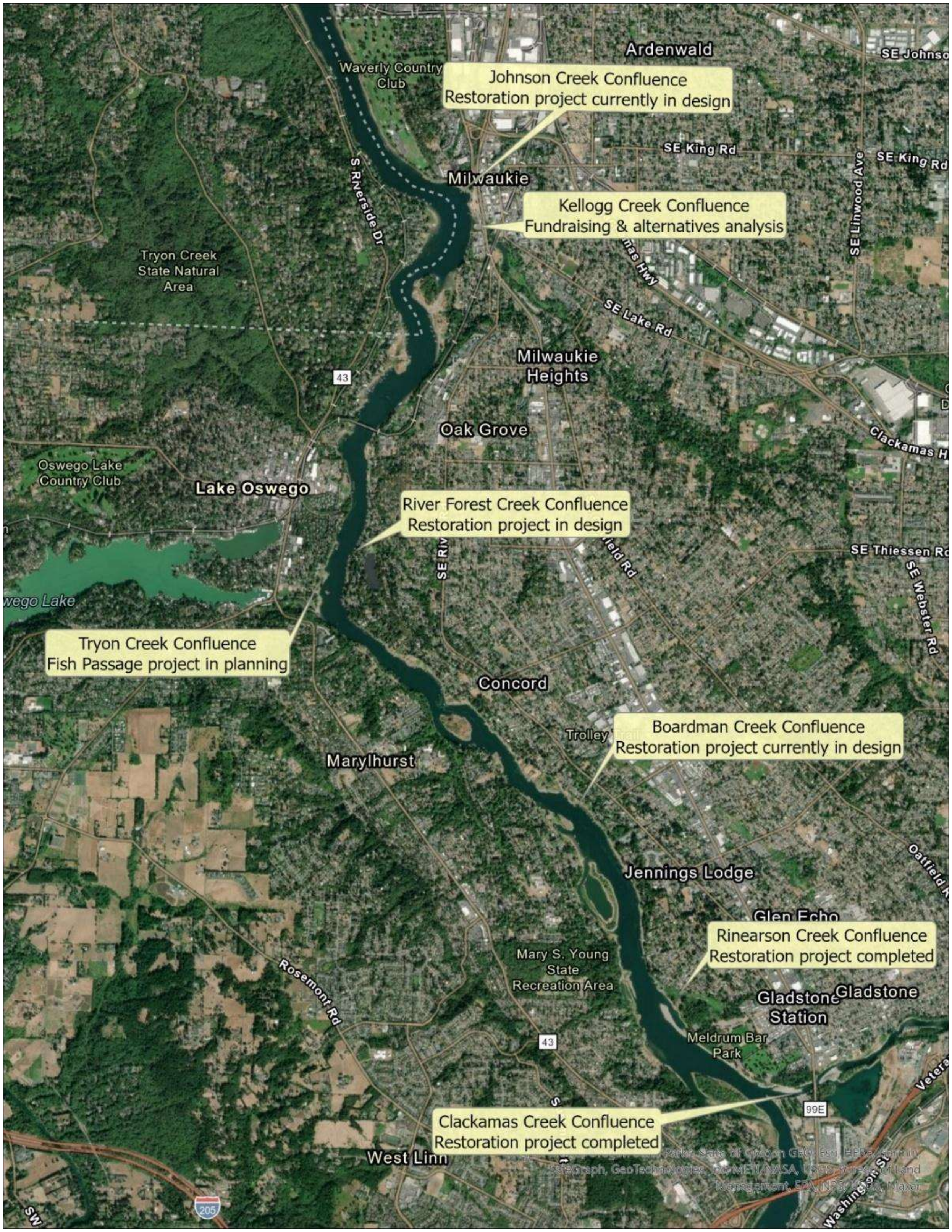
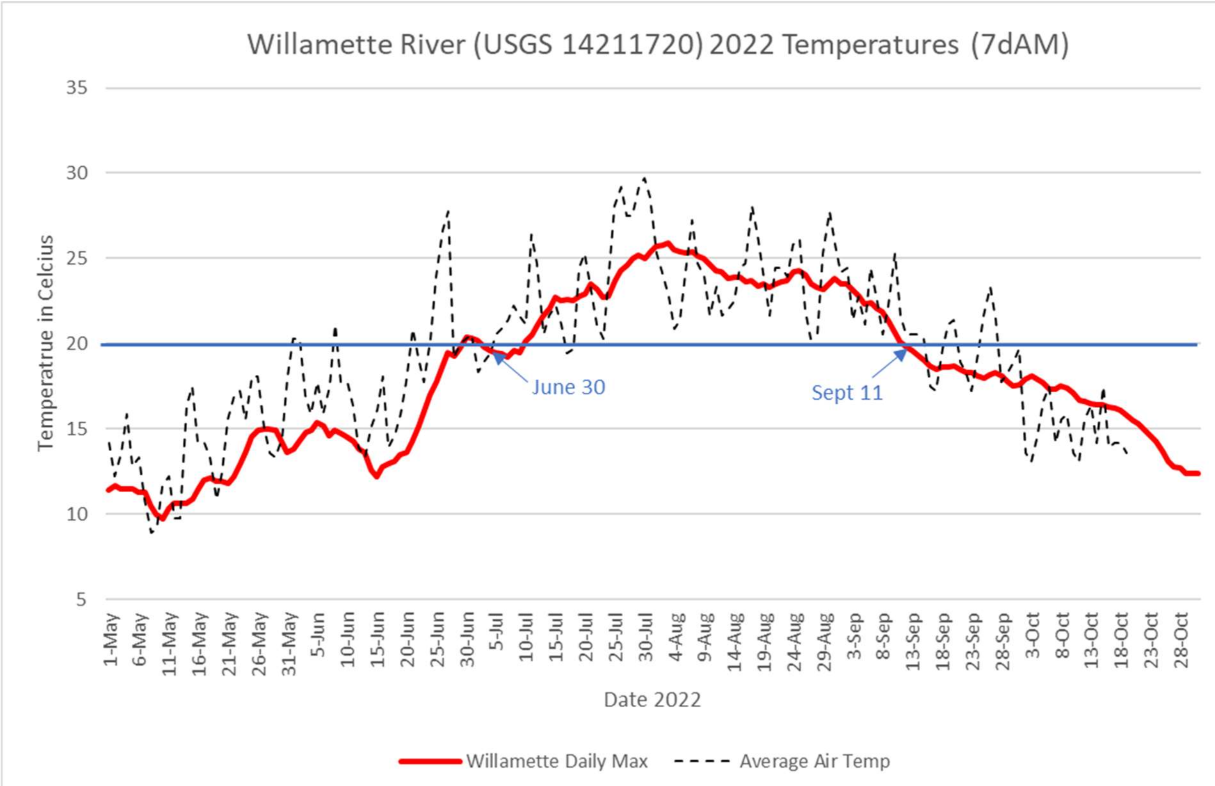


Figure 5 - Summer daily maximum water temperatures in the lower Willamette River at USGS gage station 14211720.

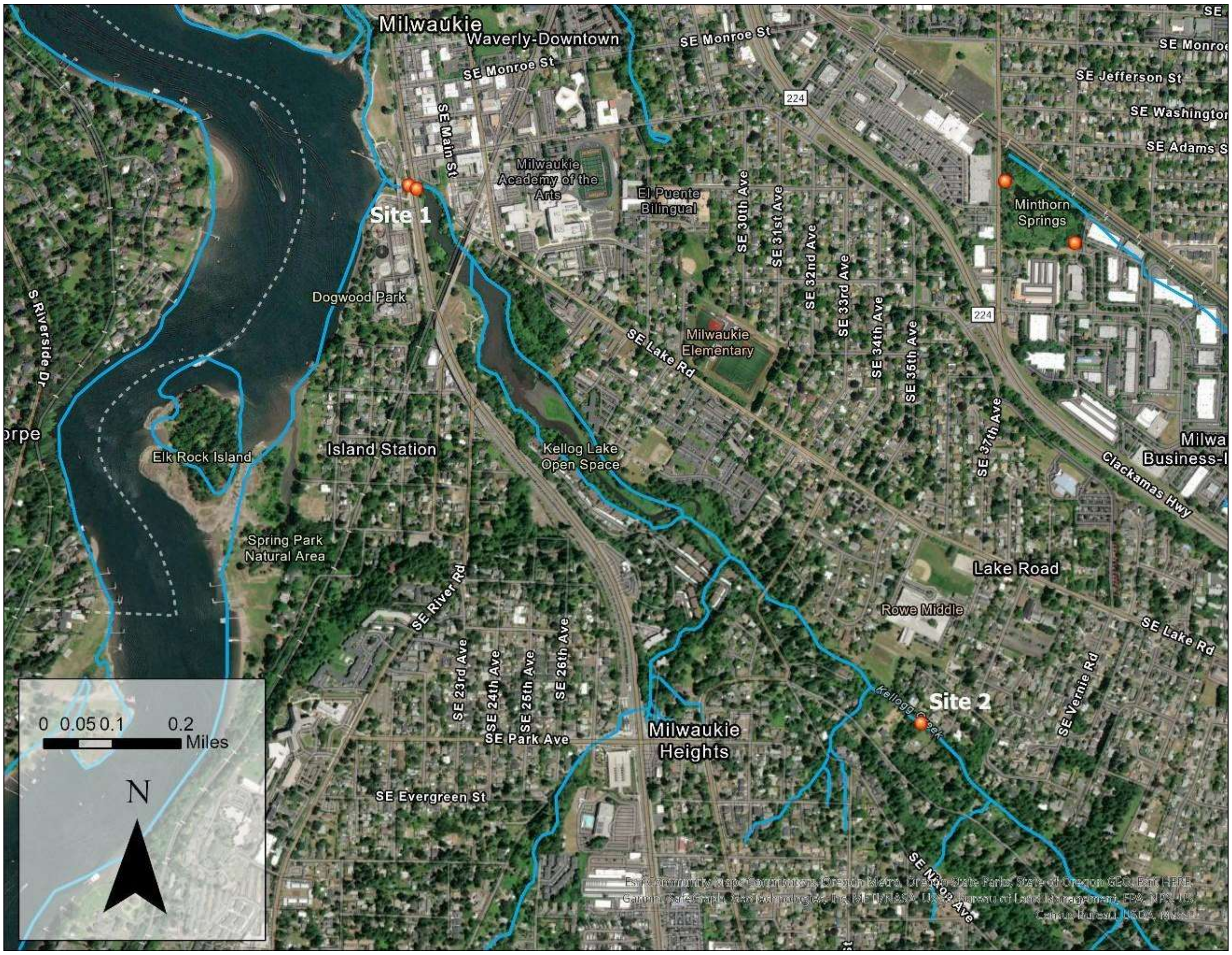


It is important to note that by definition CWR is identified as having at least a 2°C colder temperature than the daily maximum temperature of the adjacent well-mixed flow of the water body. Therefore, for this analysis, we will be looking at the averages of daily maximum temperatures NOT the 7dAM.

Kellogg Creek Confluence

Two temperature loggers were installed at the mouth of Kellogg Creek, one in the fish ladder (Site 1a) and one in the impoundment just upstream of the dam (Site 1b). The impoundment logger was stolen during the monitoring period, so all the data reported here was collected in the fish ladder. Another logger was installed on private property upstream of the impoundment behind Kellogg dam (Site 2) to determine how water temperatures were specifically affected by the widened, shallow impoundment formed behind the dam. During DEQ's CWR study (DEQ, 2020) Kellogg Creek was identified as a coldwater refuge during the summer months. However, the temperature data collected at Kellogg's mouth and upstream of the dam's impoundment this year show that the potential of Kellogg's confluence to provide CWR is not only impacted by the dam which prevents fish access into the creek, but the impoundment behind the dam is significantly increasing water temperatures to levels similar to the Willamette mainstem.

Figure 6 - Location of Kellogg Creek confluence temperature loggers at the Kellogg fish ladder (Site 1) and upstream of the dam impoundment (Site 2).

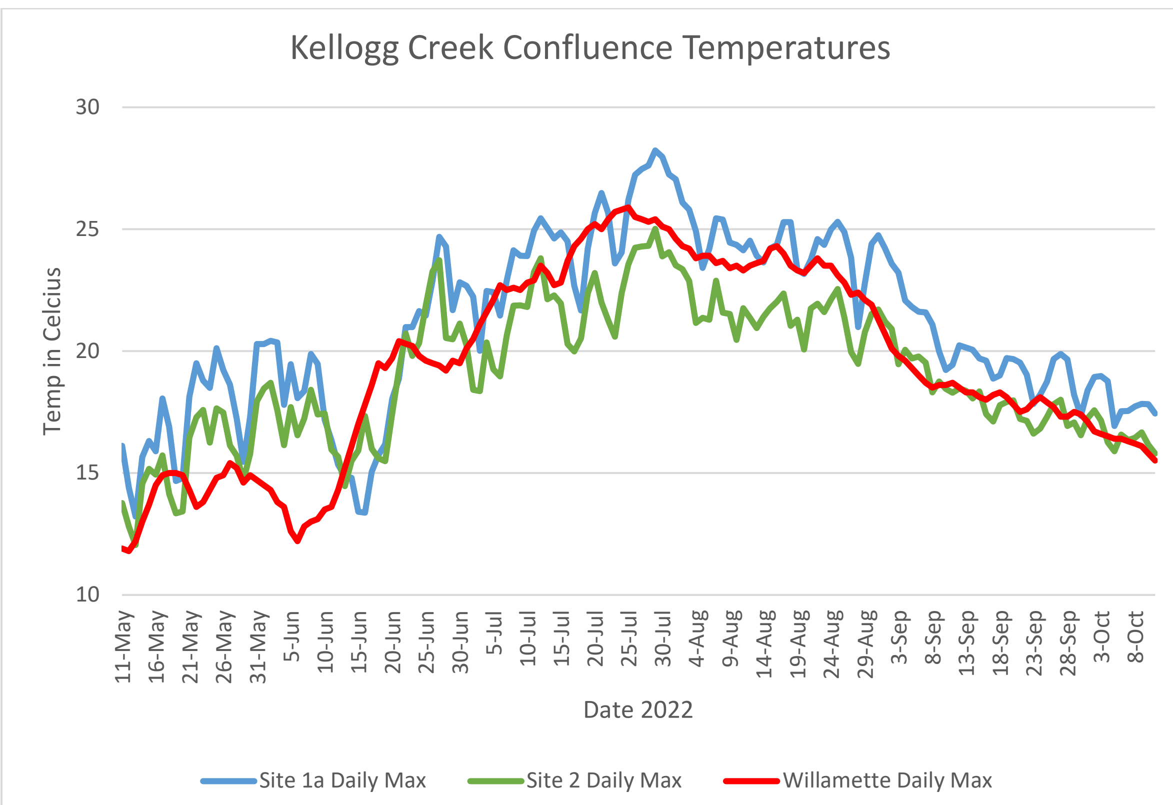


When comparing daily maximum temperatures in Kellogg Creek versus the Lower Willamette, we found that on average the daily maximums were actually higher in the Kellogg fish ladder in than in the Willamette mainstem for the months of July and August by 1.0 °C. However, we know that the dam's impoundment is wide and shallow and probably affects the water temperature through that reach. In fact, the temperature logger upstream of the impoundment shows water temperatures 1.8 °C cooler than the Willamette, indicating that the water is heating up 2.8 °C (5.0 °F) as it flows through the impoundment and into the fish ladder. In Kellogg Creek, the continual infill of the dam impoundment by sediment may be causing the channel to become shallower and wider over the years, increasing the water's exposure to the warming effects of convection and radiation.

Figure 7 - Average daily maximum temperatures of Kellogg Creek both upstream and downstream of the dam impoundment as compared with lower Willamette River temperatures.

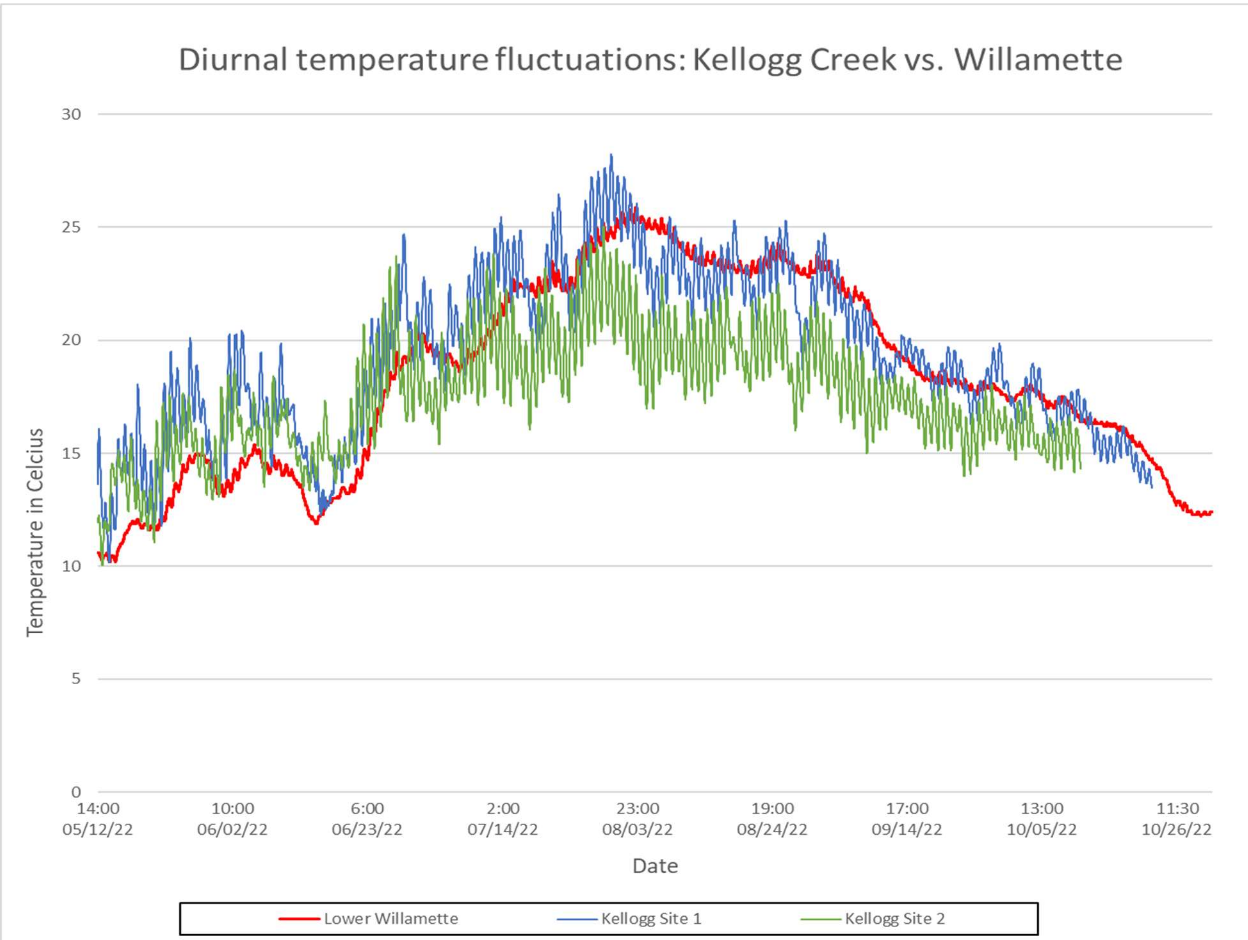
	July 2022 (°C)		**August 2022 (°C)**		**July & August 2022 (°C)**	
Location	July Mean Daily Max Temp	Change from Willamette	August Mean Daily Max Temp	Change from Willamette	Summer Mean Daily Max Temp	Change from Willamette
Willamette (USGS 14211720)	23.7	-	23.4	-	23.5	-
Mouth of Kellogg Creek (Site 1)	24.6	+0.9	24.4	+1.0	24.5	+1.0
Upstream of Kellogg Impoundment (Site 2)	21.8	-1.9	21.6	-1.8	21.7	-1.8

Figure 8 - Average daily maximum temperatures of Kellogg Creek both upstream and downstream of the dam impoundment as compared with lower Willamette River temperatures.



One of the challenges of utilizing daily maximums when looking at CWR habitat, is that maximums do not take into account daily temperature variations. The Lower Willamette is a large well-mixed water body. Larger, deeper water bodies are less influenced by daily fluctuations due to ambient air temperatures and solar radiation. Smaller, shallower creeks like Kellogg Creek are much more susceptible to these factors. If we plot these daily temperature fluctuations at the three sites mentioned above, we see that diurnal flux is much larger in Kellogg Creek than the Willamette. These daily temperature fluctuations are a more accurate representation of the temperature variations facing a fish migrating through the Lower Willamette and potentially utilizing the mouth of Kellogg Creek as CWR.

Figure 9 - Diurnal temperature fluctuations at the Kellogg Creek confluence as compared with the Lower Willamette.



This temperature analysis supports the efforts by the Council, American Rivers, ODOT, the City of Milwaukie, and other partners to create volitional fish passage at Kellogg Dam and remove the warming effect that is created by the upstream impoundment behind the dam. Once the dam and impoundment are removed then Kellogg Creek will be able to function as CWR habitat for migrating fish. Additional design considerations for the new creek channel through this reach should include design elements that will help protect and potentially improve water temperatures at the confluence. These include:

- Creation of a new single- or multi-thread channel that is narrower and deeper than the existing impoundment,

- Planting and maintaining riparian buffers with species that will shade the creek and survive periodic inundation from flood events and Willamette backwatering, and be resilient to climate change, and
- Designing habitat features that will encourage hyporheic exchange to further cool temperatures by encouraging the creek water to interact with groundwater.
- Designing habitat features that lead to formation of deep pools to be used by migrating adult salmon as they move through the lower Willamette in summer months.

River Forest Creek Confluence

Three temperature loggers were installed in River Forest Creek:

- Site 19 – at the confluence downstream of River Forest Lake
- Site 20 – upstream of River Forest Lake
- Site 21 – headwaters of River Forest Creek

The study sites were laid out this way to determine if the water from River Forest Lake was significantly impacting water temperatures and the ability of the River Forest Creek confluence to act as CWR for the Lower Willamette.

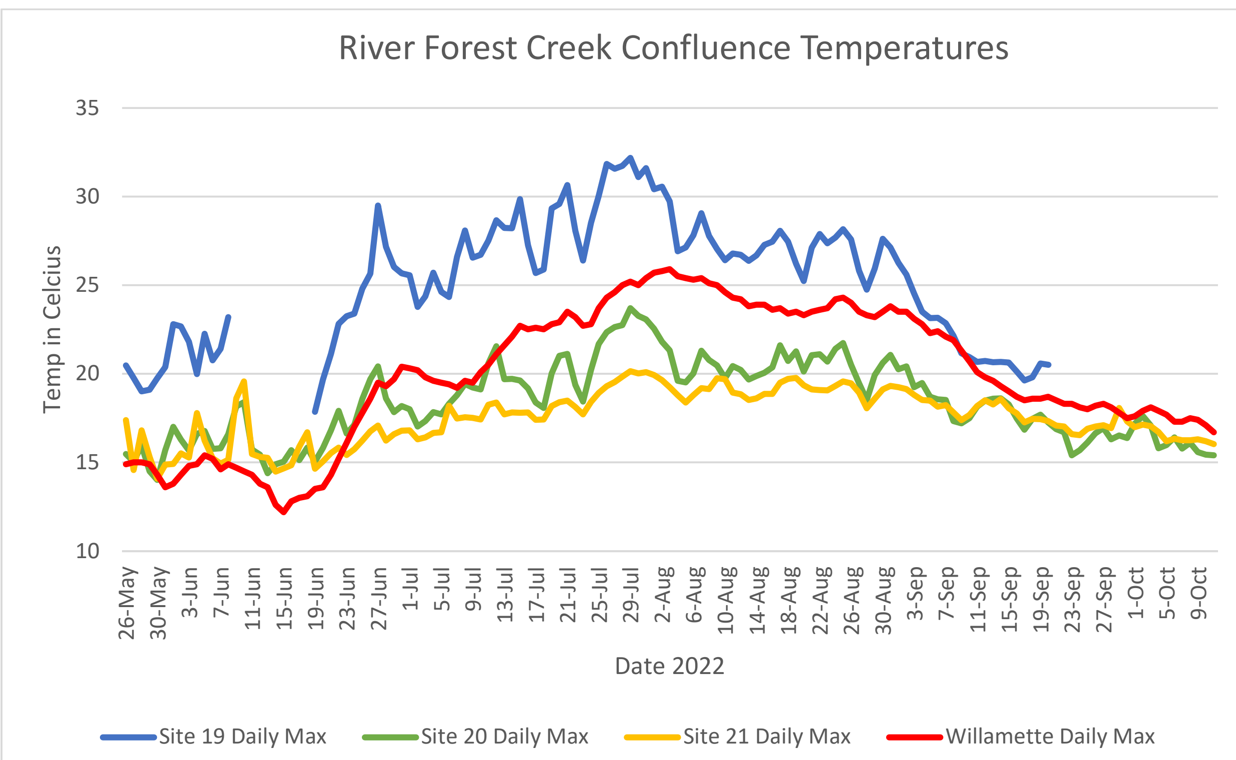
Figure 10 - Location of River Forest Creek confluence temperature loggers.

Summer water temperatures found at the mouth of River Forest Creek were some of the highest seen in our watersheds, and the average daily maximum temperature for the months of July and August was 4.2 °C higher than the Lower Willamette (see Table 3). Thankfully, flows are very low in the summer months and the creek dried up at the confluence downstream of the culvert in September as a result of silt settling at the inlet of the culvert at River Forest Road. However, just upstream of the River Forest Lake impoundment at Site 20, stream temperatures are significantly cooler than the Lower Willamette by 3.5 °C. Higher up in the watershed at Site 21, those temperatures are 4.9 °C cooler than the Willamette.

Table 3 - Average daily maximum temperatures of River Forest Creek as compared with lower Willamette River temperatures.

	July 2022 (°C)		**August 2022 (°C)**		**July & August 2022 (°C)**	
Location	July Mean Daily Max Temp	Change from Willamette	August Mean Daily Max Temp	Change from Willamette	Summer Mean Daily Max Temp	Change from Willamette
Willamette (USGS 14211720)	23.7	-	23.4	-	23.5	-
Mouth of River Forest Creek (Site 19)	28.1	+4.4	27.4	+4.0	27.7	+4.2
Upstream of River Forest Lake (Site 20)	20.0	-3.7	20.6	-2.8	20.0	-3.5
Headwaters of River Forest Creek (Site 21)	18.1	-5.6	19.1	-4.3	18.6	-4.9

Figure 11 - Average daily maximum temperatures of River Forest Creek as compared with lower Willamette River temperatures.



This data shows that River Forest Creek has the potential to function as CWR habitat if the channel could be disconnected from River Forest Lake. This also supports the findings of the Council's 2022 Watershed Action Plan, which recommends the disconnection of the River Forest Creek channel from the River Forest Lake impoundment as a priority action. Because the lake is not an in-line impoundment, it's disconnection from the creek may be possible, and further study should be conducted to determine its feasibility.

Boardman Creek Confluence

There were two temperature probes installed at the confluence of Boardman Creek. Site 22a was downstream of the last bedrock step and was a location that is influenced by backwater and tidal affects from the lower Willamette. This logger was installed to look at temperatures directly in the restoration project area being designed by the Council. Site 22b was at the Oak Lodge pump station and the temperatures there are not influenced by the backwater effects of the lower Willamette River.

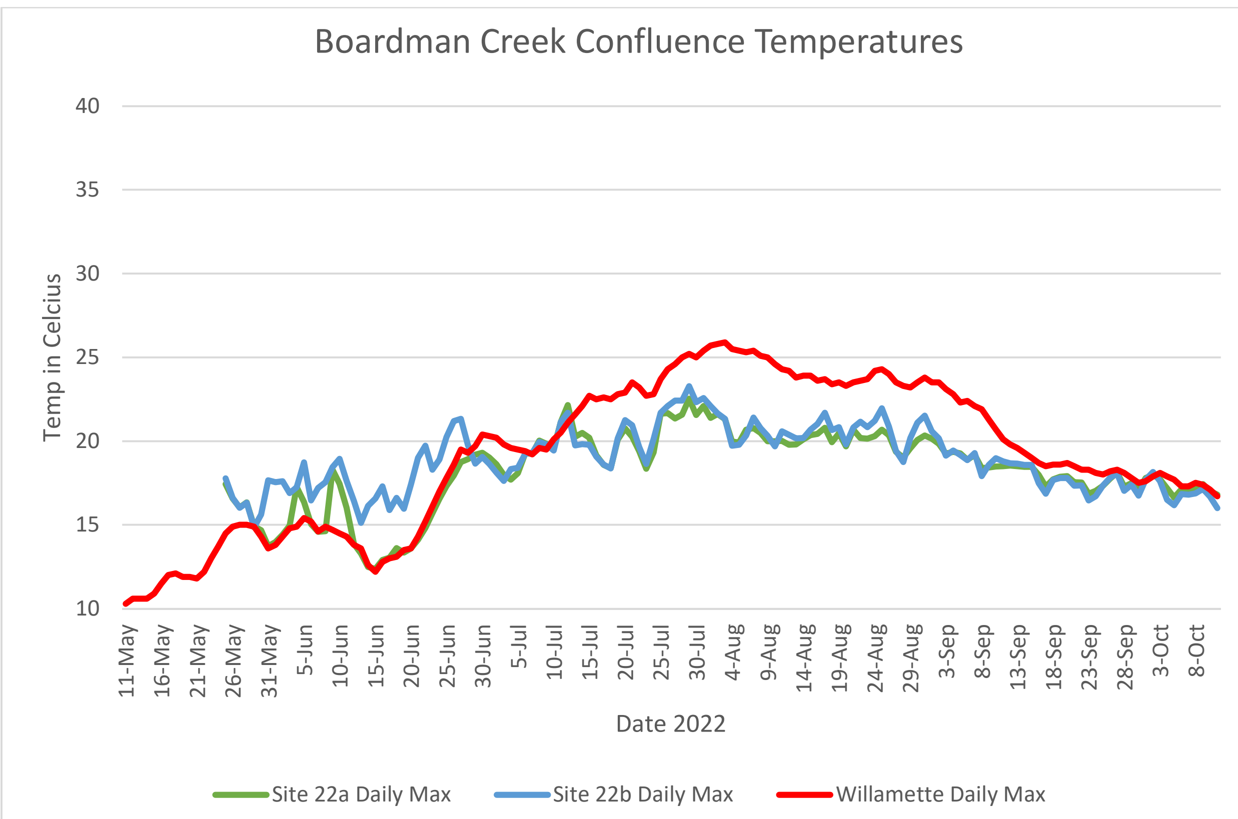
Figure 12 - Location of Boardman Creek confluence temperature loggers.

Summer water temperatures at the Boardman Creek confluence were significantly cooler than the Willamette, and the average daily maximum temperature for the months of July and August was 3.4 °C lower at Site 22a and 3.1 °C lower at Site 22b (see Table 13).

Table 4 - Average daily maximum temperatures of Boardman Creek as compared with lower Willamette River temperatures.

	July 2022 (°C)		**August 2022 (°C)**		**July & August 2022 (°C)**	
Location	July Mean Daily Max Temp	Change from Willamette	August Mean Daily Max Temp	Change from Willamette	Summer Mean Daily Max Temp	Change from Willamette
Willamette (USGS 14211720)	23.7	-	23.4	-	23.5	-
Mouth of Boardman Creek (Site 22a)	20.0	-3.7	20.3	-3.1	20.1	-3.4
Mouth of Boardman Creek (Site 22b)	20.2	-3.5	20.7	-2.7	20.4	-3.1

Figure 13 - Average daily maximum temperatures of Boardman Creek as compared with lower Willamette River temperatures.



These results show that Boardman Creek currently functions as CWR habitat in the Lower Willamette in the summer months. Although summer flows out of Boardman Creek are low, they are perennial and the confluence provides thermal refuge for fish. The Council currently is designing a habitat restoration project to create pools and install large wood to provide instream cover at this site. Construction of the project will be dependent on securing landowner agreements.

Results: Tributary inputs on Kellogg-Mt. Scott

One of the questions posed about the Kellogg-Mt. Scott watershed was how the different tributaries impact water temperatures. This information will help the Council prioritize habitat protection and restoration efforts within the Kellogg-Mt. Scott watershed to target cold water inputs. In particular we examined:

1. the confluence Mt. Scott Creek with Kellogg Creek
2. the confluence of Phillips Creek with Mt. Scott Creek
3. the confluence of Dean Creek with Mt. Scott Creek

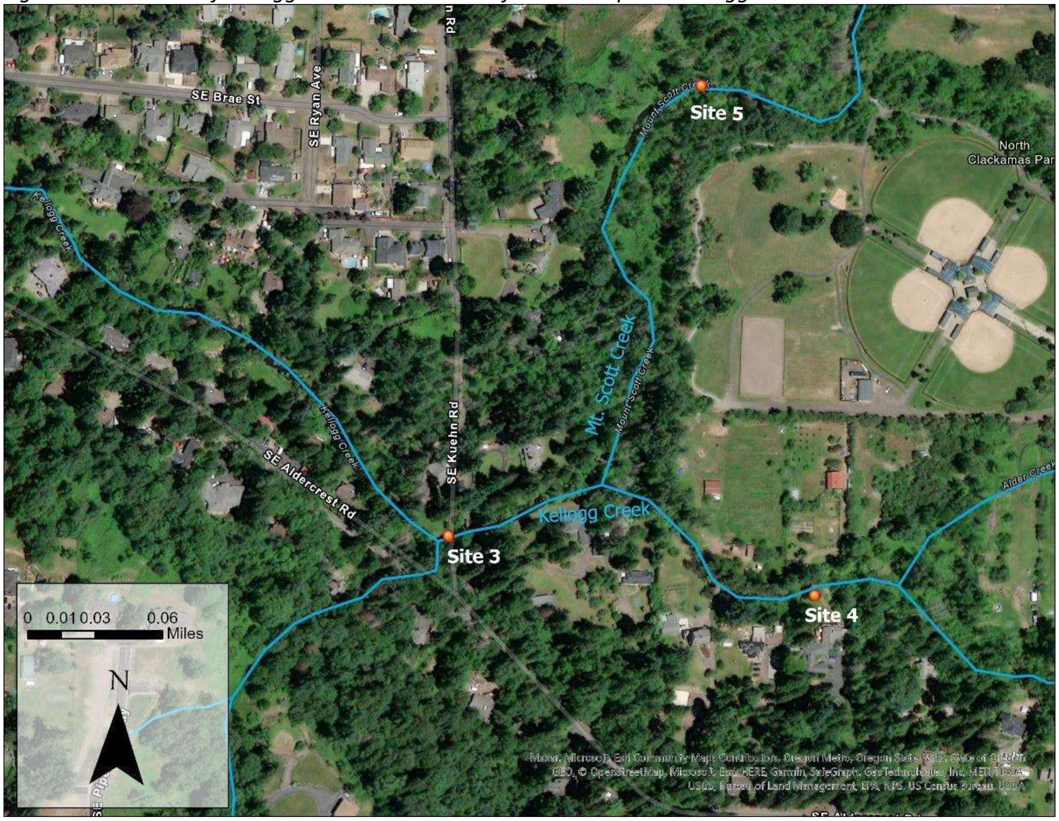
During this analysis we are predominately interested in the use of the watershed as rearing habitat as the primary beneficial use, which equates to a DEQ temperature standard of 18°C. As mentioned before, this watershed also has some potential spawning habitat would be accessible to fish once the Kellogg Dam is removed. A future study that places temperature loggers within the potential spawning sites to collect year-round data may be helpful to look at temperatures during the different spawning season for various species. This is particularly relevant for early and late spawners including fall Chinook which spawn in September/October and lamprey which spawn into May.

Kellogg-Mt. Scott Confluence

Thermographs were place both upstream and downstream of the confluence of Mt. Scott Creek with Kellogg Creek:

- Site 3 - downstream of the confluence of Kellogg with Mt. Scott
- Site 4 - Kellogg Creek upstream of the confluence
- Site 5 - Mt. Scott Creek upstream of the confluence.

Figure 14 - Location of Kellogg-Mt. Scott Creeks confluence temperature loggers.

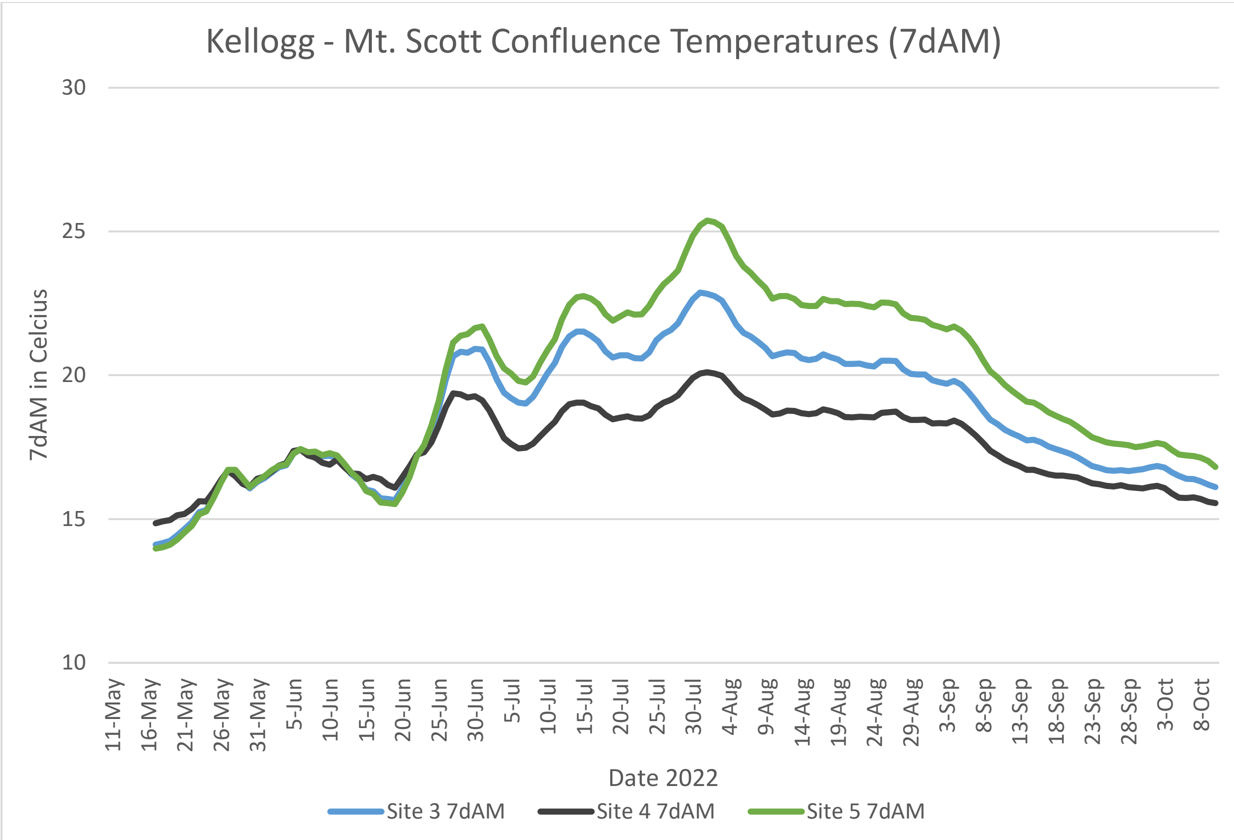


The average 7dAM in July and August was 3.7 °C lower in Kellogg Creek (Site 4) than Mt. Scott Creek (Site 5), and there was enough Kellogg flow coming into Mt. Scott that it lowered temperatures downstream of the confluence (Site 3):

- Average 7dAM at Site 3 (July -August) = 20.8 °C
- Average 7dAM at Site 4 (July -August) = 18.8 °C
- Average 7dAM at Site 5 (July -August) = 22.5 °C

These results show that these creeks exceed the DEQ standard for rearing habitat (18 °C) during the summer months, although Kellogg Creek is very close to meeting that standard. What is particularly interesting is that historically Mt. Scott Creek has often been thought of as "better" creek for potential rearing habitat because of the habitat complexity in that tributary. However, in the summer months, Kellogg Creek may actually become a thermal refuge for rearing fish in this watershed. Because of this, the Council will prioritize protection, restoration, and research efforts in Kellogg Creek. Additionally, future temperature studies in Kellogg Creek should look further into the temperature dynamics within this tributary to pin point potential cold water sources.

Figure 15 - 7dAM temperatures at the confluence of Kellogg and Mt. Scott Creeks.



Phillips-Mt. Scott Confluence

Thermographs were placed both upstream and downstream of the confluence of Mt. Scott Creek with Phillips Creek:

- Site 8 - downstream of the confluence of Phillips with Mt. Scott
- Site 4 - Kellogg Creek upstream of the confluence
- Site 5 - Mt. Scott Creek upstream of the confluence.

The 2022 temperature data shows that the 7dAM temperature of Phillips Creek (Site 10) is an average of 0.5 °C cooler than Mt. Scott Creek (Site 9) where the two creeks merge. However, because of the low flows coming out of Phillips Creek compared to Mt. Scott, the cold water coming from Phillips Creek makes very little impact on the water temperatures in Mt. Scott Creek downstream of the confluence:

- Average 7dAM at Site 8 (July -August) = 20.1 °C
- Average 7dAM at Site 9 (July -August) = 20.2 °C
- Average 7dAM at Site 10 (July -August) = 19.6°C

Figure 16 - Location of Phillips-Mt. Scott Creeks confluence temperature loggers.

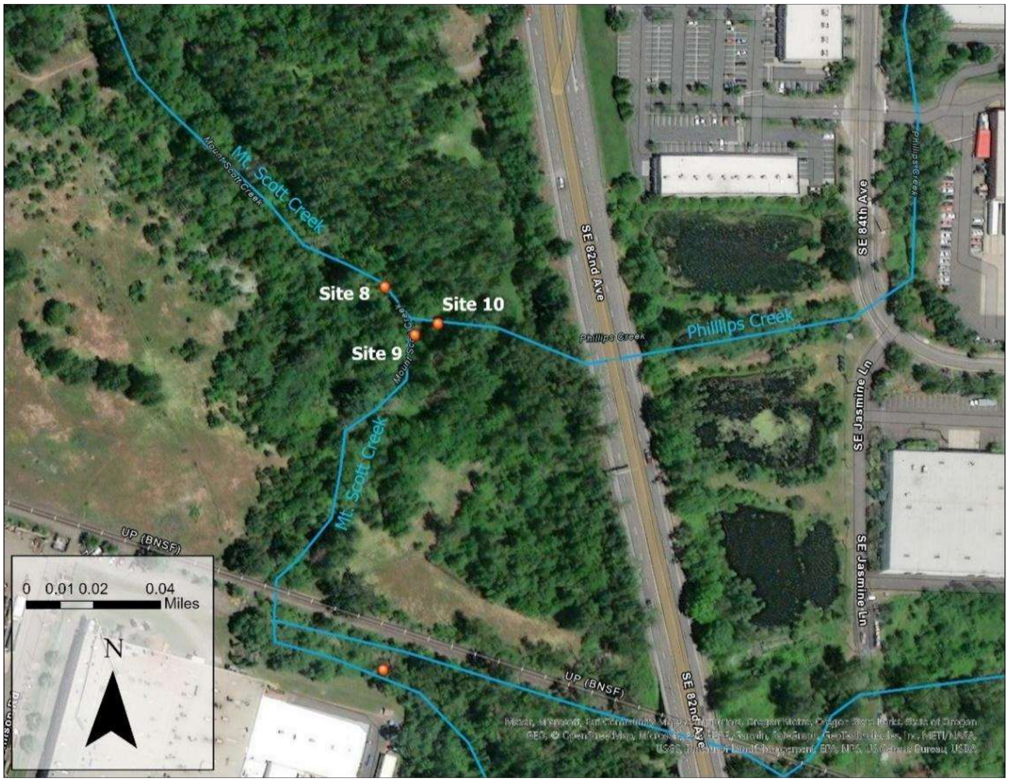
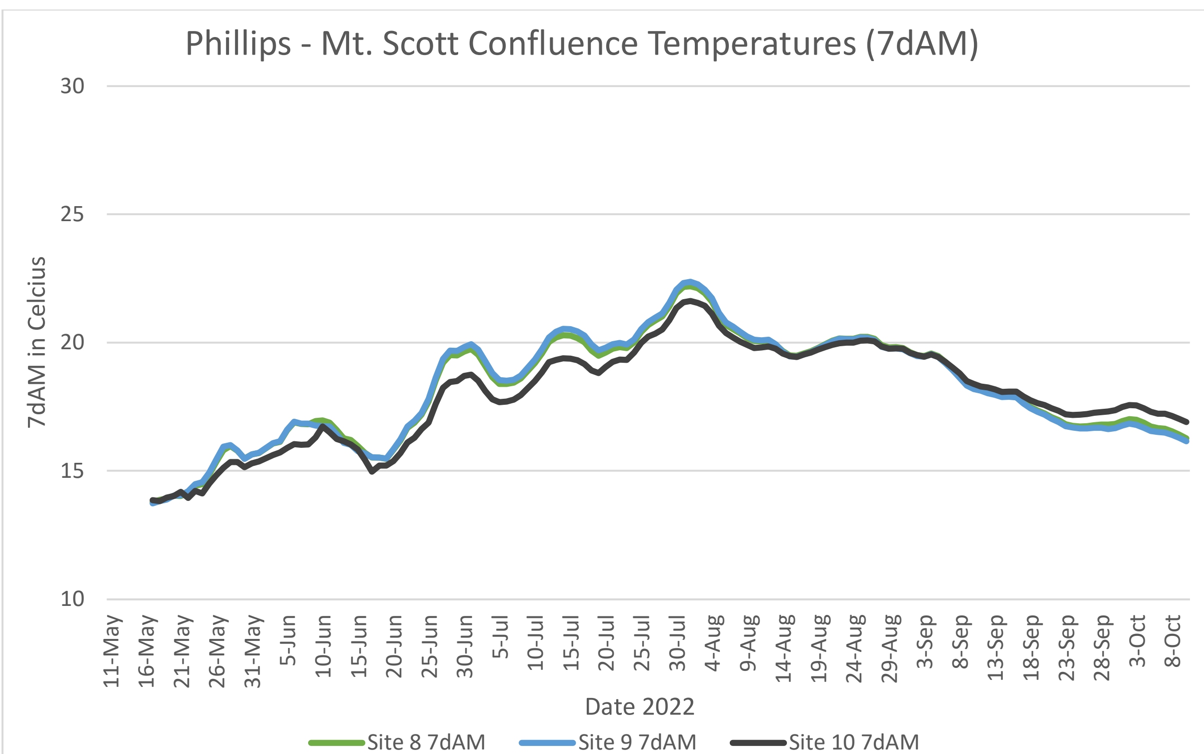


Figure 17 - 7dAM temperatures at the confluence of Phillips and Mt. Scott Creeks.



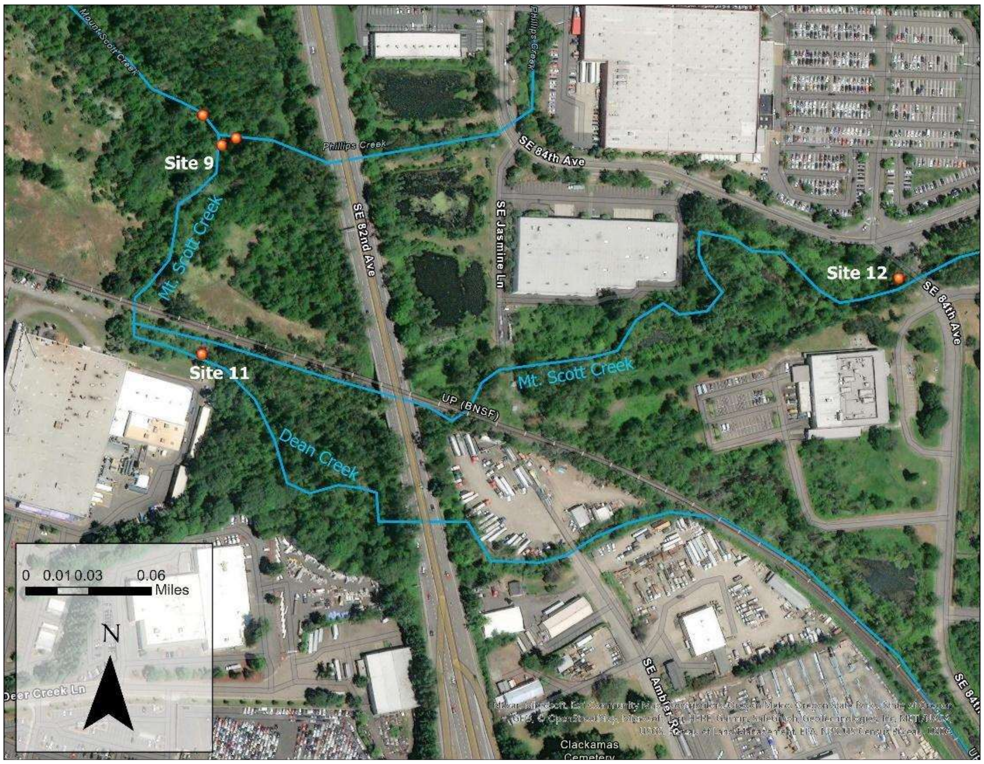
Phillips Creek, like Mt. Scott Creek, exceeds the summer temperature standards for rearing fish with temperatures above 18 °C during the months of July and August.

Dean-Mt. Scott Confluence

Thermographs were place both upstream and downstream of the confluence of Mt. Scott Creek with Dean Creek:

- Site 9 - downstream of the confluence of Dean with Mt. Scott
- Site 11 - Dean Creek upstream of the confluence
- Site 12 - Mt. Scott Creek upstream of the confluence.

Figure 18 - Location of Dean-Mt. Scott Creek confluence temperature loggers.

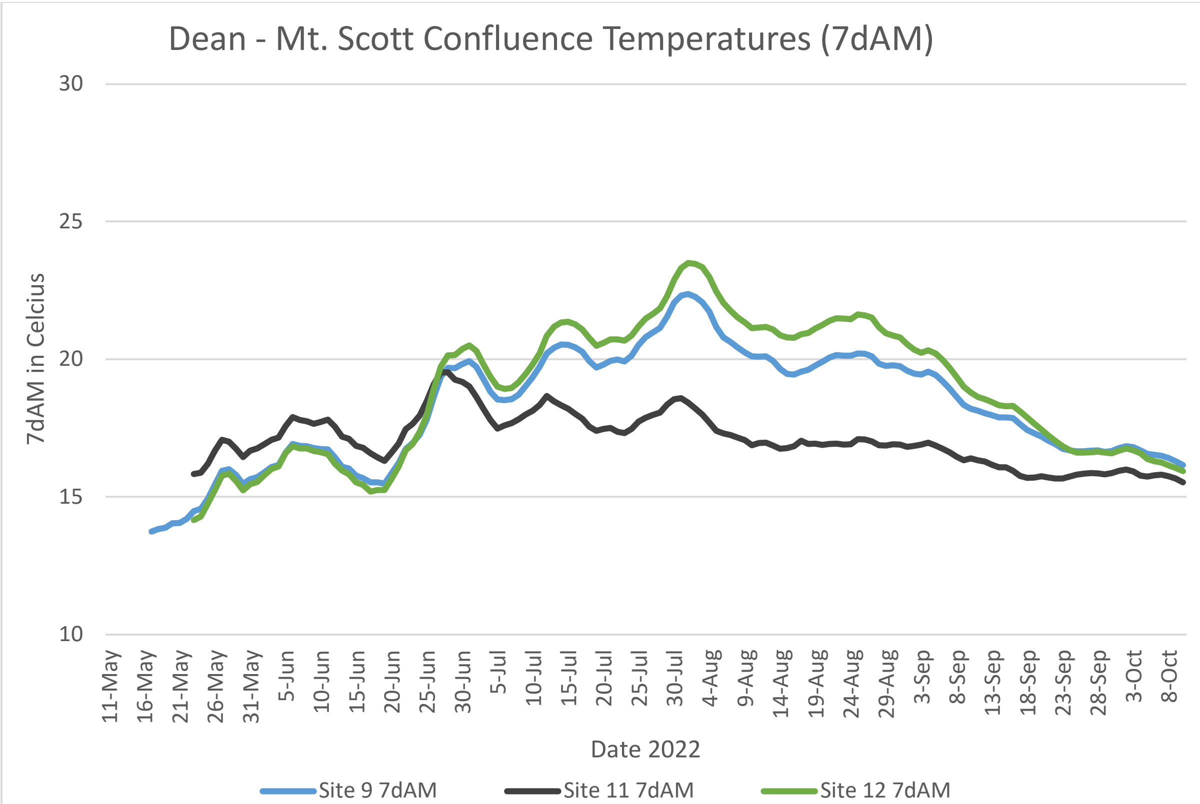


The 2022 temperature data shows that the 7dAM temperature of Dean Creek (Site 11) is an average of 3.6 °C cooler than Mt. Scott Creek (Site 12). However, because the flows in Dean Creek are much smaller than Mt. Scott, it only dropped Mt. Scott's temperature approximately 1.0 °C:

- Average 7dAM at Site 9 (July -August) = 20.2 °C
- Average 7dAM at Site 11 (July -August) = 17.6 °C
- Average 7dAM at Site 12 (July -August) = 21.1°C

Unlike Mt. Scott Creek, Dean Creek summer temperatures meet DEQ's temperature standards for rearing habitat (18 °C). This means the Dean Creek is most likely a temperature refugia for fish rearing in this watershed during the summer. Because of this, the Council will prioritize protection, restoration, and research efforts in Dean Creek.

Figure 19 - 7dAM temperatures at the confluence of Dean and Mt. Scott Creeks.



Results: 3-Creeks Natural Area

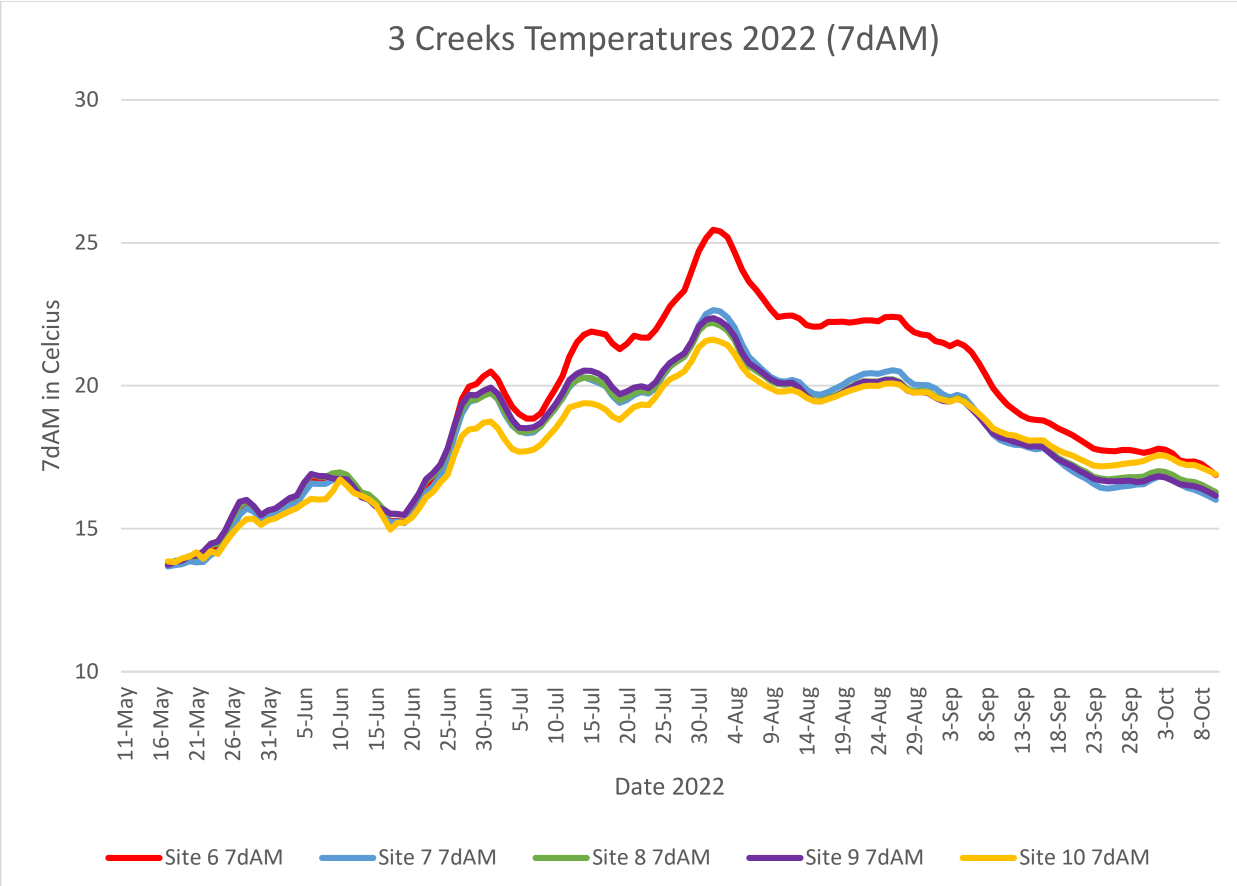
The 3-Creeks Natural Area is approximately 89 acres of streams, wetlands, and upland habitat that encompasses Mt. Scott Creek and its confluences with Phillips and Dean Creeks. The site is wedged in between industrial and commercial properties, a set of active railroad tracks, and private homes. The site is also owned by Clackamas Water Environment Services (WES) and is home to a flood control facility which stores water during the heaviest rains to protect businesses and infrastructure. There were five thermographs installed throughout 3-Creeks Natural Area. The temperature study of the confluences of Phillips Creek and Dean Creek with Mt. Scott Creek is discussed in the previous section, and shows how those two tributaries contributed colder water to the Mt. Scott mainstem.

Figure 20 - Location of 3-Creeks Natural Area temperature loggers.

When we compare those upstream temperatures (Site 8, 9, and 10) with the temperatures collected downstream at Site 7 we see very little change in water temperatures, which is interesting considering that 3-Creeks Natural Area contains some of the better habitat within the watershed with extensive riparian canopy that would hopefully cool the water. However, between Site 7 and Site 6 we did see a 1.9 °C increase in the average 7dAM in the months of July and August.

- Average 7dAM at Site 6 (July -August) = 22.1 °C
- Average 7dAM at Site 7 (July -August) = 20.2 °C
- Average 7dAM at Site 8 (July -August) = 20.1 °C
- Average 7dAM at Site 9 (July -August) = 20.2 °C
- Average 7dAM at Site 10 (July -August) = 19.6°C

Figure 21 - 7dAM temperatures in 3-Creeks Natural Area.



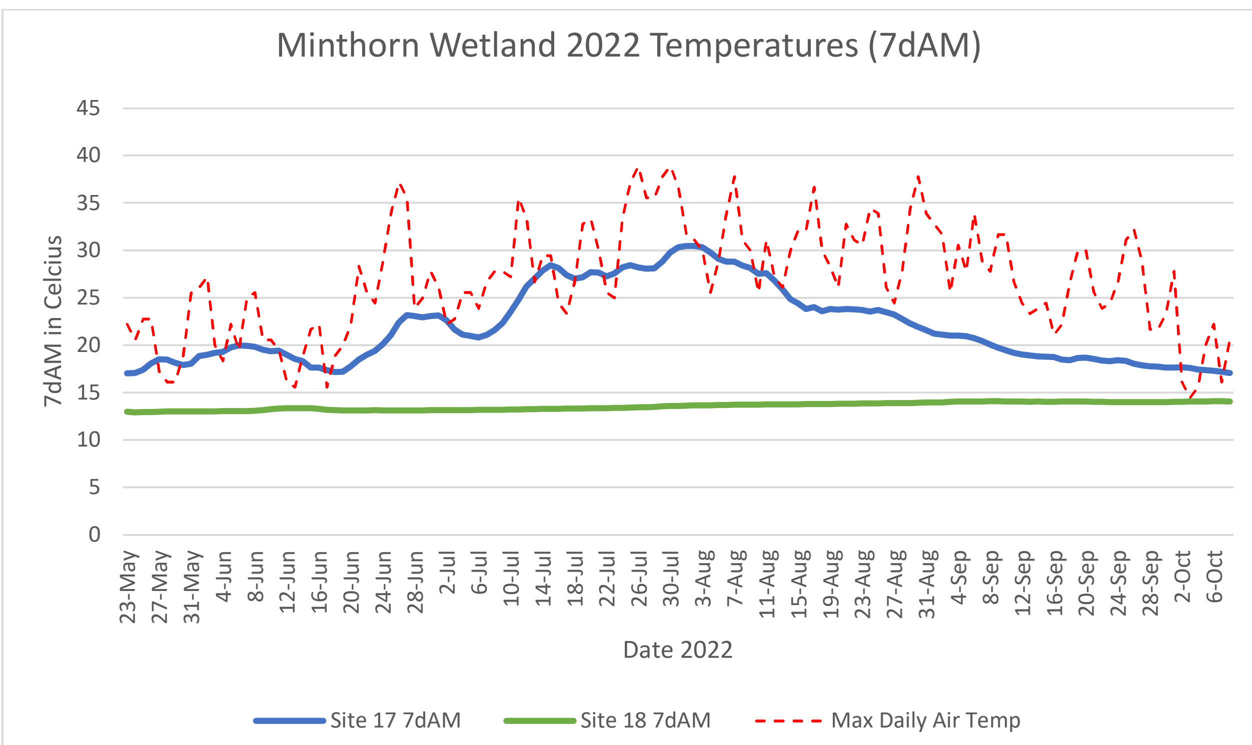
This heating affect that we see at Site 6 is potentially the result of the wide and shallow pond that exists downstream of the water control structure. As WES considers management of their flood control structure, design considerations should take into account the potential heating that occurs in that pond. Consideration should also be given to looking for other potential warm water inputs through that stretch of creek to ensure that significant commercial or industrial inputs are not occurring.

Results: Minthorn Springs Wetlands

The Wetlands Conservancy Urban Wetlands State-of-the-Catchments Summary (Labbe and Scully-Engelmeyer, 2016) noted that the water quality in Minthorn Springs Wetland is considered poor. For this investigation, we assessed the difference between water temperatures coming directly out of the spring seep at the inlet of the wetland (Site 18), versus water temperatures exiting the wetlands into Minthorn Creek (Site 17). The location of the two temperature loggers can be seen below.

Figure 22 - Location of Minthorn Springs temperature loggers.

Figure 23- 7dAM temperatures at Minthorn Springs Wetland.



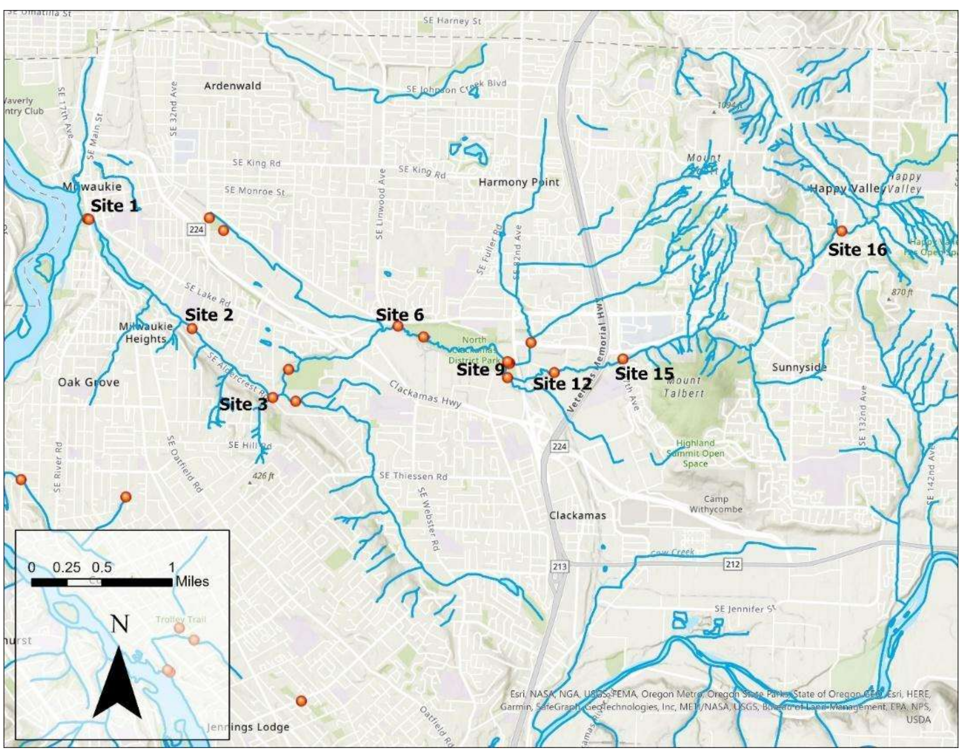
The spring-fed inlet to the wetlands maintained a consistent 13-14 °C all summer long, providing some of the coolest water seen during this study. However, the logger placed at the outlet of the wetlands showed the highest water temperatures seen, tracking just below air temperatures above 20 °C all summer and peaking over 30 °C in the beginning of August. Further study is needed to determine if the increased temperatures are simply a function of solar radiation due to lack of shade or if there are other inputs of warm water being put directly into the wetland. It would also be prudent to study whether the heat load coming out of Minthorn Springs Wetland dissipates before Minthorn Creek joins Mt. Scott Creek.

Results: Longitudinal study of Kellogg-Mt. Scott

There were many loggers installed throughout the Kellogg-Mt. Scott watershed and we wanted to conduct a longitudinal study of water temperatures from Mt. Scott Creek down to confluence of Kellogg Creek with the Lower Willamette River. For this study we pulled data from the following locations:

- Site 1 – Kellogg Creek at the dam
- Site 2 – Kellogg Creek upstream of impoundment
- Site 3 – Kellogg Creek downstream of confluence with Mt. Scott Creek
- Site 6 – Mt. Scott Creek downstream end of 3-Creeks Natural Area
- Site 9 – Mt. Scott Creek upstream end of 3-Creeks Natural Area
- Site 12 – Mt. Scott Creek at SE 84th Street
- Site 15 – Mt. Scott Creek at Mt. Talbert Natural Area
- Site 16 – Mt. Scott Creek near end of potential anadromy

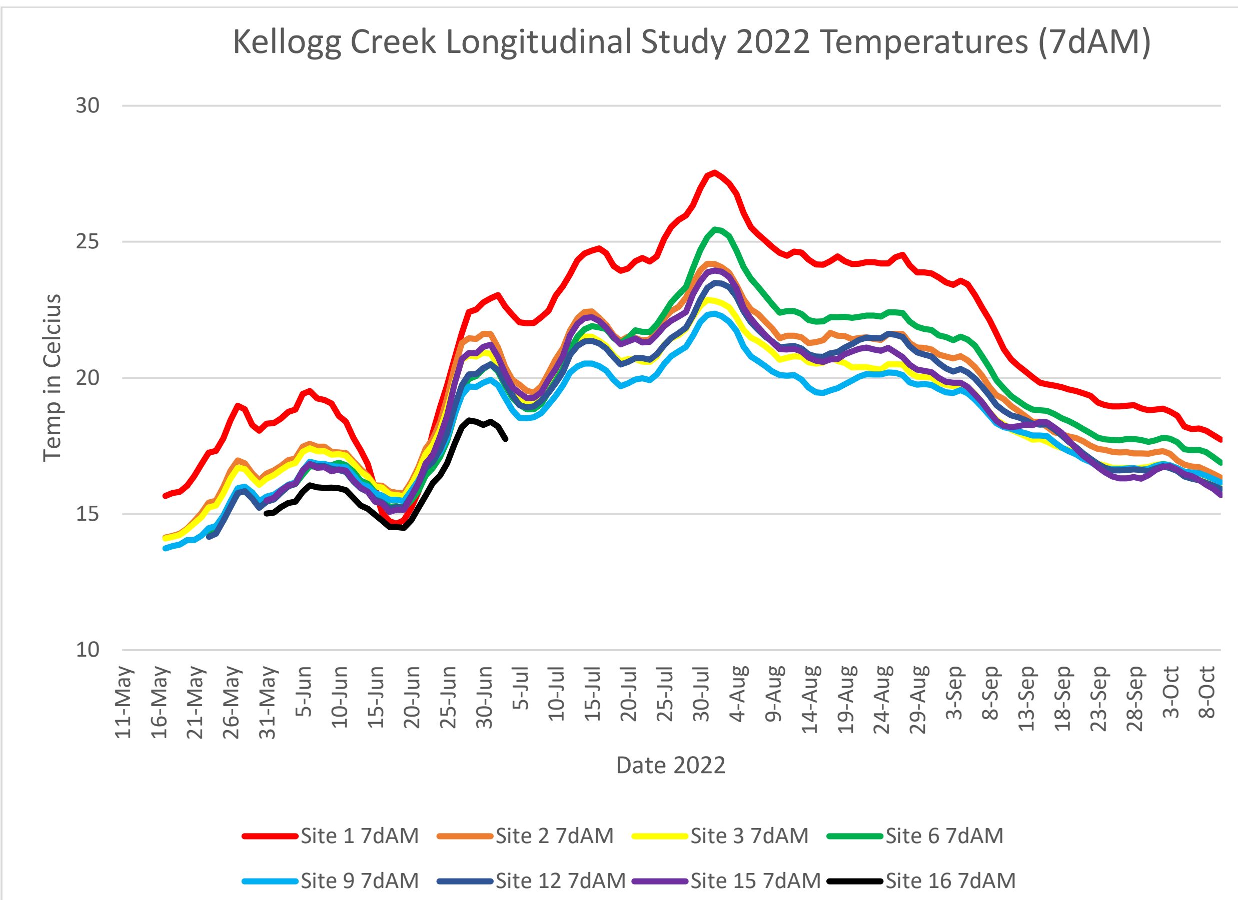
Figure 24 - Location of Kellogg-Mt. Scott loggers used for longitudinal study.



Some of the best stream temperatures seen along the length of Kellogg-Mt. Scott were at Site 9 in 3-Creeks upstream of the diversion structure, at Site 3 just downstream of the cold-water input from Kellogg Creek, and the upper reaches of Mt. Scott Creek (Site 16). Unfortunately, temperature logger at Site 16 stopped logging for an unknown reason (prove failure) in early July so we don't have a complete data set at the location. However, even with the small amount of data at Site 16 we see significant increases in temperatures between Site 15 and 16 (along Sunnyside Road) which needs further study. The Council should check DEQ to see if there are any NPDES discharge permits in this area.

- Average 7dAM at Site 1 (July-August) = 24.5 °C
- Average 7dAM at Site 2 (July-August) = 21.7 °C
- Average 7dAM at Site 3 (July-August) = 20.8 °C
- Average 7dAM at Site 6 (July-August) = 22.1 °C
- Average 7dAM at Site 9 (July-August) = 20.2 °C
- Average 7dAM at Site 12 (July-August) = 21.1 °C
- Average 7dAM at Site 15 (July-August) = 21.3 °C
- Average 7dAM at Site 16 – incomplete data set

Figure 25 - 7dAM for loggers included in Kellogg-Mt. Scott longitudinal study.



There was a large storm event mid- to late-June and the graph reflects that sudden drop in temperature. Unfortunately, most sites exceed DEQ's 18 °C temperature standard for rearing salmonids during the summer months. For this reason, protection of cold-water inputs into this watershed such as Kellogg

Creek and Dean Creek is even more important. We also see that when we removed the probes in October all the sites were still over 15 °C. This is notable considering the temperature standard for spawning fish is 13 °C. Coho typically spawn in November in colder snowmelt dominated systems. However, coho will spawn earlier in warmer tributaries since water temperatures impact maturation to spawning (Todd Alsbury, personal communication). Therefore, in areas with potential spawning gravels, a year-round temperature study is recommended. These areas have been identified in the Council's Rapid Bio-Assessment conducted in 2020.

Results: Rinearson Creek

Temperature loggers were installed in Rinearson Creek on either side of the McLoughlin Boulevard (Highway 99) corridor. Site 26 was located on the west side of River Road and Site 27 was located upstream adjacent to Olsen Wetlands.

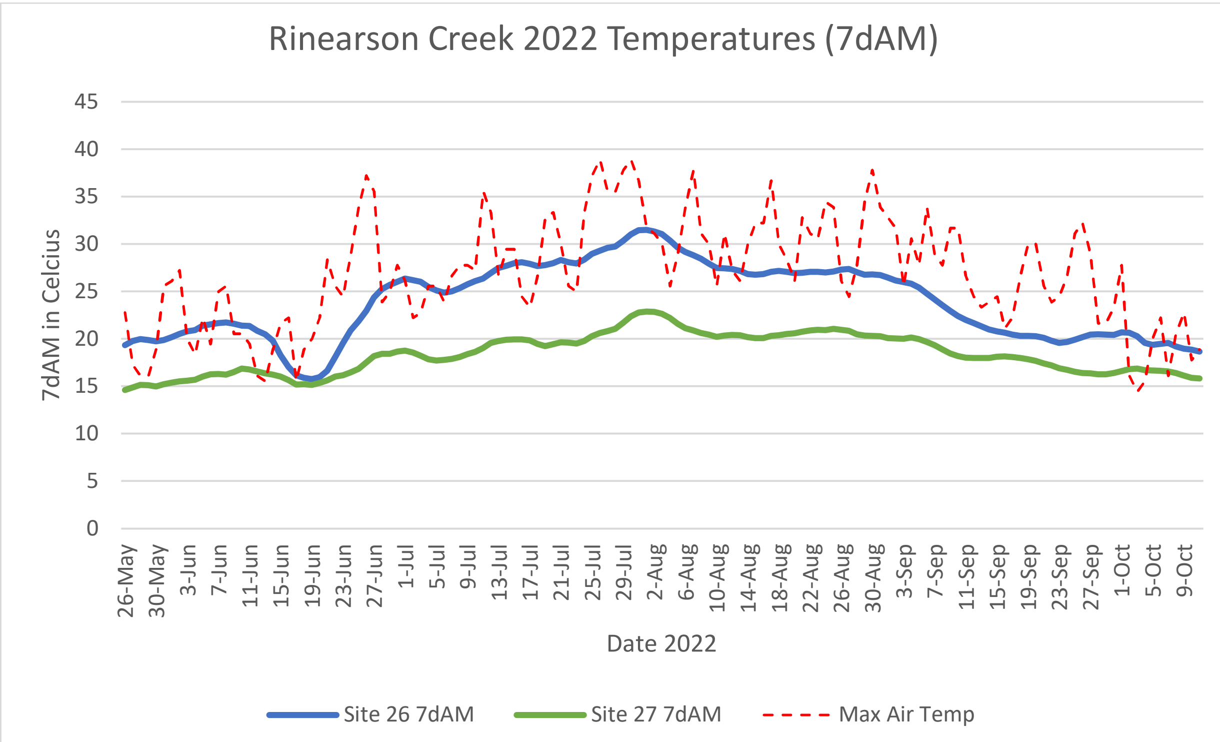
Figure 26 - Location of Rinearson Creek temperature loggers.

Although these two sample sites are only approximately 1000 feet apart as the crow flies, the temperature increase as water passes through the McLoughlin corridor was significant. On average, the 7dAM temperatures heat up by 7.5 °C as the creek flows from Site 27 to Site 26.

- Average 7dAM at Site 26 (July -August) = 27.7 °C
- Average 7dAM at Site 27 (July -August) = 20.2 °C

What is interesting about these results is that the creek appears to go underground into stormwater pipes between these two spots. Further investigation should look at other water inputs to see if there is warm water being contributed into the system from commercial or industrial sources, or if the heating is simply the result of the heat island affect in this highly developed area.

Figure 27 - 7dAM temperatures in Rinearson Creek.



At the time this report is written, we had not been able to acquire the temperature monitoring data from Columbia Restoration Group that was collected as a part of their mitigation monitoring requirements near the confluence of Rinearson Creek. It will be interesting to compare their data with our results to see whether the downstream nature area effectively cools water temperatures it flows downstream.

Results: Boardman Creek

Five temperature loggers were installed in Boardman Creek, two of which were installed at the confluence. For the purpose of this analysis, we are using the data from the second confluence logger (Site 22b) that is slightly upstream and is not impacted by backwater from the Lower Willamette River.

- Site 22a – confluence of Boardman Creek with the Willamette River
- Site 23 – North Fork of Boardman Creek
- Site 24 – South Fork of Boardman Creek
- Site 25 – South Fork headwaters of Boardman Creek

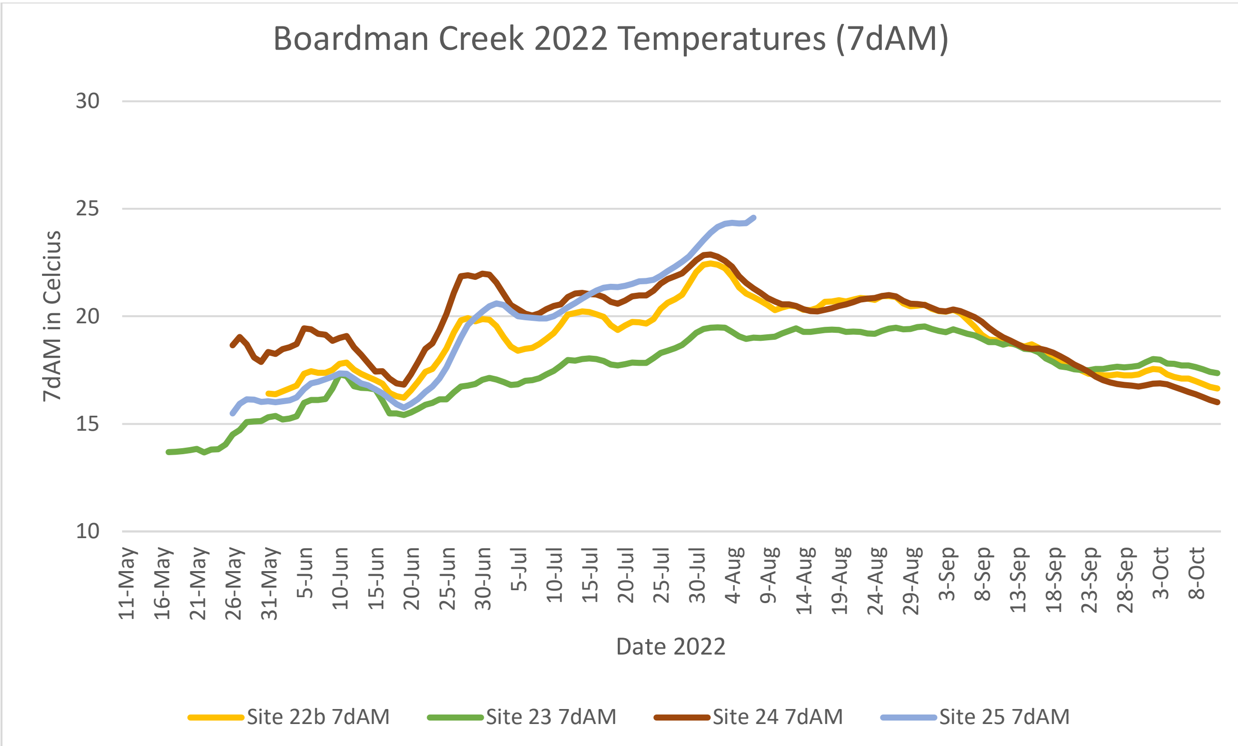
Figure 28 - Location of Boardman Creek temperature loggers.

The thermograph farthest upstream in the south fork of Boardman Creek (Site 25) was out of water from the beginning of August due to very low flows near the headwaters in the summer months. The most noticeable finding is that the water flowing into Boardman Creek from the north fork (Site 23) is 2.5 °C cooler than that of the south fork (Site 24). This affects temperatures downstream of the confluence of these two forks until the end of July when the north fork flows become too small to make an impact.

- Average 7dAM at Site 22a (July -August) = 20.4 °C
- Average 7dAM at Site 23 (July -August) = 18.6 °C
- Average 7dAM at Site 24 (July -August) = 21.0 °C
- Average 7dAM at Site 25 (July -August) = 21.7 °C

Before the Site 25 started drying up, we also see significant temperature increases as water flows from Site 25 to Site 24 in May and June as the water flows through the McLoughlin Boulevard corridor. And between Site 24 and Site 22 at the confluence there is some cooling in May, June, and July. This highlights the impact this traffic corridor has on water quality.

Figure 29 - 7dAM temperatures in Boardman Creek.



Conclusions and Recommendations

Findings

There are several key findings that we can surmise from this year's temperature monitoring data.

1. *Willamette River confluences are potential cold water refugia*
   Data from the mouth of Rinearson Creek was supposed to be collected by Columbia Restoration Group as a part of their mitigation requirements and at the time this report was written we were unable to acquire that data. Boardman Creek was identified as CWR. Both Kellogg Creek and River Forest Creek were warmer than the Lower Willamette River. However, loggers placed above Kellogg and River Forest Lakes showed that those impoundments significantly increased water temperatures. If Kellogg Dam and its associated impoundment could be removed then the mouth of Kellogg Creek would function as CWR habitat. And if River Forest Lake could be hydraulically disconnected from River Forest Creek, that confluence could also function as CWR habitat.

2. *Kellogg Creek, Dean Creek, the North Fork of Boardman Creek, and Minthorn Springs provide cold water*
   We were able to identify several cold-water sources in the North Clackamas watersheds. The water flowing from Dean Creek and Kellogg Creek upstream of its confluence with Mt. Scott Creek was significantly cooler than Mt. Scott Creek. Phillips Creek was also slightly cooler than Mt. Scott Creek. The upper reaches of Mt. Scott also appears to be quite cool; however, our logger at that location

stopped working early in the monitoring season which will require another year of monitoring to confirm this finding. The coldest water found was at Minthorn Springs, however, this water warmed significantly to become the warmest water studied as it travelled through Minthorn Springs Wetland. In Boardman Creek, the temperatures in the North Fork of Boardman Creek were significantly cooler and may function as a thermal refuge in the summer.

3. *Water heated up through the McLoughlin corridor, downstream of the upper reaches of Mt. Scott Creek along Sunnyside Road, and through water impoundments.*
   There were several areas where we recorded significant increases in water temperatures. Wide shallow impoundments of water allowed water to heat up, including Kellogg Lake, Minthorn Springs Wetland, River Forest Lake and the pond downstream of the diversion structure in 3-Creek Natural Area. We also saw increases in water temperatures along major urban arteries such as McLoughlin Boulevard and along Sunnyside Road.

Implications for Restoration, Protection, and Management

The Council is utilizing these results to prioritize their restoration, protection, and management efforts in the watersheds in our service area.

1. *Fix heat-loading effects at impoundments*
   Water temperatures increased significantly through water impoundments. Potential treatments vary at each site:
   - When Kellogg Dam is removed, the associated impoundment will be dewatered and the channel will be restored to a sinuous flowing creek.
   - River Forest Lake could potentially be disconnected hydraulically from River Forest Creek, while maintaining the lake for its surrounding residents. Further study should be conducted to determine the feasibility of accomplishing this.
   - Minthorn Springs Wetland heats up considerably in the summer and restoration of that wetland should focus on controlling summer temperatures.
   - As Clackamas WES plans restoration of their 3-Creeks property, consideration should be given to the pool downstream of the water diversion structure to determine how best to mitigate the temperature impacts at that site.

2. *Target cold water areas for protection and fish access*
   The cold-water areas (Boardman/Willamette Confluence, Dean Creek, Upper Kellogg Creek, North Fork Boardman Creek) should be prioritized for protection and fish access. These areas will provide thermal refuge for fish in the summer, and the Council will focus on removing any barriers to fish accessing these reaches, especially during summer low flows.

3. *Identify solutions for reducing heat loading through urbanized corridors with large head island effects*
   Significant temperature increases occur where streams pass through the McLoughlin (Highway 99E) corridor and the upper reaches of Mt. Scott Creek down to Mt. Talbert Nature Park. Projects should be explored that reduce the heating effect such as reducing impervious surface area, improving stormwater inputs, or preventing point-source inputs of warm water from businesses.

Further Study

As with any research project, this study has generated several more questions that need answering. Future monitoring years should study the following in more depth:

- Study temperature dynamics in Minthorn Creek to better understand both heat inputs in Minthorn Springs Wetland and water heating/cooling between the wetland and the confluence with Mt. Scott Creek.
- Study Kellogg Creek upstream of Mt. Scott to pinpoint sources of cold water and understand temperature dynamics up to the headwaters at Hearthwood Wetland.
- Conduct a year-round study of temperatures in areas that have potential spawning habitat in the Kellogg Creek watershed.
- Repeat temperature monitoring in the upper reaches of Mt. Scott Creek to verify potential cold-water sources and determine why it heats up so much as water flows down to Mt. Talbert.
- Continue long-term trend monitoring to track changes in watershed temperature impacts from climate change, development, and restoration actions.
- Compare the results of this study with the Council's fish passage barrier and eDNA studies to better understand fish utilization.

Despite the association between warm summer water temperatures and reduced salmonid survivorship, there is often little consistent long-term temperature data collected year after year in smaller streams. The Council plans on continuing our temperature monitoring program annually. Funding for repeated annual monitoring programs can be difficult to secure, and it is our hope that granting agencies recognize the importance of utilizing empirical data to inform our protection and restoration efforts.

References

Clackamas Partnership. 2018. Watershed Restoration for Native Fish Populations: Strategic Restoration Action Plan. July 2018.

Department of Environmental Quality. 2008. Temperature Water Quality Standard Implementation – A DEQ Internal Management Directive. Written by Debra Sturdevant, Water Quality Standards Coordinator. April 2008.

Department of Environmental Quality. 2020. Lower Willamette River Cold-Water Refuge Narrative Criterion Interpretation Study. Submitted to NOAA – March 2020.

Environmental Protection Agency. 2001. Issue Paper 1: Salmonid Behavior and Water Temperature. Prepared by Sally T. Sauter, John McMillan, and Jason Dunham. May 2001.

Environmental Protection Agency. 2012. Primer for Identifying Cold-Water Refuges to Protect and Restore Thermal Diversity in Riverine Landscapes. Prepared by Christian Torgersen, Joseph Ebersole, and Druscilla Keenan. February 2012.

Leinenbach, P. 2017. Evaluation of the potential CWR by tributaries in the Willamette based on NorWeST modeling.

Labbe, Ted and Kaegan Scully-Engelmeyer. 2016. The Wetlands Conservancy Urban Wetlands State-of-the-Catchments Summary. August 22, 2016.

North Clackamas Watersheds Council. 2022. North Clackamas Watersheds Action Plan 2022-2032. Prepared by Samara Group, LLC & GeoEngineers. July 2022.

North Clackamas Watersheds Council. 2020. Rapid Bio-Assessment Report: North Clackamas Watersheds. Prepared by Inter-fluve, Inc. May 2020.

Appendix A – Pre-Deployment Thermograph Calibration

Time	12:07		12:08		12:09		12:10		12:11		12:12		12:13		12:14		12:15		12:16		12:17		Average
NIST Temp	22.95		22.93		22.92		22.91		22.88		22.9		22.85		22.86		22.84		22.83		22.82		Difference
Probe #	Probe Temp	Difference	Probe Temp	Difference	Probe Temp	Difference	Probe Temp	Difference	Probe Temp	Difference	Probe Temp	Difference	Probe Temp	Difference	Probe Temp	Difference	Probe Temp	Difference	Probe Temp	Difference	Probe Temp	Difference	
21333015	22.734	0.216	22.692	0.238	22.713	0.207	22.692	0.218	22.692	0.188	22.67	0.23	22.638	0.212	22.627	0.233	22.627	0.213	22.616	0.214	22.595	0.225	**0.218**
21333016	22.702	0.248	22.713	0.217	22.692	0.228	22.681	0.229	22.681	0.199	22.649	0.251	22.67	0.18	22.649	0.211	22.616	0.224	22.606	0.224	22.616	0.204	**0.220**
21333017	22.799	0.151	22.777	0.153	22.767	0.153	22.767	0.143	22.734	0.146	22.734	0.166	22.734	0.116	22.724	0.136	22.692	0.148	22.692	0.138	22.67	0.15	**0.145**
21333018	22.852	0.098	22.842	0.088	22.842	0.078	22.82	0.09	22.81	0.07	22.777	0.123	22.777	0.073	22.756	0.104	22.745	0.095	22.767	0.063	22.745	0.075	**0.087**
21333019	22.831	0.119	22.799	0.131	22.799	0.121	22.799	0.111	22.767	0.113	22.777	0.123	22.724	0.126	22.724	0.136	22.724	0.116	22.713	0.117	22.702	0.118	**0.121**
21333023	22.831	0.119	22.842	0.088	22.82	0.1	22.799	0.111	22.799	0.081	22.777	0.123	22.767	0.083	22.745	0.115	22.734	0.106	22.734	0.096	22.713	0.107	**0.103**
21333024	22.788	0.162	22.756	0.174	22.745	0.175	22.734	0.176	22.734	0.146	22.724	0.176	22.702	0.148	22.713	0.147	22.692	0.148	22.681	0.149	22.659	0.161	**0.160**
21333025	22.81	0.14	22.788	0.142	22.777	0.143	22.756	0.154	22.756	0.124	22.732	0.168	22.724	0.126	22.702	0.158	22.681	0.159	22.702	0.128	22.692	0.128	**0.143**
21333044	22.81	0.14	22.81	0.12	22.777	0.143	22.767	0.143	22.767	0.113	22.756	0.144	22.745	0.105	22.734	0.126	22.713	0.127	22.702	0.128	22.702	0.118	**0.128**
21333043	22.81	0.14	22.81	0.12	22.788	0.132	22.788	0.122	22.788	0.092	22.756	0.144	22.767	0.083	22.745	0.115	22.745	0.095	22.713	0.117	22.692	0.128	**0.117**
21333042	22.831	0.119	22.81	0.12	22.81	0.11	22.788	0.122	22.767	0.113	22.767	0.133	22.734	0.116	22.745	0.115	22.724	0.116	22.713	0.117	22.702	0.118	**0.118**
21333041	22.852	0.098	22.831	0.099	22.82	0.1	22.81	0.1	22.777	0.103	22.767	0.133	22.756	0.094	22.724	0.136	22.734	0.106	22.713	0.117	22.724	0.096	**0.107**
21333040	22.831	0.119	22.81	0.12	22.788	0.132	22.777	0.133	22.756	0.124	22.734	0.166	22.724	0.126	22.734	0.126	22.702	0.138	22.724	0.106	22.702	0.118	**0.128**
21333039	22.788	0.162	22.788	0.142	22.756	0.164	22.767	0.143	22.734	0.146	22.724	0.176	22.724	0.126	22.692	0.168	22.692	0.148	22.681	0.149	22.681	0.139	**0.151**
21333038	22.81	0.14	22.81	0.12	22.81	0.11	22.81	0.1	22.767	0.113	22.756	0.144	22.767	0.083	22.734	0.126	22.724	0.116	22.713	0.117	22.702	0.118	**0.117**
21333037	22.841	0.109	22.852	0.078	22.842	0.078	22.842	0.068	22.81	0.07	22.799	0.101	22.788	0.062	22.745	0.115	22.767	0.073	22.745	0.085	22.756	0.064	**0.082**
21333036	22.82	0.13	22.831	0.099	22.788	0.132	22.81	0.1	22.777	0.103	22.767	0.133	22.777	0.073	22.734	0.126	22.756	0.084	22.734	0.096	22.713	0.107	**0.108**
21333035	22.852	0.098	22.82	0.11	22.82	0.1	22.82	0.09	22.799	0.081	22.777	0.123	22.767	0.083	22.777	0.083	22.745	0.095	22.734	0.096	22.724	0.096	**0.096**
21333034	22.885	0.065	22.863	0.067	22.863	0.057	22.852	0.058	22.831	0.049	22.82	0.08	22.799	0.051	22.788	0.072	22.777	0.063	22.777	0.053	22.767	0.053	**0.061**
21333033	22.81	0.14	22.788	0.142	22.788	0.132	22.777	0.133	22.745	0.135	22.745	0.155	22.734	0.116	22.692	0.168	22.692	0.148	22.681	0.149	22.67	0.15	**0.143**
21333032	22.895	0.055	22.895	0.035	22.895	0.025	22.874	0.036	22.874	0.006	22.863	0.037	22.831	0.019	22.831	0.029	22.81	0.03	22.81	0.02	22.81	0.01	**0.027**
21333031	22.788	0.162	22.788	0.142	22.777	0.143	22.767	0.143	22.734	0.146	22.756	0.144	22.724	0.126	22.702	0.158	22.692	0.148	22.692	0.138	22.681	0.139	**0.144**
21333030	22.777	0.173	22.767	0.163	22.721	0.199	22.734	0.176	22.713	0.167	22.702	0.198	22.713	0.137	22.681	0.179	22.659	0.181	22.659	0.171	22.649	0.171	**0.174**
21333029	22.842	0.108	22.842	0.088	22.82	0.1	22.82	0.09	22.81	0.07	22.788	0.112	22.767	0.083	22.756	0.104	22.767	0.073	22.734	0.096	22.734	0.086	**0.092**
21333028	22.81	0.14	22.81	0.12	22.777	0.143	22.767	0.143	22.756	0.124	22.745	0.155	22.734	0.116	22.734	0.126	22.713	0.127	22.713	0.117	22.681	0.139	**0.132**
21333027	22.949	0.001	22.927	0.003	22.906	0.014	22.885	0.025	22.874	0.006	22.863	0.037	22.863	-0.013	22.842	0.018	22.852	-0.012	22.831	-0.001	22.831	-0.011	**0.006**
21333026	22.788	0.162	22.767	0.163	22.745	0.175	22.756	0.154	22.745	0.135	22.734	0.166	22.713	0.137	22.713	0.147	22.681	0.159	22.692	0.138	22.659	0.161	**0.154**

Appendix B – Post-Deployment Thermograph Calibration

Time	1:00		1:01		1:02		1:03		1:04		1:05		1:06		1:07		1:08		1:09		1:10		Average Difference
NIST Temp	10.73		10.74		10.74		10.74		10.74		10.74		10.74		10.74		10.74		10.74		10.74		
Probe #	Probe Temp	Difference	Probe Temp	Difference	Probe Temp	Difference	Probe Temp	Difference	Probe Temp	Difference	Probe Temp	Difference	Probe Temp	Difference	Probe Temp	Difference	Probe Temp	Difference	Probe Temp	Difference	Probe Temp	Difference	
21333015	10.744	-0.014	10.754	-0.014	10.744	-0.004	10.744	-0.004	10.765	-0.025	10.754	-0.014	10.733	0.007	10.754	-0.014	10.733	0.007	10.754	-0.014	10.744	-0.004	**-0.01**
21333016	10.712	0.018	10.733	0.007	10.733	0.007	10.701	0.039	10.712	0.028	10.701	0.039	10.712	0.028	10.712	0.028	10.733	0.007	10.733	0.007	10.722	0.018	**0.02**
21333017	10.808	-0.078	10.808	-0.068	10.808	-0.068	10.83	-0.09	10.797	-0.057	10.819	-0.079	10.819	-0.079	10.797	-0.057	10.787	-0.047	10.819	-0.079	10.787	-0.047	**-0.07**
21333018	10.776	-0.046	10.765	-0.025	10.776	-0.036	10.754	-0.014	10.776	-0.036	10.744	-0.004	10.776	-0.036	10.765	-0.025	10.754	-0.014	10.754	-0.014	10.744	-0.004	**-0.02**
21333019	10.797	-0.067	10.787	-0.047	10.808	-0.068	10.797	-0.057	10.819	-0.079	10.797	-0.057	10.797	-0.057	10.808	-0.068	10.797	-0.057	10.819	-0.079	10.808	-0.068	**-0.06**
21333023	10.83	-0.1	10.819	-0.079	10.83	-0.09	10.83	-0.09	10.84	-0.1	10.797	-0.057	10.808	-0.068	10.819	-0.079	10.83	-0.09	10.808	-0.068	10.797	-0.057	**-0.08**
21333024	10.776	-0.046	10.776	-0.036	10.776	-0.036	10.776	-0.036	10.776	-0.036	10.776	-0.036	10.765	-0.025	10.776	-0.036	10.776	-0.036	10.787	-0.047	10.776	-0.036	**-0.04**
21333025	10.776	-0.046	10.776	-0.036	10.776	-0.036	10.776	-0.036	10.787	-0.047	10.797	-0.057	10.797	-0.057	10.776	-0.036	10.776	-0.036	10.797	-0.057	10.797	-0.057	**-0.05**
21333044	10.797	-0.067	10.797	-0.057	10.808	-0.068	10.808	-0.068	10.819	-0.079	10.819	-0.079	10.819	-0.079	10.83	-0.09	10.808	-0.068	10.787	-0.047	10.819	-0.079	**-0.07**
21333043	10.808	-0.078	10.808	-0.068	10.787	-0.047	10.776	-0.036	10.787	-0.047	10.787	-0.047	10.797	-0.057	10.776	-0.036	10.83	-0.09	10.787	-0.047	10.797	-0.057	**-0.06**
21333042	10.808	-0.078	10.787	-0.047	10.787	-0.047	10.776	-0.036	10.797	-0.057	10.776	-0.036	10.787	-0.047	10.776	-0.036	10.808	-0.068	10.787	-0.047	10.797	-0.057	**-0.05**
21333041	10.765	-0.035	10.754	-0.014	10.787	-0.047	10.776	-0.036	10.787	-0.047	10.776	-0.036	10.776	-0.036	10.787	-0.047	10.787	-0.047	10.797	-0.057	10.776	-0.036	**-0.04**
21333040	10.754	-0.024	10.765	-0.025	10.765	-0.025	10.776	-0.036	10.776	-0.036	10.776	-0.036	10.754	-0.014	10.776	-0.036	10.776	-0.036	10.754	-0.014	10.776	-0.036	**-0.03**
21333039	10.84	-0.11	10.84	-0.1	10.84	-0.1	10.83	-0.09	10.851	-0.111	10.851	-0.111	10.862	-0.122	10.84	-0.1	10.83	-0.09	10.819	-0.079	10.84	-0.1	**-0.10**
21333038	10.744	-0.014	10.733	0.007	10.765	-0.025	10.733	0.007	10.744	-0.004	10.754	-0.014	10.754	-0.014	10.744	-0.004	10.776	-0.036	10.744	-0.004	10.754	-0.014	**-0.01**
21333037	10.776	-0.046	10.754	-0.014	10.754	-0.014	10.776	-0.036	10.765	-0.025	10.744	-0.004	10.754	-0.014	10.754	-0.014	10.765	-0.025	10.765	-0.025	10.765	-0.025	**-0.02**
21333036	10.765	-0.035	10.744	-0.004	10.754	-0.014	10.754	-0.014	10.744	-0.004	10.765	-0.025	10.754	-0.014	10.754	-0.014	10.754	-0.014	10.744	-0.004	10.765	-0.025	**-0.02**
21333035	10.776	-0.046	10.765	-0.025	10.776	-0.036	10.787	-0.047	10.765	-0.025	10.787	-0.047	10.787	-0.047	10.765	-0.025	10.776	-0.036	10.797	-0.057	10.797	-0.057	**-0.04**
21333034	10.776	-0.046	10.797	-0.057	10.776	-0.036	10.787	-0.047	10.787	-0.047	10.776	-0.036	10.797	-0.057	10.808	-0.068	10.819	-0.079	10.776	-0.036	10.797	-0.057	**-0.05**
21333033	10.754	-0.024	10.765	-0.025	10.754	-0.014	10.765	-0.025	10.754	-0.014	10.765	-0.025	10.754	-0.014	10.754	-0.014	10.765	-0.025	10.754	-0.014	10.744	-0.004	**-0.02**
21333032	10.819	-0.089	10.787	-0.047	10.819	-0.079	10.808	-0.068	10.808	-0.068	10.787	-0.047	10.808	-0.068	10.808	-0.068	10.787	-0.047	10.787	-0.047	10.808	-0.068	**-0.06**
21333031	10.776	-0.046	10.776	-0.036	10.765	-0.025	10.765	-0.025	10.787	-0.047	10.787	-0.047	10.787	-0.047	10.776	-0.036	10.787	-0.047	10.797	-0.057	10.765	-0.025	**-0.04**
21333030	10.797	-0.067	10.787	-0.047	10.797	-0.057	10.797	-0.057	10.787	-0.047	10.808	-0.068	10.808	-0.068	10.819	-0.079	10.797	-0.057	10.808	-0.068	10.797	-0.057	**-0.06**
21333029	10.787	-0.057	10.787	-0.047	10.776	-0.036	10.765	-0.025	10.776	-0.036	10.776	-0.036	10.797	-0.057	10.776	-0.036	10.776	-0.036	10.776	-0.036	10.787	-0.047	**-0.04**
21333028	10.776	-0.046	10.776	-0.036	10.765	-0.025	10.776	-0.036	10.776	-0.036	10.754	-0.014	10.765	-0.025	10.776	-0.036	10.765	-0.025	10.776	-0.036	10.787	-0.047	**-0.03**
21333027	10.787	-0.057	10.776	-0.036	10.808	-0.068	10.787	-0.047	10.776	-0.036	10.787	-0.047	10.787	-0.047	10.797	-0.057	10.787	-0.047	10.797	-0.057	10.787	-0.047	**-0.05**
21333026	10.797	-0.067	10.787	-0.047	10.787	-0.047	10.83	-0.09	10.776	-0.036	10.83	-0.09	10.787	-0.047	10.787	-0.047	10.787	-0.047	10.787	-0.047	10.776	-0.036	**-0.05**