East Fork Lewis River
Ridgefield Pits Restoration

Basis of Design Report Preliminary Design:
Attachment 5 – Water Temperature Analysis

PREPARED BY

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Contents

1.1 OVERVIEW

This section describes water temperature characteristics of the EFLR mainstem above and through the Project reach, based on information collected by Washington Department of Ecology (DOE) (Carey & Bilhimer 2009, McCarthy 2018) and LCEP (Quantum Spatial 2020, LCEP 2018). Information is focused on the summer months from approximately July through mid-September, when low flows combined with maximum atmospheric heating elevate mainstem water temperatures to levels that exceed critical temperature thresholds for salmonid health (16-20°C as defined by various agencies for various criteria). Following this baseline temperature characterization, we present results of modeling we completed to help assess factors influencing the current temperature profile, and predicted performance of restoration alternatives #2 and #3, the respective single channel and hybrid 3-channel networks through the Ridgefield Pits section (Pits reach) of the Project reach.

1.2 BASELINE TEMPERATURE CHARACTERISTICS BASED ON FIELD OBSERVATIONS

1.2.1 EFLR upstream of Project reach

Carey and Bilhimer (2009) and LCEP/Quantum Spatial (2020) both observed a significant warming of the mainstem ELFR during the summer, beginning at approximately river mile (RM) 26 and continuing downstream to the upstream extent of the Project reach at RM 10. The trend is illustrated in Figure 1, which shows continuous water temperature observations between RM 10 and RM 21 recorded by Hobo temperature loggers during the 2020 LCEP study. Contributing factors are discussed in various DOE reports and elsewhere, but the relevance for this project is that water temperature is already significantly degraded when EFLR flow reaches the site. This presents significant challenges to reducing stream temperatures to levels acceptable to salmonids through proposed restoration actions.

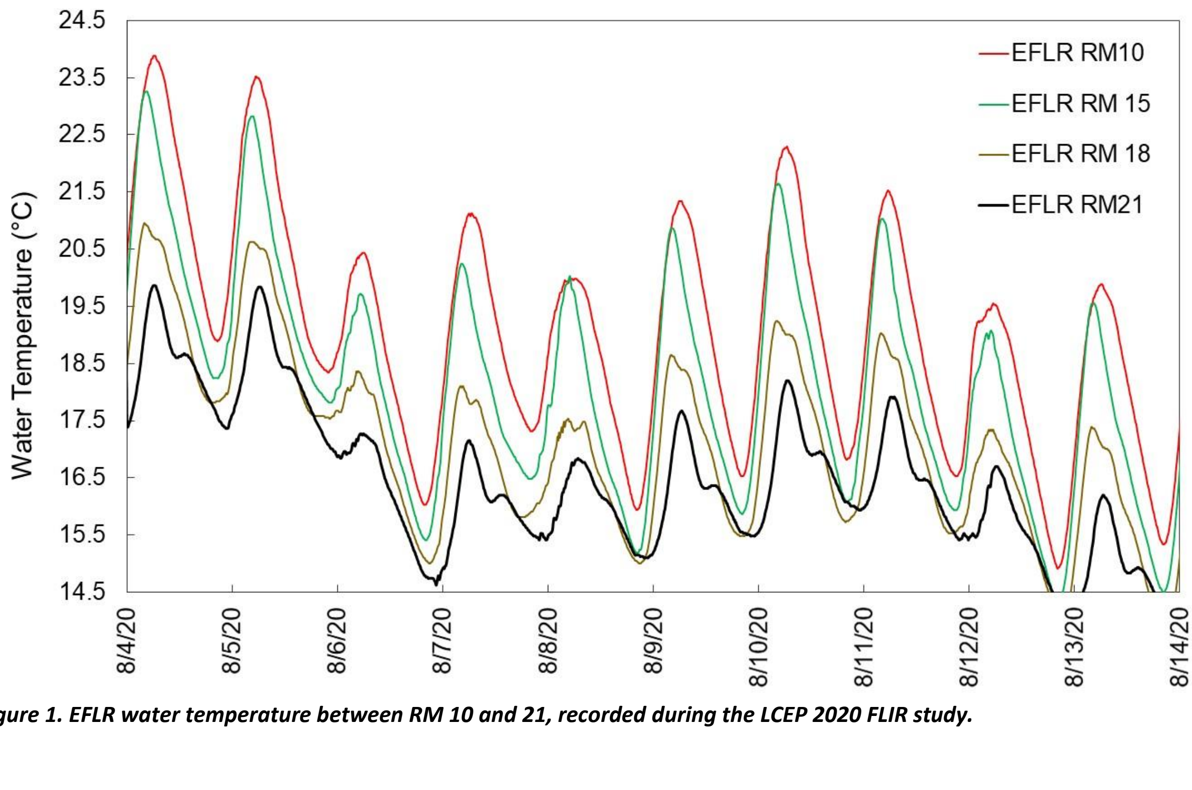


Figure 1. EFLR water temperature between RM 10 and 21, recorded during the LCEP 2020 FLIR study.

1.2.2 EFLR through Project reach

Due to its highly dynamic nature, including frequently shifting channels, areas of hyporheic flow, surface/groundwater exchange, and ongoing adjustment to the 1996 gravel pit avulsions, the Project reach exhibits a dynamic and complex water temperature profile accordingly. Carey and Bilhimer (2009) noted a transition point at approximately RM 9 where the EFLR shifts from losing flow upstream to gaining flow downstream of this location because of groundwater interaction. In the upstream losing reach a portion of surface streamflow was shown to be lost to the ground, primarily through a large gravel bar which the river meandered around at the time of the study but is now largely cut off as the main channel has assumed a more direct path. In the downstream gaining reach from RM 9 to 7.3, groundwater was presumed to be introduced, potentially cooling the river. Monitoring locations and frequency were too sparse, however, to provide conclusive evidence for groundwater introduction at any specific location within the mainstem. The authors also acknowledged that the transition to a more ponded and channel through the Ridgefield Pits could also be a contributing factor to the temperature drop that they noted.

Results from LCEP's 2020 water temperature study (Quantum Spatial 2020) are shown in Figure 2 for the Project reach. For this study, LCEP contracted Quantum Spatial to conduct an airborne thermal infrared (TIR) survey of EFLR surface water temperature on August 11, 2020. Advantages of this technique include the ability to observe water temperature over a large spatial area at high spatial resolution. Because the data is all collected over a relatively short time frame of 30 minutes or less, temperature response to atmospheric heating or cooling during the data acquisition period is largely eliminated, allowing a more or less 'instantaneous' snapshot of temperature differences over the entire survey area. A technical report for the Quantum survey (Quantum Spatial 2020) is available from LCEP, and a complete analysis of the results will be included in the upcoming report for the LCFRB-funded LCEP East Fork Lewis River Thermal Assessment study, for which the survey was flown.

The most notable feature of the thermal infrared data is a significantly cooler temperature signal detected through the Pits reach, from roughly RM 7.8 to RM 7.2. Temperature in this section is as much as 2°C cooler than what was measured upstream and downstream. This difference may be a result of two factors: 1) introduction of colder groundwater into the mainstem in the vicinity of the Ridgefield Pits, which would be consistent with Cary and Bilhimer's (2009) characterization of this area as a gaining reach; and 2) a moderating effect of this deeper section of the mainstem on atmospheric heating and cooling effects. Additional monitoring and modeling done by LCEP that is described below suggest that the latter may be primarily responsible. Downstream of RM 7.2 (roughly the downstream end of the Project reach) water temperature is seen to increase again, and within a mile is roughly equivalent to what was measured in the Project reach upstream of the Ridgefield Pits.

The thermal infrared data does not indicate any change in temperature in the vicinity of the gravel bar at RM 9, where Carey and Bilhimer (2009) described the mainstem losing nearly 10 cfs of flow underground across the prominent gravel bar located here, which they then claimed re-entered the mainstem as colder water shortly downstream of this feature. It is possible that this is no longer occurring, due to a meander cutoff that formed in years after the study and now routes most flow to the south of the bar rather than meandering around it to the north. It is also possible that a significant amount of flow is still being lost through the gravel bar and is re-surfacing further downstream, or in off-channel locations.

LCEP collected additional temperature data for the mainstem EFLR during the summers of 2018 and 2020 (Figure 3 and Table 1). This data was collected by Onset Hobo data loggers deployed at selected locations across the Project reach. Data collected in 2020 was used to calibrate the airborne thermal infrared data collected by Quantum Spatial.

Observation of the 2018 data immediately downstream and upstream of the Ridgefield Pits (Fig. 3 top, RM 7.2 and 8 respectively) shows significantly reduced diurnal fluctuation, and slightly higher overall average temperature downstream compared to upstream. The smaller diurnal temperature swing observed downstream may be the result of the large volume of deep, slow-moving water through the Pits reach acting to slow the rate of atmospheric heating and cooling, relative to shallower and faster-moving sections of the mainstem. This moderating effect would explain the differences in instantaneous temperatures measured at the two locations shown in Table 1: a slower rate of overnight cooling keeps water temperatures in the Pits reach higher than those upstream during the morning hours; during the late morning the shallower upstream reach begins to heat faster, and by mid-day temperatures are roughly equal at the two locations; heating continues at a faster rate upstream during the afternoon, and by late afternoon temperature at the upstream location is higher than downstream. Thermal infrared measurements recorded by Quantum were collected in late afternoon, and thus the pattern observed in that data is consistent with this explanation.

Several previous studies have noted potential groundwater recharge of the mainstem in the Pits reach (Cary & Bilheimer 2009; Daybreak Mine Habitat Conservation Plan 2003; McFarland and Morgan; 1996). We did not attempt to measure groundwater inputs as part of this design effort, and thus cannot estimate its relative contribution to temperature patterns noted in the Pits reach in LCEP temperature monitoring studies. Because of the volume of groundwater that would likely be required to influence the large volume of water in the Reach, we suspect that the moderation of temperatures seen the Pits reach is predominantly due to reduced atmospheric heating and cooling, with a potential smaller contribution from groundwater acting to locally cool areas. Average temperature at the downstream end of the reach was noted to be higher compared to upstream in the LCEP study (20.3 versus 19.8 °C), suggesting that groundwater inputs, if occurring, may have been small at least for the 2018 summer that was monitored. Groundwater inputs may vary from year to year based on climate patterns.

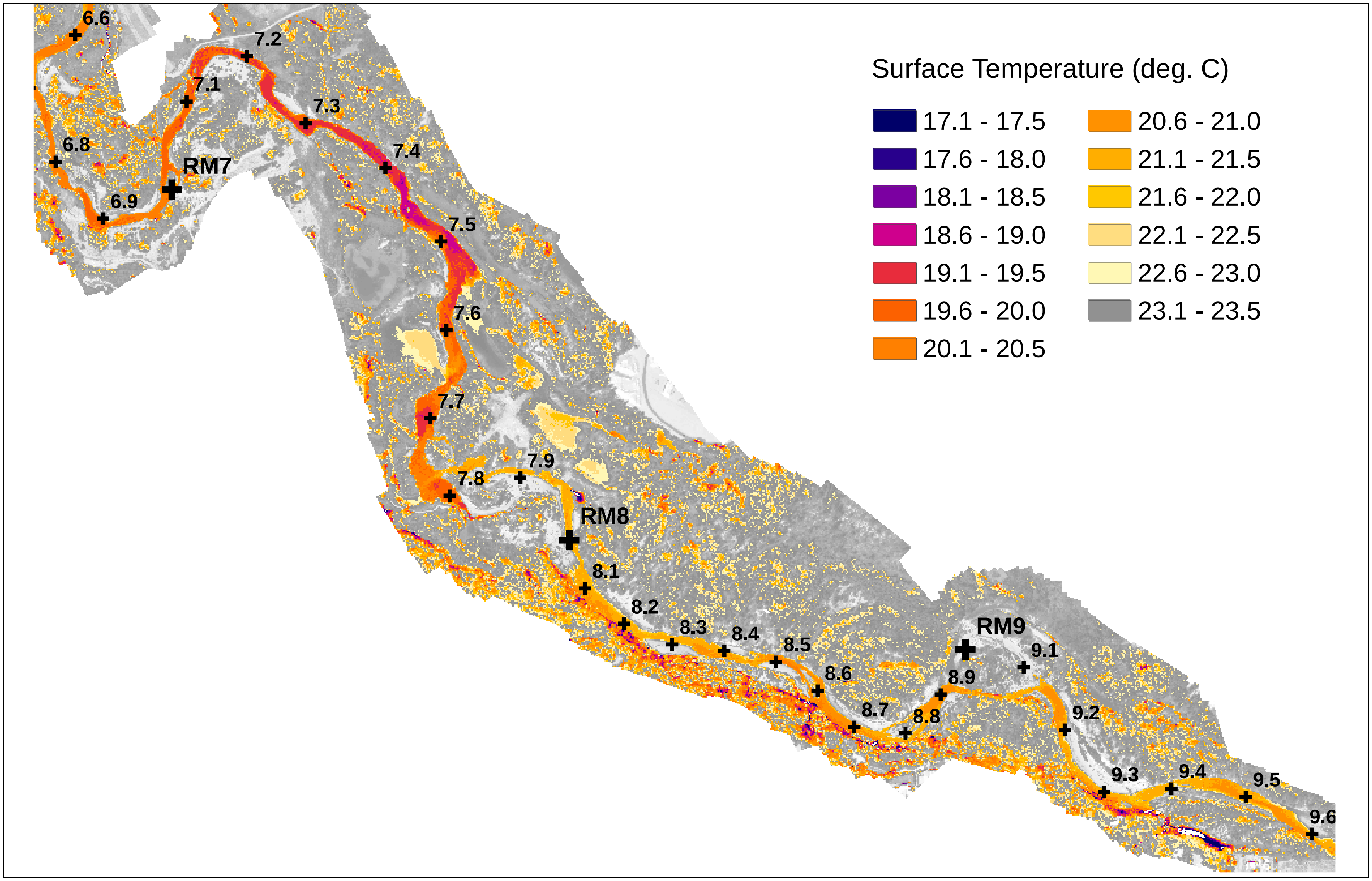
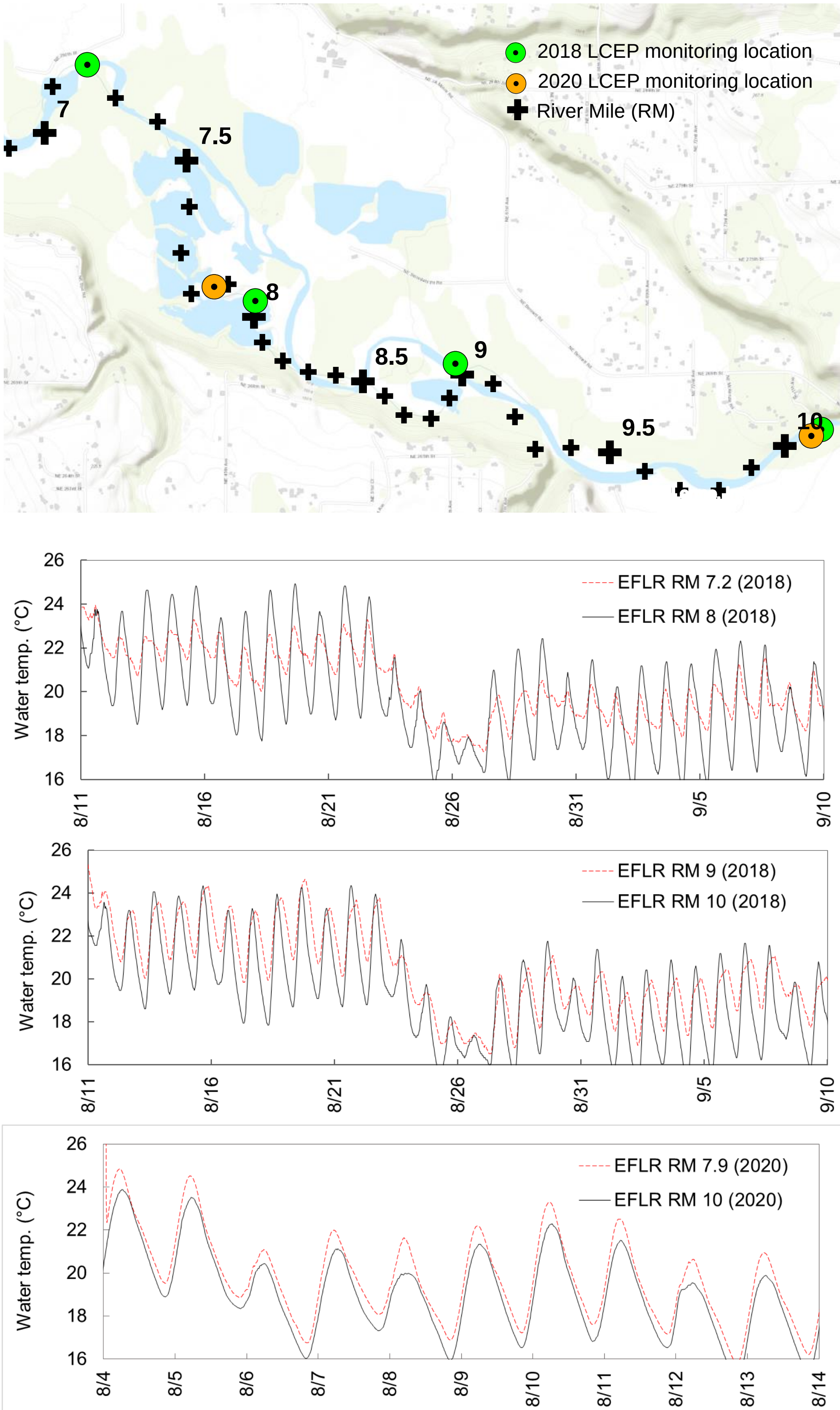


Figure 2. Surface water temperature of mainstem EFLR through the Project Reach, recorded by thermal infrared remote sensing on August 11,2020 at 3:30 pm PST. Note: most of the small cold-indicated patches along the bottom (south) margin and other small spots elsewhere outside of the mainstem are shaded land areas and should be disregarded.



Mean values

RM 6.2: 19.9

RM 7.2: 20.3

RM 8: 19.8

RM 9: 20.4

RM 10: 19.3

RM 7.9: 19.8

RM 10: 19.1

Figure 3. LCEP EFLR mainstem temperature monitoring locations and corresponding results for summers 2018 and 2020.

Table 1. Instantaneous water temperatures recorded at 9:00, 12:00, and 17:00 hours immediately downstream (RM 7.2) and upstream (RM 8.0) of the Ridgefield Pits during a selected one-week period in 2018.

Location				**09:00 hrs. on:**			
	8/12/18	8/13/18	8/14/18	8/15/18	8/16/18	8/17/18	8/18/18
RM 7.2	21.7	21.1	21.7	21.9	21.6	20.5	20.5
RM 8.0	19.8	19.3	19.9	20.1	19.6	18.1	18.7
Location				**12:00 hrs. on:**			
	8/12/18	8/13/18	8/14/18	8/15/18	8/16/18	8/17/18	8/18/18
RM 7.2	22.4	22.1	22.4	23.1	22.4	21.4	22.0
RM 8.0	22.1	22.2	22.3	22.9	21.7	21.4	22.0
				17:00 hrs. on:			
	8/12/18	8/13/18	8/14/18	8/15/18	8/16/18	8/17/18	8/18/18
RM 7.2	22.1	22.3	22.6	22.8	22.1	21.7	22.1
RM 8.0	23.2	24.4	24.3	24.4	23.1	23.2	24.1

1.2.3 Off-channel areas within Project reach

In addition to the mainstem EFLR, the Project reach includes other sources of surface water including side channels and off-channel areas in the floodplain, inundated gravel pits including the Ridgefield Pits, and the Mill and Manley creek tributary inputs. LCEP monitored water temperature at several of these during summer 2018, including previously known cold water locations, using deployed Onset Hobo data loggers and Pendant temperature loggers. Monitoring locations and corresponding results are shown in Figure 4, with location symbol colors corresponding to average daily maximum temperatures for the deployment period from late July – early September. Analysis of these results, some of which can offer additional insight into temperature patterns observed in the Pits reach of the mainstem, is as follows:

- Location T2. Off-channel area where former gravel pit #2, which has almost filled in after the 1996 avulsion, was located. The consistently cold temperature, with minimal diurnal variation, indicates the likely presence of groundwater intrusion.

- Location T3A - Side channel flowing through former gravel pit #3 which has largely filled in after the 1996 avulsion. Flow through this channel out of the mainstem has been increasing in recent years as the river continues to respond to the avulsion. As a result, the temperature profile is nearly identical to what is observed at location WSE3 (the mainstem monitoring location at RM 8, discussed above). This is illustrated in Figure 5a below.

- Location T5. Ridgefield Pit #5, which remains largely unfilled after the 1996 avulsion. The consistently warm temperature indicates a lack of groundwater intrusion into this pit. Water depth is up to 15 feet deep in some areas and we presume that the corresponding large volume of water moderates atmospheric heating and cooling and is thus responsible for the minimal diurnal temperature variation observed in the plot. If true this would be consistent with what we presume is also happening in the Pits reach of the mainstem, as discussed in Section 1.2.2 above, where that relatively large volume of water is likely moderating mainstem heating and cooling. Although they are hydrologically connected the very different temperature signals observed in the mainstem and Pit #5 suggests limited mixing between the two, and thus it is unlikely that Pit #5 is influencing mainstem EFLR water temperature. This is somewhat supported by the LCEP 2020 TIR data, however since those measurements are limited to surface water it cannot be stated with absolute certainty.

- Location T6. Ridgefield Pit #6, which remains largely unfilled after the 1996 avulsion. Thermal performance is nearly identical to what was observed, and described above, for Ridgefield Pit #5. This is expected as the two share very similar physical and geomorphic characteristics, the major difference being that Pit #6 is typically minimally connected to the mainstem throughout the summer. The fact that Pit #5, with its more frequent hydrologic connection to the mainstem, shares nearly identical thermal properties to the disconnected Pit #6 supports the conclusion that there is limited interaction between the EFLR mainstem and Pit #5.

- Location T7. Ridgefield Pit #7, which remains mostly unfilled after the 1996 avulsion but has seen some fine sediment accumulation and is shallower and smaller in volume relative to the other pits. Thermal performance is similar to what was observed downstream of the mainstem at RM 7.2 (described above in Section 1.2.2), but with a larger diurnal variation that is mostly expressed in the daytime heating portion of the cycle. This is illustrated in Figure 5b below. The close relationship between the two temperature profiles suggests mixing between the two water bodies, and the increased daytime heating in Pit 7 could be explained by its shallower, more stagnant water and reduced volume relative to the mainstem. The surface of Pit #7 sits at a lower elevation relative to that of Pit #8 during the summer, and thus it receives a very small amount of surface water from the higher pit through the narrow berm/beaver dam complex that separates the two. Pit #8, described below, is considerably cooler than Pit #7, however it does not appear that its surface water contribution is large enough to produce any cooling in Pit #7, at least during the period of record for our monitoring.

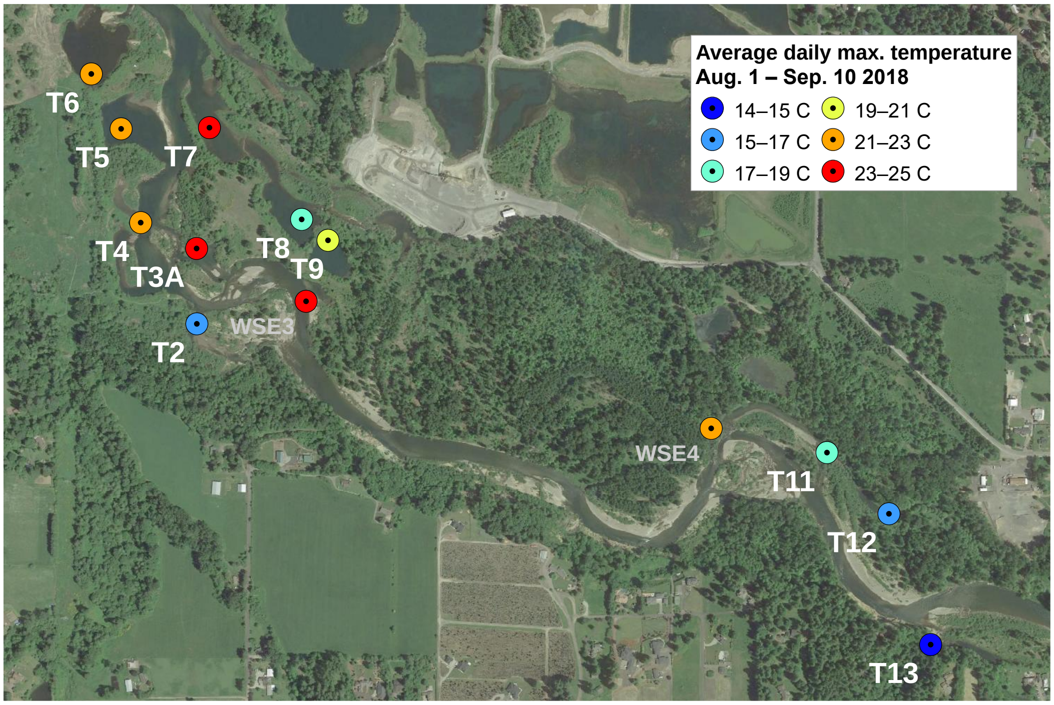
- Location T8. Ridgefield Pit #8, which remains unfilled, and largely disconnected from the mainstem EFLR except for a very small surface water contribution through Pit #7, as described above. Pit #8 connects to a series of off-channel wetlands and side channels at its upstream end. This entire network appears to be fed by groundwater consistently throughout the summer, as illustrated by the consistently cold and minimally varying temperature profile shown in Figure 4.

- Location 9. Ridgefield Pit #9, which remains disconnected from the mainstem EFLR. Surface water connection to the remaining hydrologic network within the Project reach appears minimal as well. Thermal performance is similar to Pit #8, but temperature is roughly 2 degrees higher, suggesting a smaller groundwater presence within Pit #9. The slightly increased diurnal variation seen in Pit #9 relative to Pit #8 would also be consistent with that assumption but could also be influenced by the overall shallower depth, smaller volume, and lack of surface water connection exhibited by Pit #9.

- Locations T11 and T12. Side channel adjacent to the large gravel bar at RM 9, where Carey and Bilhimer estimated significant loss (~10 cfs) of surface water from the mainstem to groundwater, through this feature. If still occurring a portion of this groundwater may be re-surfacing in this side channel, which would explain the relatively cold temperature profiles observed here. Both locations show a slightly increasing temperature trend throughout the period of record, which would be consistent with a decreasing volume of groundwater loss and re-expression associated with decreasing EFLR mainstem flows as summer progresses.

- Location T13. Mill/Manley creeks confluence. This location had the coldest water of all the locations monitored, primarily due to the contribution from Mill Creek. Other studies by DOE have shown Manley Creek to be warmer, however the beaver pond complex that is present at its downstream end immediately upstream of the confluence zone remains relatively cold throughout the summer, as is illustrated in the LCEP TIR data.

It is worth noting that although several surface water locations off the mainstem have been observed to be cooler than the mainstem, likely due to groundwater intrusion, most of these areas remain disconnected from the mainstem at typical low summer EFLR flows when elevated temperatures are of most concern. This disconnection may serve to preserve these cold-water areas, but it also means that during these times fish in the mainstem would not be able to access these areas for thermal refuge. This refuge would only be provided to fish that entered these areas prior to the disconnection occurring. Hydraulic modeling provides us with an estimate of the flow magnitudes required to establish these connections, but until the model is fully calibrated, we cannot provide exact values. In general, though, most areas are likely to remain disconnected at flows less than ~80 cfs, roughly the long-term average daily flow for the month of August (USGS Heisson gage monthly flow statistics).


Average daily max. temperature
Aug. 1 – Sep. 10 2018
14–15 C
15–17 C
17–19 C
19–21 C
21–23 C
23–25 C
T6
T5
T7
T4
T3A
T8
T9
WSE3
T2
WSE4
T11
T12
T13

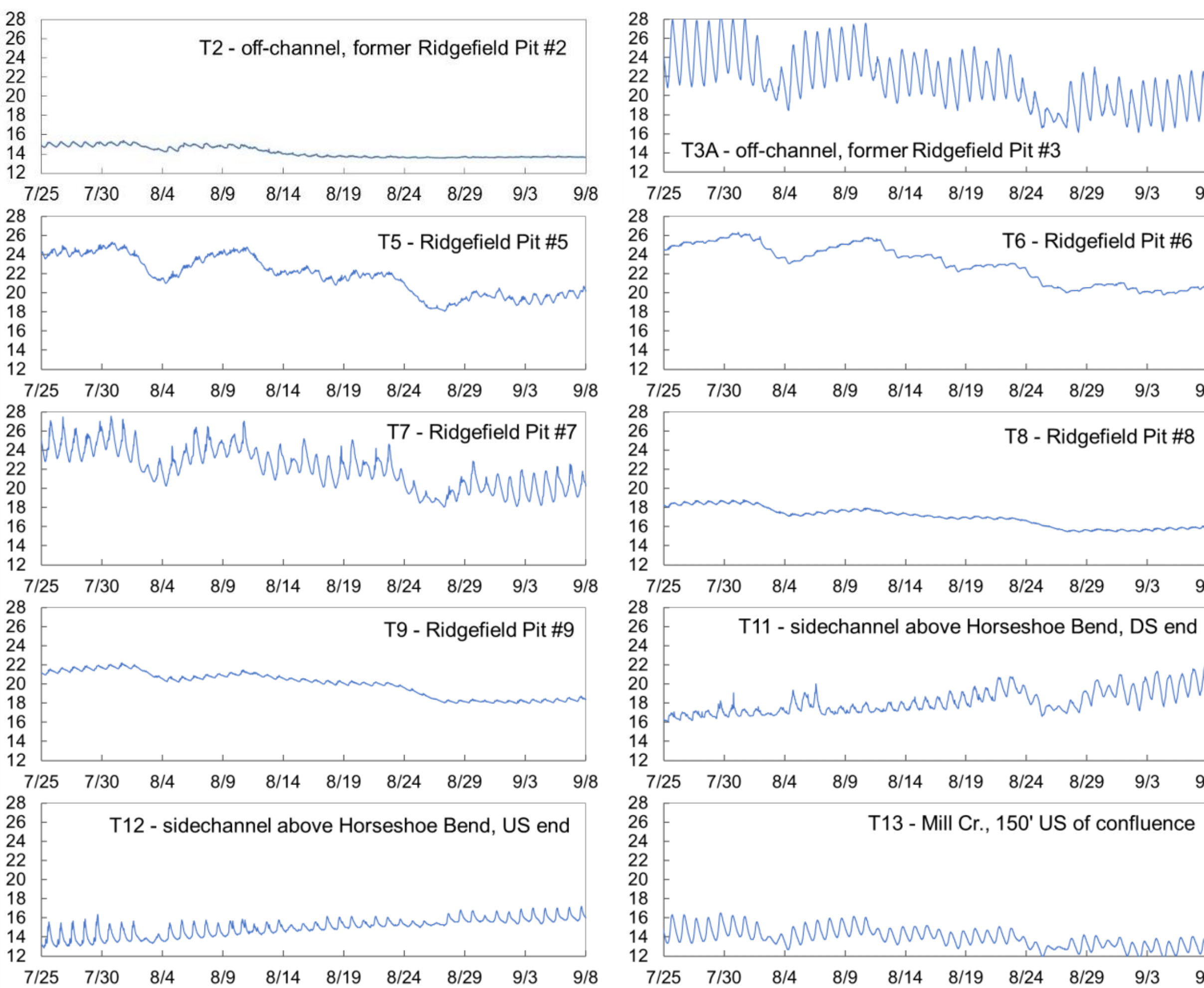

T2 - off-channel, former Ridgefield Pit #2
T3A - off-channel, former Ridgefield Pit #3
T5 - Ridgefield Pit #5
T6 - Ridgefield Pit #6
T7 - Ridgefield Pit #7
T8 - Ridgefield Pit #8
T9 - Ridgefield Pit #9
T11 - sidechannel above Horseshoe Bend, DS end
T12 - sidechannel above Horseshoe Bend, US end
T13 - Mill Cr., 150' US of confluence
28
26
24
22
20
18
16
14
12
7/25
7/30
8/4
8/9
8/14
8/19
8/24
8/29
9/3
9/8

Figure 4. LCEP off-channel temperature monitoring locations and corresponding results for summer 2018. Note WSE3, WSE4, and T4 are mainstem locations and thus not included in results presented here.

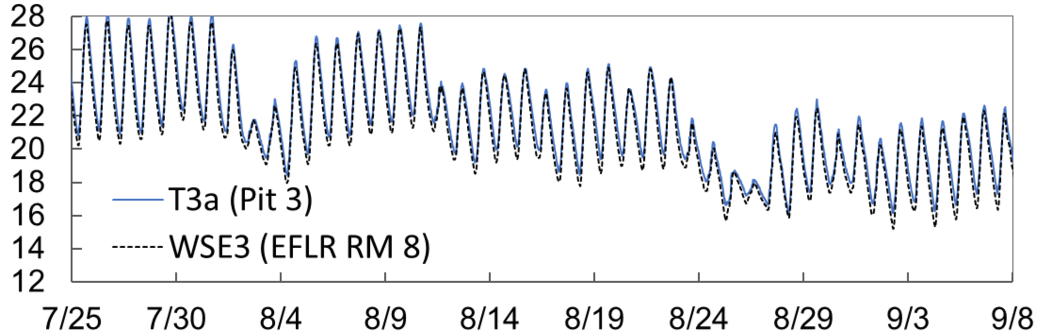


Figure 5a. Comparison of water temperature monitored by LCEP at Pit #3 with that of the EFLR mainstem measured at RM 8, during summer 2018.

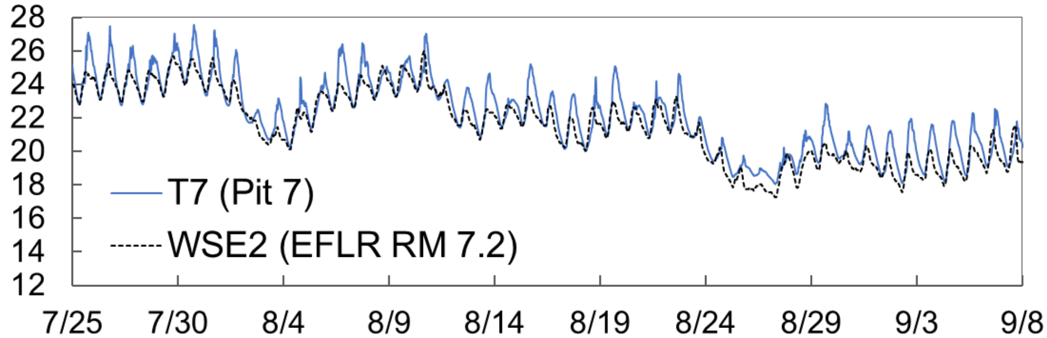


Figure 5b. Comparison of water temperature monitored by LCEP at Pit #7 with that of the EFLR mainstem measured at RM 7.2, just downstream of the Ridgefield Pits reach, during summer 2018.

1.3 WATER TEMPERATURE MODELING

1.3.1 Thermal model overview and inputs

We modeled water temperature using the Tuflow Advection/Dispersion (A/D) add-on module to the Tuflow FV hydraulic model (Tuflow FV 2020, 2013). The module couples water temperature and atmospheric heat information (incident solar radiation, air temperature, humidity, precipitation, and cloud cover) applied at model input boundaries with hydraulic engine outputs to simulate changes in water temperature throughout the model domain using two-dimensional, depth averaged heat transfer equations. The Tuflow hydraulic engine allows flow inputs to be applied at individual grid cell locations, and thus we were also able to simulate groundwater (i.e. cool water) intrusion at locations of interest and predict how it might influence stream temperature dynamics. We ran unsteady (time varying flow) temperature simulations for the Existing Conditions model using input data from the summer 2018 monitoring period to try and replicate temperatures that were observed in the field during that time. Following this model verification process the same simulations were then run for the Alternatives #2/#3 comparison. Table 2 and Figures 6-7 summarize inputs to the A/D module and respective values we applied.

Table 2. Data sources and values applied as Tuflow FV A/D module inputs for water temperature modeling.

Hydraulic and A/D module inputs	Model Location Applied	Data Source
Input Flow	Upstream boundary	USGS Heisson gauge. See Figure 6.
River temperature	Upstream boundary	LCEP August 2018 EFLR hourly data at RM 8.
Longwave solar radiation	Full grid	Zion Klos, Link 2018. See Figure 7.
Shortwave solar radiation	Full grid	Zion Klos, Link 2018. See Figure 7.
Air temperature	Full grid	[1]Kelso, WA hourly observations, August 2018.
Rel. humidity	Full grid	[1]Kelso, WA hourly observations, August 2018.
Cloud Cover	Full grid	[1]Kelso, WA hourly observations, August 2018.
Precipitation	Full grid	[1]Kelso, WA hourly observations, August 2018.
Groundwater temperature	Selected point locs.	[2]Best guess

Notes: 1) data source = https://www.wunderground.com/history/daily/us/wa/kelso/KKLS/date; 2) groundwater magnitude, temperature, and input locations were estimated to the best of our ability based on field observations.

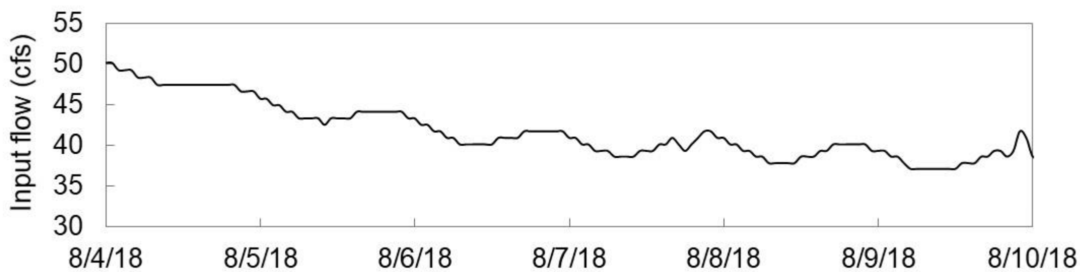


Figure 6. Input flow applied to Tuflow FV water temperature model. Selected flows were chosen to coincide with temperature monitoring observations recorded in 2018, during a period which saw typical low-flow conditions.

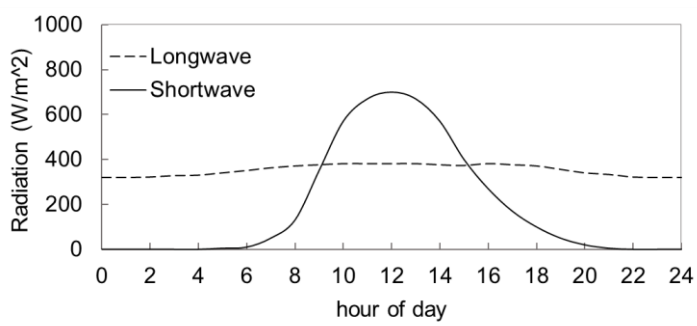
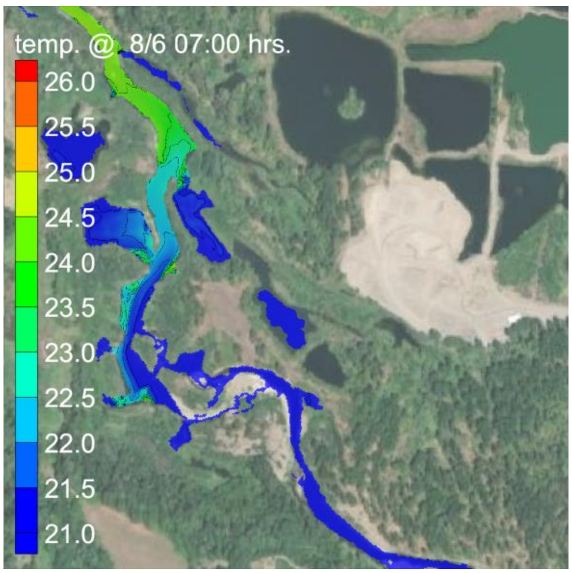
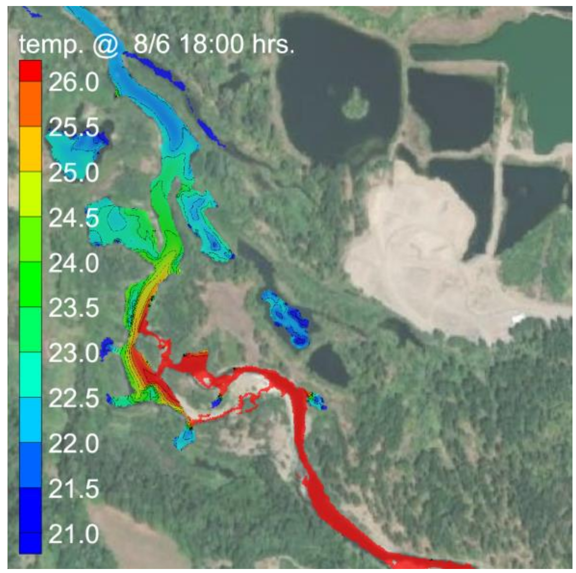


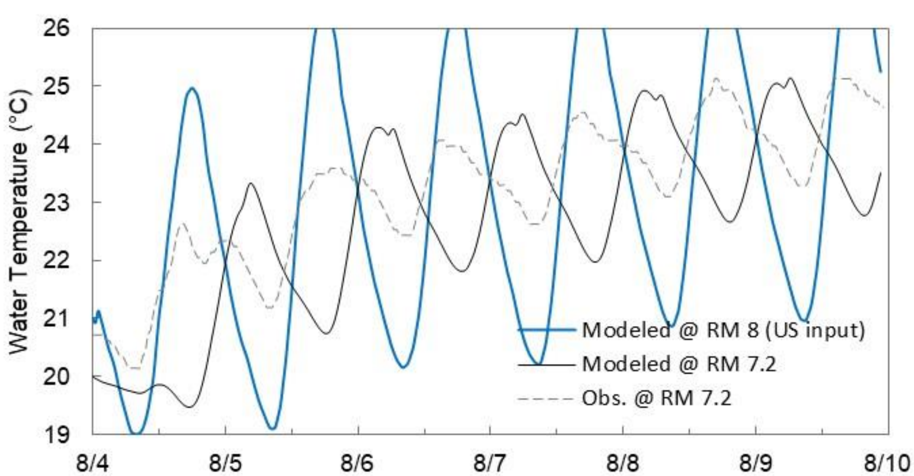
Figure 7. Daily incident solar radiation profiles applied as atmospheric heating inputs in Tuflow FV A/D module. Values are based on studies done by Zion Klos and Link, 2018.

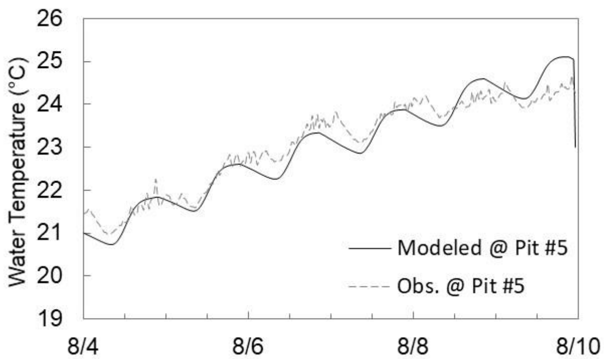
1.3.2 Ridgefield Pits reach, Existing Condition

We ran unsteady low-flow water temperature simulations for the Pits reach to attempt to reproduce existing water temperature patterns that have been observed. Results are shown in Figure 8, including instantaneous map plots at select times (morning versus evening), and time series at select mainstem locations. The model reproduces the reversal of temperature across the Pits reach that occurs between morning and evening, as has been observed, however there is a time shift of several hours relative to the observed condition. This may be due to factors inherent in the startup process for the model simulations, however we have not fully resolved this pattern to date. The model does predict the attenuation of the diurnal signal as water transits the Pits reach, as was seen in the observed data. Model results for Pit 5 are very close to what was observed and confirm a lack of mixing between this off channel area and the mainstem despite the hydraulic connection that is maintained. Model results for Pit 7 generally follow the observed data, but somewhat underpredict the larger daytime heating events. This may be due to the invert elevations of the model being set too high and isolating the pit from the mainstem to a higher degree compared to actual conditions. Overall, model results generally predict the water temperature characteristics observed in the Pits reach for the period compared and lend support to our conclusion presented earlier – which is that diurnal variations in atmospheric heating are the primary driver of temperature changes in this reach. Groundwater influence may be an additional, but smaller factor.









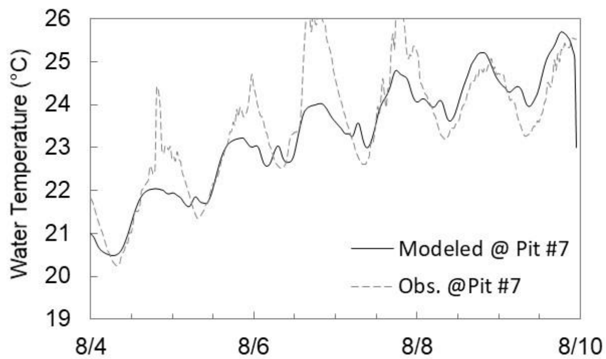


Figure 8. Output results for the Existing Condition water temperature simulation. Top: mapped outputs across the Pits reach shown at 7:00 am (left) and 18:00 pm (right). Middle: time series plots for the model input temperature (upstream) and simulated temperature at the downstream end versus observed temperature at the downstream end. Bottom: Simulated versus observed temperatures in Pits # 5 and #7.

1.3.3 Ridgefield Pits reach, restoration alternatives #2 & #3

LCEP ran low-flow water temperature simulations for proposed restoration alternatives #2 (single thread channel through the Pits reach); and #3 (3-channel network through the Pits reach) to evaluate the anticipated thermal performance relative to each other and to the Existing Condition. Selected temperature and heat inputs were identical to those applied for the Existing Condition, to maintain consistent conditions at the model boundaries (i.e., input flow applied at the upstream boundary, and atmospheric heating applied uniformly over the entire model domain).

The primary concern regarding temperature performance of the restoration alternatives is the potential for accelerated daytime heating within the hybrid 3-channel network of Alternative 3 relative to the single restored Alternative 2 channel, due to the shallower water depths of the Alternative 3 network. At the current design iteration, the Alternative 2 channel averages approximately 0.4 meters at the low-flow (~40 cfs) condition, with depths in the Alternative 3 channels averaging ~0.2 meters. Corresponding channel width/depth ratios, at low-flow, are 45 and 60 respectively for Alternatives 2 and 3. Figure 9 illustrates water depths in the Alternatives 2 and 3 channels under the low-flow conditions simulated.

It should be noted that for both alternatives the overall volume of water in the reach will be considerably less relative to the existing condition, and thus the moderating effect on diurnal heating currently exhibited will be lost. Anticipated shading provided by riparian vegetation placed along restored banks should prevent additional daytime heating, however the reach will likely exhibit temperature characteristics seen in the up and downstream reaches, unless groundwater can successfully be introduced.

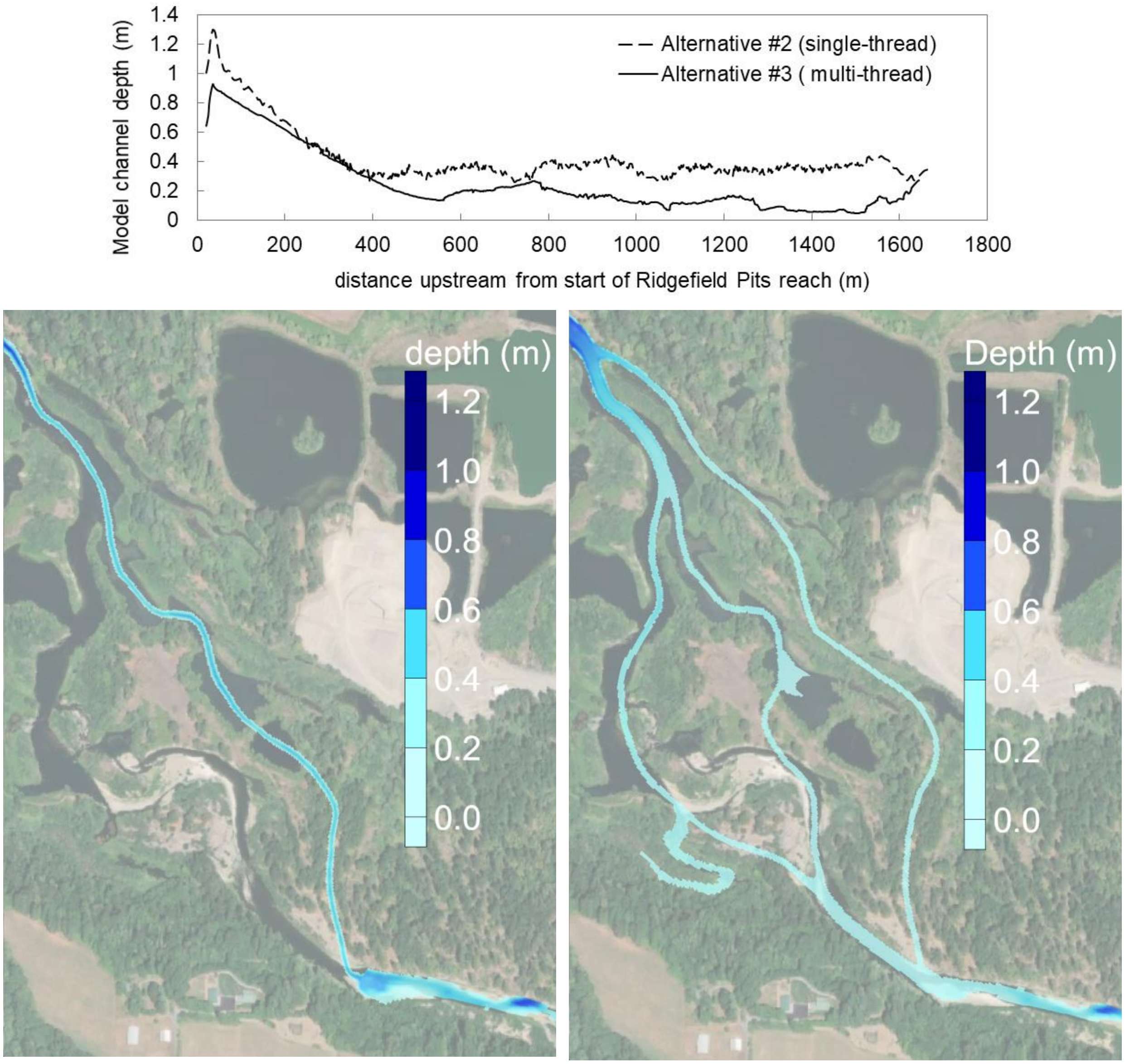


Figure 9. Model channel water depths for restoration Alternatives 2 and 3 under low-flow conditions simulated. Top: longitudinal depth profile extending up channel through Pits reach. Bottom: map profiles.

Temperature results for Alternatives 2 and 3 are compared in Figure 10, for the baseline condition of <u>no groundwater input</u>. The top plots show a uniform temperature profile throughout the reach for both alternatives, with no variation between upstream (US) and downstream (DS) temperatures. This is true throughout day and night. Temperatures that were observed in 2018 are included for comparison, and show the effect that the deeper, existing Pits reach has on moderating diurnal heating and cooling within the reach, resulting in lower daily maximum temperatures, and higher daily minimum temperatures, relative to both restoration alternatives.

The lower plot in Figure 10 compares temperatures at the downstream end of the reach for Alternative 2 versus 3. Model results show slightly cooler overall temperatures for the Alternative 3 hybrid network relative to the single channel Alternative 2. This evidenced by a larger rate of overnight cooling of these channels versus the Alt 2 single-thread, which compensates for increased heating during the day, since the nighttime cooling period is considerably longer relative to the shorter daytime period when air temperatures typically exceed water temperature and solar radiation is of significance. As a result, daily peak temperatures for Alternative 3 are very slightly lower compared to Alternative 2, while daily maximums remain nearly identical.

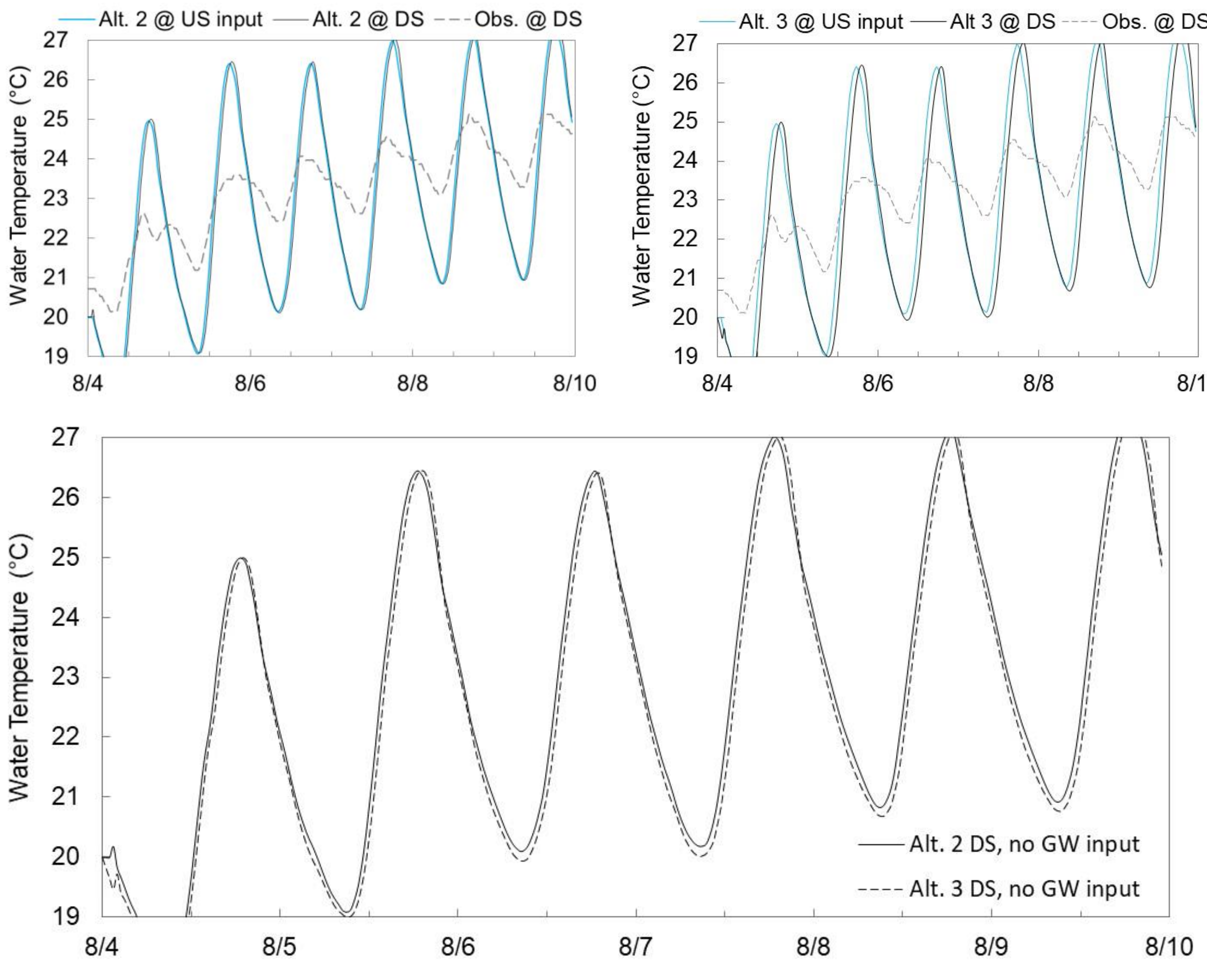


Figure 10. Simulated water temperature for restoration Alternatives 2 and 3, with identical boundary conditions applied as for the Existing Condition model described above, including atmospheric heating effects. Top: Upstream input versus resulting downstream temperatures for Alternative 2 (left) and Alternative 3 (right). Bottom: comparison of resulting downstream temperature for Alternative 2 versus 3.

As a final test identical simulations were run but with groundwater applied at selected locations, to predict the response of both alternatives to this potential cooling influence. Groundwater input locations are shown in Figure 11. Groundwater quantities were kept quite small, at 0.2 cfs for each location. Because of the potential for the multi-thread Alternative 3 channel network to intercept groundwater at a greater number of locations relative to Alternative 2, more inputs were correspondingly added to that model as shown.

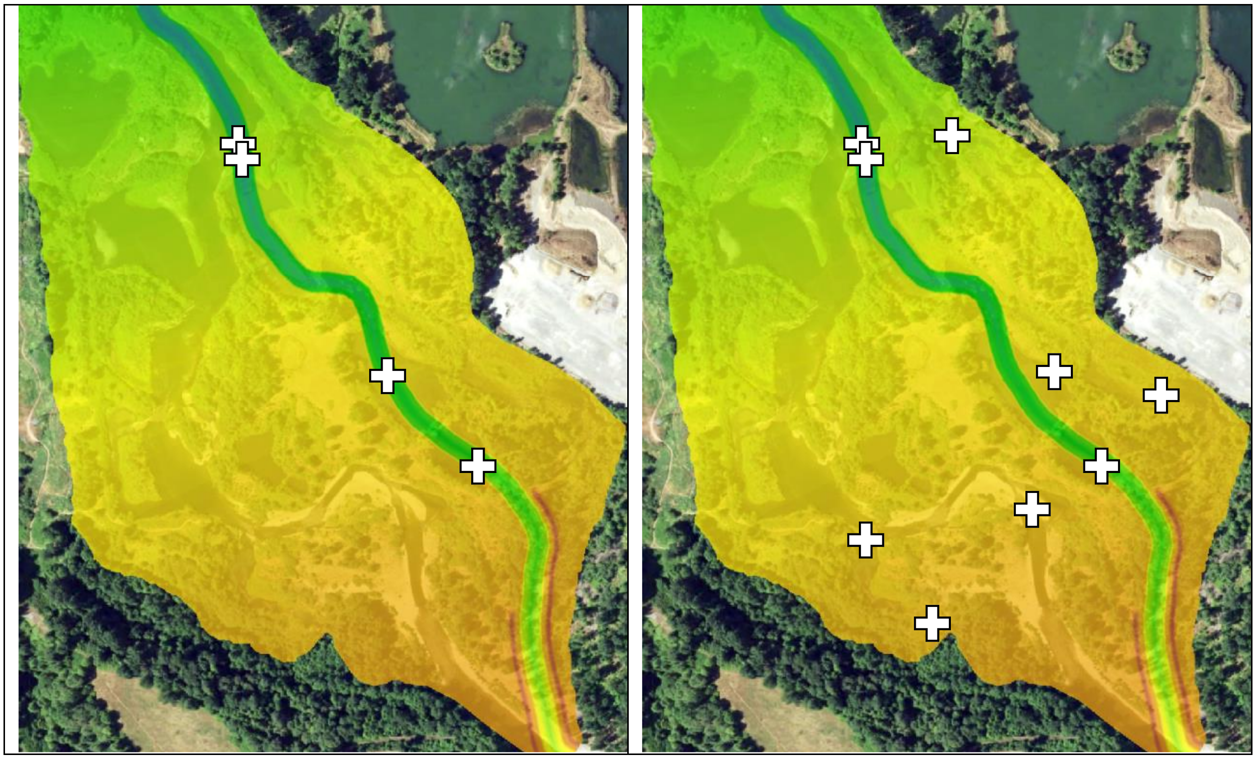
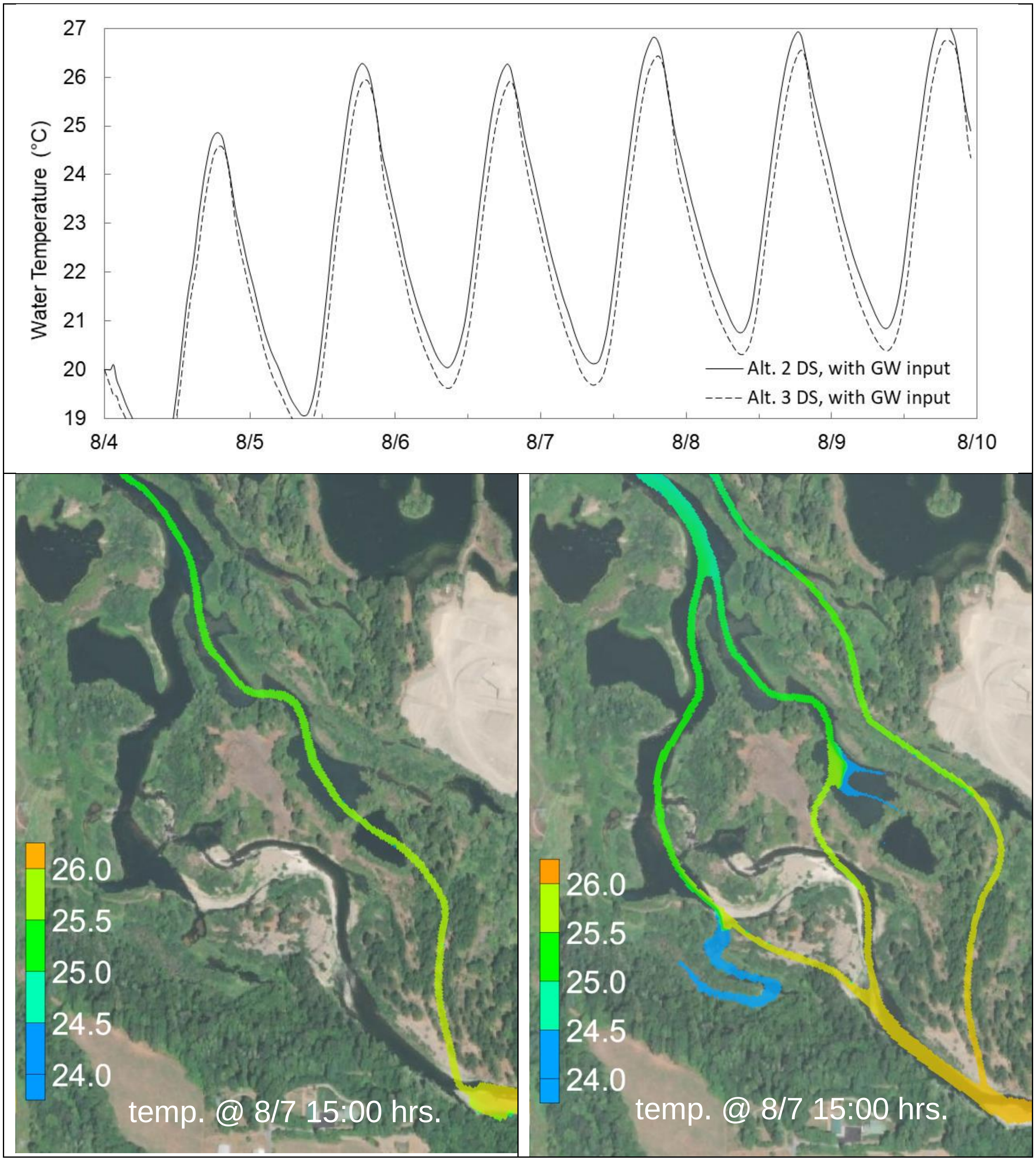


Figure 11. Simulated water temperature for restoration Alternatives 2 and 3, with identical boundary conditions applied as for the Existing Condition model described above, including atmospheric heating effects. Top: Upstream input versus resulting downstream temperatures for Alternative 2 (left) and Alternative 3 (right). Bottom: comparison of resulting downstream temperature for Alternative 2 versus 3.

Model results for the Alternatives simulations with groundwater inputs added are shown in Figure 12. The model again indicates slightly better temperature performance for Alt. 3 compared to Alt. 2, with the groundwater further enhancing this improvement. Overall temperature at the downstream end of the reach is lower for Alt. 3, with minimum peak temperatures reduced by approximately 0.4 degrees. Temperature response across the reach shows some retention of cool water areas in the Alt. 3 channels, whereas larger volume of water in the Alt. 2 single channel largely dilutes the cool groundwater inputs. Alt. 3 has also been designed with alcoves intended to intercept groundwater at locations where they have been observed, and these are shown to remain cool in the model simulations.



1.4 WATER TEMPERATURE ANALYSIS SUMMARY

1.4.1 Observed and simulated trends

The following bullets summarize water temperature characteristics for the Project reach during low flow summer conditions when temperatures are of concern, as described in the preceding sections:

- EFLR mainstem temperatures already exceed most water quality standards at the upstream extent of the Project reach near RM 10 at Daybreak Park (Figure 1).
- Further degradation of EFLR temperature through the Project reach is minimal (Figures 2 and 3, Table 1).
- EFLR mainstem temperature exhibits large diurnal variation in summer due to atmospheric heating and cooling. This variation is reduced through the Ridgefield Pits, where the high volume of slow-moving water attenuates heating and cooling effects, resulting in lower daily high and higher daily low temperatures relative to upstream and downstream reaches (Figure 3).
- Much of the spatial variation in temperature observed in the vicinity of the Pits can be attributed to the moderating effect of the Pits reach on atmospheric heating and cooling. Temperature modeling supports this conclusion (Section 1.3.2).
- Some groundwater may currently influence water temperature through the Pits reach, but this appears to be a relatively small influence, at least during the period of time that was monitored (Section 1.3.2, and additional modeling not presented).
- Groundwater influence is tied to the water table, which fluctuates based on climate and weather patterns. Thus, influence of groundwater on the EFLR mainstem is likely to vary from year to year. This has been evidenced by LCEP’s 2021 water temperature monitoring, which showed considerably less cold water in off-channel and side channel areas relative to 2018.
- Little evidence of mixing is observed between the larger Ridgefield Pits #5 and #7 and the EFLR mainstem despite being hydrologically connected throughout the summer (Figures 4,5). Model results support this conclusion (Figure 8)
- Several off-channel and side channel areas have been observed to hold cold surface water during the summer, presumably due to groundwater intrusion (Figure 4). Most of these however do not remain hydrologically connected to the EFLR mainstem during most summer flows, limiting their potential as thermal refuge for juvenile salmonids.
- The confluence of Mill and Manley creeks with the EFLR mainstem presents the largest area of current thermal refuge within the Project reach.
- Overall, the highly dynamic nature of the Project reach results in a complex and dynamic water temperature profile. Restoration actions should retain and potentially enhance positive aspects of this.

1.4.2 Implications for restoration alternatives

The following bullets summarize implications of the observed and simulated EFLR temperature performance for the restoration alternatives that have been considered for the Pits reach, relative to each other and the Existing Condition.

Existing Condition:

- Slow moving, large volume of water with reduced diurnal temperature variation relative to upstream and downstream. Lower daily maximum and higher daily minimum temperatures.
- No current riparian shading, and not likely to improve due to large channel widths.
- From a temperature standpoint, the larger pits (#5 and #7) which remain connected to the mainstem during summer do not appear to degrade its temperature. Other negative factors such as habitat for predators must also be considered.

Alternatives #2 and #3, relative to Existing:

- Based on modeling, water temperatures for both Alternatives will likely exhibit the larger diurnal temperature variations currently seen upstream and downstream of the Pits reach. Thus, daily peak temperatures will be higher, and daily minimum temperatures will be lower, relative to the Existing condition.
- Overall water temperature may be reduced relative to the Existing Condition due to an anticipated rise in the groundwater table from proposed grading.
- Extensive riparian planting along channels that are considerably narrower than the Existing Condition should provide extensive shading and reduce solar heating of the reach during the day, potentially reducing diurnal temperature variation.

Alternative #2 versus #3

- Model results indicate slight improvement in temperature performance for the hybrid three-channel network in Alternative 3 versus the single channel in Alternative 2. Despite the greater water depth and smaller width-to-depth ratio exhibited by Alternative 2, the corresponding reduction in heating is offset by a greater overnight cooling effect seen in the shallower, smaller Alternative 3 channels.
- Temperature performance in Alternative 3 was seen to be further enhanced by simulated groundwater inputs, which persist longer and have more influence in the shallower, lower volume multi-thread channels relative to the single channel.
- Due to time constraints, channels for the Alternative 3 design were not optimized for low flow. Further iterations of low-flow geometry may be possible to further enhance its temperature performance.

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