Lower East Fork Lewis River Thermal Assessment

Findings and Initial Thermal Refuge Project Concepts for the Lower East Fork Lewis River (RM 4 – 21)

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1 Introduction

1.1 OVERVIEW

This report summarizes findings from a water temperature assessment for the lower East Fork Lewis River (EFLR) conducted by the Lower Columbia Estuary Partnership (LCEP) from approximately June 2020 through April 2022. The assessment covered approximately 17 miles of the EFLR mainstem and its floodplain, from just upstream of La Center, Washington at river mile (RM) 4.5 to Lucia Falls at RM 21, as well as sections of selected tributaries where access could be obtained. The primary purpose of the study was to identify existing and potential cold-water locations available for use as 'thermal refuges' by native anadromous salmonid species during summer months when water temperature in the EFLR and many of its tributaries regularly exceeds State of Washington water quality limits. Thermal refuges may be critical for the survival of salmonids during summer heat events (Wang et al., 2020). The study was identified as a high priority need for the EFLR basin in the 2009 Lower East Fork Lewis Habitat Restoration Plan (HRP) (LCFRB, 2009), due to concerns about the impact of elevated summer river temperatures on endangered salmonid populations, the lack of data characterizing the spatiotemporal profile of the mainstem river temperature, and the availability of other off-channel refuge areas for these species to utilize. The study relied on new remotely sensed thermal infrared (TIR) data and in-stream water temperature measurements combined with previously existing in-stream water temperature measurements to characterize existing summertime temperature conditions and identify existing cold-water locations. This was followed by a site prioritization process guided by a Technical Oversight Group (TOG), which generated a ranked list of potential thermal refuge projects to benefit EFLR salmonids. Initial project concepts were then created for three of the highest-ranking projects, again with the support and guidance of the TOG. Those concepts are included as Appendix A of this report.

1.2 BACKGROUND

Summer temperatures in the mainstem EFLR are known to exceed the preferred ranges for native salmon and trout species (LCFRB, 2010). Although temperature assessments have been done for the lower EFLR as part of various WA Department of Ecology (McCarthy, 2018; Carey & Bilhimer, 2009) and other studies, additional information is needed to support the development of temperature-related restoration actions within the lower river that address this threat to these species. Specifically, there has been a need to comprehensively describe the spatiotemporal temperature profile of the mainstem river and the influence that cold/warm water sources have on overall temperature. Additional data has been needed to detect and describe existing and potential locations of thermal refuge habitat in the lower river that may provide suitable rearing conditions during periods of near-lethal water temperatures (LCFRB, 2009). The 2009 HRP listed a temperature and groundwater assessment to fill this data gap as a priority action for salmon recovery. The present study addresses the surface-water temperature component of that identified need. We did not perform any groundwater assessment, and that component remains as a critical data gap. Thermal refuges have been defined as discrete patches where water temperatures are colder relative to the surrounding water by approximately 2°C or more (Torgersen et al., 2012). We have applied this definition to characterize thermal refuges in the present study.

1.2.1 Study Area

The HRP describes the lower EFLR as the downstream 15-mile reach, extending from the confluence of the EFLR and the Lewis River at RM 0.0 upstream to RM 15.0. The present study extends from approximately RM 4.5, at the confluence of Lockwood Creek and the EFLR, upstream to RM 21 at Lucia Falls (Figure 1), thereby covering most of the lower EFLR. Because there is little to no existing or potential thermal refuge downstream of RM 4.5, we excluded that reach from the study. Upstream, we included the reach extending from RM 15–21 in our temperature surveys to better characterize the spatial distribution of temperature throughout the full geographic extent where the temperature gradient was known to be significant prior to the study.

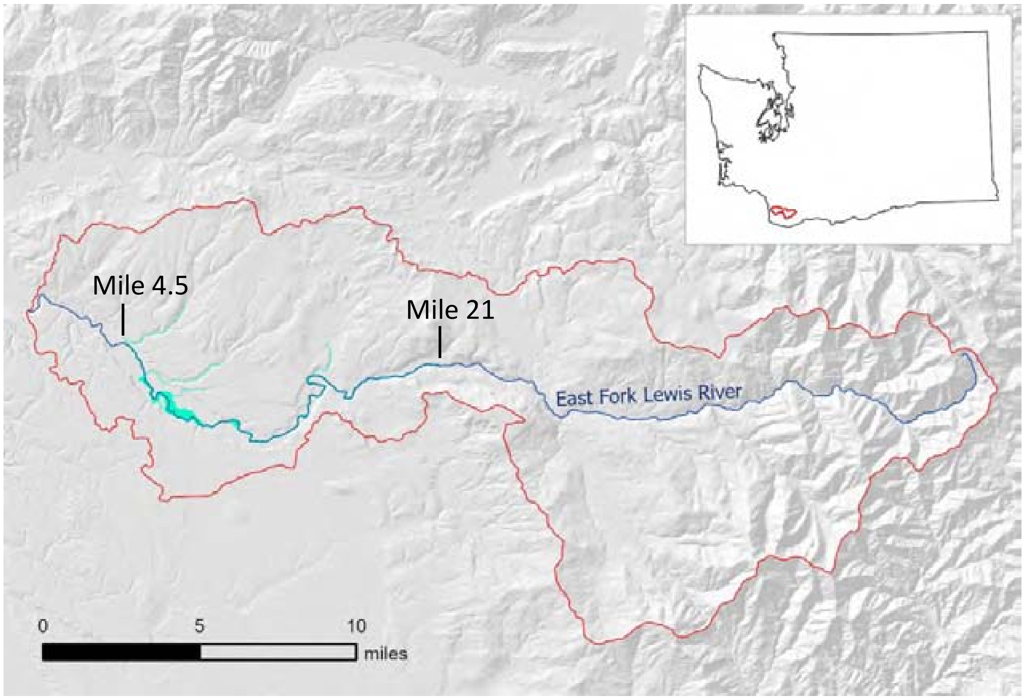


Figure 1. Geographic extent of the EFLR temperature assessment, extending from river mile 4.5 to river mile 21.

1.3 SUPPORTING STUDIES

To better understand the existing thermal characteristics of the lower EFLR and begin to strategize the preservation, enhancement, and creation of cold-water thermal refuge areas to benefit native salmon and trout species we relied on a wide body of existing literature. This includes previous temperature studies focused on the EFLR, general studies of the physical characteristics and natural processes that contribute to the thermal diversity of streams, as well as an emerging body of literature related to restoring and enhancing thermal refuge in streams.

1.3.1 East Fork Lewis River Temperature

Several water temperature and related studies have been completed for the EFLR. We relied on a number of these completed within the past 15 years to help plan the present study and inform our selection of potential thermal refuge project locations. Carey and Bilhimer (2009) examined groundwater and surface water exchange along the EFLR, using seepage surveys, vertical hydraulic gradient measurements, and continuous streambed temperature measurements. These measurements identified gaining and losing reaches of the river where groundwater may be entering or leaving. This information can have significant implications for stream temperature, with gaining reaches possibly having more potential for lower water temperatures due to the cooling effect of groundwater, relative to losing reaches. We attempted to correlate these findings with stream temperature data collected in the present study and applied them as a criterion in its thermal refuge project prioritization process. Potential sites within reaches identified as gaining received a higher score relative to those located in losing reaches.

McCarthy (2018) analyzed stream temperature data collected in 2005 and 2017 at several EFLR locations. Clark County has monitored stream temperatures in EFLR tributaries for the past several years and provided these data for inclusion in this study. LCEP completed a water temperature assessment of the Ridgefield Pits reach of the EFLR (extending from approximately RM 7–10) over three years from 2018–2021 as part of its Ridgefield Pits Project preliminary design (LCEP, 2021). This included water temperature modeling in addition to continuous temperature monitoring.

1.3.2 Physical Temperature-related Stream Processes and Restoring Thermal Refuge

There is an abundance of literature describing the importance of stream temperature, and thermal refuge, to the health of native cold-water aquatic species and ecosystems. Several of these studies, and others, also describe the physical characteristics and natural processes that create thermal refuge and thermal diversity in streams. A growing number of studies have suggested methods for restoring, creating, or enhancing thermal refuge features, with some having documented recent attempts at doing so in various streams. A few of these studies have been particularly useful to our understanding of the thermal characteristics of the EFLR, and for developing the strategy outlined in this report for maximizing thermal refuge opportunities along the lower EFLR. Kurylyk et al. (2015) highlights the need for developing comprehensive thermal refuge management strategies for river systems as reliance on thermal refuge is expected to increase in a warming climate and provides practical recommendations on how these measures can be accomplished based on insight derived from recent research in the Miramichi River, New Brunswick. Bakke et al. (2020) describes a recently implemented approach for restoring hyporheic exchange through streambed engineering. Gorman et al. (2020) also highlights the importance of hyporheic flow contributions to thermal refuge and suggests methods for enhancing this important surface-subsurface connection in a white paper exploring its potential use in the upper Chehalis River Basin. Hester and Gooseff (2010) further highlight the importance of the hyporheic zone and its associated functions and suggest techniques for restoring hyporheic connections in degraded river systems. Excluding the more traditional approach of reducing stream warming through riparian restoration, temperature-oriented restoration is an emerging science, and recent decades have seen a number of related pilot restoration projects, here in the Pacific Northwest and elsewhere. Because stream temperature is closely coupled with natural physical and biogeochemical stream processes, improved temperature performance may be just one of multiple outcomes of such projects aimed at process-based restoration. Bakke, 2020, for example, observed improved temperature, water chemistry, sediment retention, and flood reduction for a project aimed at restoring the hyporheic zone with an engineered streambed. Other projects, such as creation of alcoves or diversion structures to concentrate existing colder surface water, may be more directly aimed at water temperature specifically.

1.4 PROJECT GOALS

The lower EFLR Thermal Assessment included the following goals:

- Measure and map the summertime temperature profile of the lower EFLR, including key tributaries and off-channel areas, and highlight existing cold-water locations.
- Identify strategies for creating, enhancing, restoring, and preserving thermal refuge locations which target adult and juvenile life stages of endangered and threatened salmonid species.
- Identify locations where these strategies can be implemented and prioritize these locations for potential actions based on a set of defined metrics.
- Develop initial concept sketches for the 3-4 highest priority locations.
- Convene a technical oversight group of various stakeholders to provide project guidance including the prioritization of thermal refuge project locations and development of project concepts.
- Revise habitat project recommendations in the HRP where applicable to incorporate thermal refuge information and potential actions identified in this study.

2 Site Conditions

The following sections describe site setting and conditions for the lower EFLR as they relate to water temperature; species affected by elevated summertime water temperatures; and existing and potential opportunities for creating, enhancing, and restoring thermal refuge. More extensive descriptions of East Fork subbasin characteristics can be found in the HRP (LCFRB, 2009), and the Lower Columbia Salmon Recovery and Fish & Wildlife Subbasin Plan (LCFRB, 2010). Much of the information below is taken directly from the Salmon Recovery and Fish & Wildlife Subbasin Plan.

2.1 SITE SETTING

The EFLR has its source in the Cascade Mountains of Washington at approximately 4,300’ elevation and flows westerly approximately 43 miles to its confluence with the mainstem (North Fork) Lewis

River, located near sea level. Lucia Falls, at RM 21.3 (the approximate upstream extent of this study) blocks passage of anadromous fish except steelhead and some coho. Below Lucia Falls, the EFLR flows through a narrow valley and canyon until it widens near RM 14 into a broad alluvial valley. Stream gradient drops dramatically through this reach, causing large sediment aggradations. Below RM 14, the EFLR is characterized by extensive meandering, braiding, and channel shifting, particularly between RM 6 and RM 10 (LCFRB, 2010). Channel shifting has been exacerbated by human activity throughout the last several decades. The lowest 6 miles of the EFLR are very low gradient and experience backwater effects from the Columbia River, located 9 miles downstream (3 miles below the confluence of the EFLR and mainstem Lewis R.) (LCFRB, 2010). The climate of the EFLR watershed is typified by mild, wet winters and warm, dry summers. Although most of the basin is rainfall dominated, much of the upper basin receives abundant snowfall, leading to spring freshet events, and winter flooding in the case of rain on snow events (LCFRB, 2010). Much of the upper basin (above RM 14) is forested and managed as commercial forest. The lower basin is a mix of forested, residential, and agricultural lands. Large fires burned extensive portions of the basin between 1902 and 1952 and have had lasting effects on basin hydrology, sediment transport, soil conditions, and riparian function. Rural residential development and recreational uses in the lower basin have increased significantly in recent years (LCFRB, 2010).

Several small tributaries enter the lower EFLR within the study reach. Those with documented use by anadromous salmonid species and which were part of this assessment include Lockwood Creek, Mason Creek, Dean Creek, and Lower Rock Creek (Figure 2).

Figure 2. EFLR tributaries included as part of the lower EFLR Thermal Assessment. River miles shown as circles.

2.2 HYDROLOGY

The EFLR and its tributaries have a rainfall-dominated hydrograph typical of western Cascades streams. Estimates of average monthly flows for the downstream end of the study area (RM 7.5) are shown in Figure 3. These values were obtained through a basin-area correction of data from the USGS gage at Heisson (RM 20). Monthly flows reflect the climatic setting described above, with highest flows occurring from late fall through spring, and low flows throughout the summer to mid-fall. This pattern is further emphasized in Figure 4, which shows daily mean flows recorded at Heisson over the period of record beginning in 1929 to 2010. These data highlight the extreme low flow occurrences in the 30–60 cfs range which are not uncommon during summer and early to mid-fall.

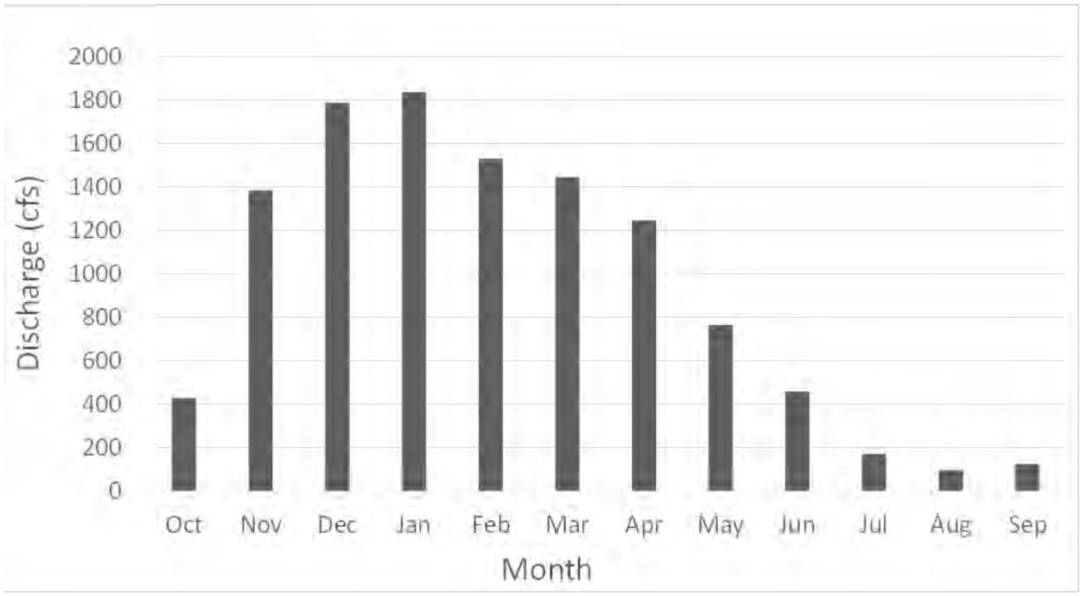
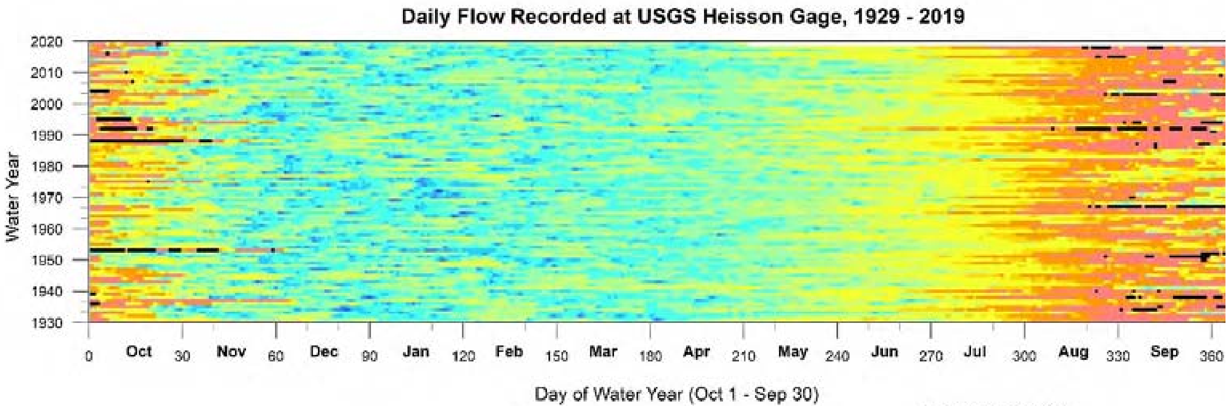


Figure 3. Estimate of monthly average flows for the EFLR, calculated using a basin-area correction on data from the USGS gage at Heisson (RM 20) for the past 30 ears. Plot taken from LCEP (2021).



Total days	# of days w/ daily flow between:				% of total days w/ daily flow between:			
	30–35	35–40	40–60	60–100	30–35	35–40	40–60	60–100
32,718	33	280	2,703	4,004	0.1%	0.9%	8.3%	12.2%

Daily Flow (cfs)

■	30 – 40	■	500 – 1,000
■	40 – 60	■	1,000 – 2,500
■	60 – 80	■	2,500 – 5,000
■	80 – 100	■	5,000 – 1,000
■	100 – 250	■	10,000 – 15,000
■	250 – 500	■	15,000 – 21,000

Figure 4. EFLR average daily flows (in cfs) recorded at USGS Heisson gage from 1929–2019, including low-flow statistics.

Low summer flows are of concern from the perspective of water temperature as lower volumes have the potential for increased atmospheric heating. Water withdrawals for agricultural, industrial, and residential use can further exacerbate the situation. Total water use was previously estimated to increase from 10% (2000) to 20% (by 2020) of late summer flow volume based on earlier predictions of population growth. The watershed is near closure for surface water rights, and for some existing surface water rights low-flow restrictions are in place to protect aquatic biota (LCFRB, 2010).

2.3 RIPARIAN FUNCTION AND LARGE WOOD RECRUITMENT

Riparian conditions along the entire EFLR have been heavily impacted by residential, agricultural, and mining development, as well as historic fires and timber harvesting. Impacts are most substantial in the lower portion of the basin, particularly below RM 10. The majority of the mainstem has lost substantial portions of riparian forest, and tributaries also have poor conditions. Out of 36 sub-watersheds in the basin, only 4, located in headwater locations, were rated as functional in a prior assessment (LCFRB, 2010). Large wood recruitment potential is limited in the basin due to past forest fire impacts and harvest of riparian areas. A prior assessment by the U.S. Forest Service (USFS) in 1995 showed that 87% of riparian stands in the upper basin had either young, sparse hardwood stands or were burned in the early part of the century and now contain mature, dense hardwoods, and as a result have low to moderate potential for LWD recruitment. USFS stream surveys in the basin during the 1990s found that 92% of surveyed streams had poor recruitment ratings (< 40 pcs. per stream mile) (LCFRB, 2010).

2.4 FLOODPLAIN FUNCTION

The lower EFLR flows through a broad alluvial valley that was historically well connected to the river and consisted nearly entirely of wetlands. The river itself was largely an anabranching system between RM 7 and 10, with upstream and downstream areas transitioning to a meandering, sinuous, stream type (LCEP, 2021a; LCFRB, 2010). Impacts to the valley bottom were already well underway prior to the first aerial photos in 1939. The 1939 aerials show farms and residences throughout the valley bottom, although the valley bottom, including in the project area, was considerably more vegetated than today. Various episodes of instream and floodplain gravel mining can be seen throughout the lower river in the aerial photos, with mining occurring at least as early as the 1930s and continuing today (LCEP, 2021a). With the progression of time and increasing human impacts, the river gradually became more single-threaded, more incised, less complex, and less connected to its floodplain and channel migration zone. Aquatic habitat has suffered accordingly (LCEP, 2021).

2.5 WATER TEMPERATURE

Elevated water temperatures during summer and early fall are of primary concern to salmon recovery efforts in the lower EFLR basin. Juvenile salmon and steelhead use both the mainstem and its tributaries as critical rearing habitat during summer months, and thus are exposed to temperatures that commonly exceed critical thresholds for salmonid health. Stream temperatures in the lower EFLR mainstem commonly exceed the 16° C (60.8° F) Washington State standard for salmonid habitat (WAC 173-201A-200 core summer salmonid habitat temperature criterion), and occasionally exceed 23°C (73.4°F) downstream of Lewisville Park (~RM 14). Temperatures above 22° C are considered lethal to some species of salmon and trout (LCFRB 2009). McCarthy (2018) provides temperature monitoring results from 2005 at several locations along the EFLR mainstem and its tributaries. Clark County has also monitored mainstem and tributary temperatures for several years, and that data, for the lower EFLR, has been incorporated into this study.

The temperature profile of the EFLR is a result of combined natural physical factors and human impacts on the watershed described in Sections 2.1–2.4 above. Warm, dry summers in the Pacific Northwest result in naturally occurring low flows during the summer and early fall (Fig. 4). The combination of reduced water volumes and increased daytime solar radiation lead to increased heating of the river in the daytime during this period. This is further exacerbated by human impacts, including: 1) removal of trees and other shade-producing vegetation from streams and stream banks; 2) reduction of already low summertime stream flows due to water withdrawals; 3) channel modifications and widening that increase stream surface exposed to solar radiation; 4) loss of floodplain and hyporheic (sub-surface) connectivity due to development, channel simplification, channel incision, and reduced large wood recruitment; and 5) discharges of warm water from point sources, such as residential ponds adjacent to tributary reaches (LCFRB 2009, WADOE 2021). Human impacts are expected to further degrade stream temperatures in the future, with increased development pressures on river flows and effects of climate change.

The EFLR and its tributaries are subject to large diurnal variations in atmospheric heating and cooling during the summer months, which are closely coupled to resulting stream temperatures during this low flow period. A typical temperature profile is illustrated in the hourly water temperature data shown in Figure 5 that was recorded at RM 12 of the EFLR as part of this study.

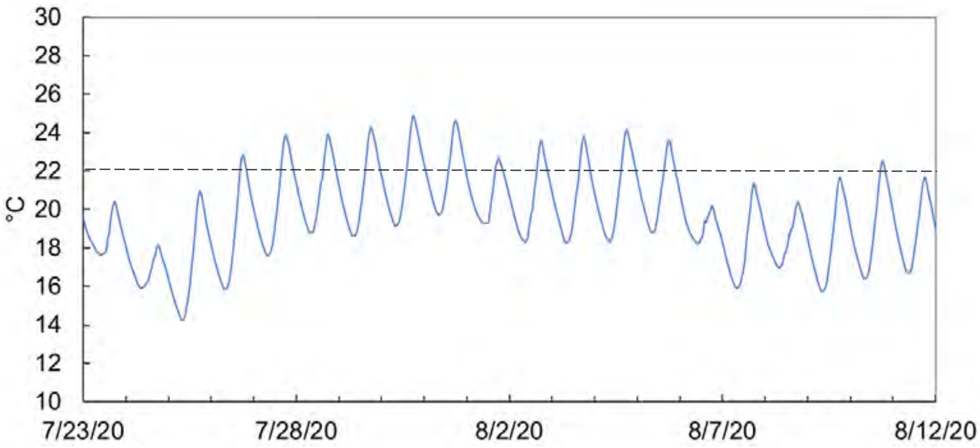


Figure 5. EFLR hourly temperature recorded at RM12 during summer 2020 as part of this study. Temperatures exceeding 22°C (indicated by the dotted line), are widely considered lethal to salmon and trout species for extended exposure times.

These data show that while the WA State standard of 16°C for acceptable summer salmon habitat is exceeded for long portions of the summer, temperatures also remain below critical thresholds for survival (shown here as 22°C) for most of the time, exceeding these limits only during late afternoons and early evenings. Water temperatures published by Washington Department of Ecology and other agencies are often reported as daily maximums, or 7-day average daily maximums, and thus do not reflect the true length of time during which fish are exposed to harmful and non-harmful stream temperatures. Because times of exposure to lethal temperatures are relatively short, fish may be able to seek out thermal refuge zones during these periods, given the opportunity, thereby reducing stress levels.

An additional consideration is that much of the mainstem heating occurs upstream, and as a result water temperature already exceeds regulatory levels when flow reaches the lower EFLR. This was observed by McCarthy (2018), and in the present study as well as discussed below. Because practical restoration efforts are unlikely to reduce mainstem temperatures, creation, enhancement, and protection of thermal refuge areas throughout the reach, as addressed in this study, are likely to be the most effective techniques for protecting salmon from harmful water temperatures in the lower EFLR.

2.6 SALMONID USE

Because elevated water temperatures in the lower EFLR are typically limited to summer and early fall, focal salmon species whose life history strategies place them in the river system during this period are the primary ones that could be expected to benefit from thermal refuge. These include adult and juvenile coho, Chinook, and summer steelhead, and juvenile winter steelhead. Both coho and steelhead are stream-type species whose juvenile populations rear in freshwater for more than one year, subjecting them to elevated water temperatures. Migration periods for adult coho and summer steelhead also include summer and early fall months. With a migration period typically extending from August through November (LCFRB 2010), early migrating adult Fall Chinook salmon could also potentially benefit from thermal refuge in the lower EFLR.

3 Methods

The following sections describe methods employed for each phase of the project, including monitoring methods to characterize summertime water temperatures in the lower EFLR and its tributaries; a limited assessment of landscape-scale mainstem riparian conditions; selection of existing and potential thermal refuge sites; and prioritization of selected sites for project development.

3.1 WATER TEMPERATURE MONITORING

We monitored water temperature in the mainstem, side channels, and off-channel areas throughout the lower EFLR to characterize temperature patterns and identify existing cold-water locations. The study employed three methods for monitoring water temperature: 1) high resolution thermal-infrared (TIR) airborne remote sensing of surface water temperature throughout the reach; 2) in-stream, instantaneous measurements using handheld instruments; and 3) in-stream continuous records using deployed temperature loggers. We also compiled all previous continuous records that we could find from prior LCEP and Clark County monitoring studies, to provide an additional water temperature data resource for the lower EFLR. All measurements taken as part of this study were completed during the summers of 2020–2022.

3.1.1 Thermal Infrared (TIR) Airborne Water Temperature Remote Sensing

Remote measurements of surface water temperature can be made with a sensor that detects thermal radiation (3–5 and 8–14 μm wavelengths). By placing such a sensor on an aircraft, a spatially continuous temperature profile can be obtained for a large area in a short amount of time, thereby minimizing measurement bias due to diurnal atmospheric heating and cooling of the water column that occurs throughout a summer day. This technique then provides a roughly instantaneous snapshot of temperature across the coverage area, making it effective for assessing spatial heterogeneity of stream temperature at multiple scales, which would be impractical using in-stream methods.

LCEP contracted NV5 Geospatial (formerly Quantum Spatial) to acquire and process TIR imagery of the lower EFLR, its floodplain, and four of the study area tributaries: Lockwood Creek, Dean Creek, Mason Creek, and Lower Rock Creek. The objectives of this assessment were to characterize the spatial heterogeneity of water temperature throughout the entire reach, including identification of patterns of heating and cooling along the lower EFLR mainstem (and attempts to correlate these patterns with gaining and losing reaches identified in Carey and Bilhimer (2009)); as well as to identify cold-water locations which may be important thermal refuge areas. Use of in-stream monitoring methods to accomplish this over the full 16.5-mile length of the study reach would not be practical. A complete description of the detailed methodology employed for the TIR survey (and a limited analysis of the results presented by the sub-contractor), is included as Attachment 1 of this report.

3.1.2 In-stream Handheld Water Temperature Measurements

In-stream measurements of water temperature by field staff using handheld digital YSI measurement devices served two purposes: 1) confirmation/validation of the TIR airborne water temperature results; and 2) additional temperature assessment for areas not covered by the TIR survey or areas where the TIR survey failed to collect data due to complications from existing topography or heavy canopy presence. We specifically targeted locations where the TIR imagery indicated a presence of cold water, as well as sections of the mainstem where significant temperature trends (increasing or decreasing) were indicated. For these locations we created a high-density grid of survey points and measured temperature at each point, recording temperatures of interest. For all locations surveyed using handheld equipment, we took readings throughout the water column. This provided more information relative to the TIR survey, which provides information on surface temperatures only. Field staff also recorded physical habitat conditions at potential thermal refuge locations of interest.

3.1.3 In-stream Continuous Water Temperature Time Series

In-stream continuous water temperature time series were obtained primarily for the purpose of ground control to radiometrically calibrate the TIR measurements. This data is used during post processing of the raw thermal image data to obtain accurate, absolute temperature readings that are consistent with actual water temperatures (as recorded by the data loggers). More detail on the calibration process can be found in Attachment 1. A total of eight Onset Hobo U20L data loggers were deployed along the lower EFLR mainstem, with an additional two placed in Mason and Rock creeks. The resulting spatial interval between loggers was within the maximum distance recommended by the NV5 Geospatial data acquisition team. Recording time interval was set at 5 minutes, to ensure proper overlap with timing of the flight data acquisition. Logged data was only required for the duration of the TIR airborne flight, however field logistics resulted in some loggers deployed for a week or more from mid-July through mid-August of 2020.

In addition to the data recorded as part of this project, we compiled all previous LCEP water temperature records collected for the lower EFLR, as well as some recent data collected by Clark County, into an online map of monitoring locations and associated temperature data plots. This publicly accessible tool can be used to examine summertime water temperature characteristics of the lower EFLR. The map will continue to be updated in the future as more historic data is located or future data is acquired. A summary of the currently included data is provided in Table 1. Much of this data was collected by LCEP as part of restoration project design efforts at various sites within the lower EFLR.

Table 1. Continuous water temperature monitoring data compiled as part of this study.

Monitoring Org.	Project/Study	Acquisition Years	Locations
LCEP	Dyer Creek Project Design	2021	Dyer Cr. floodplain wetland and lower EFLR RM 6–7
LCEP	Mason Creek Project Design	2021	Mason Cr. floodplain wetland
LCEP	EFLR Thermal Assessment	2020	Lower EFLR mainstem, RM 5.5 – 21
LCEP	Ridgefield Pits Project Design	2018	Lower EFLR mainstem, RM 7–9
Clark County	ELFR Tributary Sampling	2019, 2020	Lower EFLR tributaries.

3.2 THERMAL REFUGE STRATEGY AND SITE SELECTION

We identified general strategies for creating, protecting, and enhancing thermal refuge opportunities for salmonids in the lower EFLR based on the temperature results obtained from this and previous studies, land use/landcover information, and land ownership. Kurylyk et al. (2015) describes several thermal refuge concepts which they identified in the context of a comprehensive thermal refuge management strategy for the Miramichi River in New Brunswick. We have applied these same concepts here for the lower EFLR. Riparian planting is evaluated at two different scales: a) localized as part of an enhancement strategy; and b) landscape-scale reforestation. These can serve different purposes, and thus are discussed separately here.

3.2.1 Thermal Refuge Enhancement

A thermal restoration enhancement strategy includes actions to expand existing cold-water locations and/or improve habitat conditions in existing locations to make them more suitable and/or accessible for salmonid use. Examples include controlling advective thermal mixing between cold-water tributaries and the river mainstem, localized riparian revegetation, addition of habitat structures (large wood) to provide cover from predators, floodplain/channel re-grading to increase fish access and/or spatial area, and grading to enhance hyporheic or groundwater connectivity. Reaches of the lower EFLR where existing side and off-channel cold-water locations are concentrated are most likely to benefit from an enhancement strategy, as well as other isolated locations where fish access exists. Enhancement actions would also likely provide significant benefit throughout the four tributaries included in this study.

3.2.2 Thermal Refuge Creation

A thermal restoration creation strategy includes actions to create cold-water locations. Examples could include groundwater augmentation, as well as restoration of hyporheic processes, as described in Bakke et al. (2020) for a project that was recently implemented in an urban stream in Washington. Reaches of the lower EFLR with known groundwater inputs, such as the gaining reaches identified by WDOE, as well as reaches with large concentrations of active side channels (where hyporheic connections may be able to be restored) may offer good potential for implementing a creation strategy.

3.2.3 Thermal Refuge Protection

Existing cold-water locations that could provide thermal refuge benefits and are not currently located within existing public land should be prioritized for protection. This protection should be extended to locations which possess sources, such as tributaries and groundwater inputs, that provide cold water to these sites. Enhancement and creation opportunities may also exist at locations to be prioritized for protection and should also be considered.

3.2.4 Thermal Refuge Site Selection

Confirmed cold-water locations obtained from monitoring in this and previous studies, in combination with additional supporting information, were used to identify potential thermal refuge project sites based on the strategies outlined above. In developing this initial list, we focused on ecological benefits only of potential thermal refuge enhancement and creation projects. We did not consider social constraints such as property ownership and construction access at this time, as we did not want to omit potential areas based on these factors, which could change in the future. Social constraints were applied later in the site prioritization process. Table 2 lists supporting data used to help select potential thermal refuge sites, in combination with the creation and enhancement strategies presented above. We also sought guidance from members of the Technical Oversight Group as an additional means of selecting potential sites. Group members were selected based on the unique perspectives of this reach of the river that each possess, and as a result they were able to offer additional insight on potential project locations that was not readily obtainable from the available data.

Table 2. Supporting information used to help locate potential thermal refuge projects along the lower EFLR and floodplain.

Source	Application
Thermal IR (TIR) Imagery	Identify longitudinal temperature trends in the mainstem, and isolated side/off-channel cold-water locations. Mainstem reaches exhibiting decreasing or stabilizing temperatures in the downstream direction may indicate favorable locations for fish to congregate, and thus could serve as focal areas for implementing thermal refuge projects.
Identified Cold Water Locations	Prioritize enhancement projects at these locations that increase spatial extent, habitat quality, and/or access for salmonids.
Lidar	Identify low elevation side/off-channel areas, especially adjacent to steep slope breaks where hyporheic zone activation or groundwater augmentation may be possible. Evaluate geomorphic stability of potential site locations. Evaluate canopy height and density.
Historical Imagery	Evaluate geomorphic stability of potential locations and other habitat quality indicators.
Lower East Fork Lewis Habitat Restoration Plan (HRP)	We evaluated the thermal refuge potential for all sites identified in the HRP. Some of the sites included recommended thermal actions, while others did not but appear to have potential. Both of these groups are prioritized in this plan.
Clark County Legacy Lands existing and targeted acquisition areas	Evaluate where existing thermal refuge opportunities are currently protected and should be protected; prioritize thermal refuge enhancement and creation projects on public lands.

3.3 LANDSCAPE-SCALE MAINSTEM RIPARIAN ASSESSMENT

We performed a limited, qualitative assessment of riparian conditions along the lower EFLR mainstem to estimate the potential for landscape-scale riparian restoration along the mainstem to serve as an effective thermal strategy within the reach. This consisted of a literature review to better understand the complex relationship between riparian shading and stream temperature for different types of river systems, and a cursory GIS assessment of existing and potential effective shading within the reach. The analysis was considered separately from the strategies identified above due to the relative effectiveness of shading along a mainstem river such as the EFLR versus localized shading of a side-channel or off-channel location. While it seems likely that an isolated location disconnected from the mainstem would directly benefit from shading, it is unclear to what extent temperatures along the mainstem EFLR would be impacted by riparian restoration at varying spatial scales. As is frequently noted in the wide body of related literature, properly functioning riparian zones can benefit stream quality, including stream temperature, in several ways beside the direct benefit of reducing solar radiation. Because our analysis was limited relative to the overall scope of this study, we focused on the direct benefit of providing shade only and did not consider potential benefits of these indirect effects.

3.4 THERMAL REFUGE SITE PRIORITIZATION

With guidance from a technical oversight group (TOG) (see Section 3.5 below) we developed a prioritization scheme specific to this study to rank the identified potential thermal refuge projects based on various ecological and social criteria that we defined. Separate ecological and social scores were calculated. Ecological scores were the primary basis for ranking sites however the social scores are an important indicator of the likelihood of implementation for a given site. Scoring criteria, including assigned weights and score possibilities for each metric are shown in Table 3. The sites that were then chosen for initial concept design were then selected based on combined ecological and social scores, and additional guidance from the TOG.

Table 3. Prioritization scheme used to rank potential locations identified for thermal refuge creation and enhancement projects.

Project Criteria	Criteria Weighting	Factors considered in scoring	Assigned Scores
Ecological			
Cold-water source	1	Quality/reliability of cooling source.	Tributary: 4 Groundwater: 3 Other: 2 Shade: 1
Size of cold-water area	1	Spatial area of cold water.	Large: 3 Medium: 2 Small: 1
Stepping-stone/connectivity	0.5	Spatial distance to nearest thermal refuge.	> 1 mile: 4 0.5–1 mile: 3 0.25–0.5 mile: 2 < 0.25 mile: 1
Mainstem proximity	1	Ease of access for fish from mainstem.	On: 4 0–200': 3 200–300': 2 > 300': 1
Surrounding habitat quality	0.4	General habitat suitability for fish use.	Good: 3 Fair: 2 Poor: 1
Consistent with physical processes	0.7	Site conditions and proposed treatments match geomorphic setting.	High: 2 Med.: 1 Low: 0
Dept. of Ecology identified reach type	0.4	Potential groundwater connectivity.	Gaining: 2 Losing: 1
HRP priority	0.5	Site habitat potential.	High (110–140): 3 Medium (75–110): 2 Low: (45–75): 1 Not included: 0
Treatment strategy	1	Reliability of thermal restoration strategy.	Enhance: 2 Create new: 1
Riparian uplift potential	0.3	Opportunity for increased riparian benefits.	High: 3 Medium: 2 Low: 1
Social			
Land ownership	1	Benefits of public vs. private land ownership.	Public: 2 Potential Public: 1 Private: 0
Construction access	0.5	Ease of access to site.	Road: 1 Road/River: 0
Existing project inclusion	1	Is this concept already being developed as part of an existing or planned project?	No: 1 Yes: 0
Partner support	0.5	Benefits of broad community support.	Yes: 1 No/unknown: 0

3.5 TECHNICAL OVERSIGHT GROUP

The Technical Oversight Group (TOG) was convened to engage local East Fork Lewis River stakeholders and experts in the thermal assessment process. Four meetings were held between October 2021 and June 2022. The TOG reviewed data collection results and provided input on existing conditions, potential thermal sites, and protection and enhancement opportunities. The TOG provided input on the site prioritization process, the final selection of restorations sites, and the concept alternatives presented for the selected sites. This input was invaluable and compiled expertise and knowledge from a wide variety of agencies, organizations, and professional backgrounds. The TOG represented organizations and members are listed in Table 4.

Table 4: Thermal Oversight Group membership

Agency/Organization	Area of Expertise	Name
Clark County	Legacy Lands/ public Lands management	Kevin Tyler
Clark County	Water quality	Jeff Schnabel
Clark County	Riparian enhancement	Blaine Kisler, Julie Christian
Lower Columbia Fish Enhancement Group	Fish habitat enhancement	Brice Crayne
Lower Columbia Fish Recovery Board	Habitat enhancement funding	Steve West
Washington Dept. of Ecology	Water quality	Devan Rostorfer
Washington Dept. Fish and Wildlife	Fish habitat enhancement	Alex Uber

4 Results

4.1 WATER TEMPERATURE MONITORING

4.1.1 Thermal Infrared (TIR) Airborne Water Temperature Remote Sensing

A complete technical report detailing the acquisition, processing, and results of the TIR imagery was generated by NV5 Geospatial (the data subcontractor) and is included as Attachment 1 of this report. The report was generated prior to our field verification of the results, during which some discrepancies between the TIR data and the field verification data became apparent. The following discussion highlights some of the major findings relevant to thermal refuge in the lower EFLR and discusses discrepancies in TIR results that we noted in our field verification. These discrepancies were commonly of two types: 1) false cold-water detections recorded by the TIR sensor in locations where steep topography and/or canopy cover blocked a direct line of sight between the sensor and the presumed water surface (in many cases these cold detections occurred in areas where no water existed, and thus the sensor was likely detecting cold air at the ground, or other surface); and 2) longitudinal trends in the mainstem EFLR temperature indicated in the TIR imagery that field measurements did not reproduce.

<u>Survey Extent</u>

Extent of coverage for the TIR survey, which extended from RM 4–25 of the lower EFLR, is shown in Figure 6. The coverage extended four miles above the upstream extent of the thermal study, due to additional time being available after the target coverage area was completed. Figure 6 also shows locations where in-stream loggers were placed for use in calibration during post processing.

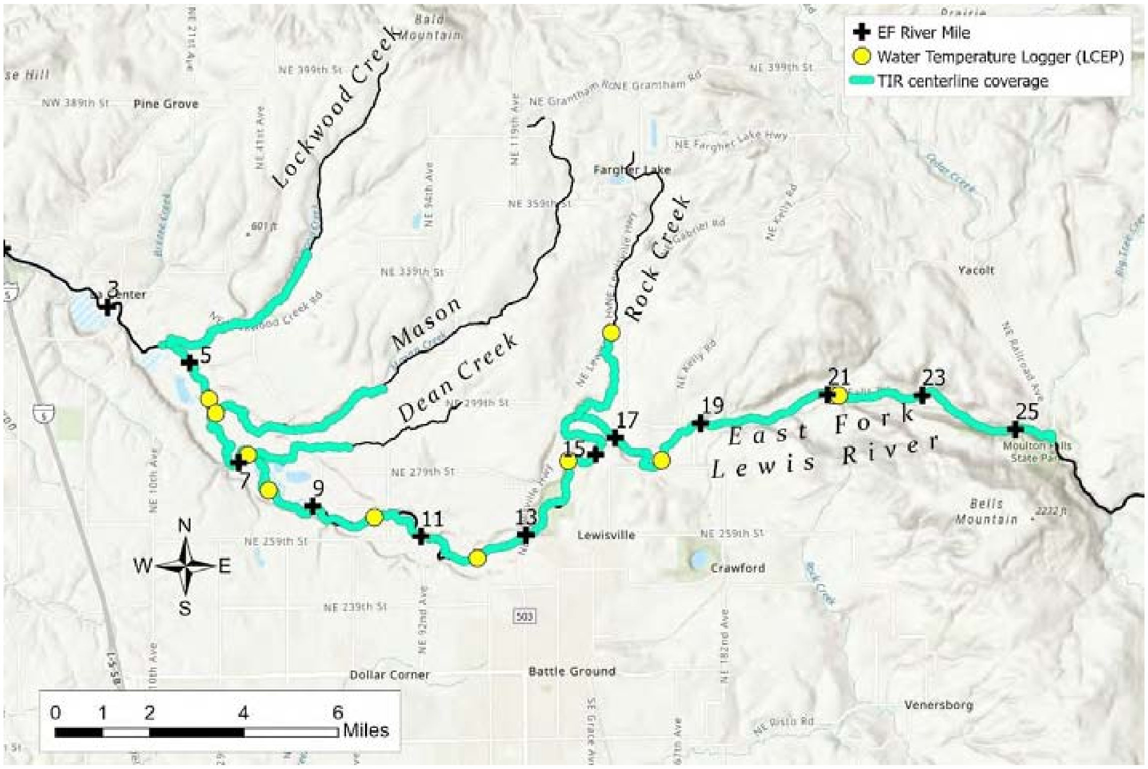


Figure 6. Extent of coverage (shown as blue area) for the TIR airborne survey, including the lower EFLR from RM 4–25 and four primary tributaries. Locations of installed data loggers used for image calibration are also shown.

Results Interpretation – False Positives and Field Verification

Figure 7 shows an example of the processed raster TIR imagery at a location near RM 16 of the lower EFLR, just downstream of the confluence with Lower Rock Creek. This snapshot illustrates the types of discrepancies we discovered in the data after completing our field verification of the results, which are described below. It should be noted that all field verification occurred in the summer of 2021, approximately one year after the data was acquired in August of 2020. Delivery of the data did not happen until fall of 2020, and thus it was not possible to field verify the results during the same summer that the data was acquired. We presume that environmental conditions during the two summers were similar enough to justify the conclusions that we arrived at, based on a comparison of EFLR flows and temperatures for the two different monitoring periods.

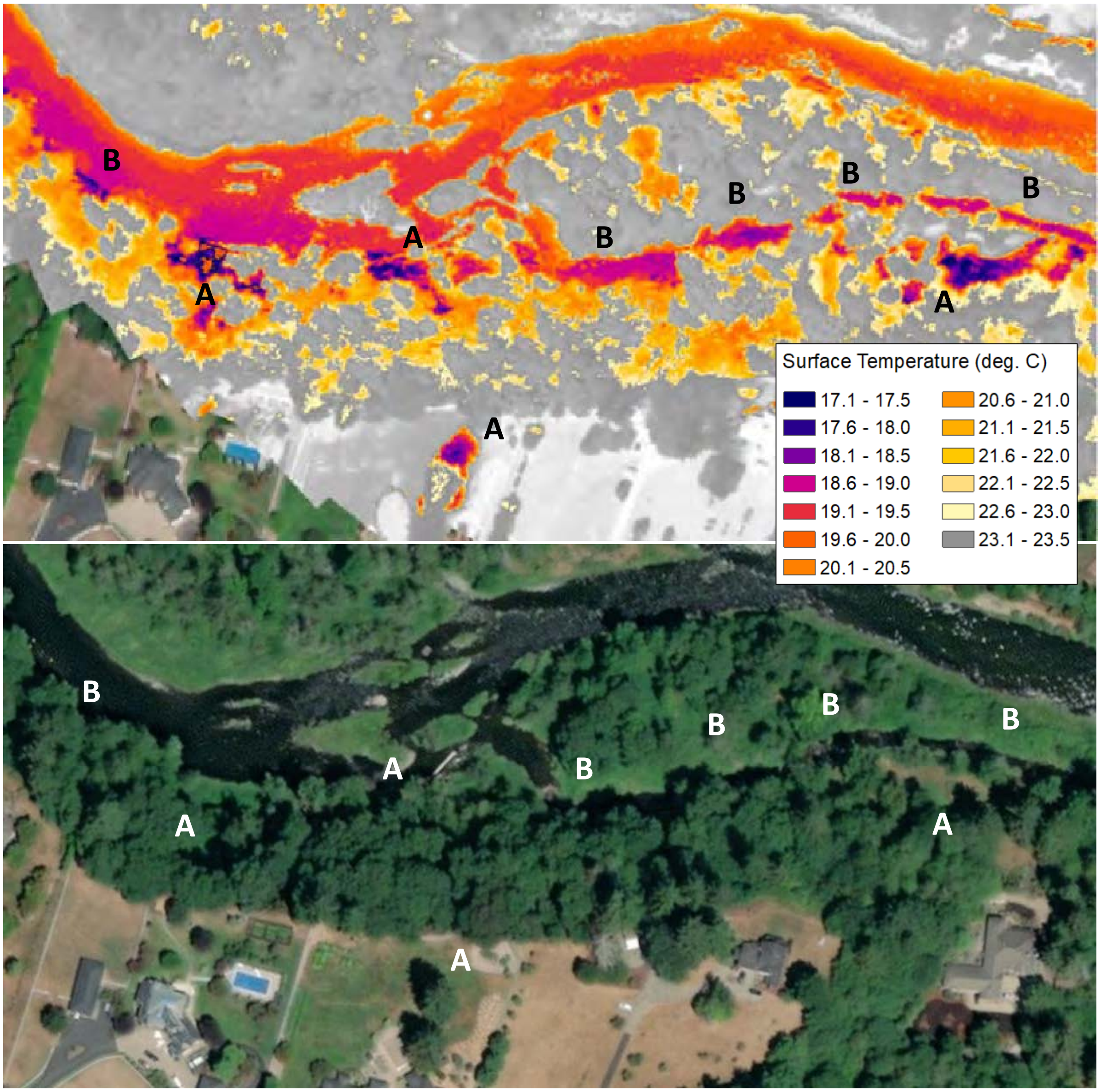
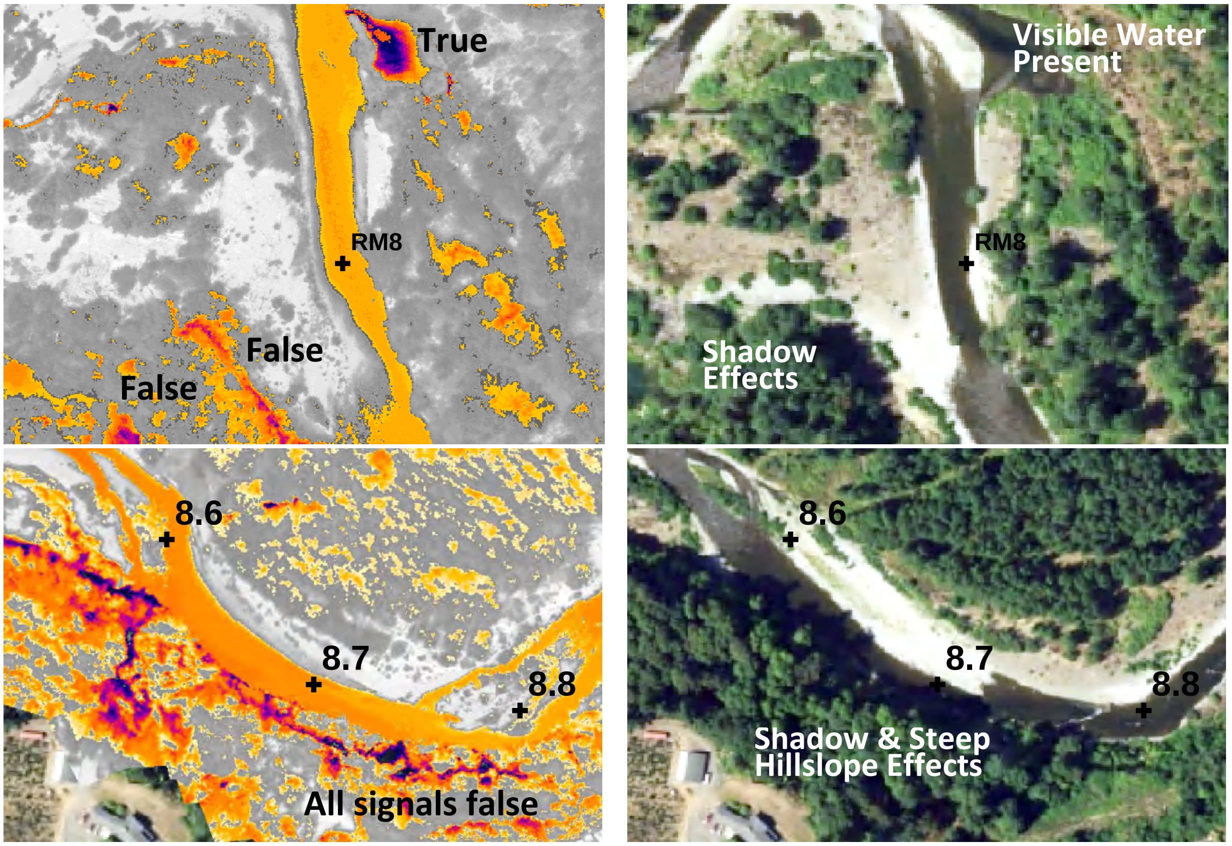


Figure 7. Top: Processed raster TIR imagery for a sample location near lower EFLR RM16 just below the confluence with Lower Rock Cr. Areas labeled 'A' are cold-indicated areas but have an obvious lack of water after inspection of visible RGB imagery. These are false positives due to shadows or other effects, and cold water was likely not present. Areas labeled 'B' are areas obscured by shadows in the visible RGB imagery. These could be true cold-water areas or false positives due to shading or other effects. Field verification is needed to verify. Bottom: Visible RGB airborne imagery used as reference for identifying shaded or otherwise obscured areas for field verification.

Examination of the TIR imagery in Figure 7 (top) reveals some temperature variation in the mainstem EFLR, which is somewhat visually exaggerated due to the discrete (rather than continuous) temperature symbology being applied which results in sharp color variations between adjacent temperature ranges. Another obvious characteristic of the image is the indicated presence of several colder off-channel areas, some well disconnected from the mainstem. These areas were prevalent throughout the full extent of the imagery, and many became suspect after examining corresponding RGB visible imagery (Fig. 7 (bottom)). Some areas (labeled 'A' in Fig. 7) showed an obvious lack of water in the visible imagery and could be immediately ruled out as cold-water locations. Others (labeled 'B' in Fig. 7) were obscured by the presence of shadows from adjacent vegetation, making it difficult to discern underlying water from dry ground. Determination of which of these signals were due to true cold-water locations and eliminating false positives due to other factors became a primary focus of the field verification effort in summer of 2021. After sampling temperature at a number of these locations during field verification, we determined that many surveyed locations throughout the imagery were indeed false positives, due to either shading effects, steep north-facing topographic features, or a combination of both. Figure 8 shows some examples of what was found during field verification, and how the RGB visible imagery can be used as an aide in separating actual cold-water areas from false positive signals. It should be noted that in order to use visible imagery as a reference for separating true cold-water locations from false positives, an image from an appropriate time period should be selected. Images taken during non-summer, or otherwise higher flow periods may show considerably different water conditions from what existed during the summertime, base flow period when the TIR imagery was acquired.



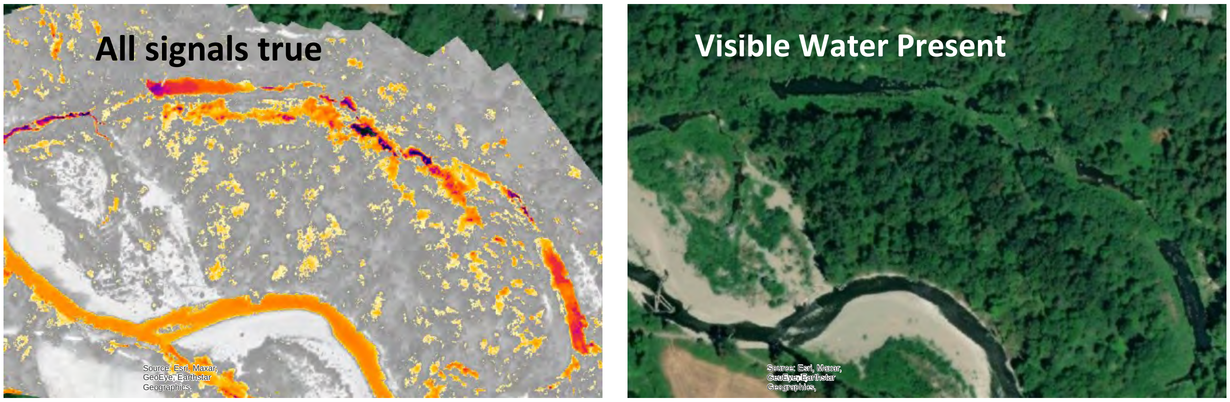
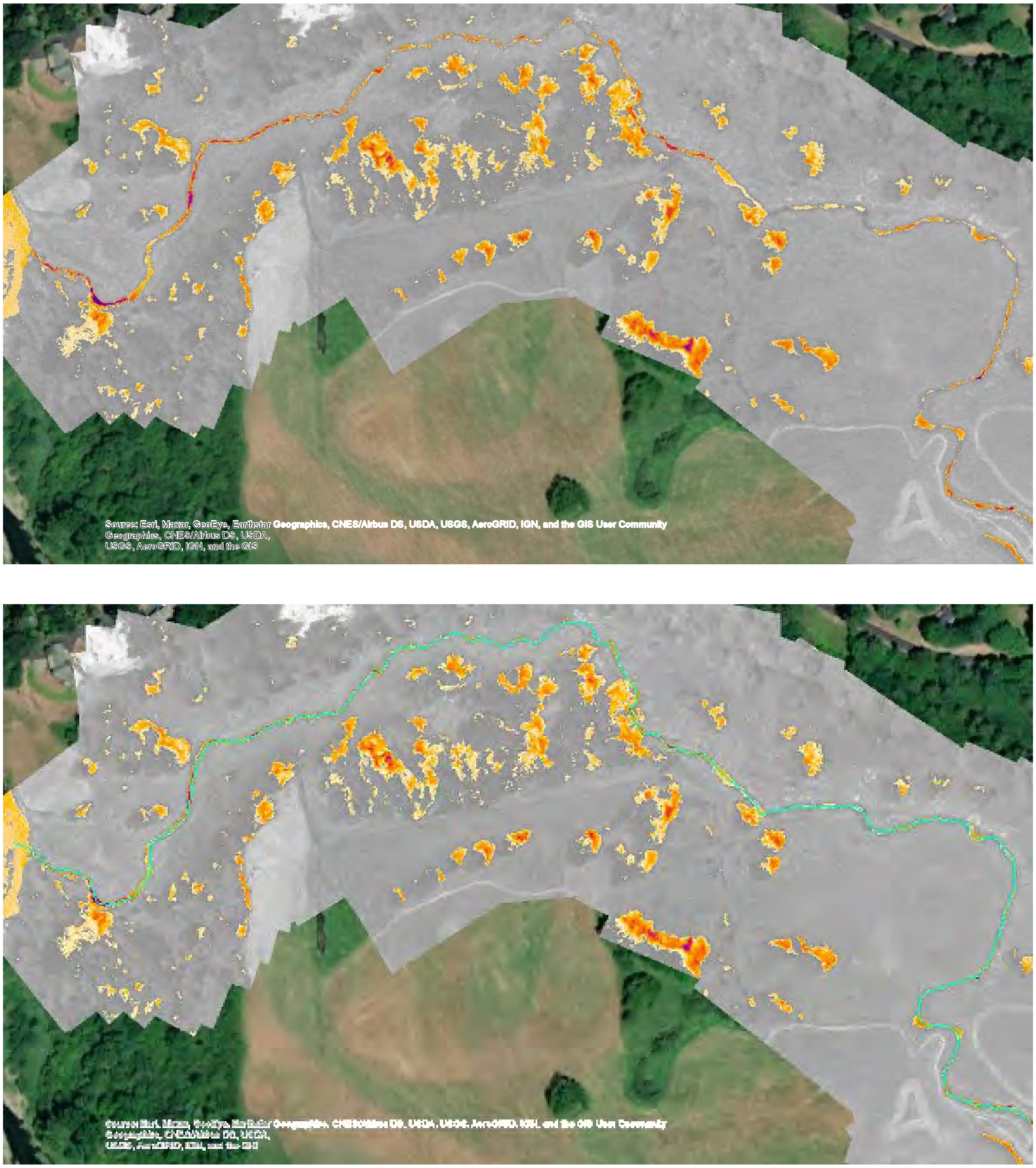


Figure 8. Example locations where TIR results were field verified, with results indicated. Top: True and false positive locations near EFLR RM 8 above Ridgefield Pits; Middle: Extended series of false positive signals near RM 8.7, which resulted from a combination of tree and steep hillslope shading (no actual water was found to be present in these locations); Bottom: confirmed series of true cold-water locations near RM 10.5 just above the Daybreak Park and bridge.

TIR results for the tributaries that were surveyed generally included several false positive signals due to shading and hillslope effects, however with the aid of GIS stream lines it is possible to discern actual cold-water locations in the tributaries from these false features. These effects were most pronounced where canopy cover was heaviest or in confined canyon areas, both of which are more prevalent outside of the floodplain. The floodplain areas showed mixed results – for Mason Creek, which is largely devoid of canopy cover, the cold-water signal is easier to discern from false signals relative to Lockwood Creek, which has considerable canopy in the floodplain. Property access did not allow for field verification of most tributaries, and thus the TIR data generated for these areas should be used with caution. TIR results along lower Mason and Lockwood Creeks are shown in Figures 9 and 10 respectively. Stream lines are included for reference as the shading effects evident throughout the imagery can obscure the true stream location. The effect of shading is quite evident when comparing the two locations, with the cold water of Mason Creek standing out against the open floodplain areas, while along the more vegetated Lockwood Creek floodplain false positive signals from shading are more prevalent. Figure 11 shows the TIR results along a reach of upper Lockwood Creek upstream of the floodplain. Here the shading effects are even more pronounced, making it even more difficult to discern the true stream signal without the aid of the GIS stream line.



Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Figure 9. TIR results along lower Mason Creek. Due to the lack of canopy, TIR sensor was effective in detecting the true cold-water signature of this stream. False positives are present in treed areas but easy to discern from the obvious stream signature even without the aid of the GIS streamline (included in bottom image for reference).

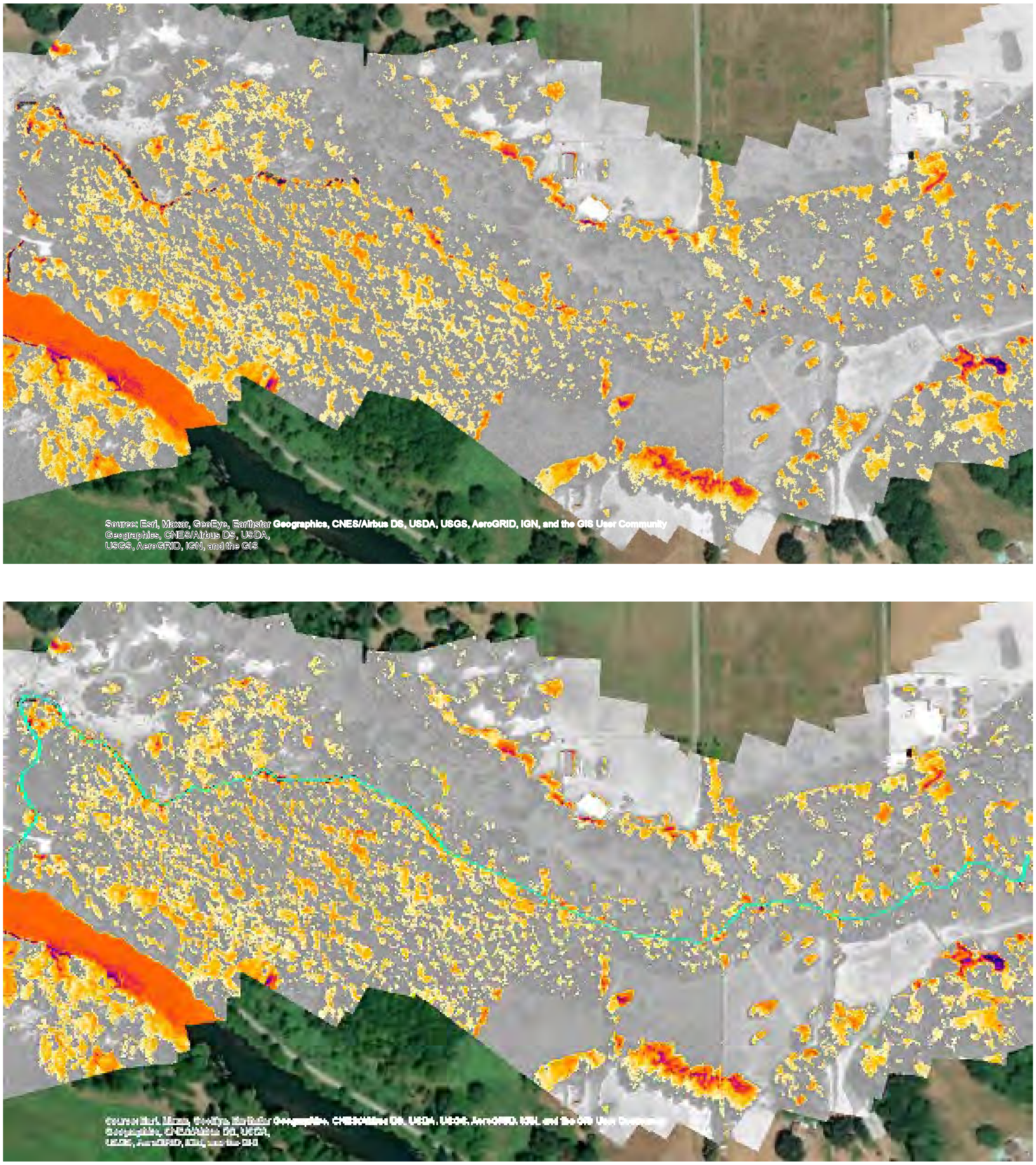
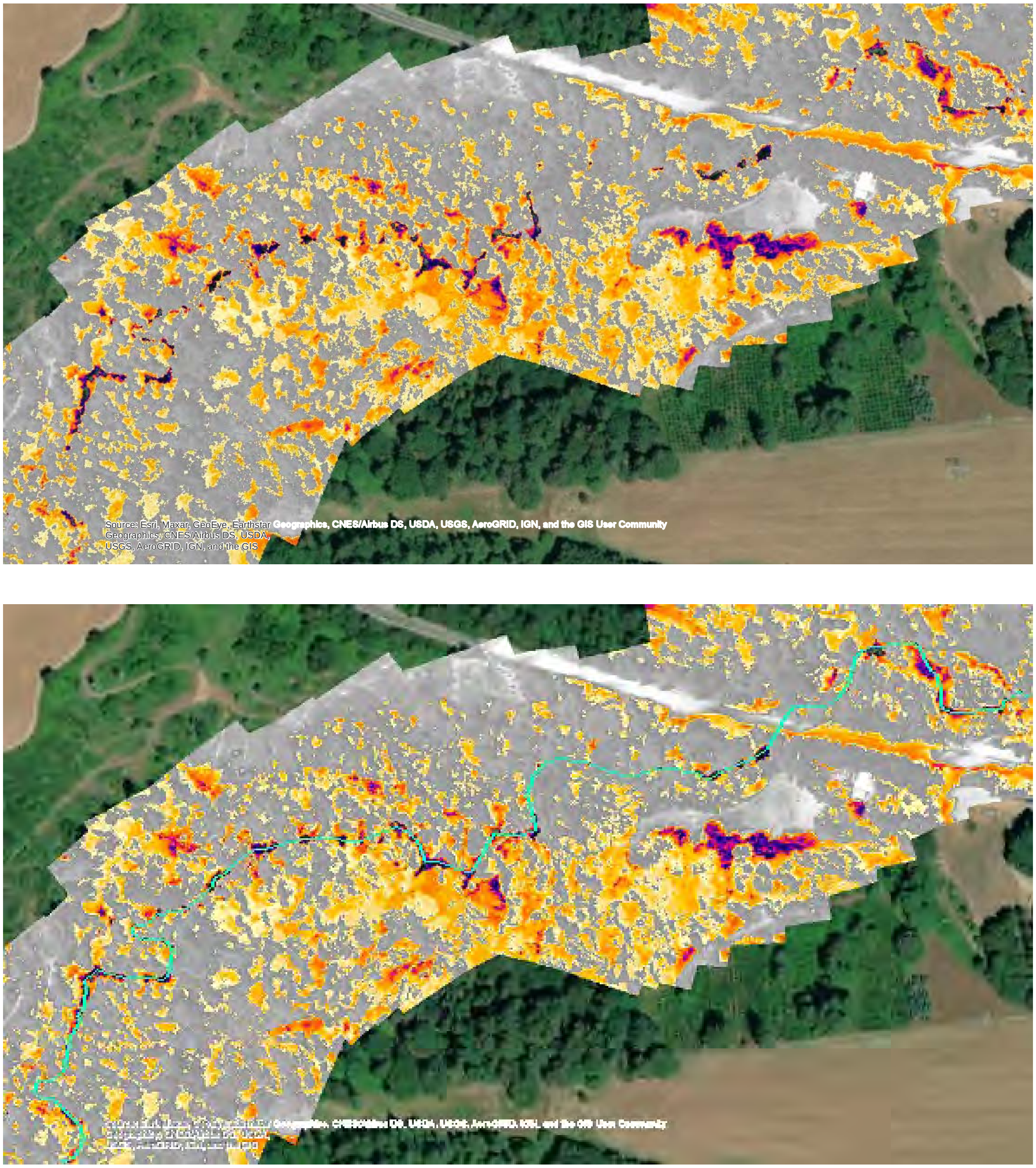


Figure 10. TIR results along lower Lockwood Creek. Increased canopy relative to Mason Creek floodplain results in more false positive signals for Lockwood Creek and more difficulty discerning the true stream location without the aid of the GIS streamline included in bottom image.



Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Figure 11. TIR results along upper Lockwood Creek upstream of the floodplain. Heavy canopy combined with steeper valley walls contribute to an increased number of false positive signals and higher difficulty in discerning the true cold signature of the stream without the aid of the GIS streamline shown in the bottom image.

The TIR imagery was not post-processed after field validation was completed and thus the false positive signals are retained in the final data product. This must be taken into consideration when using this data for future purposes. The same is true for the ‘Significant Features Sites’ layer that was generated by the TIR subcontractor (NV5) and intended to highlight cold-water features. This layer should also be used with caution. LCEP has created a separate layer of what it considers currently existing cold-water locations in the lower EFLR, and this layer is displayed in the online final results map for the project, available here (see Appendix B for list of included layers and full hyperlink).

Results Interpretation – Lower EFLR Mainstem Temperature Trends

One of the most useful outcomes we found for the TIR imagery was the longitudinal variation of temperature along the 21 miles of lower EFLR mainstem that it captured. To capture this trend, temperature measurements throughout the reach must be obtained at essentially the same time to avoid measurement bias from diurnal changes in stream temperature caused by variations in daily solar radiation. For small diurnal temperature changes a larger window of acquisition time may be acceptable but if the stream is changing temperature rapidly throughout the day, then the data must be collected more rapidly to avoid these errors. Because the TIR data was acquired from an airborne platform (helicopter) the full 21-mile reach was surveyed within a 1-hour timeframe, from 14:18 – 15:21 hrs. PST on August 11, 2020. In-stream temperature calibration data obtained from deployed loggers showed an average increase in stream temperature during this period of 0.55 °C for the entire reach (Table 5). Thus, any spatial variation in temperature greater than this value is presumed to be the result of a temperature trend that may be occurring for a variety of reasons. The relationship between acquisition time and daily stream heating is also illustrated in the plot in Figure 12. The relatively small increase in stream temperature during the flight acquisition window minimizes errors introduced into temperature trend analysis by diurnal temperature variations. This illustrates one of the major advantages of acquiring stream temperature data over a large spatial area using airborne imagery.

Table 5. Temperature readings, and calculated temperature increases due to diurnal heating, from instream data loggers used for TIR data calibration, during the TIR acquisition period. Average hourly increase in temperature for the reach surveyed is 0.55 °C.

Time	Logger Temp. S/N 535	Calc. inc.	Logger Temp. S/N 538	Calc. inc.	Logger Temp. S/N 631	Calc. inc.	Logger Temp. S/N 529	Calc. inc.	Logger Temp. S?N 534	Calc. inc.	Logger Temp. S/N 526	Calc. inc.	Logger Temp. S/N 543	Calc. inc.
8/11/20 14:01	17.92		20.48		19.46		18.79		16.06		17.20		15.37	
8/11/20 14:11	17.94	0.02	20.60	0.12	19.58	0.12	18.91	0.12	16.11	0.05	17.30	0.09	15.46	0.10
8/11/20 14:21	17.99	0.05	20.72	0.12	19.65	0.07	19.03	0.12	16.06	-0.05	17.42	0.12	15.63	0.17
8/11/20 14:31	18.03	0.05	20.84	0.12	19.77	0.12	19.15	0.12	16.20	0.14	17.53	0.12	15.70	0.07
8/11/20 14:41	18.11	0.07	20.96	0.12	19.87	0.09	19.27	0.12	16.23	0.02	17.63	0.10	15.68	-0.02
8/11/20 14:51	18.15	0.05	21.08	0.12	19.94	0.07	19.39	0.12	16.30	0.07	17.72	0.09	15.77	0.10
8/11/20 15:01	18.20	0.05	21.20	0.12	20.03	0.09	19.53	0.14	16.32	0.02	17.82	0.09	15.92	0.14
Avg. temp	10 min.	0.05		0.12		0.10		0.12		0.04		0.10		0.09
increase	Hrly.	0.29		0.72		0.57		0.74		0.26		0.62		0.55

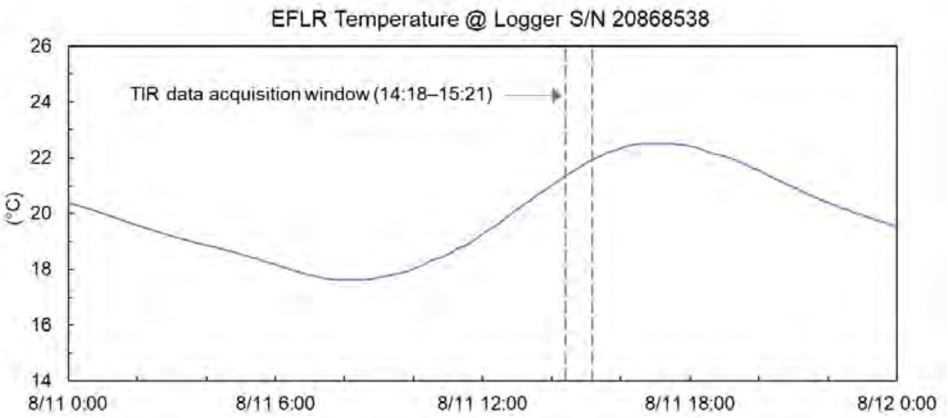


Figure 12. Diurnal temperature increase at selected location in the lower EFLR relative to the duration of the TIR data acquisition flight. Temperature increase within the flight acquisition window averaged 0.55 °C throughout the reach.

Figure 13 shows a plot of longitudinal temperature variation for the TIR survey reach, from RM 4.5–25 along the lower EFLR. Data points were extracted from the TIR data along a longitudinal mainstem profile. The dominant trend that is observed is a general increase in temperature proceeding downstream, from approximately 15.9°C at RM 25 to 20°C at RM 4.5, an average increase of 0.2° C/mile. This is consistent with results of prior research by Carey and Bilhimer (2009) and McCarthy (2018) and is an expected outcome along a reach of river that receives a significant amount of solar radiation, such as the present-day EFLR. Variation exists within this increasing trend, including notable decreases in temperature observed over some segments including RM 25 to 23, RM 21.5 to 21, RM 14 to 13, RM 8 to 7.5, and RM 5 to 4.

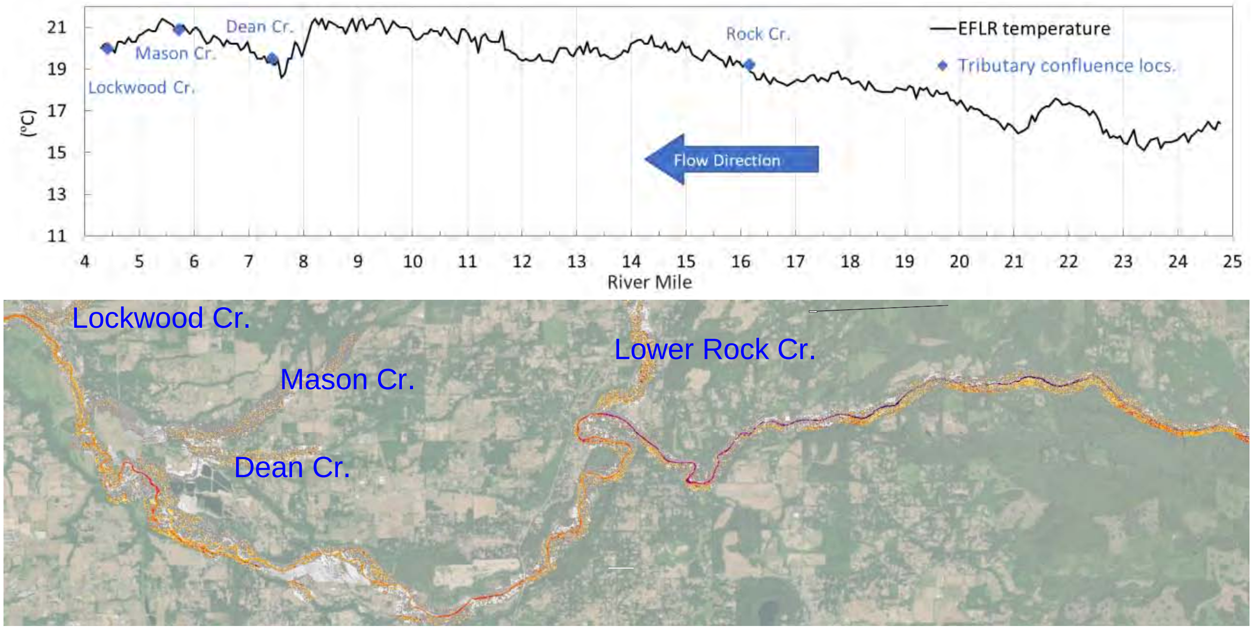


Figure 13. Longitudinal temperature plot for the lower EFLR mainstem channel from RM 4–25, extracted from the final TIR imagery. Top: Temperature plot. Points are locations where tributaries enter. Bottom: TIR imagery showing extent of survey.

We attempted to identify factors contributing to the decreasing temperature trends described above, particularly those within the downstream portion of the study reach, where most restoration opportunity exists. Carey & Bilhimer (2009) identified various gaining and losing reaches along the EFLR, based on seepage studies they conducted for their Washington Department of Ecology (WDOE) study. Gaining reaches are segments where discharge measurements were higher downstream relative to upstream, indicating a likely influx of groundwater and possible resulting cooling of the river. Losing reaches are segments where discharge measurements were lower downstream relative to upstream, indicating a potential loss of surface water to the ground and associated increase in heating. We mapped identified gaining reaches onto the temperature trend plot generated from our TIR imagery to see where these coincided with the decreasing temperature trends that we observed. Results are shown in Figure 14. Overall, we do see overlap between the two analyses, with at least some level of decrease observed over a portion of each of the WDOE gaining reaches.

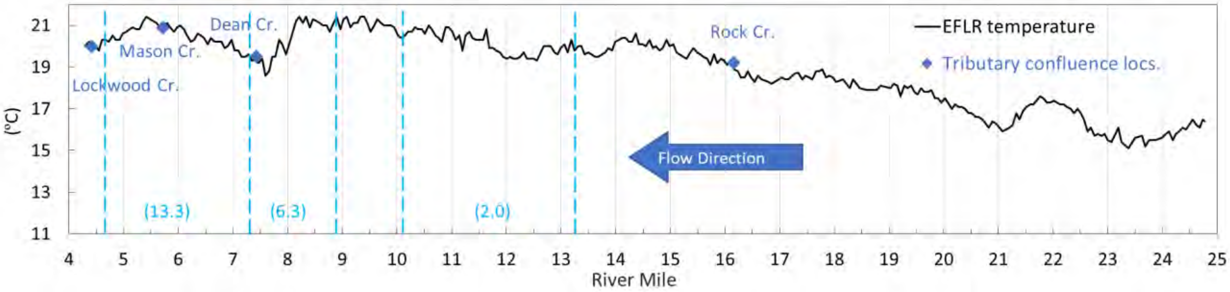


Figure 14. Longitudinal temperature plot for the lower EFLR mainstem channel from RM 4–25 as shown in Figure 13, with groundwater gaining reaches identified by Washington DOE (Carey and Bilhimer 2009) overlayed (dotted lines). Estimated groundwater inputs for each gaining reach (in cubic feet per second) are included in parentheses.

For RM 21.5–20.5, TIR data indicates a decreasing temperature trend where a WDOE gaining reach was not identified. We did not investigate this location for possible causes of this trend. A small decrease in temperature was noted from RM 14–12, which partially overlaps with the WDOE gaining reach from RM 13.2–10.1. The relatively small magnitude of decrease is consistent with DOE's relatively small estimate for groundwater influx (2.0 cfs).

The sharp decrease in temperature from RM 8–7.2 coincides with a relatively large magnitude gaining reach (6.3 cfs influx of groundwater for RM 8.9–7.3) identified by WDOE. These may be correlated, however additional temperature analysis we conducted for this reach as part of the Ridgefield Pits preliminary design project (LCEP 2021b) revealed an additional factor that may be contributing to the perceived temperature trend. This segment of the lower EFLR avulsed into the abandoned Ridgefield Pits gravel mines during flooding in 1996, and as a result has become a very low gradient, deep segment of river. This large volume of slow-moving water has more heat capacity relative to shallower, faster moving reaches, and thus imparts a moderating effect on diurnal temperature fluctuations due to solar radiation effects. In this case, measuring temperature throughout the reach simultaneously results in what appears to be a temperature trend but in fact is more closely related to this moderating effect. This is illustrated in Figure 15, which shows water temperature recorded by data loggers at the upstream (RM 8) and downstream (RM 7.2) ends of the reach during a 2-day period in August 2018 similar to August 2020 when the TIR imagery was acquired. As described above, the magnitude of diurnal variation is considerably larger at the upstream end of the Ridgefield Pits, compared to downstream, where the temperature swing has been moderated as water flows through the slow-moving reach. As a result, early morning monitoring shows higher temperatures downstream of the Pits relative to upstream, because the water moving through the Pits has retained more heat overnight relative to upstream. The observed temperature difference decreases throughout the morning until near mid-day when temperatures equalize. Proceeding into afternoon (when the TIR data was acquired) and evening, observed temperatures are higher upstream of the Pits relative to downstream, as the water moving through the Pits heats more slowly due to the increased volume of water. The observed difference increases through the afternoon and then decreases and the pattern flips and repeats itself beginning early the following morning.

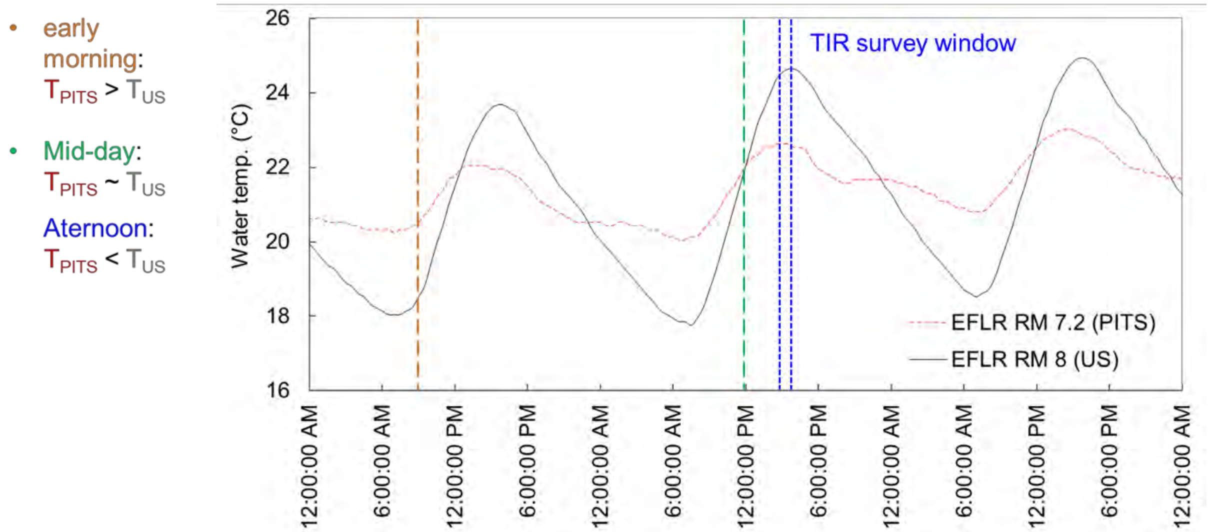


Figure 15. Temperature data comparison between stations located upstream of Ridgefield Pits at RM 8 (US) and just downstream at RM 7.2 (PITS), collected during August 2020. Moderating effect of the high-volume, slow moving Ridgefield Pits reach on diurnal temperature fluctuations is illustrated by the smaller amplitude signal observed downstream. This effect results in higher morning temperatures and lower afternoon/evening temperatures to be observed downstream, relative to upstream, throughout the course of a summer day.

While it is possible that some degree of cooling due to groundwater exchange may be occurring through the Ridgefield Pits reach, as suggested by Carey and Bilhimer (2009), the phenomenon observed and described above highlights the importance of examining localized temperature trends suggested by TIR imagery more closely. In this case, temporally varying information was needed to supplement the TIR imagery, which provided spatially varying information over essentially a single point in time. While a perceived decreasing temperature trend was observed from the standalone TIR image, the actual physical process resulting in this observation was something different. Long-term mean temperatures calculated from the 2018 loggers deployed at both ends of the reach confirm this, having shown an actual increasing temperature trend through the reach (19.8 °C @ RM 8, 20.3 °C @ RM 7.2).

A decreasing temperature trend was also observed in the TIR imagery from RM 5.5 – RM 4, which overlaps with a portion of the WDOE gaining reach from RM 7.3–4.6. In-stream measurements taken during summer of 2022 did not reproduce this trend, but rather indicated a slight temperature increase (from 20.6°C to 21.7°C at the time of measurement) consistent with most of the overall study reach. We were not able to inquire with the data subcontractor as to why this trend is indicated in the TIR data, due to the lapse in time between the TIR survey and field verification. We presume that the in-stream data is correct.

4.1.2 In-stream Handheld Water Temperature Measurements

Locations where we monitored water temperature in July 2021 using handheld YSI meters are shown in Figure 16. These include mainstem and off-channel areas where TIR imagery results were verified and additional locations that the TIR survey did not cover. Bed and surface temperatures were measured at each location and compared to average mainstem temperatures measured at that time and close by, to identify thermal anomalies. Most measurements were taken from late morning through afternoon after the mainstem had heated up sufficiently to make it easier to detect cold water. These measurements allowed us to eliminate false positive detections of cold water in the TIR imagery and determine what we believe is a comprehensive picture of existing cold-water locations within the lower EFLR floodplain. These areas are shown in Figure 17 and consist of off-channel and side-channel locations. They do not include any tributaries (even though most of the lower EFLR tributaries are colder than the mainstem), as we did not survey any tributaries using this method due to the limited scope of field time as well as property access issues. Absolute bed and surface temperature values recorded at all of the sampling locations shown in Figure 16 are available from the ArcGIS online results map for the project, available here (see Appendix B for list of included layers and full hyperlink).

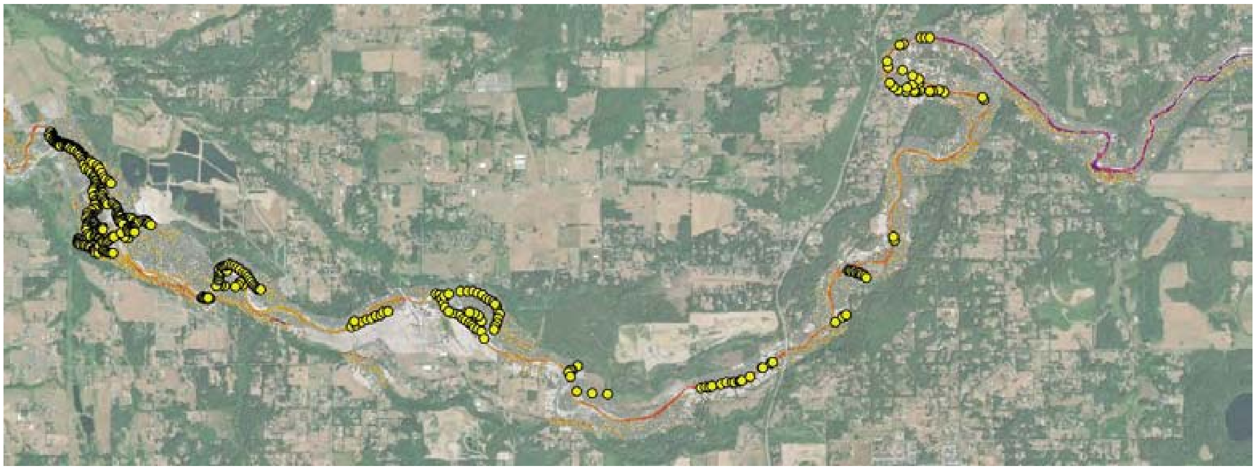


Figure 16. Locations along the lower EFLR where water temperature was measured in July 2021 using handheld YSI meters. These include mainstem, side channel and off-channel areas. Tributaries were not surveyed using this method.

Figure 17. Locations along the lower EFLR where cold water (defined as a minimum of 2 degrees colder than the mainstem temperature) was detected, out of all the locations sampled (shown in Fig. 16). These include off-channel and side channel areas only - no cold water was detected in the mainstem, and tributaries were not sampled using this method and thus are not included, even though most do meet our defined cold-water criteria.

The criterion we used to designate cold water suitable for thermal refuge in this study is defined as water that is a minimum of 2 degrees colder than the mainstem temperature at any given time. This criterion has been applied in other LCEP thermal studies (LCEP, 2018), EPA's Columbia River Cold Water Refuges Plan (EPA, 2021) and is the definition the Oregon Department of Environmental Quality uses based on EPA guidance (Torgersen et al., 2012).

4.1.3 In-stream Continuous Water Temperature Time Series

Temperature data loggers were installed at 9 mainstem locations and in each of the 4 tributaries included in the study (Lockwood, Mason, Dean, and Lower Rock Creeks). Locations are shown in Figure 18.

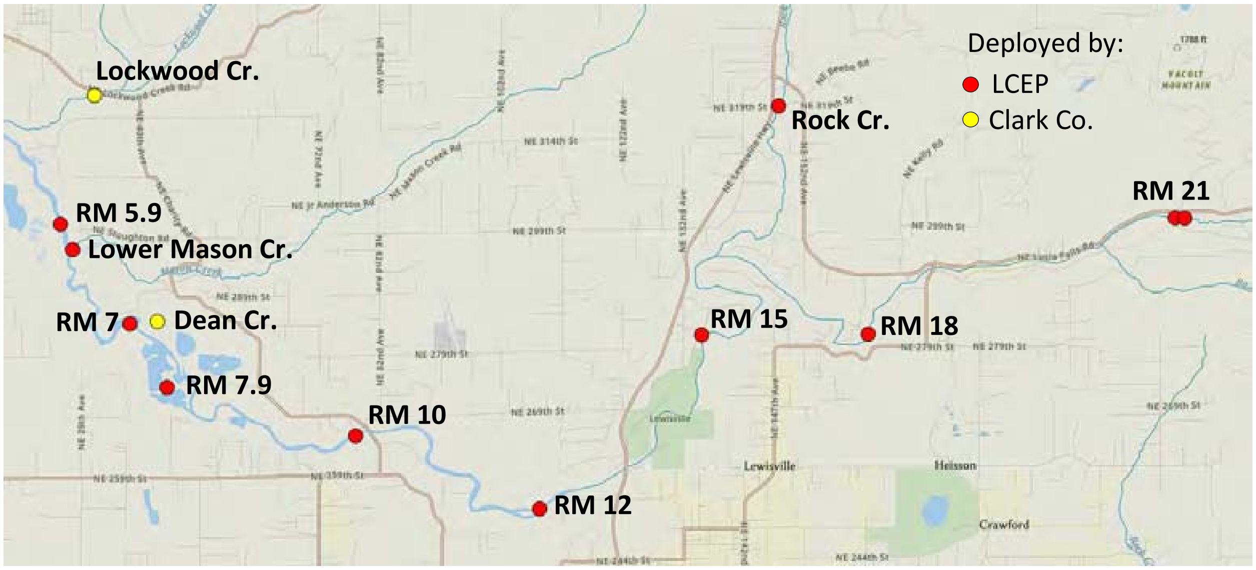


Figure 18. Deployment locations for instream temperature loggers used for TIR imagery calibration. Loggers were deployed in August 2020 prior to the flight acquisition period, by LCEP and Clark County.

Because the data do not provide significant information directly related to thermal refuge, we present a limited discussion here. Data plots for all locations are included in the project final results map available here (see Appendix B for list of included layers and full hyperlink). Plots for selected locations only are shown in Figure 19 (19a: locations upstream of and including RM 10; 19b: locations downstream of and including RM10) below. These illustrate the diurnal temperature variation that is typical for the river, with varying amplitude depending on location; the overall heating trend that occurs proceeding downstream; and the colder signals of two of the monitored tributaries (Mason and Lower Rock creeks).

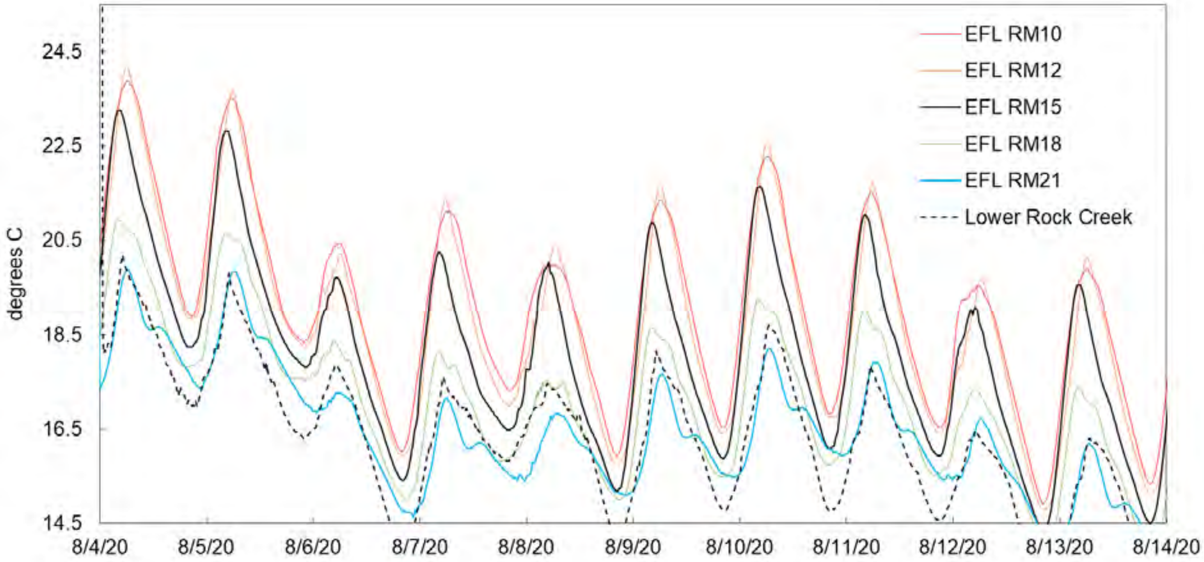


Figure 19a. Logged temperature data from August 2020 for selected locations upstream of and including EFL RM10. Of note are the overall increasing temperature trend proceeding downstream; the characteristic diurnal temperature variation with overall magnitude differing depending on river location; and the colder water present in Rock Creek.

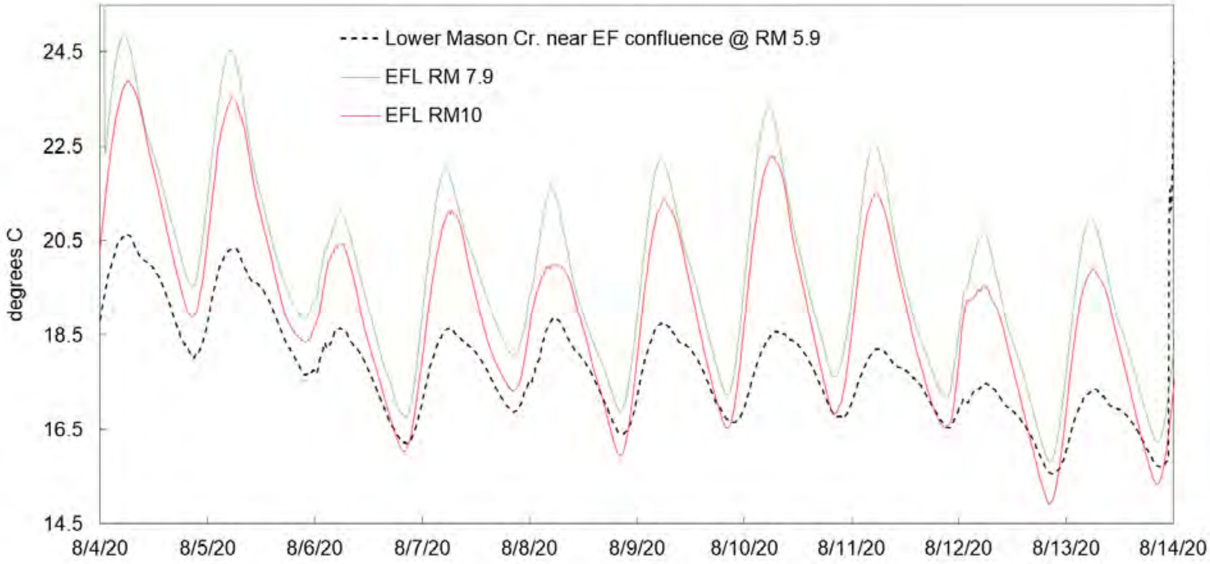


Figure 19b. Logged temperature data from August 2020 for selected locations downstream of and including EFL RM10. Of note are the overall increasing temperature trend proceeding downstream; the characteristic diurnal temperature variation; and the colder water present in Mason Creek.

4.2 LANDSCAPE-SCALE RIPARIAN ASSESSMENT

The direct effect of riparian shading on water temperature, as a result of reducing solar radiation, can vary based on spatial scale and several other physical factors. At localized side or off-channel locations isolated from mainstem or groundwater influx, riparian canopy may maintain colder water relative to the mainstem by reducing heating from solar radiation during the daytime hours and maintaining cooler air temperature. We have seen evidence of this at locations we assessed, as shown in Figure 20 where water temperature recorded at an off-channel location near RM 9 is plotted, with temperature recorded in the mainstem at the same time included for reference. The heavily shaded off-channel location maintains a more constant temperature throughout the summer and is generally at least 2°C cooler than the mainstem throughout most of the early–mid summer when the exposed mainstem is most influenced by solar heating effects. Diurnal temperature variation is also generally smaller relative to the mainstem due to the reduction in solar heating provided by the canopy. These observations demonstrate that sites considered for thermal enhancement or creation projects that lack canopy cover may benefit significantly from revegetation actions that increase shading.

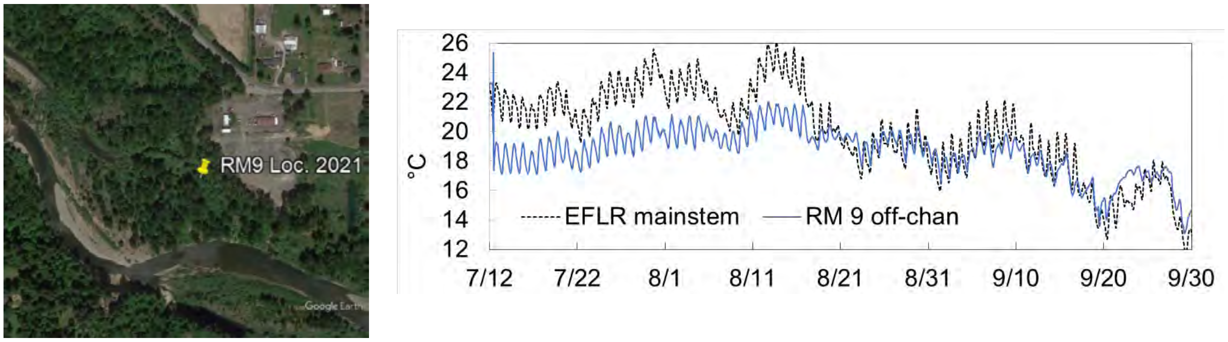


Figure 20. Logged temperature data from summer 2021 at an off-channel location adjacent to the EFLR at RM9. Mainstem EFLR temperature is included for reference and is significantly warmer than the off-channel due to solar heating effects.

It is unclear whether groundwater plays a role in reducing water temperature at the off-channel location discussed above, however our observations suggest that locations which do receive significant influxes of groundwater, or colder tributary water, typically exhibit even colder temperatures and less diurnal variation in temperature relative to what was observed there. An example is shown in Figure 21, for a location that was monitored in summer 2018 where groundwater influx was suspected. The temperature remains very cold throughout the summer with little diurnal variation, despite the lack of canopy. Based on these observations, we presume that for potential thermal enhancement or creation sites where groundwater is expected to play a significant role, riparian revegetation may not be as beneficial relative to sites where surface water (which is exposed to air temperatures) is primarily influenced by atmospheric effects.

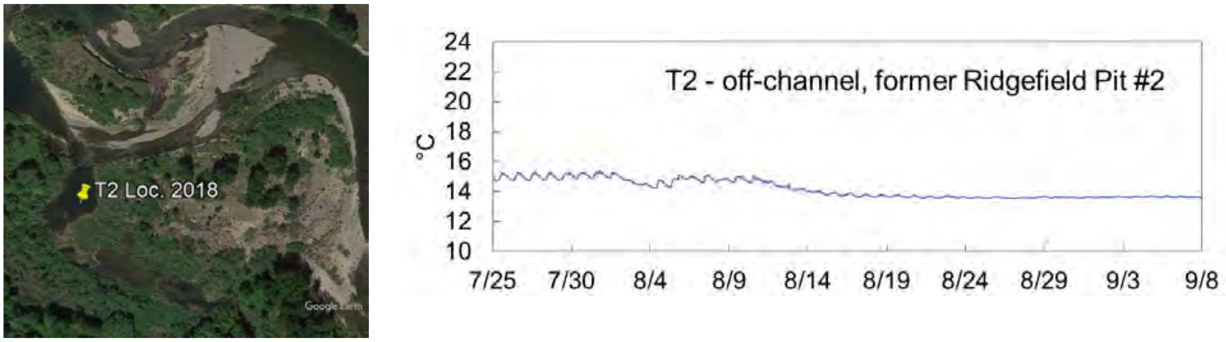
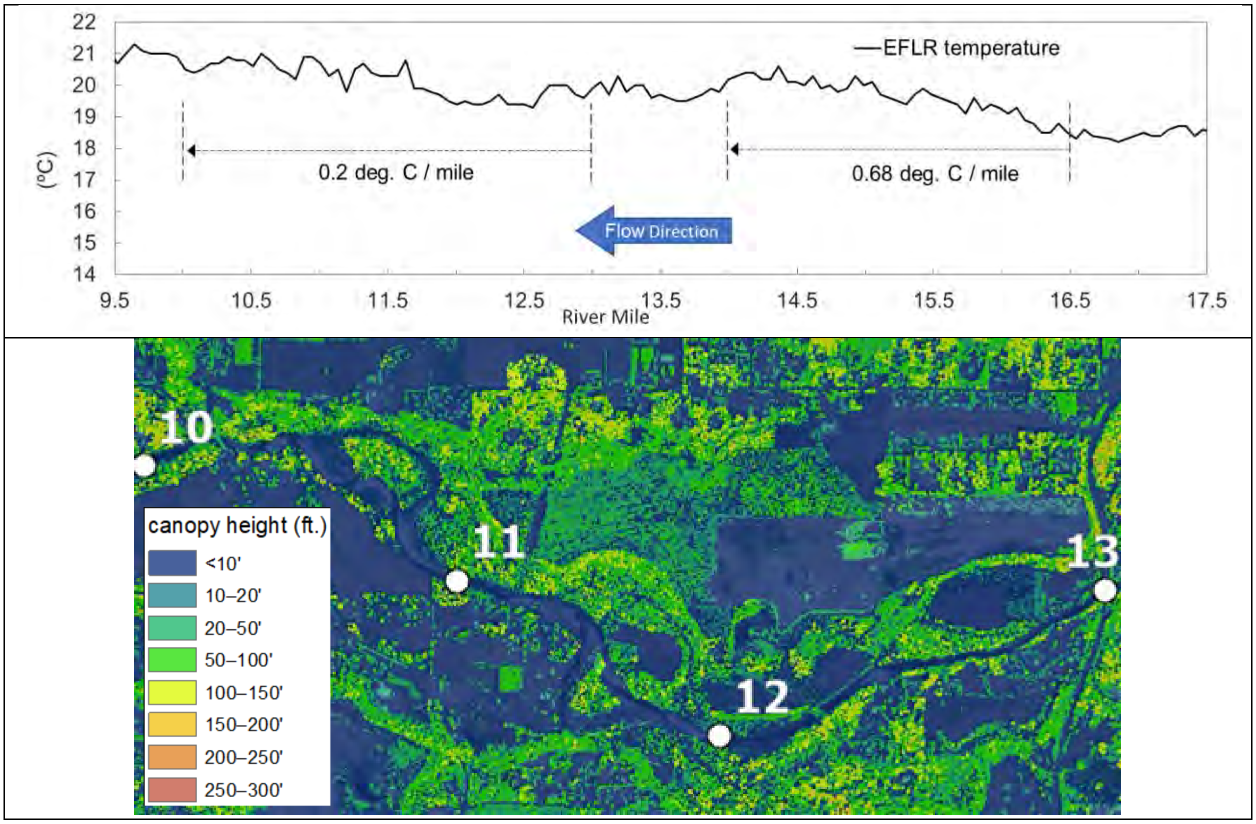


Figure 21. Logged temperature data from August 2020 for selected locations <u>downstream of</u> and including RM10 at Daybreak Park. Logging interval was 6 minutes. Of note are the colder water present in Mason Creek; and the colder water indicated at RM 5.5 which deviates from the overall heating trend proceeding downstream as well as the characteristic diurnal variation. This data has not been confirmed in the field as of completion of this report.

While local riparian revegetation actions can benefit off-channel or side-channel locations isolated from the mainstem, we believe it is unlikely that such isolated activities implemented along selected locations of the mainstem lower ELFR would provide any direct temperature benefits for the mainstem river, as the total effective shade for the entire reach would change very little for a given action, or even several depending on their relative locations. As part of this study, we conducted a brief and largely qualitative assessment of the potential for revegetation conducted over the landscape scale (i.e., along a few miles or more) to reduce heating, and resultant water temperature increase, along the lower EFLR during the summer. A detailed quantitative analysis of the effects of riparian shading on stream temperature, like ones presented in various literature (Chen et al. (1998), Johnson & Wilby (2015), Kalny (2010), Sahatjian (2014)), was well beyond the resources allocated for this study but is recommended to further the limited conclusions presented herein and in other EFLR temperature studies. For now we present some general conclusions based on a cursory analysis of the Thermal TIR and other recent high-resolution data that is now available, and suggest a method that could be employed for a more comprehensive study.

McCarthy (2018) performed a detailed shade analysis along the lower 32 miles of the EFLR mainstem as part of a Washington DOE Bacteria and Temperature Assessment for the EFLR watershed. Current effective shade and system potential effective shade were estimated using DOE’s TTools and Shade models. The study documents the important thermal role of riparian vegetation in forested and agricultural areas, and accordingly provides a general recommendation to continue to restore native riparian vegetation on stream banks, particularly in areas with large shade deficits in the middle watershed. The study does not attempt to quantify potential benefits of these actions, however. Thermal properties including the resultant temperature of a given stream are part of a complex and dynamic system of heat exchange and mass transfer (Larson, 1996), with several variables that may impact the degree to which riparian vegetation may contribute to overall heating, or reduction in heating. For example, many sections of the EFLR along the middle watershed are upwards of 80-100’ wide bank-to-bank during summer base flow periods. At these widths, even dense canopy of very mature heights realized after several decades may only be capable of providing partial effective shade. Other characteristics, including bank height and river orientation relative to sun angle, can also influence effective potential shade with or without the presence of vegetative canopy. The study acknowledges these types of complexities but does not consider their role in determining where revegetation efforts would be most effective.

We observed temperature trends in the TIR imagery collected as part of this study that do not seem consistent with existing canopy data derived from recent LiDAR we used in this study (USGS Western Washington 3DEP 2016 LiDAR Project, USGS Cascades South 3DEP 2019 LiDAR project). This is illustrated in Figure 22, which plots the longitudinal TIR image-derived temperature profile for EFLR RM 9.5–17.5, and lidar-derived canopy heights for two segments of interest within this reach. The segment extending from RM 16.5–14 shows a rate of temperature increase of 0.68° C/mile, which is nearly 3.5 times greater than the overall rate calculated for the complete lower EFLR (0.2 °C / mile for the reach that was surveyed from RM 4.5–25), despite relatively heavy presence of mature canopy throughout this reach. This is in contrast with the segment from RM 13–10 which showed a rate of temperature increase of just 0.2° C/mile despite a relative lack of mature canopy and relatively large average stream width, which we would have expected to result in larger temperature increases rather than smaller. For this analysis we considered 'mature' canopy heights to be those exceeding 100′, which may be an over- or underestimate depending on individual tree species. For the reach where higher temperature increase was documented, canopy height exceeded 150′ along much of the stream bank. The results suggest that canopy presence alone may not act to reduce water temperatures in the lower EFLR even over relatively long stretches of river, and that all physical factors present that can impact water temperature should be taken into consideration when strategizing landscape scale planting efforts.



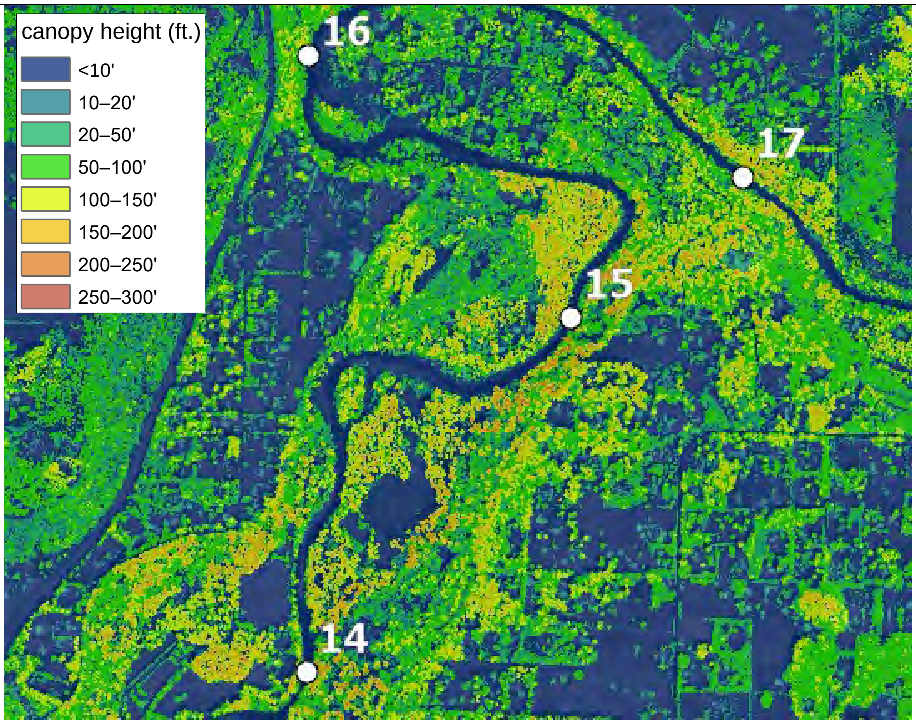


Figure 22. Top: Longitudinal temperature plot for lower EFLR mainstem from RM 9.5–17.5 extracted from TIR imagery. Rates of temperature increase are shown for RM 16.5–14; and RM 13–10. Middle and bottom: Vegetation canopy heights derived from LiDAR data (USGS Cascades South 3DEP, 2019) for the RM 13–10 and RM 16.5–14 segments, respectively.

Assessment of landscape scale riparian shading thermal uplift potential may be accomplished through software applications including recent improved shade estimation tools for GIS or other robust shade routines, coupled with water temperature models such as Heat Source (Boyd, 1996) or various suites of hydrodynamic and water quality models capable of accepting solar heating input parameters. High quality, high-resolution input data to serve as input to these models has also become readily available in recent years with the prevalence of LiDAR and UAV-derived elevation information. McCarthy (2018) did not provide details about the source data used in that study to estimate watershed-scale effective and potential effective shading, but we presume significant improvements in quality and resolution of source data have been achieved in the time since that assessment was completed. Dugdale et al. (2019) describe an approach they developed for modeling temperature of a stream in Scotland, which uses canopy information derived from drone-based structure from motion modeling as input to the Heat Source. This method, or something similar, would be useful to model existing EFLR temperature and to predict changes in temperature patterns associated with different landscape-scale planting strategies before significant funding expenditures are allocated to these efforts.

ArcGIS Pro has shade analysis tools which can be used to assess shadows generated by 3D elevation features. We developed a 3D elevation surface of existing vegetation canopy derived from the LiDAR sources used in this study (see references above) and qualitatively assessed its existing shading impacts at selected locations. Results are shown in Figure 23. These tools could potentially be used to generate quantitative shade estimates that could be input to water temperature models;

however, this was beyond the scope of this study. The qualitative, screen-based analysis, however, provided useful insight into current shading extents and could be used by itself as a tool for prioritizing landscape-scale riparian revegetation locations. Field verification of results would be recommended to ensure the shading extents predicted by the tools are representative of actual conditions. Some observations of note in Figure 23 include:

- Figure 23a: Despite relatively mature canopy along the south bank, stream widths of 100′ and more reduce effective shading to less than 50% of the stream area. Additional plantings may not improve this significantly until canopy has fully matured over several decades.
- Figure 23b: Significant shading is provided in morning and afternoon. Steep valley walls, not apparent in the graphic, are present here and also contribute to shading. Despite the presence of relatively mature canopy, this segment exhibits some of the highest rates of temperature increase throughout the entire study area for which TIR airborne imagery was acquired (see Fig. 22 and preceding discussion).
- Figure 23c: Extensive lack of canopy and relatively wide stream results indicate little to no shading in this reach. Interestingly, the TIR data show a relatively low rate of temperature increase through this reach relative to the overall study area, despite the lack of canopy. Based on this it is difficult to say if riparian plantings would lower heating rates substantially in this reach.

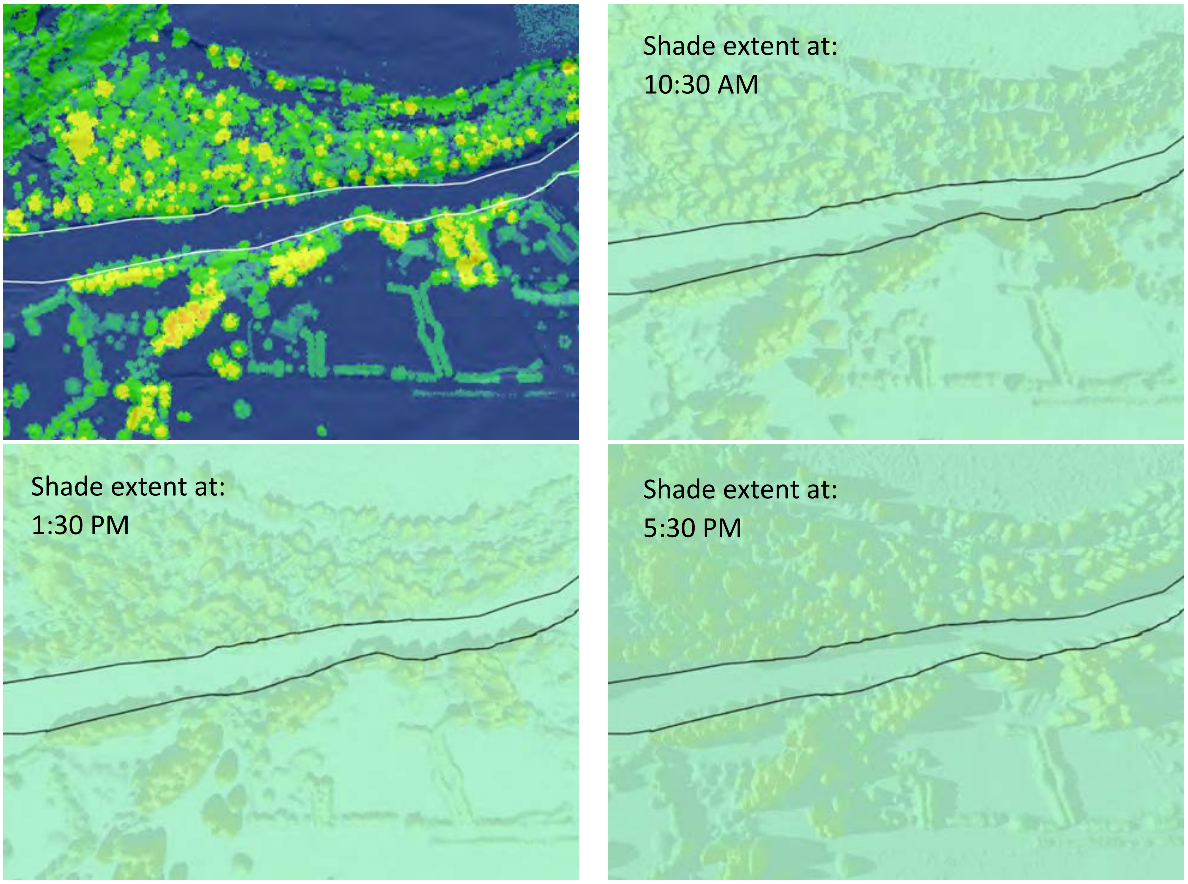


Figure 23a. Lidar-derived canopy height and resultant shade provided along RM 12.5–12.8 of the lower EFLR, estimated from ArcGIS Pro shade analysis. Top left: Canopy height, with higher canopies (> ~100′) shown as yellow or orange; lower as green (~20–100′); and lack of canopy as blue. Other images: Resulting shade predicted at selected times on a typical early summer day (July 2 was modeled). Stream extent at base flow levels is indicated by black lines.

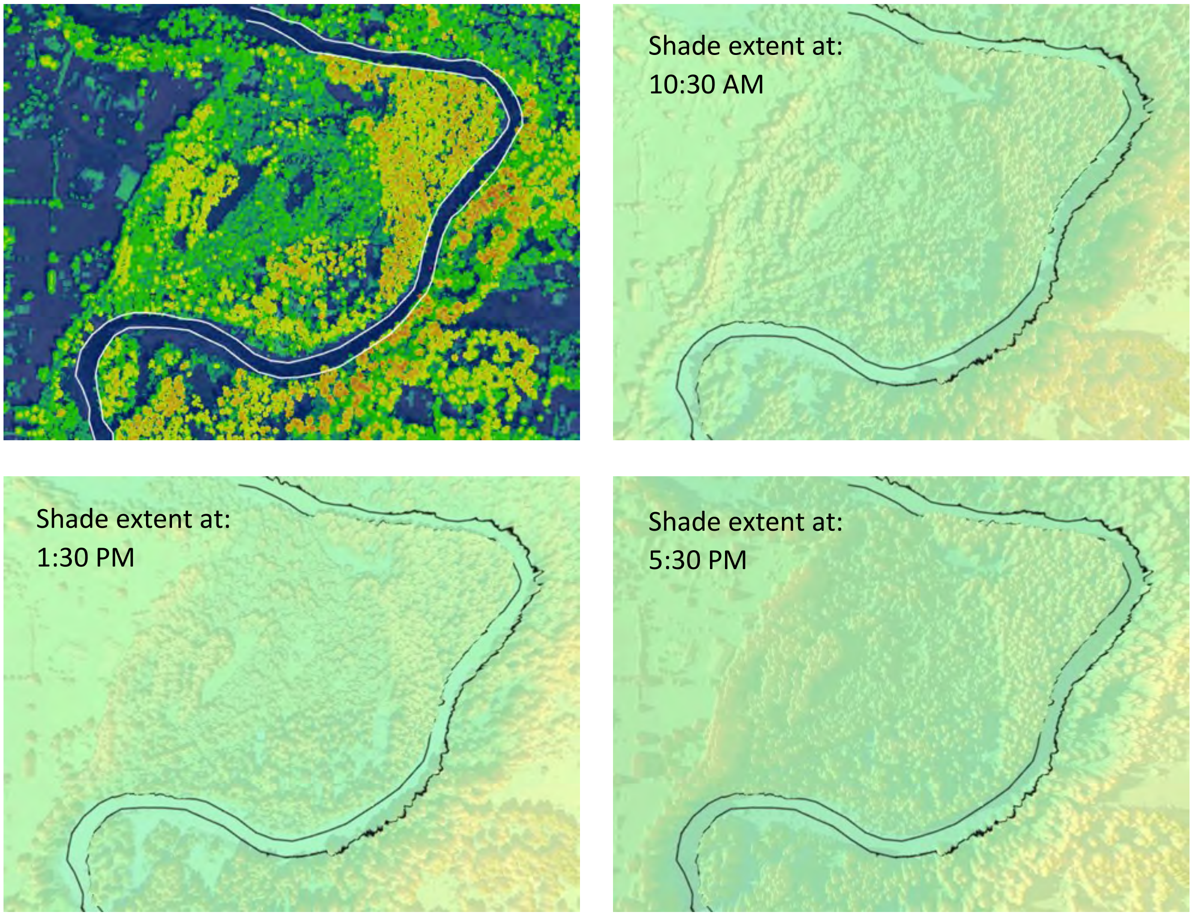
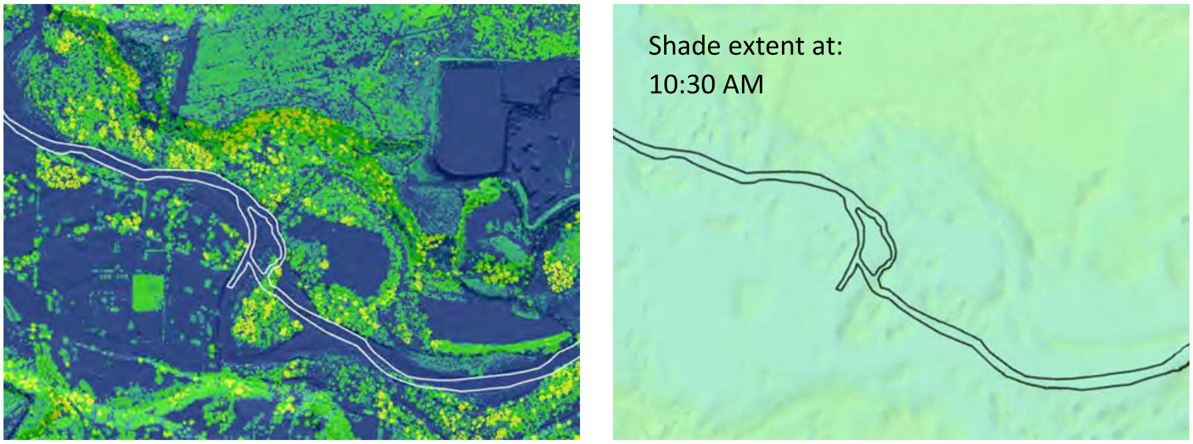


Figure 23b. Lidar-derived canopy height and resultant shade provided along RM 14.5–15.8 of the lower EFLR, estimated from ArcGIS Pro shade analysis. Top left: Canopy height, with higher canopies (> ~100') shown as yellow or orange; lower as green (~20–100'); and lack of canopy as blue. Other images: Resulting shade predicted at selected times on a typical early summer day (July 2 was modeled). Stream extent at base flow levels is indicated by black lines.



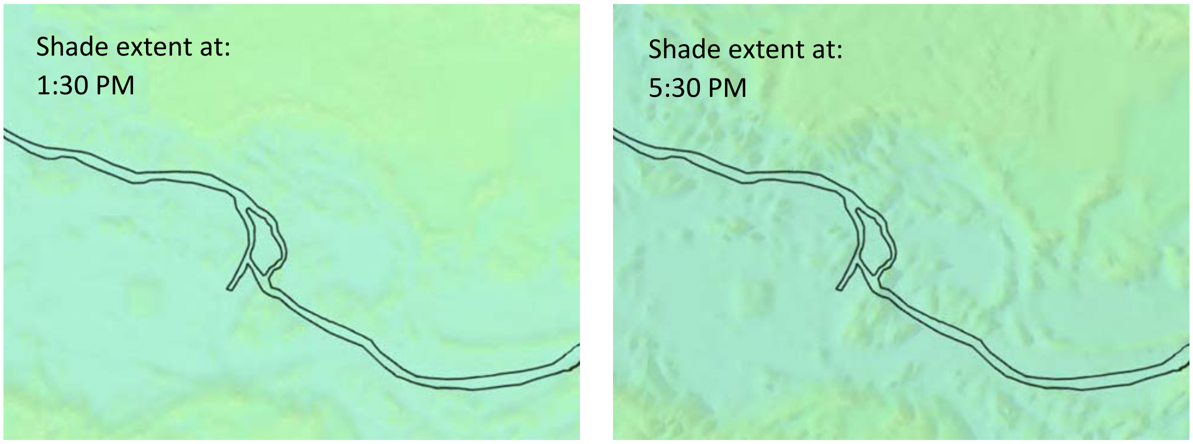


Figure 23c. Lidar-derived canopy height and resultant shade provided along RM 11–12.2 of the lower EFLR, estimated from ArcGIS Pro shade analysis. Top left: Canopy height, with higher canopies (> ~100') shown as yellow or orange; lower as green (~20–100'); and lack of canopy as blue. Other images: Resulting shade predicted at selected times on a typical early summer day (July 2 was modeled). Stream extent at base flow levels is indicated by black lines.

The shading assessment presented here considers only the direct impact of riparian vegetation on stream temperatures, namely the potential reduction of exposure to solar heating provided by canopy cover. Indirect impacts and the numerous other habitat benefits that riparian vegetation can provide are well documented (McCarthy (2018) and others) in the literature. These factors should also be taken into consideration as part of any landscape-scale revegetation strategy.

4.3 THERMAL REFUGE POTENTIAL PROJECT SITE SELECTION

4.3.1 Thermal Refuge Creation and Enhancement

A total of 29 sites were selected as potential locations for thermal refuge creation and enhancement projects for the lower EFLR and floodplain, based on the methodology and supporting data outlined in Section 3. Locations of these sites are shown in Figure 24, which also shows relative locations of potential habitat restoration projects identified in the HRP.

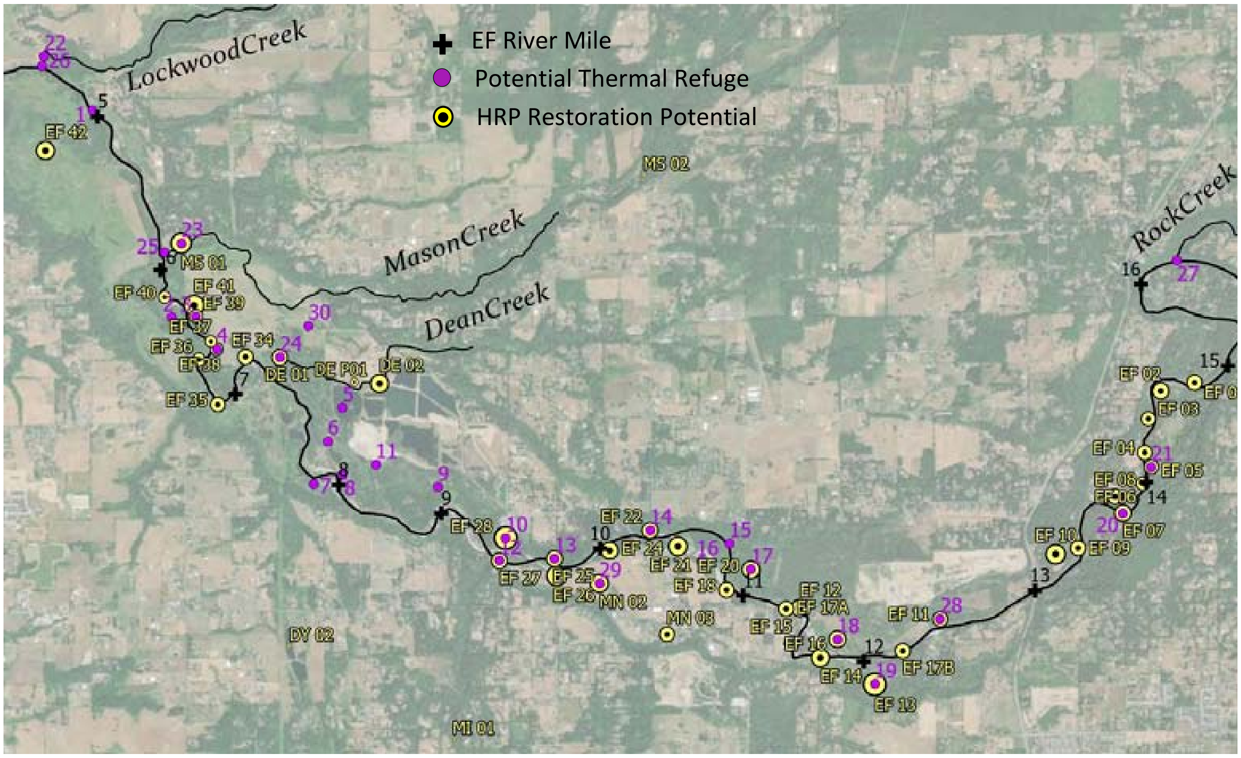


Figure 24. Potential thermal refuge projects identified for this plan, and relative locations of potential restoration projects identified in the EFLR HRP. HRP sites are symbolized based on importance, with larger symbols indicating higher priority sites.

4.3.2 Thermal Refuge Protection

Figure 25 shows the extent of public land along the lower EFLR and tributaries (including properties owned by Clark County and Columbia Land Trust), overlayed with cold-water side and off-channel locations identified in this project. Most identified locations are currently within these publicly protected areas. Exceptions include left-bank locations near RM 14; the Mill/Manley creek confluences along the left bank at RM 9.5; the disconnected right-bank side channel between RM 10 and 11, which was the former EFLR mainstem channel prior to a westward migration that has been occurring over the last decade; and areas between RM 7.5 and 8 located adjacent to the abandoned Ridgefield gravel pits. These are all areas which should be prioritized for protection due to the presence of existing potential refuge locations. Presently, the area adjacent to the Ridgefield Pits is in the design phase of a planned restoration project which includes acquisition of this land by the county. As seen in Figure 25, there is presently little to no protected land along the four tributaries included in the project. We did not assess what, if any, protection measures could be implemented along these streams in this study.

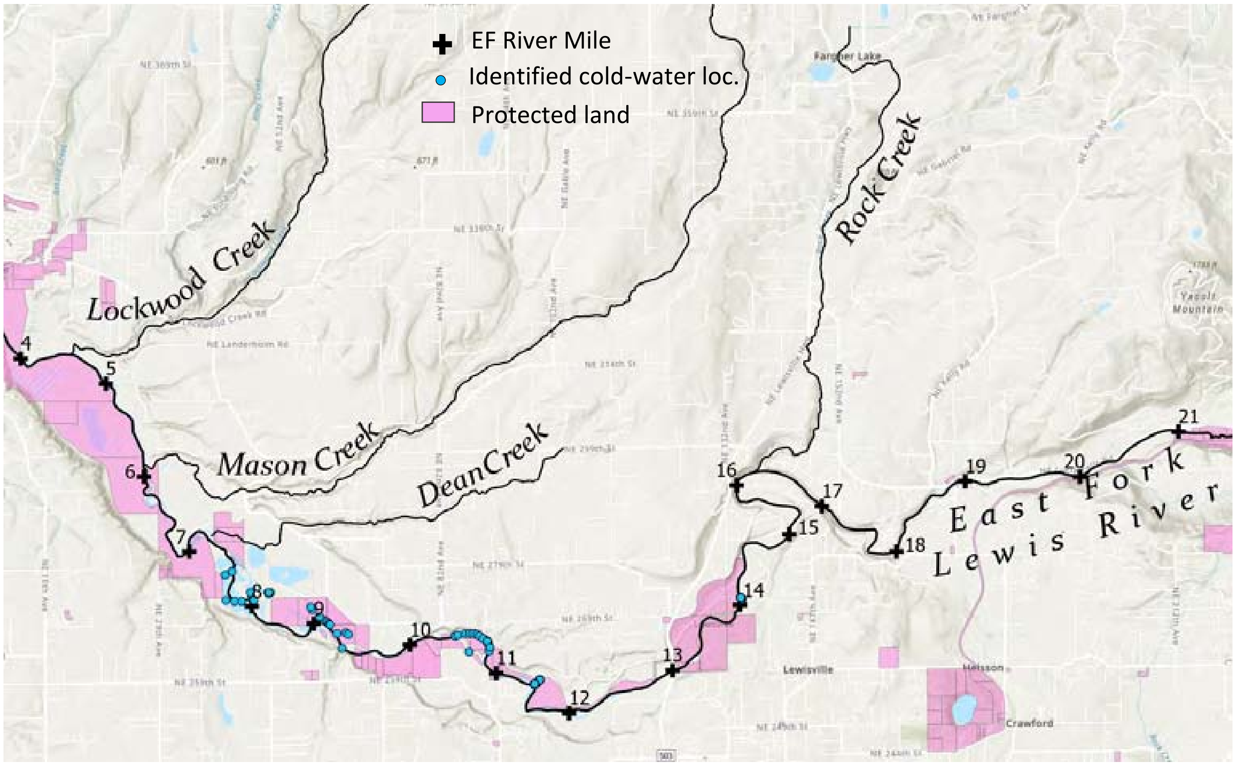


Figure 25. Extent of protected lands (including Clark County and local land trust properties) along the lower EFLR, with cold-water side and off-channel locations identified in this study overlayed.

4.4 THERMAL REFUGE POTENTIAL PROJECT SITE PRIORITIZATION FOR LOWER EFLR

The 29 sites identified as potential thermal refuge project locations were evaluated by the Technical Oversight Group over the course of four separate meetings. This included refinement of site scoring and ranking process presented in Section 3.4. Potential sites were then scored by LCEP staff, and prioritization results were reviewed and finalized with final feedback from the Technical Oversight Group. A ranked list of the potential project sites is presented in Table 6, with average scores resulting for each metric that was evaluated.

Table 6a. Potential thermal refuge project sites, shown in descending order by ecological score.

			Ecological Score Results (LCEP Average)											**Social Constraints Score Results (LCEP Average)**				
Site ID	**Location**	**HRP Site ID**	CW Source (1–4)	Size (1–3)	Fills Gap (0.5–2)	Mainstem Proximity (1–2)	Habitat Quality (0.4–1.2)	DOE Gaining Reach (0.4–0.8)	Treatment Strategy (1–2)	Physical Processes (0–1.4)	Riparian Uplift Pot. (0.3–0.9)	EF HRP Priority (0–1.2)	**Normalized Ecological Score (0-100)**	Owner-ship (0–2)	Construction Access (0–0.5)	Incuded in Active Project? (0–1)	Partner Support (0.5–1)	**Normalized Social Score (0-100)**
15	**Side chan. RM 10.3-10.8 R bank**		3.7	3.0	1.8	1.5	1.2	0.8	2.0	1.4	0.4	0.0	**79.2**	1.3	0.0	1.0	0.3	**66.7**
12	**Off-chan. RM 9.4 L Bank (Mill/Manley conf.)**		4.0	2.7	1.8	1.5	1.2	0.4	2.0	0.9	0.4	0.8	**78.7**	0.7	0.3	1.0	0.0	**50.0**
23	**Mason Cr. floodplain**	MS-01	4.0	1.3	2.0	0.7	0.4	0.8	2.0	1.4	0.9	1.2	**70.8**	2.0	0.5	0.0	0.5	**75.0**
1	**EF Mainstem RM 4.5–5.5**		2.3	3.0	2.0	2.0	0.8	0.8	2.0	0.9	0.8	0.0	**70.5**	2.0	0.5	1.0	0.3	**95.8**
28	**Manley Cr. floodplain**	MN-02	4.0	2.0	1.5	0.5	0.4	0.4	2.0	1.4	0.9	1.2	**67.7**	0.0	0.5	1.0	0.0	**37.5**
10	**Side chan. RM 9-9.5 R bank**	EF-28	3.0	3.0	0.7	1.2	0.9	0.4	2.0	1.4	0.4	1.2	**66.7**	2.0	0.5	0.0	0.3	**70.8**
21	**Off-chan. RM 14.1 L bank**	EF-05	3.7	1.0	2.0	1.5	1.2	0.4	2.0	0.9	0.3	0.8	**63.8**	0.0	0.0	1.0	0.0	**25.0**
24	**Dean Creek floodplain**	DE-01/-02	4.0	1.3	1.5	0.5	0.4	0.8	2.0	0.9	0.9	1.2	**62.1**	1.0	0.5	0.3	0.3	**54.2**
25	**Mason Cr. confluence**		4.0	1.0	2.0	2.0	0.8	0.8	2.0	0.2	0.7	0.0	**61.8**	1.0	0.5	0.0	0.2	**41.7**
4	**Off-chan. RM 6.6 R bank**	EF-38	3.0	1.7	1.5	1.5	0.5	0.8	2.0	0.9	0.8	0.8	**61.8**	0.0	0.5	1.0	0.0	**37.5**
27	**Off-chan. RM 12.5, R bank**	EF-11	3.0	1.3	2.0	1.5	0.8	0.8	1.7	0.9	0.6	0.8	**61.0**	2.0	0.5	1.0	0.0	**87.5**
19	**Off-chan. RM 12 L bank**	EF-13	3.0	1.0	2.0	1.0	1.2	0.8	1.7	0.9	0.5	1.2	**60.0**	0.0	0.5	1.0	0.0	**37.5**
20	**Side chan. RM 13.7 L bank**	EF-07	3.0	1.7	2.0	1.5	1.2	0.4	1.7	0.7	0.3	0.8	**59.5**	2.0	0.0	1.0	0.0	**75.0**
6	**Ridgefield Pits 7/8**		3.0	2.7	1.3	1.7	0.4	0.8	1.7	0.9	0.7	0.0	**59.0**	0.7	0.2	0.0	0.2	**25.0**
11	**Side chan. along Storedahl**		3.0	2.7	1.5	0.5	0.8	0.8	2.0	0.9	0.4	0.0	**54.6**	0.3	0.5	0.0	0.2	**25.0**
26	**Lockwood Cr. confluence**		4.0	1.0	2.0	2.0	0.4	0.4	2.0	0.0	0.7	0.0	**53.8**	0.0	0.5	1.0	0.0	**37.5**
18	**Off-chan. RM 11.5 R bank**	EF-16	3.0	1.0	1.3	1.5	0.9	0.8	1.7	0.9	0.5	0.8	**53.6**	2.0	0.5	1.0	0.0	**87.5**
2	**Off-chan. RM 6.3 L Bank**		3.0	1.7	1.2	1.5	0.8	0.8	1.7	1.2	0.6	0.0	**52.8**	2.0	0.5	1.0	0.0	**87.5**
3	**Off-chan. RM 6.4 R bank**	EF-39	2.3	1.7	1.2	1.5	0.8	0.8	1.7	0.9	0.6	0.8	**52.1**	0.0	0.5	1.0	0.0	**37.5**
17	**Off-chan. RM 10.7 R bank**	EF-20	3.0	1.3	0.5	1.3	1.2	0.8	1.7	0.9	0.3	1.2	**52.1**	2.0	0.0	1.0	0.0	**75.0**
22	**Lockwood Cr. floodplain**		3.0	1.0	2.0	1.2	0.5	0.4	2.0	0.9	0.9	0.0	**49.5**	0.0	0.5	1.0	0.0	**37.5**
7	**Off-chan. RM 7.85 L bank**		3.0	1.3	1.5	1.5	0.4	0.8	2.0	0.5	0.8	0.0	**48.5**	0.7	0.5	0.0	0.2	**33.3**
13	**Off-chan. RM 9.7 R bank**	EF-25	3.0	1.0	1.2	1.3	1.2	0.4	1.7	0.9	0.3	0.8	**48.5**	0.0	0.2	1.0	0.0	**29.2**
29	**Beaver dam complex near Dean Cr.**		4.0	1.0	1.5	0.5	0.4	0.8	2.0	0.7	0.9	0.0	**48.5**	1.0	0.5	1.0	0.5	**75.0**
14	**Off-chan. RM 10.2 R bank**	EF-22	3.0	1.0	1.2	1.5	0.9	0.8	1.7	0.5	0.3	0.8	**47.2**	0.3	0.0	1.0	0.0	**33.3**
8	**Off-chan. RM 7.95 R bank**		3.0	1.0	1.3	1.7	0.5	0.8	2.0	0.5	0.6	0.0	**45.4**	0.3	0.2	0.0	0.2	**16.7**
5	**Daybreak Pits**		3.0	1.3	1.5	1.5	0.5	0.8	1.0	0.5	0.6	0.3	**42.3**	0.0	0.5	1.0	0.0	**37.5**
16	**Off-chan. RM 10.7 L bank**		3.0	1.0	0.7	1.5	0.8	0.8	1.7	0.7	0.6	0.0	**40.3**	2.0	0.5	1.0	0.0	**87.5**
9	**Off-chan. RM 8.9**		3.0	1.0	1.2	0.5	0.8	0.4	1.3	0.2	0.5	0.0	**26.4**	2.0	0.5	0.0	0.0	**62.5**

Table 6b. Potential thermal refuge project sites, shown in descending order by social score.

			Ecological Score Results (LCEP Average)											Social Constraints Score Results (LCEP Average)				
Site ID	**Location**	**HRP Site ID**	CW Source (1–4)	Size (1–3)	Fills Gap (0.5–2)	Mainstem Proximity (1–2)	Habitat Quality (0.4–1.2)	DOE Gaining Reach (0.4–0.8)	Treatment Strategy (1–2)	Physical Processes (0–1.4)	Riparian Uplift Pot. (0.3–0.9)	EF HRP Priority (0–1.2)	**Normalized Ecological Score (0-100)**	Owner-ship (0–2)	Construction Access (0–0.5)	Incuded in Active Project? (0–1)	Partner Support (0.5–1)	**Normalized Social Score (0-100)**
1	**EF Mainstem RM 4.5–5.5**		2.3	3.0	2.0	2.0	0.8	0.8	2.0	0.9	0.8	0.0	**70.5**	2.0	0.5	1.0	0.3	**95.8**
27	**Off-chan. RM 12.5, R bank**	EF-11	3.0	1.3	2.0	1.5	0.8	0.8	1.7	0.9	0.6	0.8	**61.0**	2.0	0.5	1.0	0.0	**87.5**
18	**Off-chan. RM 11.5 R bank**	EF-16	3.0	1.0	1.3	1.5	0.9	0.8	1.7	0.9	0.5	0.8	**53.6**	2.0	0.5	1.0	0.0	**87.5**
2	**Off-chan. RM 6.3 L Bank**		3.0	1.7	1.2	1.5	0.8	0.8	1.7	1.2	0.6	0.0	**52.8**	2.0	0.5	1.0	0.0	**87.5**
16	**Off-chan. RM 10.7 L bank**		3.0	1.0	0.7	1.5	0.8	0.8	1.7	0.7	0.6	0.0	**40.3**	2.0	0.5	1.0	0.0	**87.5**
23	**Mason Cr. floodplain**	MS-01	4.0	1.3	2.0	0.7	0.4	0.8	2.0	1.4	0.9	1.2	**70.8**	2.0	0.5	0.0	0.5	**75.0**
20	**Side chan. RM 13.7 L bank**	EF-07	3.0	1.7	2.0	1.5	1.2	0.4	1.7	0.7	0.3	0.8	**59.5**	2.0	0.0	1.0	0.0	**75.0**
17	**Off-chan. RM 10.7 R bank**	EF-20	3.0	1.3	0.5	1.3	1.2	0.8	1.7	0.9	0.3	1.2	**52.1**	2.0	0.0	1.0	0.0	**75.0**
29	**Beaver dam complex near Dean Cr.**		4.0	1.0	1.5	0.5	0.4	0.8	2.0	0.7	0.9	0.0	**48.5**	1.0	0.5	1.0	0.5	**75.0**
10	**Side chan. RM 9-9.5 R bank**	EF-28	3.0	3.0	0.7	1.2	0.9	0.4	2.0	1.4	0.4	1.2	**66.7**	2.0	0.5	0.0	0.3	**70.8**
15	**Side chan. RM 10.3-10.8 R bank**		3.7	3.0	1.8	1.5	1.2	0.8	2.0	1.4	0.4	0.0	**79.2**	1.3	0.0	1.0	0.3	**66.7**
9	**Off-chan. RM 8.9**		3.0	1.0	1.2	0.5	0.8	0.4	1.3	0.2	0.5	0.0	**26.4**	2.0	0.5	0.0	0.0	**62.5**
24	**Dean Creek floodplain**	DE-01/-02	4.0	1.3	1.5	0.5	0.4	0.8	2.0	0.9	0.9	1.2	**62.1**	1.0	0.5	0.3	0.3	**54.2**
12	**Off-chan. RM 9.4 L Bank (Mill/Manley conf.)**		4.0	2.7	1.8	1.5	1.2	0.4	2.0	0.9	0.4	0.8	**78.7**	0.7	0.3	1.0	0.0	**50.0**
25	**Mason Cr. confluence**		4.0	1.0	2.0	2.0	0.8	0.8	2.0	0.2	0.7	0.0	**61.8**	1.0	0.5	0.0	0.2	**41.7**
28	**Manley Cr. floodplain**	MN-02	4.0	2.0	1.5	0.5	0.4	0.4	2.0	1.4	0.9	1.2	**67.7**	0.0	0.5	1.0	0.0	**37.5**
4	**Off-chan. RM 6.6 R bank**	EF-38	3.0	1.7	1.5	1.5	0.5	0.8	2.0	0.9	0.8	0.8	**61.8**	0.0	0.5	1.0	0.0	**37.5**
19	**Off-chan. RM 12 L bank**	EF-13	3.0	1.0	2.0	1.0	1.2	0.8	1.7	0.9	0.5	1.2	**60.0**	0.0	0.5	1.0	0.0	**37.5**
26	**Lockwood Cr. confluence**		4.0	1.0	2.0	2.0	0.4	0.4	2.0	0.0	0.7	0.0	**53.8**	0.0	0.5	1.0	0.0	**37.5**
3	**Off-chan. RM 6.4 R bank**	EF-39	2.3	1.7	1.2	1.5	0.8	0.8	1.7	0.9	0.6	0.8	**52.1**	0.0	0.5	1.0	0.0	**37.5**
22	**Lockwood Cr. floodplain**		3.0	1.0	2.0	1.2	0.5	0.4	2.0	0.9	0.9	0.0	**49.5**	0.0	0.5	1.0	0.0	**37.5**
5	**Daybreak Pits**		3.0	1.3	1.5	1.5	0.5	0.8	1.0	0.5	0.6	0.3	**42.3**	0.0	0.5	1.0	0.0	**37.5**
7	**Off-chan. RM 7.85 L bank**		3.0	1.3	1.5	1.5	0.4	0.8	2.0	0.5	0.8	0.0	**48.5**	0.7	0.5	0.0	0.2	**33.3**
14	**Off-chan. RM 10.2 R bank**	EF-22	3.0	1.0	1.2	1.5	0.9	0.8	1.7	0.5	0.3	0.8	**47.2**	0.3	0.0	1.0	0.0	**33.3**
13	**Off-chan. RM 9.7 R bank**	EF-25	3.0	1.0	1.2	1.3	1.2	0.4	1.7	0.9	0.3	0.8	**48.5**	0.0	0.2	1.0	0.0	**29.2**
21	**Off-chan. RM 14.1 L bank**	EF-05	3.7	1.0	2.0	1.5	1.2	0.4	2.0	0.9	0.3	0.8	**63.8**	0.0	0.0	1.0	0.0	**25.0**
6	**Ridgefield Pits 7/8**		3.0	2.7	1.3	1.7	0.4	0.8	1.7	0.9	0.7	0.0	**59.0**	0.7	0.2	0.0	0.2	**25.0**
11	**Side chan. along Storedahl**		3.0	2.7	1.5	0.5	0.8	0.8	2.0	0.9	0.4	0.0	**54.6**	0.3	0.5	0.0	0.2	**25.0**
8	**Off-chan. RM 7.95 R bank**		3.0	1.0	1.3	1.7	0.5	0.8	2.0	0.5	0.6	0.0	**45.4**	0.3	0.2	0.0	0.2	**16.7**

4.5 THERMAL REFUGE POTENTIAL PROJECT DESCRIPTIONS

Name/Location: East Fork mainstem, RM 4.5–6.0 **ID#:** 01

EF River Mile: 4.5–6.0

EDT Reach Tier: 1 (EF Lewis 4A, 4B, 4C)

Temperature Dependent Species Use: coho (migration, rearing) (HRP, 2009)

Location Description: 1.5-mile reach of lower EFLR mainstem, including both sides of river from approximately Lockwood Cr. downstream to Mason Cr. upstream.

Site Description: Tidal section of river (up to ~RM 5.7) with low gradient. Bank incision and levees limit floodplain connectivity. Within a WA DOE gaining reach. Limited riparian cover on both banks, however revegetation efforts are occurring along L bank. Some large wood is present however potential recruitment is limited. Left bank is Clark County owned floodplain. R bank is mostly private ownership.

Site Thermal Conditions: TIR imagery collected in 2020 indicated a downstream cooling trend of > 1°C through this reach however we did not observe any decrease during field verification in summer 2022. A few very small, isolated pockets of cooler water at the bed were observed during this time, particularly at the tributary confluences.

Project Objective: Enhance existing habitat conditions through large wood placements and continued riparian bank revegetation, particularly along publicly owned L bank.

Special Considerations: This location was selected for a potential project based on results of TIR imagery which indicated a possible downstream cooling trend in this reach. This trend was not observed during subsequent field surveys, however small pockets of colder water were found which could potentially still benefit from proposed enhancement work.

Data Gaps/Needs: Higher resolution temperature data throughout reach, and fish monitoring at detected cold-water locations to confirm use by juvenile salmonids during summer months.

Name/Location: Off-channel RM 6.3 L bank **ID#:** 02

EF River Mile: 6.3

EDT Reach Tier: 1 (EF Lewis 5A)

Temperature Dependent Species Use: Chinook (spawning, rearing, migration); coho (migration, rearing); steelhead (migration, rearing) (HRP, 2009)

Location Description: Off-channel area along L bank, upstream of Mason Creek confluence. Ownership unclear but appears private. Within a WA DOE gaining reach.

Site Description: Relic channel scar with water present in summer. Mainstem in this section has moderate gradient relative to upstream and downstream.

Site Thermal Conditions: TIR imagery did not detect colder water here relative to the mainstem. Field visits were not conducted.

Project Objective: Utilize existing favorable elevation gradient and possible groundwater gains (project is within DOE gaining reach) to enhance hyporheic exchange and potential groundwater augmentation. Subsequent riparian enhancement to reduce solar heating if initial objective is accomplished.

Special Considerations: May be on privately owned land.

Data Gaps/Needs: Ground-based temperature observations; groundwater/hyporheic zone assessment to determine potential for groundwater/hyporheic connection.

Name/Location: Off-channel RM 6.4 R bank **ID#:** 03

EF River Mile: 6.4

EDT Reach Tier: 1 (EF Lewis 5A)

Temperature Dependent Species Use: Chinook (spawning, rearing, migration); coho (migration, rearing); steelhead (migration, rearing) (HRP, 2009)

Location Description: Off-channel area along R bank, upstream of Mason Creek confluence. Ownership unclear but appears private. Within a WA DOE gaining reach.

Site Description: Relic channel scar with water present in summer. Mainstem in this section has moderate gradient relative to upstream and downstream. Identified as a potential project site in the EFL Habitat Restoration Plan (Site EF 39, HRP 2009)

Site Thermal Conditions: TIR imagery did not detect colder water here relative to the mainstem. Field visits were not conducted.

Project Objective: Utilize existing favorable elevation gradient and possible groundwater gains (project is within DOE gaining reach) to enhance hyporheic exchange and potential groundwater augmentation. Subsequent riparian enhancement to reduce solar heating if initial objective is accomplished.

Special Considerations: May be on privately owned land.

Data Gaps/Needs: Ground-based temperature observations; groundwater/hyporheic zone assessment to determine potential for groundwater/hyporheic connection.

Name/Location: Off-channel RM 6.6 R bank **ID#:** 04

EF River Mile: 6.6

EDT Reach Tier: 1 (EF Lewis 5B)

Temperature Dependent Species Use: Chinook (spawning, rearing, migration); coho (migration, rearing); steelhead (migration, rearing) (HRP 2009)

Location Description: Off-channel area along R bank, upstream of Mason Creek confluence. Privately owned. Within a WA DOE gaining reach. A chum channel restoration project was completed here previously by Friends of the East Fork.

Site Description: Off-channel location downstream of Dyer Creek. Identified as a potential project site in the EFL Habitat Restoration Plan (Site EF 38, HRP 2009)

Site Thermal Conditions: TIR imagery indicated cold water in the channel however this could be a false positive measurement (see discussion above in Section 4.1.1). On the ground measurements in summer of 2022 at location where feature enters the mainstem confluence were warmer than the mainstem at the time (22.5 versus 21.9 °C). Further up in channel was not measured.

Project Objective: Potentially improve downstream connection to mainstem to improve fish access during summer baseflow months (without compromising existing thermal conditions, if they are found to be favorable). Restore riparian bank vegetation along lower portion of the channel.

Special Considerations: Privately owned land. Unclear if the channel remains cold during summer months - it was selected based on results of TIR imagery, which need on the ground verification. Selected actions should complement, rather than detract from the prior restoration work completed here.

Data Gaps/Needs: Ground-based temperature observations; groundwater/hyporheic zone assessment to determine potential for groundwater/hyporheic connection.

Name/Location: Daybreak gravel pits **ID#:** 05

EF River Mile: 7.5–8

EDT Reach Tier: 1 (Dean Cr. 1B)

Temperature Dependent Species Use: coho (spawning, rearing); steelhead (spawning, rearing) (HRP 2009)

Location Description: Active Daybreak gravel mining site adjacent to former Ridgefield gravel pits.

Site Description: In-active Daybreak gravel mining pit ponds which are no longer being mined.

Site Thermal Conditions: Monitoring results from the Storedahl Daybreak Mine Habitat Conservation Plan indicate that the deeper ponds (#5,3) are stratified during summer with cooler waters to 12 °C located at depth and warmer surface temperatures.

Project Objective: Enhance thermal conditions in the adjacent reach of Dean Creek through introduction of colder water from the Daybreak ponds. This could be accomplished by pumping.

Special Considerations: Several, including private ownership by an active mining operation, lack of adequate flow in Dean Creek during summer, limited water volume in Daybreak Ponds. Future plans for the Daybreak Pits upon termination of the mining operation should also be considered.

Data Gaps/Needs: Additional information related to surface/groundwater exchange within the Dean Creek floodplain including the Daybreak Ponds (background information is available in the Storedahl Daybreak Pits Habitat Conservation Plan).

Name/Location: Ridgefield Pits #7/8 **ID#:** 06

EF River Mile: 7.5

EDT Reach Tier: 1 (EF Lewis 6B)

Temperature Dependent Species Use: Chinook (spawning, rearing); coho (spawning, rearing); steelhead (spawning, rearing) (HRP 2009)

Location Description: Former Ridgefield Pits gravel mining operation ponds #7/8. EF avulsion occurred in 1996.

Site Description: Water depths in both ponds are unknown. Pond #7 water quality may be poor due to stagnant water and extensive aquatic vegetation. The two ponds are separated by a large beaver dam during summer, which limits flow from Pond #8 to Pond #7.

Site Thermal Conditions: Pond #7 is connected to the mainstem EFLR and is warm during summer. Pit #8 is disconnected from the mainstem during summer and remains cold from groundwater input.

Project Objective: Increase flow from Pond #8 to Pond #7 through removal of beaver dam and re-grading. Add large wood to Pond #7 to enhance habitat and provide cover.

Special Considerations: This site is located within the larger Ridgefield Pits Floodplain Restoration project area and thus will be included as part of that project's actions (see Ridgefield Pits Preliminary Design Report (LCEP 2021) for details). Stand-alone project objective identified above could be considered if the larger Ridgefield Pits Floodplain Project is not implemented.

Data Gaps/Needs:

Name/Location: Off-channel RM 7.85 L bank **ID#:** 07

EF River Mile: 7.85

EDT Reach Tier: 1 (EF Lewis 6B)

Temperature Dependent Species Use: Chinook (spawning, rearing); coho (spawning, rearing); steelhead (spawning, rearing) (HRP 2009).

Location Description: Off-channel area in location of former Ridgefield gravel pit #2, where cold water was detected in TIR imagery and on the ground monitoring.

Site Description: Cold water was detected here in TIR imagery and multiple summers of on the ground monitoring. The site has seen rapid change since the 1996 avulsion, through filling and channel migration. Private ownership.

Site Thermal Conditions: Confirmed cold water. Little variation in diurnal temperature profile indicates likely groundwater presence.

Project Objective: As a stand-alone project this site would likely benefit from large wood placement and riparian revegetation. Potential grading to increase thermal refuge area may also be possible.

Special Considerations: This site is located within the larger Ridgefield Pits Floodplain Restoration project area and thus will be included as part of that project's actions (see Ridgefield Pits Preliminary Design Report (LCEP 2021) for details). Stand-alone project objective identified above could be considered if the larger Ridgefield Pits Floodplain Project is not implemented. Privately owned.

Data Gaps/Needs: Higher resolution Ground-based temperature observations; groundwater/hyporheic zone assessment to determine potential for groundwater/hyporheic connection (for stand-alone project concept).

Name/Location: Off-channel RM 7.95 R bank **ID#:** 08

EF River Mile: 7.95

EDT Reach Tier: 1 (EF Lewis 6B)

Temperature Dependent Species Use: Chinook (spawning, rearing); coho (spawning, rearing); steelhead (spawning, rearing) (HRP 2009)

Location Description: Off-channel area in location of former Ridgefield gravel pit #1, where cold water was detected in TIR imagery and on the ground monitoring.

Site Description: Cold water was detected here in TIR imagery and multiple summers of on the ground monitoring. The site has seen rapid change since the 1996 avulsion, through filling and channel migration. Private ownership.

Site Thermal Conditions: Confirmed cold water. Little variation in diurnal temperature profile indicates likely groundwater presence.

Project Objective: As a stand-alone project this site would likely benefit from large wood placement and riparian revegetation.

Special Considerations: This site is located within the larger Ridgefield Pits Floodplain Restoration project area and thus will be included as part of that project's actions (see Ridgefield Pits Preliminary Design Report (LCEP 2021) for details). Stand-alone project objective identified above could be considered if the larger Ridgefield Pits Floodplain Project is not implemented. Privately owned land.

Data Gaps/Needs: Higher resolution Ground-based temperature observations; groundwater/hyporheic zone assessment to determine potential for groundwater/hyporheic connection (for stand-alone project concept).

Name/Location: Off-channel RM 8.9 R bank **ID#:** 09

EF River Mile: 8.9

EDT Reach Tier: 1 (EF Lewis 6C)

Temperature Dependent Species Use: Chinook (spawning, rearing); coho (spawning, rearing); steelhead (spawning, rearing) (HRP 2009)

Location Description: Off-channel area north of EFLR mainstem adjacent to the Storedahl Daybreak mining operation.

Site Description: Ponded area, possible a former gravel mining pond remnant. Cold water was detected here while verifying TIR imagery with on the ground monitoring in 2022 (the site was not covered in the TIR survey, however). Poor current habitat quality with stagnant water and dense aquatic vegetation. Public ownership (Clark County).

Site Thermal Conditions: Cold water was detected here while verifying TIR imagery with on the ground monitoring in 2021 (the site was not covered in the TIR survey, however).

Project Objective: Connect to adjacent cold off-channel locations (potentially Sites #10 and/or #11) through grading to create a larger network of thermal refuge in this area. Additional enhancement through large wood placements.

Special Considerations:

Data Gaps/Needs:

Name/Location: Side-channel RM 9-9.5 R bank **ID#:** 10

EF River Mile: 9.0–9.5

EDT Reach Tier: 1 (EF Lewis 6C)

Temperature Dependent Species Use: Chinook (spawning, rearing); coho (spawning, rearing); steelhead (spawning, rearing) (HRP 2009)

Location Description: Side-channel north of EFLR upstream of Daybreak mine operation.

Site Description: Relic channel location north of mainstem EFLR. Limited or no connection to mainstem during baseflow conditions. Unclear to what extent this channel receives groundwater, but it is heavily shaded so solar radiation is limited. Monitoring indicates surface water is maintained throughout the summer months. Habitat quality appears to be good. Public ownership (Clark County). Identified as a potential project site in the EFL Habitat Restoration Plan (Site EF 28, HRP 2009)

Site Thermal Conditions: Cold water was detected here while verifying TIR imagery with on the ground monitoring in 2021.

Project Objective: Enhancements could include large wood addition, grading, and beaver dam analogs. Apex log jams could be placed at the upstream connection to the mainstem EFLR to encourage scour and split flow into the side channel (at desired times).

Special Considerations:

Data Gaps/Needs:

Name/Location: Side-channel along Storedahl Daybreak mining operation **ID#:** 11

EF River Mile: 7.5–8.5

EDT Reach Tier: 1 (EF Lewis 6B, 6C)

Temperature Dependent Species Use: Chinook (spawning, rearing); coho (spawning, rearing); steelhead (spawning, rearing) (HRP 2009).

Location Description: Side-channel north of EFLR adjacent to Storedahl Daybreak mine operation.

Site Description: Relic channel path connecting a series of off-channel ponded areas near the downstream end that maintain cold water throughout the summer, possibly due to groundwater/ seepage from the Daybreak Pits. Connected to the mainstem through Ridgefield Pit #7 during high flow months, but largely disconencted during the summer. Upper end of the channel remains mostly dry during summer. Good riparian cover further upstream but lacking cover around the ponded areas downstream. Private ownership throughout.

Site Thermal Conditions: Confirmed cold water. Little variation in diurnal temperature profile indicates likely groundwater presence.

Project Objective: As a stand-alone project this site would likely benefit from large wood placement and riparian revegetation. Potential grading to increase thermal refuge area may also be possible, potentially connecting with Site 9 at the upstream end.

Special Considerations: This site is located within the larger Ridgefield Pits Floodplain Restoration project area and thus will be included as part of that project's actions (see Ridgefield Pits Preliminary Design Report (LCEP 2021) for details). Stand-alone project objective identified above could be considered if the larger Ridgefield Pits Floodplain Project is not implemented. Privately owned.

Data Gaps/Needs:

Name/Location: Off-channel RM 9.4 L bank. Mill/Manley confluence zone **ID#:** 12

EF River Mile: 9.4

EDT Reach Tier: 1 (EF Lewis 6C)

Temperature Dependent Species Use: Chinook (spawning, rearing); coho (spawning, rearing); steelhead (spawning, rearing) (HRP 2009)

Location Description: Confluence of Mill and Manley creeks with lower EFLR.

Site Description: Mill Creek flows directly to the lower EFLR, entering just downstream of a large partially vegetated gravel/cobble bar. Manley Creek enters a beaver dam complex with ponded off-channel areas that drain to Mill Creek just above the confluence with the mainstem. Both creeks, and the beaver dam complex, maintain cold water throughout the summer. Mill Creek is thought to be receiving large amounts of sediment due to WADOT roadwork upstream that has created stream diversions and rerouting. These impacts may degrade potential work done at this site. Private ownership in confluence zone, some public land within the beaver dam complex. Identified as a potential project site in the EFL Habitat Restoration Plan (Site EF 27, 2009)

Site Thermal Conditions: Cold water was detected here in TIR imagery and in several on the ground monitoring studies. Known cold water source and juvenile rearing area.

Project Objective: Enhancements could include large wood addition within the beaver dam complex to enhance rearing potential, grading to expand thermal refuge area and/or improve fish access. Sediment issues in Mill Creek due to transpoupstream

Special Considerations: Private ownership. Sediment issues in Mill Creek, lower EFLR channel migration near confluence zone.

Data Gaps/Needs: Sediment issues in Mill Creek due to upstream transportation projects need to be studied to assess potential for any work at the confluence zone. Mainstem EFLR is migrating to the north in the vicinity of the confluence zone, which could also compromise work done here.

Name/Location: Off-channel RM 9.7 R bank **ID#:** 13

EF River Mile: 9.7

EDT Reach Tier: 1 (EF Lewis 6C)

Temperature Dependent Species Use: Chinook (spawning, rearing); coho (spawning, rearing); steelhead (spawning, rearing) (HRP 2009)

Location Description: River right across from West Daybreak floodplain area.

Site Description: Old channel locations, within 100' of existing mainstem channel Likely active at moderate winter flow levels but not active during summer baseflow conditions. This is an active channel adjustment, which needs to be considered during design. Identified as a potential project site in the EFL Habitat Restoration Plan (Site EF 25, 2009)

Site Thermal Conditions: Not studied. No water is typically present in summer.

Project Objective: Potentially create thermal refuge location by reactivating channel through grading and establishing groundwater/hyporheic connectivity.

Special Considerations: Private ownership. Channel not currently active during summer months.

Data Gaps/Needs: Groundwater assessment to determine potential for channel activation.

Name/Location: Off-channel RM 10.2 R bank **ID#:** 14

EF River Mile: 10.2

EDT Reach Tier: 1 (EF Lewis 8A)

Temperature Dependent Species Use: Chinook (spawning, rearing); coho (spawning, rearing); steelhead (spawning, rearing) (HRP 2009)

Location Description: River right just upstream from Daybreak Bridge.

Site Description: Off-channel location perched ~5' above the mainstem downstream, possibly due to scour at the bridge location. Good riparian condition. Identified as a potential project site in the EFL Habitat Restoration Plan (Site EF 22, HRP 2009)

Site Thermal Conditions: Cold water (4 °C cooler than the mainstem) was identified at this location in the EFLR Habitat Restoration Plan (HRP 2009). Suggests hyporheic or spring flow into the area. TIR imagery indicates cold water here, but this may be a false reading due to shadows. Not field verified.

Project Objective: Potentially create, or enhance existing, thermal refuge through grading. Add large wood to further enhance rearing habitat.

Special Considerations: Private ownership. Project would require a detailed scour analysis sufficient to meet bridge program requirements and must be approved by bridge program manager prior to starting work. Could be grouped with Sites 15,16,17 for a larger project in this area.

Data Gaps/Needs: Additional temperature monitoring. Groundwater/hyporheic assessment to determine potential for channel activation.

Name/Location: Side-channel RM 10.3–10.8 R bank **ID#:** 15

EF River Mile: 10.3–10.8

EDT Reach Tier: 1 (EF Lewis 8A, 8B)

Temperature Dependent Species Use: Chinook (spawning, rearing); coho (spawning, rearing); steelhead (spawning, rearing) (HRP 2009).

Location Description: Side-channel along R bank upstream of Daybreak Bridge.

Site Description: This was the former main channel location until the river began a gradual migration to a smaller side channel to the west roughly 20 years ago, which became the main channel approx. 10 years ago. The area is now a series of beaver dam complexes, fed by a small tributary (Charter Oak Creek). It is unclear to what extent this area receives inundation from the mainstem, but it remains disconnected during summer months at the upstream end. Property ownership extent within the wetted area is unclear. The adjacent hillside to the east is privately owned, while the wooded floodplain area to the west is owned by Clark County. Riparian cover over the wetted area is poor, with little canopy cover.

Site Thermal Conditions: Confirmed cold water throughout in both TIR imagery and on the ground measurements. A temperature logger was installed but was lost so an extended temperature record is not available.

Project Objective: Enhance existing thermal refuge habitat through wood placements and riparian revegetation. Potentially add apex wood jams at upstream end to encourage split flow and increased inundation from the mainstem during high flow conditions, to promote scour and flushing. This is the largest area of existing cold water for the lower EFLR that was identified in this study, and adjacent privately owned areas should be prioritized for protection/acquisition.

Special Considerations: Potential private ownership. Extensive beaver activity in the area. Could be grouped with Sites 14,16,17 for a larger project in this area.

Data Gaps/Needs: Long term temperature records throughout the beaver dam complexes and in Charter Oak Creek.

Name/Location: Off-channel RM 10.7 L bank **ID#:** 16

EF River Mile: 10.7

EDT Reach Tier: 1 (EF Lewis 8B)

Temperature Dependent Species Use: Chinook (spawning, rearing); coho (spawning, rearing); steelhead (spawning, rearing) (HRP 2009).

Location Description: Small off-channel area adjacent to a large gravel bar on river left upstream of Daybreak Bridge.

Site Description: Partially vegetated gravel and cobble bar with a small backwater area partially connected to the mainstem at the downstream end during base flow months. Frequency of upstream connection unknown. Public land owned by Clark County.

Site Thermal Conditions: TIR imagery indicated cold water presence here, which was verified with on the ground measurements. Extent of cold water was quite limited during field visit in summer 2021.

Project Objective: Enhance thermal refuge potential and access through grading, wood placement and riparian revegetation. Potentially add apex wood jams at upstream end to encourage split flow and increased inundation from the mainstem during high flow conditions, to promote scour and flushing.

Special Considerations: This is in an active mainstem channel migration area so long term stability and risk of potential avulsion due to project actions must be considered. Could be grouped with Sites 14,15,17 for a larger project in this area.

Data Gaps/Needs: Long term temperature records. Groundwater/hyporheic assessment.

Name/Location: Off-channel RM 10.7 R bank **ID#:** 17

EF River Mile: 10.7

EDT Reach Tier: 1 (EF Lewis 8B)

Temperature Dependent Species Use: Chinook (spawning, rearing); coho (spawning, rearing); steelhead (spawning, rearing) (HRP 2009)

Location Description: River right floodplain upstream from Daybreak Bridge.

Site Description: This is an old meander scar/overflow channel, not connected at summer flow levels. There are good gravels and existing LWD present. Site temperatures suggest suitable groundwater connectivity. Identified as a potential project site in the EFL Habitat Restoration Plan (Site EF 22, HRP 2009) and a project was implemented by Clark County, who owns the property, in 2013-2015.

Site Thermal Conditions: TIR imagery was inconclusive, however prior studies supporting the EFL HRP indicated presence of cold water and potential groundwater connectivity. It was not visited as part of the present study.

Project Objective: Potentially create, or enhance existing, thermal refuge through grading to increase groundwater connectivity. Add large wood to further enhance rearing habitat. Any project actions should complement restoration work that has already been done at the site by Clark County.

Special Considerations: Project actions should not jeopardize restoration actions that have been implemented at the site by Clark County. Could be grouped with Sites 14,15,16 for a larger project in this area.

Data Gaps/Needs: Additional temperature monitoring. Groundwater/hyporheic assessment to determine potential for channel activation.

Name/Location: Off-channel RM 11.5 R bank **ID#:** 18

EF River Mile: 11.5

EDT Reach Tier: 1 (EF Lewis 8B)

Temperature Dependent Species Use: Chinook (spawning, rearing); coho (spawning, rearing); steelhead (spawning, rearing) (HRP 2009)

Location Description: River right floodplain upstream from Daybreak Bridge.

Site Description: This is an old meander scar/overflow channel. Identified as a potential project site in the EFL Habitat Restoration Plan (Site EF 22, HRP 2009) and a project was implemented by Clark County, who owns the property, in approximately 2015 (SalmonPort Proj ID 11-1313).

Site Thermal Conditions: TIR imagery was inconclusive, however on the ground monitoring in summer 2022 confirmed cold water presence in the restored side channel (temperatures ranging from 11.9 to 14 °C). Prior study supporting the EFL HRP also indicated presence of cold water and potential groundwater connectivity. It is unclear how the restoration project implemented by Clark County has impacted thermal conditions at the site since then.

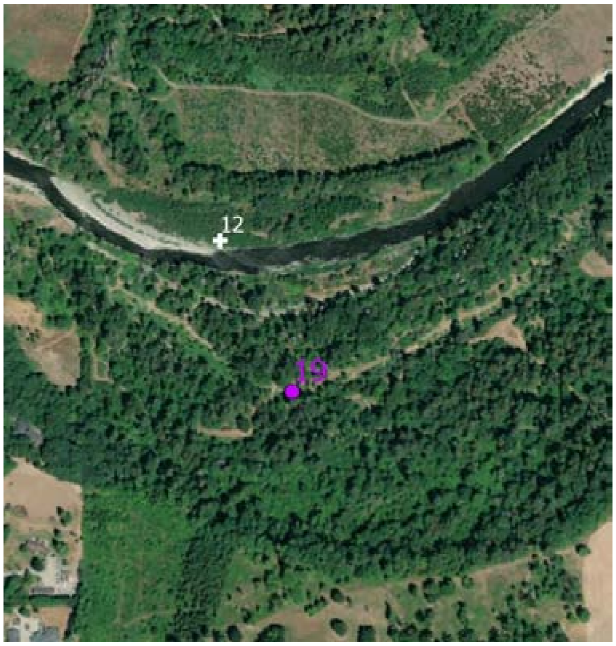
Project Objective: Potentially create, or enhance existing, thermal refuge through grading to increase groundwater connectivity. Add large wood to further enhance rearing habitat. Improve connection to the mainstem at

downstream end of channel to improve fish access. Currently, the site drains through a small opening in a levee-like feature (shown in top photo, looking from mainstem). This must be done without compromising thermal characteristics of the site. Any project actions should complement the restoration work that has been done at the site by Clark County.

Special Considerations: Project actions should not jeopardize restoration actions that have been implemented at the site by Clark County.

Data Gaps/Needs: Additional temperature monitoring. Groundwater/hyporheic assessment to determine potential for increased channel activation. Topographic data to assess downstream connectivity.

Name/Location: Side/off-channel RM 12 L bank **ID#:** 19



EF River Mile: 11.7–12.3

EDT Reach Tier: 1 (EF Lewis 8B)

Temperature Dependent Species Use: Chinook (spawning, rearing); coho (spawning, rearing); steelhead (spawning, rearing) (HRP 2009)

Location Description: River left off-channel complex.

Site Description: Large network of abandoned meander scars. Small tributary with temperatures ~2° less than mainstem, according to the EFL Habitat Restoration Plan (Site EF 13, HRP 2009). The site was not visited during the present study. Private ownership.

Site Thermal Conditions: Unknown other than information provided in the EFL Habitat Restoration Plan. TIR imagery was inconclusive, and the site was not assessed on the ground in this study.

Project Objective: Potentially create, or enhance existing, thermal refuge through grading to increase groundwater connectivity. Add large wood to further enhance rearing habitat.

Special Considerations: Private land ownership.

Data Gaps/Needs: Additional temperature monitoring. Groundwater/hyporheic assessment to determine potential for channel activation.

Name/Location: Side channel RM 13.7 L bank **ID#:** 20

EF River Mile: 13.7–13.9

EDT Reach Tier: 1 (EF Lewis 8B)

Temperature Dependent Species Use: Chinook (spawning, rearing); coho (spawning, rearing); steelhead (spawning, rearing) (HRP 2009)

Location Description: River left side channel across from Lewisville Park.

Site Description: Existing side channel, with lack of channel structure, complexity, and spawning size gravels. Identified as a potential project site in the EFL Habitat Restoration Plan (Site EF 07, HRP 2009). Public ownership (Clark County).

Site Thermal Conditions: TIR imagery indicated presence of cold water however ground assessments determined that these were false readings due to shadow and hillslope effects. Temperatures were found to be equivalent to the mainstem throughout the channel.

Project Objective: Utilize engineered streambed approach to create thermal refuge pockets by establishing hyporheic flow which re-expresses downstream as colder surface water. See Bakke et al (2020) for an example of successful implementation of this concept in an urban stream in Seattle. Potentially add spawning gravels and other habitat enhancements such as large wood placements.

Special Considerations: Need to evaluate potential flow reduction and other effects on the mainstem if this project were to be implemented.

Data Gaps/Needs: Additional temperature monitoring. Groundwater/hyporheic assessment to determine potential for channel activation. Topographic data to assess channel gradients (mainstem and side-channel).

Name/Location: Off-channel RM 14.1 L bank **ID#:** 21

EF River Mile: 14.1

EDT Reach Tier: 1 (EF Lewis 8B)

Temperature Dependent Species Use: Chinook (spawning, rearing); coho (spawning, rearing); steelhead (spawning, rearing) (HRP 2009)

Location Description: River left near Boy Scout camp. Across river and just upstream from Lewisville Park swim beach.

Site Description: Located on Boy Scouts of America property. There is a small tributary that enters the mainstem here which contains cool water during the summer. Good adjacent mainstem spawning habitat. Identified as a potential project site in the EFL Habitat Restoration Plan (Site EF 05, HRP 2009), which also highlighted its thermal potential.

Site Thermal Conditions: Not detected by TIR imagery, however on the ground assessment was done to verify findings in EF HRP. We measured temperatures of 10.5 °C in the tributary and 15-17 °C in the mainstem at the immediate confluence location during summer of 2022, confirming the HRP results.

Project Objective: As identified in the EF HRP: Create off-channel area connected to the mainstem at low summer flows that is sourced by hyporheic and tributary flow. Add additional habitat enhancement features including instream large wood and bank complexity.

Special Considerations: Private land, although landowner has expressed willingness to discuss project opportunities. Any potential landowner concerns such as erosion, flooding, or safety should be addressed in project design.

Data Gaps/Needs: Additional temperature monitoring. Dissolved oxygen, Groundwater/hyporheic assessment to determine potential for channel activation.

Name/Location: Lockwood Creek floodplain **ID#:** 22

EF River Mile: 4.5

EDT Reach Tier: 2 (L1)

Temperature Dependent Species Use: coho (spawning, rearing); steelhead (spawning, rearing) (HRP 2009)

Location Description: Lockwood Creek floodplain just upstream of confluence with mainstem.

Site Description: The west (R) bank of Lockwood Creek at its confluence with the mainstem has little riparian cover and may be exposed to significant solar heating during summer afternoons as a result. The site is privately owned.

Site Thermal Conditions: Lockwood Creek is at least 2 degrees cooler than the mainstem where it enters the mainstem, creating potential thermal refuge habitat.

Project Objective: Riparian revegetation along the R bank to reduce solar heating during summer afternoons.

Special Considerations: Private ownership. Unclear if there is currently any shading provided by shrub canopy and steep banks along Lockwood Creek at confluence zone.

Data Gaps/Needs: Shade assessment.

Name/Location: Mason Creek floodplain **ID#:** 23

EF River Mile: 6

EDT Reach Tier: 2 (M1)

Temperature Dependent Species Use: coho (spawning, rearing); steelhead (spawning, rearing) (HRP 2009)

Location Description: Mason Creek floodplain.

Site Description: The floodplain portion of Mason Creek has experienced channel simplification, incision, lack of wood cover and invasive vegetation growth over the last several decades, due to historical channel relocations, riparian clearing and agricultural use. The floodplain is a combination of private ownership and Clark County land.

Site Thermal Conditions: Mason Creek remains at least 3-4 °C cooler than the mainstem EFLR during the summer. This has been confirmed in this study as well as past monitoring efforts.

Project Objective: Enhance channel structure and habitat. Enhance the quantity and quality of habitat features including pools and riffles, bank complexity and cover, and instream wood placements. Increase availability of off-channel habitat that is connected to Mason Creek during summer flow levels. Look for opportunities to increase floodplain connectivity. Reforest riparian and floodplain areas with native and locally-adapted species.

Special Considerations: Partial private ownership. County has recently acquired some of the land, and this project is currently in a design phase sponsored by LCEP. See Mason Creek Preliminary Design Report for additional detail (LCEP, 2022).

Data Gaps/Needs:

Name/Location: Dean Creek floodplain **ID#:** 24

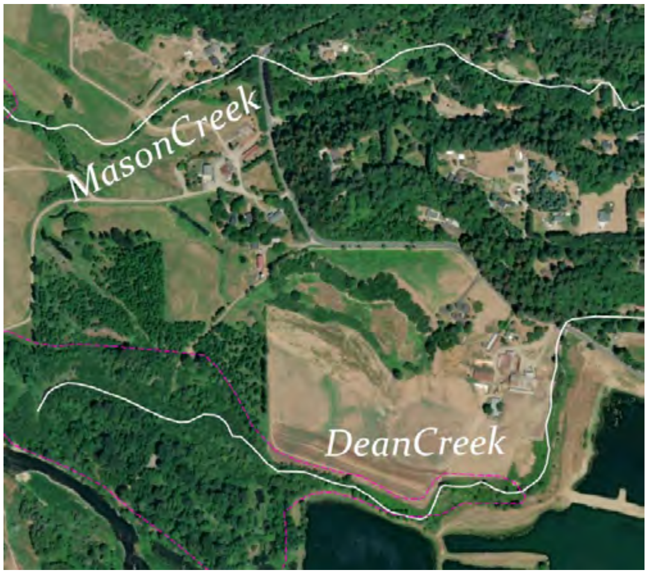
EF River Mile: 7.2

EDT Reach Tier: 2 (D1)

Temperature Dependent Species Use: coho (spawning, rearing); steelhead (spawning, rearing) (HRP 2009)

Location Description: Dean Creek floodplain upstream and downstream of Storedahl property,

Site Description: The floodplain portion of Dean Creek has been heavily impacted and has many of the same issues as the Mason Creek floodplain, in addition to being impacted by adjacent mining operations. These include channel incision, lack of floodplain connectivity, lack of channel structure and habitat, degraded riparian conditions, and abundant invasive species. The floodplain portion of Dean Creek is also subject to high temperatures, little to no flow, and pollution (sediment, fecal coliform) during most of the summer. The floodplain is mostly in private ownership through and above the Storedahl Daybreak mines, and Clark County land downstream of Storedahl to the confluence.



Site Thermal Conditions: Dean has little to no flow throughout much of the summer but is subject to high temperatures when flow is present during this period.

Project Objective: Enhance channel structure and habitat. Enhance the quantity and quality of habitat features including pools and riffles, bank complexity and cover, and instream wood placements. Increase availability of off-channel habitat that is connected to Dean Creek during summer flow levels. Look for opportunities to increase floodplain connectivity. Reforest riparian and floodplain areas with native and locally adapted species. Potentially re-route Dean Creek into Mason Creek through the Swanson Channel, a series of Beaver Ponds which are spring fed and thought to retain colder water during the summer months.

Special Considerations: Private ownership. Little to no surface flow in Dean Creek throughout much of the summer could inhibit implementing a project here.

Data Gaps/Needs: Temperature and surface flow duration data for summer months. Groundwater/hyporheic study to understand ground/surface water exchange and assess potential channel activation during summer.

Name/Location: Mason Creek confluence **ID#:** 25

EF River Mile: 6

EDT Reach Tier: 1 (EF 5A); 2 (M1)

Temperature Dependent Species Use: Chinook (spawning, rearing, migration); coho (migration, rearing); steelhead (migration, rearing) (HRP 2009)

Location Description: Confluence of Mason Creek with lower EFLR mainstem.

Site Description: The Mason Creek confluence with the lower EFLR has experienced has experienced channel simplification, incision, and lack of wood cover. Some wood is present in the mainstem immediately upstream of the confluence, but this may not persist, and the confluence zone is devoid of cover. The R bank floodplain is privately owned, the L bank was recently purchased by Clark County.

Site Thermal Conditions: Mason Creek remains at least 3-4 °C cooler than the mainstem EFLR during the summer. This has been confirmed in this study and past monitoring efforts.

Project Objective: Enhance habitat at the confluence zone to provide cover and rearing habitat for juvenile salmonids, where cold water from Mason Creek enters the warmer mainstem EFLR. Actions would include large wood placement and riparian revegetation.

Special Considerations: Partial private ownership.

Data Gaps/Needs:

Name/Location: Lockwood Creek confluence **ID#:** 26

EF River Mile: 4.5

EDT Reach Tier: 1 (EF 4A); 2 (L1).

Temperature Dependent Species Use: coho (migration, rearing); steelhead (migration, rearing) (HRP 2009)

Location Description: Confluence of Lockwood Creek with lower EFLR mainstem.

Site Description: The Lockwood Creek confluence with the lower EFLR has experienced has experienced channel simplification, incision, and lack of wood cover. The confluence zone is also devoid of cover. Both banks at the confluence zone are privately owned.

Site Thermal Conditions: Lockwood Creek remains at least 2 °C cooler than the mainstem EFLR during the summer at the confluence zone. This has been confirmed in this study and past monitoring efforts.

Project Objective: Enhance habitat at the confluence zone to provide cover and rearing habitat for juvenile salmonids, where cold water from Lockwood Creek enters the warmer mainstem EFLR. Actions would include large wood placement and riparian revegetation.

Special Considerations: Private ownership.

Data Gaps/Needs:

Name/Location: Off-channel RM 12.5 R bank **ID#:** 27

EF River Mile: 12.5

EDT Reach Tier: 1 (EF 8B)

Temperature Dependent Species Use: Chinook (spawning, rearing); coho (migration, rearing); steelhead (migration, rearing) (HRP 2009)

Location Description: River right off-channel near RM 12.5.

Site Description: Old channel scar/backwater area that is disconnected from the mainstem during summer base flows. Public ownership (Clark County).

Site Thermal Conditions: TIR imagery did not indicate cold water here and no additional on the ground measurements were done for the present study. Monitoring completed for the EF HRP showed temperatures here being 5 °C warmer relative to the mainstem.

Project Objective: Potentially create thermal refuge through grading to increase groundwater connectivity. Add large wood to further enhance rearing habitat.

Special Considerations: Low gradient area with warm stagnant water may limit certainty of success. As a result, this project ranked low overall. Needs further assessment.

Data Gaps/Needs: Groundwater monitoring.

Name/Location: Manley Creek floodplain **ID#:** 28

EF River Mile: 4.5

EDT Reach Tier: 2 (Manley 1B).

Temperature Dependent Species Use: coho (migration, rearing); steelhead (migration, rearing) (HRP 2009)

Location Description: Lower Manley Creek downstream of 259th Ave.

Site Description: This portion of Manley Creek has experienced channel simplification and incision, severe riparian degradation, channel relocations, reduced wood cover, and invasive species proliferation due to residential development, transportation infrastructure, agriculture, and upstream gravel mining. The property is owned by Columbia Land Trust, with a memorandum of understanding that it will eventually be transferred to County ownership (HRP 2009).

Site Thermal Conditions: TIR imagery indicates presence of cold water. Although this was not verified on the ground during the study, monitoring results from further downstream in the beaver pond complex near the confluence with the EFRL, and other studies, suggest that lower Manley Creek remains cold enough throughout the summer to provide thermal refuge.

Project Objective: Habitat enhancements to existing thermal refuge location through large wood placement and riparian revegetation.

Special Considerations: Several other restoration efforts have occurred along this section of Manley Creek, including planting by Clark County and various actions by groups including Friends of the East Fork. Any additional actions directed at maintaining and improving thermal refuge conditions should complement these efforts rather than jeopardize their intended purposes.

Data Gaps/Needs:

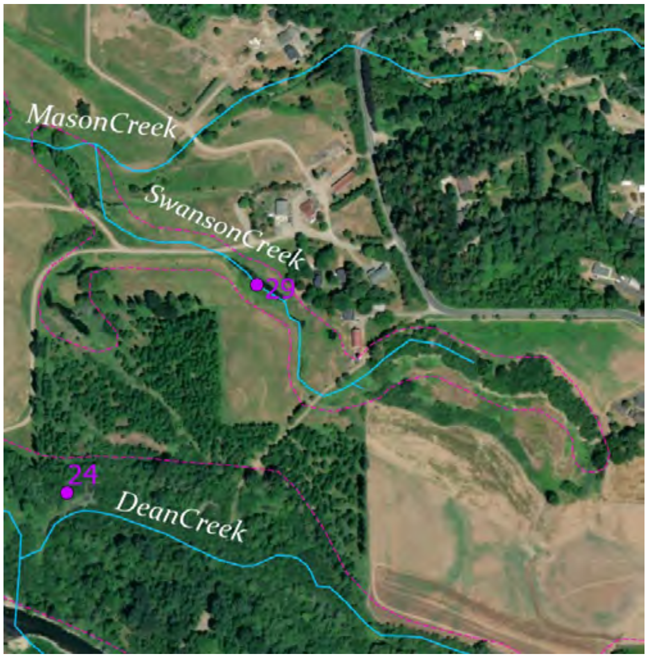
Name/Location: Beaver dam complex near Dean Creek (Swanson Creek) **ID#:** 29

EF River Mile: 7

EDT Reach Tier: 2 (Swanson Creek).

Temperature Dependent Species Use: coho (migration, rearing) (HRP 2009)

Location Description: Floodplain between Mason and Dean creeks.



Site Description: This series of ponded areas and disconnected sections of Swanson Creek within the larger Mason/Dean Creek floodplain was not assessed in the field as part of this study but was identified as an area of interest for potential thermal refuge by members of the Technical Oversight Group that are familiar with the area. As with other areas throughout this large floodplain, the site has experienced channel simplification, incision, lack of wood cover and invasive vegetation growth over the last several decades, due to historical channel relocations, riparian clearing and agricultural use. The site is a combination of private ownership and Clark County land.

Site Thermal Conditions: The site is outside of the extent of the TIR imagery that was collected and was not monitored on the ground in this study. Feedback received from members of the Technical Oversite Group suggest that these ponded areas are spring fed and remain cold during summer.

Project Objective: Habitat enhancements to existing thermal refuge location through large wood placement; riparian revegetation; potential grading to reconnect disconnected sections of creek and increase groundwater recharge; removal/modification of existing passage barriers. It was also suggested to potentially re-route Dean Creek through this area, into Mason Creek (see Dean Creek floodplain project #24 above).

Special Considerations: The site is largely privately owned with roads, residences, and active agriculture which may significantly limit opportunity here.

Data Gaps/Needs: Water temperature, groundwater assessment.

5 Summary and Conclusions

Elevated water temperature in the lower East Fork Lewis River (EFLR) of Washington during summer months is a well-documented issue that threatens the health and survival of multiple threatened and endangered salmonid species native to the river. The issue is expected to worsen due to effects of climate change and continued development within the watershed. Research has shown that salmonids utilizing various river systems during periods of elevated water temperatures, such as the EFLR during the summer, often seek out colder areas as respite from stress-inducing high temperatures (Torgersen et al. 2012, U.S. EPA 2021, Wang et al. 2022, others). These areas, referred to as 'thermal refuge' in this report and elsewhere, may be critical for survival of these species. This study addressed an identified need for mapping the thermal profile of the EFLR and its inundated floodplain areas during warm summer months and applying that information to 1) identify locations where thermal refuge for salmonids is currently available; and 2) develop a strategy for identifying additional thermal refuge opportunities.

We mapped surface water temperature at very high resolution (< 1 m) using airborne thermal-infrared (TIR) imagery, in August of 2020. We followed this with in-stream temperature measurements during summer of 2021 and 2022 to verify results of the TIR survey. Comparison of results revealed some limitations of the TIR technology for our application, including frequent false detections of cold water in areas with shadows resulting from tall canopy or steep hillsides; and some notable longitudinal temperature trends along the EFLR mainstem, which in-stream measurements were unable to replicate. Most of these were downstream decreasing temperature trends of varying length and gradient which would have been of interest for siting thermal refuge locations. Some discrepancies were resolved through further analyses, while causes for others remain unclear. We did not follow up with the TIR contractor, due to the lapse in time between product delivery and the next available opportunity to complete in-stream observations. Despite the limitations of the TIR data that were revealed, we found it to be an effective tool overall for identifying general temperature patterns and trends and identifying cold water locations that do exist and may not have been observed otherwise. Follow up in-stream surveys revealed some additional cold-water at depth in the mainstem and off-channel areas which could not be identified through the TIR technology. Most were highly localized, and likely areas of groundwater/hyporheic exchange. The fact that we identified these types of features in the limited spatial area we were able to survey on foot suggests that they may be more numerous and could potentially be serving an important role as existing thermal refuge for juvenile salmonids.

Overall results of the water temperature mapping showed that most existing thermal refuge opportunities in the lower EFLR that we were able to document consists of small (generally < 1 acre) areas that are either disconnected from mainstem surface flow or connected only at their downstream end, to a degree which limits inflow from the mainstem. It appears that temperatures in these features remain cold relative to the mainstem due to varying combinations of groundwater recharge, hyporheic exchange, cold tributary inflow, and limited exposure to solar radiation provided by canopy cover. We applied this information in combination with a several other data sources and related literature on thermal refuge to develop a thermal refuge strategy for the lower ELFR and generate a list of sites where opportunities exist now or may be implemented. This list was developed and prioritized with the assistance of a Technical Oversight Group of stakeholders possessing unique perspectives on the study area.

A total of 29 potential thermal refuge project locations were identified, many of which overlap with project locations identified in the 2009 East Fork Habitat Restoration Plan (HRP). Because that plan included a broader set of objectives, the concepts suggested therein may differ from the thermal refuge actions which are the focus of this plan. For locations with overlap between the two plans, we recommend revising the HRP to include any potential actions identified here that are not already included. While all 29 sites appear to have some degree of thermal refuge potential based on our assessment, many have social constraints such as land ownership which would likely inhibit project implementation. We chose to include these projects in the strategy despite these constraints, as social factors are subject to change in the future. Some sites, including at least three identified in the HRP, have already had restoration projects implemented. These projects were not necessarily focused on thermal refuge, and thus may offer additional thermal refuge opportunity. It is imperative that any additional proposed actions move forward only with consent from prior project sponsors and do not jeopardize the intent of those prior actions.

Of the 29 sites, we selected four for initial concept development as part of this project. These are included as Appendix A. The four were selected with input from the Technical Oversight Group, and generally received combined high ecological and social scores and are not already being considered for implementation as part of other projects (such as Ridgefield Pits and Mason Creek).

Based on prior temperature studies of the EFLR (McCarthy (2018), Carey & Bilhimer (2009)) as well as the TIR survey and qualitative canopy assessment completed in this study, we believe that the lower EFLR <u>mainstem</u> offers limited potential for providing thermal refuge opportunities for salmonids. Confluence zones of cold-water tributaries to the mainstem, such as Lockwood, Mason, and Mill Creeks, could provide some of this limited potential. The Ridgefield Pits Floodplain Restoration (LCEP, 2021) is also expected to provide temperature benefits, through extensive re-grading and channel re-alignment that should raise the water table and increase groundwater connection in a severely impacted floodplain area. Heating of the EFLR upstream of ~RM 14 is occurring despite what appears to be a relatively intact canopy throughout much of this area, suggesting that other factors are responsible which may not be able to be addressed. One of these is water withdrawals, which could have the ability to impact mainstem temperatures. We were not able to complete an assessment of current and future allocated withdrawals in the subbasin as part of this study, but an updated investigation including exploration of opportunities to reduce withdrawals and increase mainstem base flow is recommended. These actions could be included in an overall thermal refuge strategy for the lower EFLR.

Improvements in canopy cover further downstream where more potential exists could reduce further heating of the mainstem but may be unlikely to reduce temperatures to levels below critical thresholds for salmonid health. An updated shade analysis using recently improved GIS routines and applied as input to a coupled hydrodynamic and water temperature model could provide a better understanding of how water temperature might respond to large scale riparian revegetation efforts along the lower EFLR mainstem. The types of small cold-water locations described above that we did observe in the mainstem in our limited surveys could be providing important refuge for juvenile salmonids but seem unlikely to benefit adults based on the feature sizes that we observed. A better understanding of the extent of these features would be useful and could help to identify additional potential projects in the mainstem, but a practical method for obtaining this information at high resolution over the full extent of the lower EFLR has not been identified.

With limited opportunity in the mainstem, the thermal refuge locations identified in this project are largely confined to off-channel and side channel locations, apart from some tributary confluences. Most of these locations would be beneficial to juvenile salmon only based on the life history strategies of species that are present in the system during the summer. Tributaries then are likely to provide the best, and potentially the only suitable thermal refuge for adult salmonids. We were not able to assess these locations as part of this study due to property access issues, however they should be prioritized for protection as well as potential thermal refuge project opportunities.

Lastly we need to give a shout out to Clark County and their ability to protect and preserve areas important for salmonids/natural resources. They have a specific clause that references salmonids in their lands acquisition and have dedicated funds ($8 M bond).

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Appendix A: Concept Designs for Selected Projects

The project concepts presented below were selected for initial concept development based on a combination of the ecological and social ranking outcomes in addition to other factors. Many sites that received higher ecological rankings relative to ones that were ultimately selected were bypassed due to either limiting social factors or inclusion in project designs that are already being implemented, or both. Mason Creek floodplain (Site ID 23), for example, is the third highest ranking project ecologically, but was not selected for a concept because it is currently in active design. This is also true of many of the identified thermal opportunities located within the spatial extent of the Ridgefield Pits Floodplain Restoration project which is also currently in active design. The Dean Creek floodplain (Site ID 23) ranked high ecologically and was a particular area of interest for several TOG members. However, land ownership in this area remains a significant barrier to project scoping and implementation, and thus the project was not selected for concept development. The East Fork mainstem (RM 4.5–5.5, Site ID 1) initially ranked high ecologically and socially and was selected for concept development. Additional recent field reconnaissance completed just before the project deadline challenges our initial assumptions about the potential value of this location for thermal refuge opportunity, and as a result we have not presented this project here. Unfortunately, we were not able to go back and re-score the sites at this late time.

We believe then that the projects described below represent a handful of readily implementable opportunities to enhance, protect and potentially create thermal refuge for salmonids in the lower EFLR.

Lower EFLR Thermal Refuge Project Site ID 15: R. bank side channel upstream of Daybreak Bridge	**Reach:** EF Lewis 8A,8B **River Mile:** 10.3–10.8 **Ref. page in main doc:** 53 **Ecological rank:** #1 of 29 **Ecological score:** 79/100 **Social rank:** #11/29 **Social score:** 67/100

Site Description

Large side-channel complex on river right just upstream of Daybreak Bridge and Daybreak Park. This was the former main channel location until the river began a gradual migration to a smaller side channel to the west roughly 20 years ago, which became the main channel approx. 10 years ago. The area is now a series of beaver dam complexes, fed by a small tributary (Charter Oak Creek). It is unclear to what extent this area receives inundation from the mainstem, but surface water appears to remain disconnected during summer months at the upstream end. A small downstream connection appears to be maintained at the outlet of the downstream pond. Property ownership extent within the wetted area is unclear. The adjacent hillside to the east is privately owned, while the wooded floodplain area to the west is owned by Clark County. Riparian cover over the wetted area is poor, with little mature canopy cover.

Site Thermal Conditions

Confirmed cold-water throughout the site in both TIR imagery and in-stream measurements. A temperature logger was installed but was lost so an extended temperature record is not available. However, temperatures throughout the ponded areas ranged from 14–17 °C on afternoons when in-stream measurements occurred. Surface temperatures measured with TIR imagery generally ranged from approximately 16–19 °C. All these values are at least 2 °C less than EFLR mainstem temperatures that exceeded 21 °C during those times. We estimated a total of approximately 1.2 acres of wetted area that may currently be suitable as thermal refuge for this site.

Proposed Treatment Strategy

The project ranked high and was selected for initial concept design because of the relatively large extent of cold-water that is already present and the somewhat degraded habitat conditions. Improving habitat conditions by adding things such as complexity and cover would provide better access and rearing opportunity for juvenile salmonids at a location that currently provides a suitable thermal environment. We believe that the site should also be prioritized for protection, again due to the large extent of existing cold-water, relative to overall availability in the lower EFLR. Proposed actions include:

- Enhance existing thermal refuge habitat through wood placements and riparian revegetation.
- Potentially add apex wood jams at upstream end to encourage split flow and increased inundation from the mainstem during high flow conditions, to promote scour and flushing.
- This is the largest area of existing cold water for the lower EFLR that was identified in this study, and adjacent privately owned areas should be prioritized for protection/acquisition.
- Expand actions above to adjacent sites that were identified for thermal refuge opportunities (Site IDs 14, 16,17) where possible, to create a larger expanse of thermal refuge throughout this area.

Potential Constraints

- The site is bounded by a privately-owned steep hillside to the north and east, and by the mainstem EFLR to the south and west. Construction access then would need to be routed across the mainstem and could be complicated by the steep L bank.
- This section of the river is also quite dynamic, with several mainstem migrations having occurred recently. This could present a risk as far as the long-term stability and functionality of the project site, and a geomorphic assessment should be carried out as part of project feasibility assessment.

Data and Analysis Requirements

- Continuous surface and groundwater temperature measurements throughout at least one summer to help identify and assess the extent and quality of cold-water sources that feed the site.
- Topographic survey to assess extent of upstream and downstream connections to the mainstem.
- Geomorphic analysis to assess site and mainstem stability.
- Fish monitoring to assess extent of current salmonid use.
- Assessment of options for construction access.

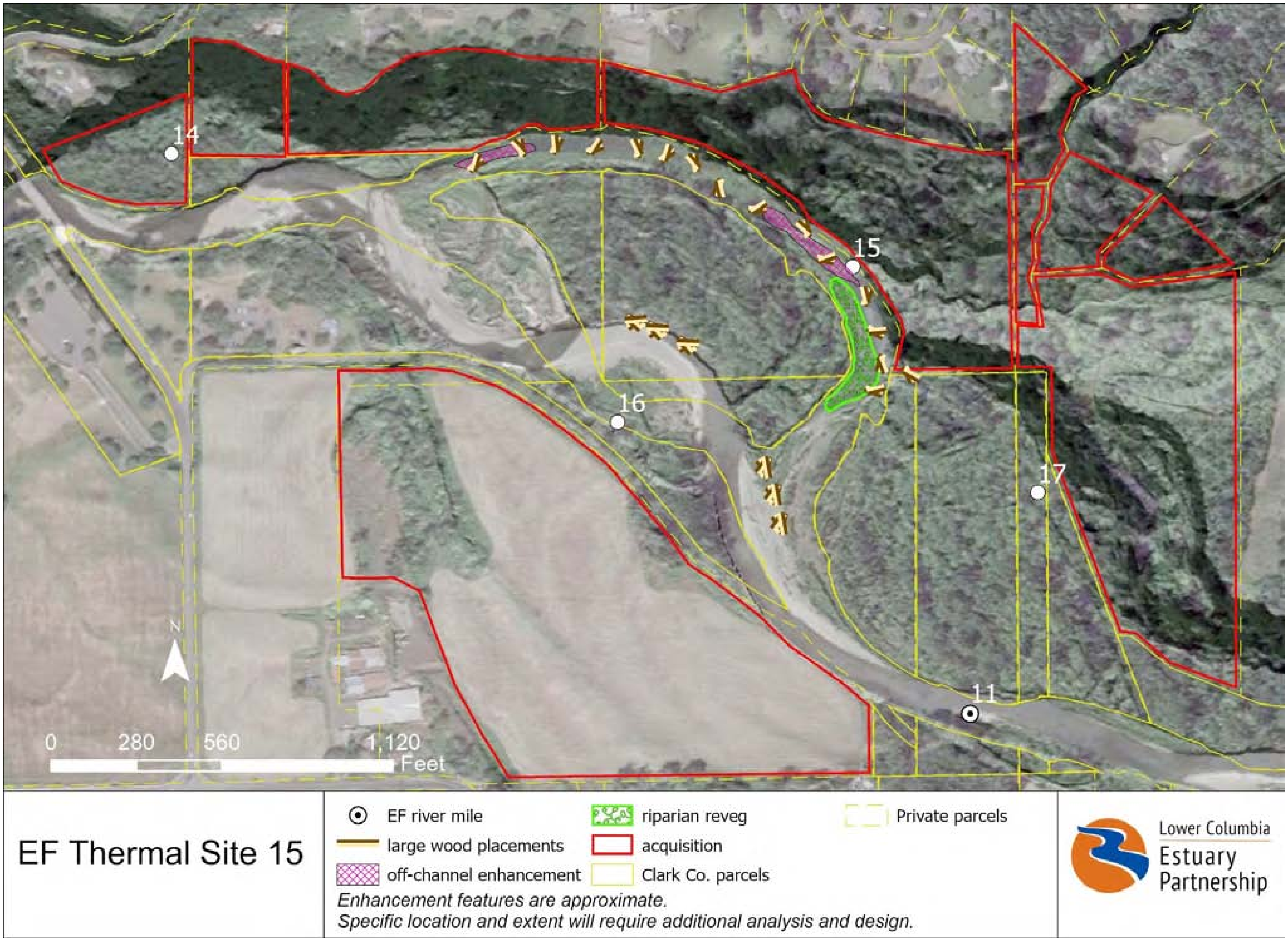


Figure A1. Preliminary concept design for lower EFLR thermal refuge project site #15.

Lower EFLR Thermal Refuge Project Site ID 20: L. bank side channel across from Lewisville Bridge	**Reach:** EF Lewis 8B **River Mile:** 13.7–13.9 **Ref. page in main doc:** 58 **Ecological rank:** #13 of 29 **Ecological score:** 60/100 **Social rank:** #7/29 **Social score:** 60/100

Site Description

Large side-channel on river left across from Lewisville Park. The site was also identified in the HRP as a possible habitat project (Site EF07 in East Fork Lewis River Habitat Restoration Plan) and was ranked in the mid-to-high range (final benefit score of 109, versus scores of 140 and 83 for the highest and lowest ranked projects respectively) in that plan. The site currently lacks channel structure, complexity, and spawning size gravels. The site is owned by Clark County.

Site Thermal Conditions

TIR imagery indicated presence of cold water however ground assessments determined that these were false readings due to shadow and hillslope effects. Temperatures were found to be equivalent to the mainstem throughout the channel.

Proposed Treatment Strategy

Despite a modest ecological ranking in the site prioritization and an absence of cold-water, the project was selected for initial concept design due to the opportunity it may present to implement a somewhat novel approach for creating thermal refuge through streambed engineering. The process was recently implemented in an urban stream setting in Seattle which is described by Bakke et al. (2020). For that project, temperature reductions of greater than 1.5 °C were observed for individual plunge pool features that were engineered. The approach, illustrated in Figure A2 (from Bakke et al. 2020), involves establishing hyporheic connection through creation of plunge pools to cool surface water and then re-express it downstream where it can be utilized as thermal refuge. With an isolated but continuous connection to the EFLR mainstem, and a grade that appears suitable for plunge pool creation, the site may offer a good opportunity to implement and test this thermal refuge technique. Proposed actions include:

- Create series of plunge pools throughout the side channel using an engineered streambed approach as implemented and described in Bakke et al. (2020) (Figure A2).
- Add other streambed habitat elements including spawning gravels, and large wood placements
- Riparian revegetation

Potential Constraints

- Construction access could potentially be an issue if the site needs to be accessed from Lewisville Park across the mainstem. Road access may be possible via the adjacent Camp Hope property however landowner permission would be needed.
- Channel grade may not be sufficient to allow for creation of multiple plunge pools that would likely be required to achieve adequate temperature reduction.

Data and Analysis Requirements

- Topographic survey to assess existing channel grade.
- Geomorphic analysis to assess side channel and mainstem stability.
- Effect of project on steelhead spawning in this area.
- Assessment of options for construction access.

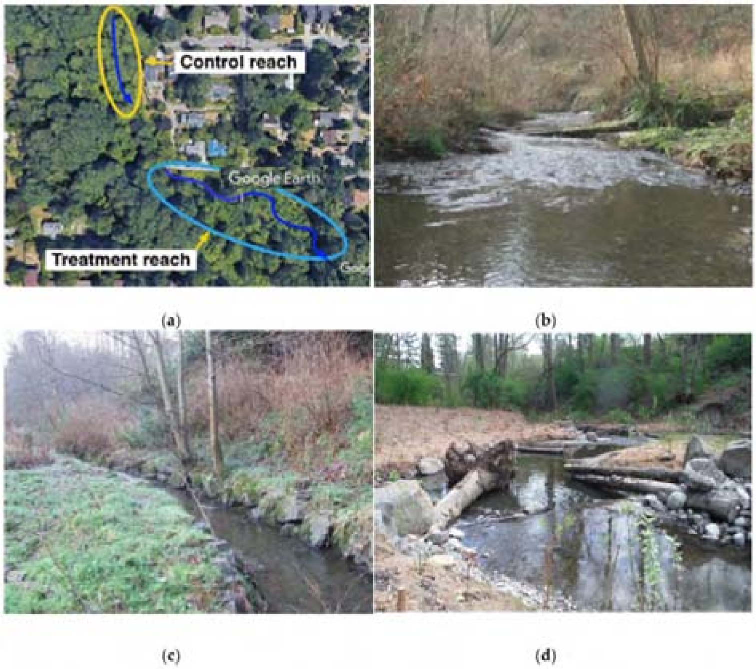


Figure 3. Views of Kingfisher Control and Treatment reach, including: (**a**) Aerial photo showing locations of the Kingfisher Control and Treatment reaches, (**b**) photo of the control reach, and photos of treatment reach (**c**) before, and (**d**) after, construction, taken from close to same vantage point (the "before" is taken closer to the south slope, on the right side of this photo).

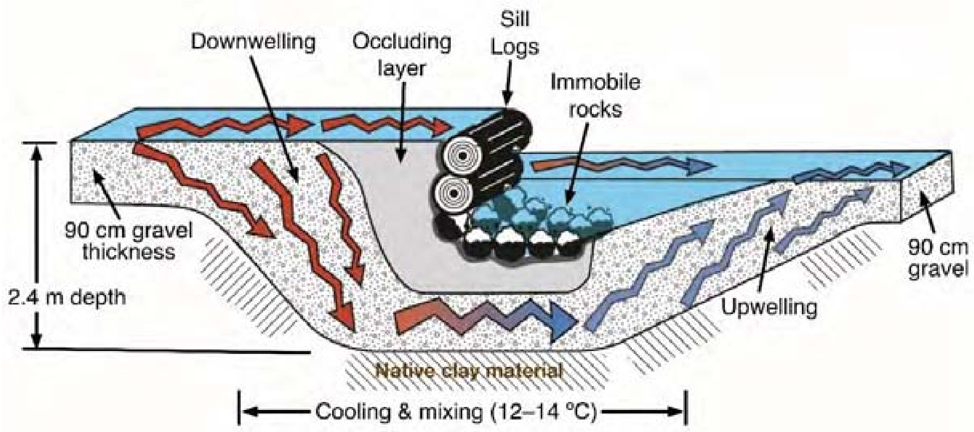


Figure A2. Proposed thermal refuge creation concept, as implemented and described in Bakke et al. (2020). Top: treatment and control reach where project was implemented. Bottom: Plunge pool concept that was implemented at the site and is proposed here.

Lower EFLR Thermal Refuge Project Site ID 21: L. bank alcove across from Lewisville Bridge	**Reach:** EF Lewis 8B **River Mile:** 14.1 **Ref. page in main doc:** 58 **Ecological rank:** #7 of 29 **Ecological score:** 64/100 **Social rank:** #26/29 **Social score:** 25/100

Site Description

The site is located on Boy Scouts of America property. There is a small tributary that enters the mainstem here which contains cold-water during the summer. Good adjacent mainstem spawning habitat. The site was also identified in the HRP as a possible habitat project (Site EF05 in East Fork Lewis River Habitat Restoration Plan) and was ranked in the low-to-mid range (final benefit score of 96, versus scores of 140 and 83 for the highest and lowest ranked projects respectively) in that plan. Despite the relatively low score it was selected for a preliminary concept design in that plan, possibly due to the thermal refuge opportunity it may offer.

Site Thermal Conditions

Not detected by TIR imagery, however on the ground assessment was done to verify findings in EF HRP. We measured temperatures of 10.5 °C in the tributary and 15-17 °C in the mainstem at the immediate confluence location during summer of 2022, confirming the HRP results.

Proposed Treatment Strategy

This site received a relatively low ecological ranking primarily due to its small size, and a low social ranking due to private ownership. We include it as a concept here for the following reasons: 1) Despite its small size it may offer potential for high quality refuge based on measured temperatures in the 10–15 °C range; 2) It has already had a concept brought forward in the HRP; 3) Landowner contact that occurred subsequent to project scoring has indicated a potential openness to project implementation and/or construction access; and 4) proximity to Site #20 could offer opportunity for both projects to be constructed simultaneously.

Proposed actions are consistent with the project concept developed for EF Site 05 in the HRP and include:

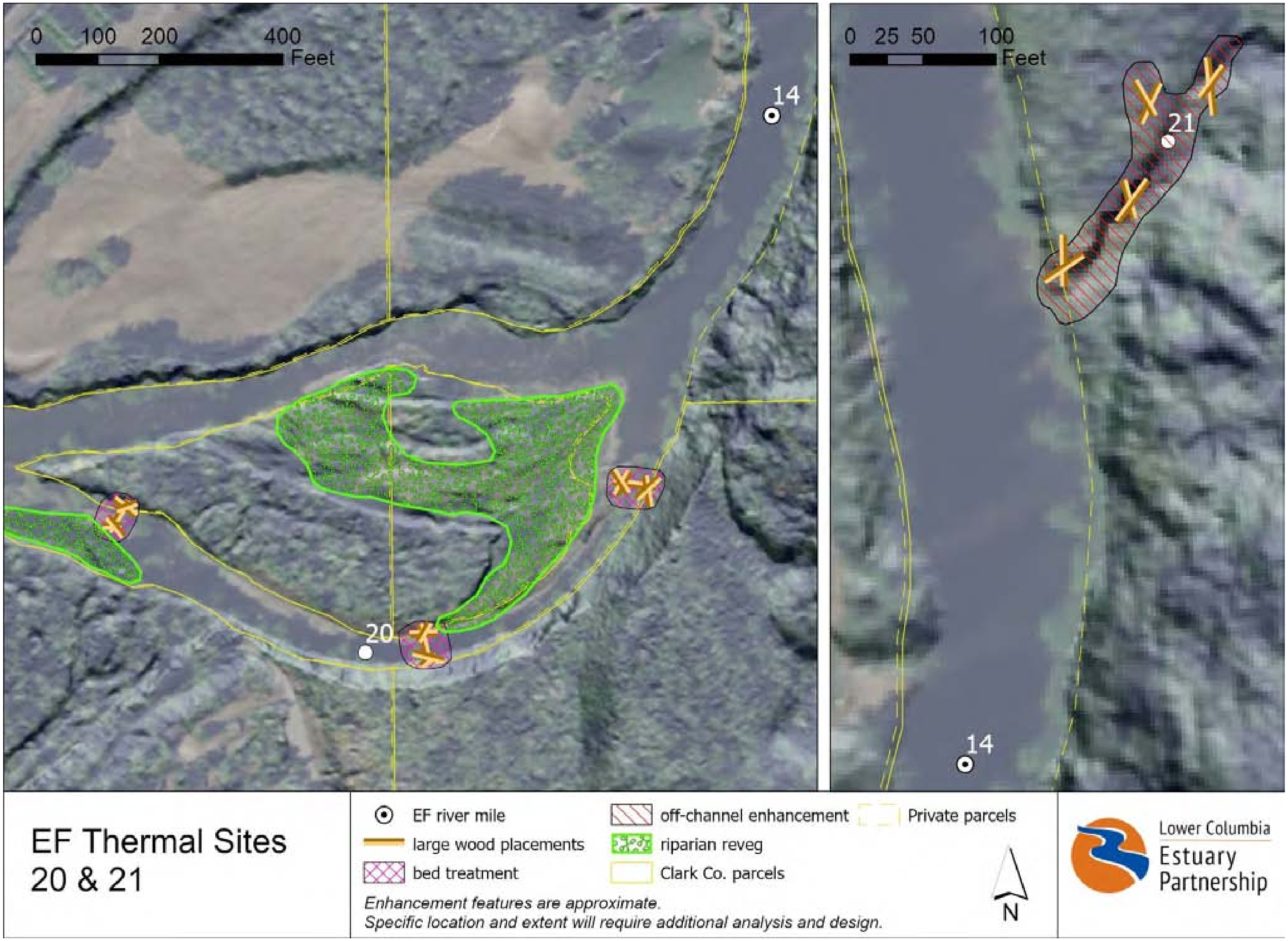
- Utilize grading to create off-channel area connected to the mainstem at low summer flows that is sourced by hyporheic and tributary flow.
- Add additional habitat enhancement features including instream large wood and bank complexity.

Potential Constraints

- Private land, although landowner has expressed willingness to discuss project opportunities. Any potential landowner concerns such as erosion, flooding, or safety must be addressed in project design.

Data and Analysis Requirements

- See HRP Project EF-05.



Enhancement features are approximate.
Specific location and extent will require additional analysis and design.

Figure A3. Preliminary concept designs for lower EFLR thermal refuge project site #20 and #21.

Lower EFLR Thermal Refuge Project Site ID 18:
R. bank Off-channel RM 11.5

Reach: EF Lewis 8B
River Mile: 11.5
Ref. page in main doc: 56
Ecological rank: #17 of 29
Ecological score: 54/100
Social rank: #3/29
Social score: 88/100

Site Description

This is an old meander scar/overflow channel. The site was identified as a potential project site in the EFL Habitat Restoration Plan (Site EF 22, HRP 2009) and a project was implemented by Clark County, who owns the property, in approximately 2015 (SalmonPort Proj ID 11-1313). That project added large wood in the off-channel area. The site has a small connection to the mainstem at the downstream end through a small opening in a levee-like feature (shown in left photo below viewed from mainstem looking into site, and middle photo below viewed from inside site looking towards mainstem). It is unclear if this connection is maintained for the duration of the summer.

Site Thermal Conditions

TIR imagery was inconclusive, however on the ground monitoring in summer 2022 confirmed cold water presence in the restored side channel (temperatures ranging from 11.9 to 14 °C). Prior study supporting the EFL HRP also indicated presence of cold water and potential groundwater connectivity. It is unclear how the restoration project implemented by Clark County has impacted thermal conditions at the site since then.

Proposed Treatment Strategy

The project ranked medium for potential ecological benefits. It was selected for initial concept design due to the combined presence of existing cold-water and restoration actions that have already occurred at the site to improve habitat. Further action to improve access for fish could increase the utility of this site as a thermal refuge. Additionally, limited social constraints and straightforward access increase ease of implementation. Proposed actions include:

- Grading to improve connection to the mainstem and provide increased access for juvenile salmonids. Currently, the site drains through a small opening in a levee-like feature. This could be opened to increase accessible area, and potentially re-graded to increase duration of the connection. Any actions would need to be done in a manner that does not compromise the existing thermal characteristics of the site.
- Add additional large wood structures near the downstream connection to further enhance access and rearing habitat; and promote scour.
- Additional grading to potentially increase thermal refuge area.

Potential Constraints

Any actions proposed for this site must be carefully evaluated for potential impacts to restoration work that has already been completed by Clark County. Additional actions should complement the work that was done previously.

Data and Analysis Requirements

- Continuous surface and groundwater temperature measurements throughout at least one summer to help identify and assess the extent and quality of cold-water sources that feed the site.
- Topographic survey to assess extent of downstream connection to the mainstem.
- Geomorphic analysis to assess site and mainstem stability.
- Fish monitoring to assess extent of current salmonid use.

Figure A4. Preliminary concept design for lower EFLR thermal refuge project site #18.

Appendix B: Data Products and Availability

Several existing reference data sources were used in this study in addition to data that was collected. Much of the spatial data that was used to help inform site identification and prioritization has been compiled in an online accessible map as part of the deliverables for this project. This application is publicly accessible and can serve as a convenient tool for further assessment of thermal refuge opportunities in the lower EFLR tool for interested users. The map can be found at:

https://lcep.maps.arcgis.com/apps/mapviewer/index.html?webmap=92609a2e4c99482aae8ca5e9b2931ecd

A summary of the included data is provided in Table A1 below.

Table A1. Summary of spatial data used in the lower EFLR Thermal Study that is included in the online map application accessible at the link above.

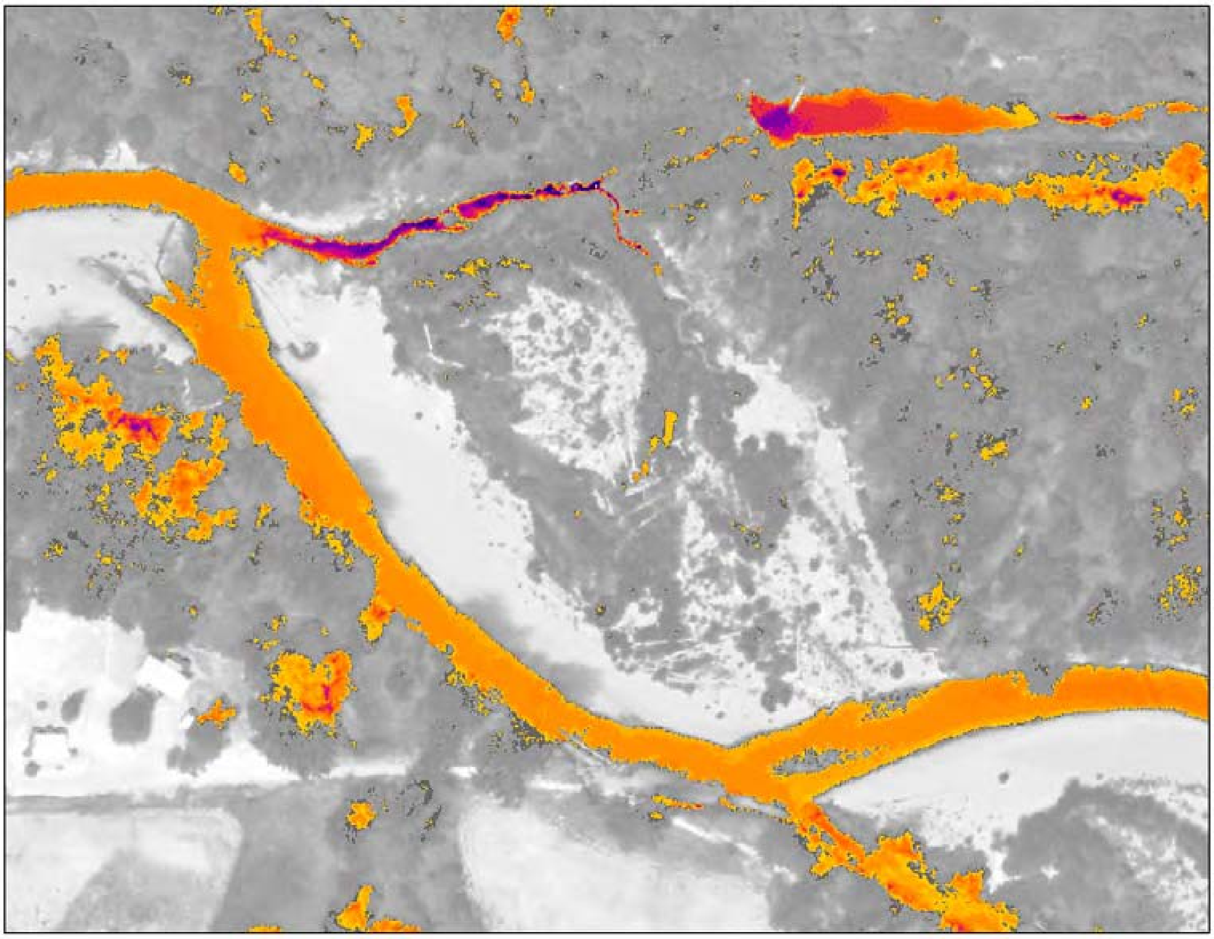
Data Layer	Description	Use Notes
1. Site review comments	Review comments from TOG members that were provided as part of the thermal refuge site selection and prioritization	
2. EF thermal project concepts	29 locations identified for potential thermal refuge projects in this study	30 are shown, but the lower Rock Creek confluence (ID# 30) was eventually removed from consideration after further review.
3. EF thermal project concept boundaries	Approximate spatial extent of some of the projects considered.	Rough initial estimate only.
4. HRP project locations	Locations identified for restoration in the 2009 East Fork Lewis Habitat Restoration Plan (HRP 2009)	Symbols are sized based on final ranked score, with higher scoring projects larger.
5. Continuous water temperature monitoring results	Compilation of existing continuous water temperature measurements for the various studies shown in Table 1 in the main report body (Section 3.1). Includes results plots only, as image attachments.	- This dataset will be added to as new data is collected and additional existing data is procured. - Water surface elevation data is also included where available. - Raw data is available from Lower Columbia Estuary Partnership.
6. TIR field-verification confirmed cold-water locations	Locations where cold-water suitable for thermal refuge was found during in-stream field verification of TIR results.	This should not be assumed to represent all existing cold-water locations in the lower EFLR, but rather locations within the

		sampling extent there cold-water was measured.
7. TIR field verification sampling locations	Extent of in-stream field sampling to verify TIR results. All points included in the grid were sampled during either summer 2021 or summer 2022.	
6. EFLR mile markers	Mile marker reference for the lower EFLR.	
7. Public Lands	Clark County ownership.	
8. Thermal infrared results	Raster tiles showing results colormap for the airborne TIR temperature survey that was completed.	See legend in map to interpret temperatures.
9. Lidar bare earth hillshade	DEM hillshade tiles created from LiDAR data sources used in this study.	Sources include USGS Western Washington 3DEP 2016 LiDAR Project, and USGS Cascades South 3DEP 2019 LiDAR project

Attachment 1: East Fork Lewis River Thermal Infrared (TIR) Airborne Imagery Technical Report.

Final documentation produced by NV5 Geospatial (formerly Quantum Spatial) as part of the deliverables package for the Thermal Infrared (TIR) temperature survey they conducted for this project on August 11 2020 is included below and also as a separate file attachment to this report. LCEP completed extensive on the ground field verification of the TIR imagery following delivery of this report, which revealed some important discrepancies with the results that it presents. These are discussed in detail in Section 4.1.1 of the main body of this report and should be taken into consideration by any future users of this product.

Survey: Aug 11, 2020
Report: Nov 30, 2020



East Fork Lewis River - Thermal Infrared Airborne Imagery - Technical Data Report

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Cover Photo: Thermal infrared imagery of side channels along the EF Lewis River, WA.

INTRODUCTION

Lower Columbia Estuary Partnership contracted Quantum Spatial Incorporated (QSI) on May 19th, 2020 to collect thermal infrared (TIR) survey data during the summer of 2020 for the main channel of the East Fork Lewis River and its four tributaries: Lockwood Creek, Dean Creek, Mason Creek, and Rock Creek in southwest Washington. Flown on August 11th, 2020, the survey covers an estimated 50.2 km (30.2 miles) of the East Fork Lewis River and its tributaries, from the mainstem EF Lewis River at the headwaters near Heisson, WA to the confluence with Lockwood Creek just south of La Center, WA. Since the flow in the tributaries is relatively small and their channels are heavily vegetated, Lower Columbia Estuary Partnership's staff provided an estimate channel route for QSI's flight crew to aid in flight planning and data acquisition.

TIR data was collected to aid the Lower Columbia Estuary Partnership's team and stakeholders with evaluating the thermal regime and to identify critical cold-water refuge areas available to salmonids and inform habitat restoration design to protect, restore, or enhance these features.

This report accompanies the delivered TIR data and support files, and documents contract specifications, data acquisition procedures, processing methods, and analysis of the final dataset. TIR acquisition dates and times are shown in Table 1, a complete list of contracted deliverables provided to the Lower Columbia Estuary Partnership is shown in Table 2, and the project extent is shown in (Figure 2).

Table 1: TIR acquisition dates and stream reaches collected on the East Fork Lewis River

River Survey Description	Section River km	Survey Date	Survey Window (PST)
EF Lewis Mainstem	0 – 33	August 11, 2020	14:18 – 15:21
Lockwood Cr.	0 – 5.3	August 11, 2020	15:40 – 15:50
Dean Cr.	0 – 3	August 11, 2020	15:22 – 15:31
Mason Cr.	0 – 5.7	August 11, 2020	15:32 – 15:39
Rock Cr.	0 – 1.6	August 11, 2020	15:01 – 15:05

Deliverable Products

Table 2: Products delivered to the Lower Columbia Estuary Partnership

East Fork Lewis River TIR 2020 Products **Projection: UTM Zone 10 North** **Horizontal Datum: NAD83 (2011)** **Vertical Datum: NAVD88 (GEOID12B)** **Units: Meters, Celsius**	
Rasters	Thermal Infrared Imagery (*.tif): • Calibrated, rectified images (cell values = Celsius x 10) • Calibrated imagery mosaics (cell values = Celsius x 10)
Vectors	Shapefiles (*.shp) • Stream centerlines • Accuracy checks • TIR image center points and sensor exterior orientation (EO) • Longitudinal temperature profile (LTP) • Significant feature sampling (SFS)
Supplemental	• "xlsx" folder contains longitudinal temperature profiles (LTP) and significant feature sampling (SFS) in MS Excel format (*.xlsx) • "Color Ramps" folder contains customized layer files (*.lyr) for visualization in ArcMap • "Maps and Figures" folder contains maps and figures used for the report (*.png)

Thermal Infrared Imagery Acquisition Planning

Flight Planning and Timing

In preparation for data collection, QSI's team reviewed the project area and developed a specialized flight plan to ensure complete coverage of the East Fork Lewis River study area. In an agreement with the Lower Columbia Estuary Partnership's team, QSI planned to acquire the data during afternoon hours (13:00 – 17:00 Pacific Daylight Time) to maximize the thermal contrast between the river water and the banks; timing also targeted clear skies and warm air temperatures. A helicopter was flight planned to track the river channel over the survey area at an altitude of 400 – 500 meters above ground level (AGL). A shapefile of the estimated channel route was provided by Lower Columbia Estuary Partnership to guide QSI's acquisition crew in locating the channel along poor visibility sections where water flow is low, and vegetation is dense. The acquisition crew also adjusted the flight route during acquisition based on live thermal signature feed.

Thermal Infrared Sensor: FLIR SC6000

Thermal infrared images were collected using a FLIR SC6000 sensor (8 – 9.2 μm) mounted to Bell 206 Long Ranger helicopter (tail number N801CL). The sensor was installed in an enclosed fiberglass capsule mounted at the bottom of the helicopter with a designated opening for the down facing lens (Figure 1). The FLIR SC6000 sensor uses a focal plane array of detectors to sample incoming radiation based on the technology of Quantum Well Infrared Photodetector (QWIP). The sensor's array records the change of state of electrons in a crystal structure reacting to incident photons. This technology is faster and more sensitive than polymer thermal detectors. A cooling mechanism is required for this sensor to stabilize its internal temperature and minimize thermal drift during acquisition. To resolve the challenge in achieving uniformity across the detector array, a factory scheme is generated to reduce non-uniformity across the image frame; nevertheless, differences in temperature (typically <0.5° C) might be observed near the edge of the image frame. Flight planning ensures sufficient image overlap so that frame edges can be excluded from the river channel in the TIR image mosaics. The resulting thermal infrared image frames were recorded directly from the sensor to an on-board computer as raw counts which were then converted to radiant temperatures. Sensor and acquisition specifications for the East Fork Lewis River TIR study are listed in Table 3.

The positional coordinates of the helicopter (geographic coordinates: latitude, longitude, and altitude) and the orientation (pitch, yaw, roll) were recorded continuously throughout the data collection missions. The geographical coordinates of the aircraft were measured twice per second (2 Hz) by an onboard differential GPS unit, while the orientation values were measured 200 times per second (200 Hz) from an onboard inertial measurement unit (IMU). Airborne GPS data was post-processed into a smoothed best estimate of trajectory (SBET) using Applanix PPRTX data for corrections. TIR images were acquired at 1 image per second (1Hz). To ensure sufficient image overlap and ground sampling distance (GSD), flight speed did not to exceed 50 knots and flying altitude targeted 400 meter above ground level (AGL). Images were indexed by GPS time (event time) and paired with the SBET to resolve the exterior orientation of the sensor for each image event. Flight parameters were selected to optimize contracted pixel resolution while providing an image ground footprint wide enough to capture the active channel with the stream occupying 30 – 60% of the image.

Table 3: Summary of TIR sensor and acquisition specifications

FLIR System SC6000 (LWIR)	
Wavelength:	8 – 9.2 μm
Noise Equivalent Temperature Differences (NETD):	0.035 °C
Pixel Array:	640 (H) x 512 (V)
Encoding Level:	14 bit
Horizontal Field-of-View:	35.5°
Sensor Focal Length	25 mm
Acquisition Dates:	August 11th, 2020
Planned Flying Height Above Ground Level (AGL):	400 meters
Image Ground Footprint Width:	300 – 500 meters
Ground Sampling Distance (GSD)	≤ 0.5 meter

Figure 1: Sensor and aircraft setup (similar to the setup used for the project)

Ground Control

In-Stream Temperature Sensors

Water temperature recorded by in-stream temperature sensors are used to radiometrically calibrate the thermal signature of the imagery. A total of 10 stream temperature data loggers were deployed in the survey area by Lower Columbia Estuary Partnership's field crew (Figure 2). Eight data loggers were deployed along the East Fork Lewis River's mainstem and two were installed in Mason Creek and Rock Creek. While the goal is to generate a thermally seamless mosaic, temporal thermal offsets might occur as a result of the data collection timing. To prevent such an outcome, the mainstem and each of the tributaries was calibrated and mosaicked separately. A small number of loggers are expected to be excluded from the calibration process especially when their data cause thermal discrepancies between different sections of the mosaic.

Atmospheric Parameters

Radiometric calibration of the TIR imagery requires atmospheric data collected by local weather stations. Records of atmospheric parameters, namely: air temperature and relative humidity, are extracted during the flight window (Figure 2).

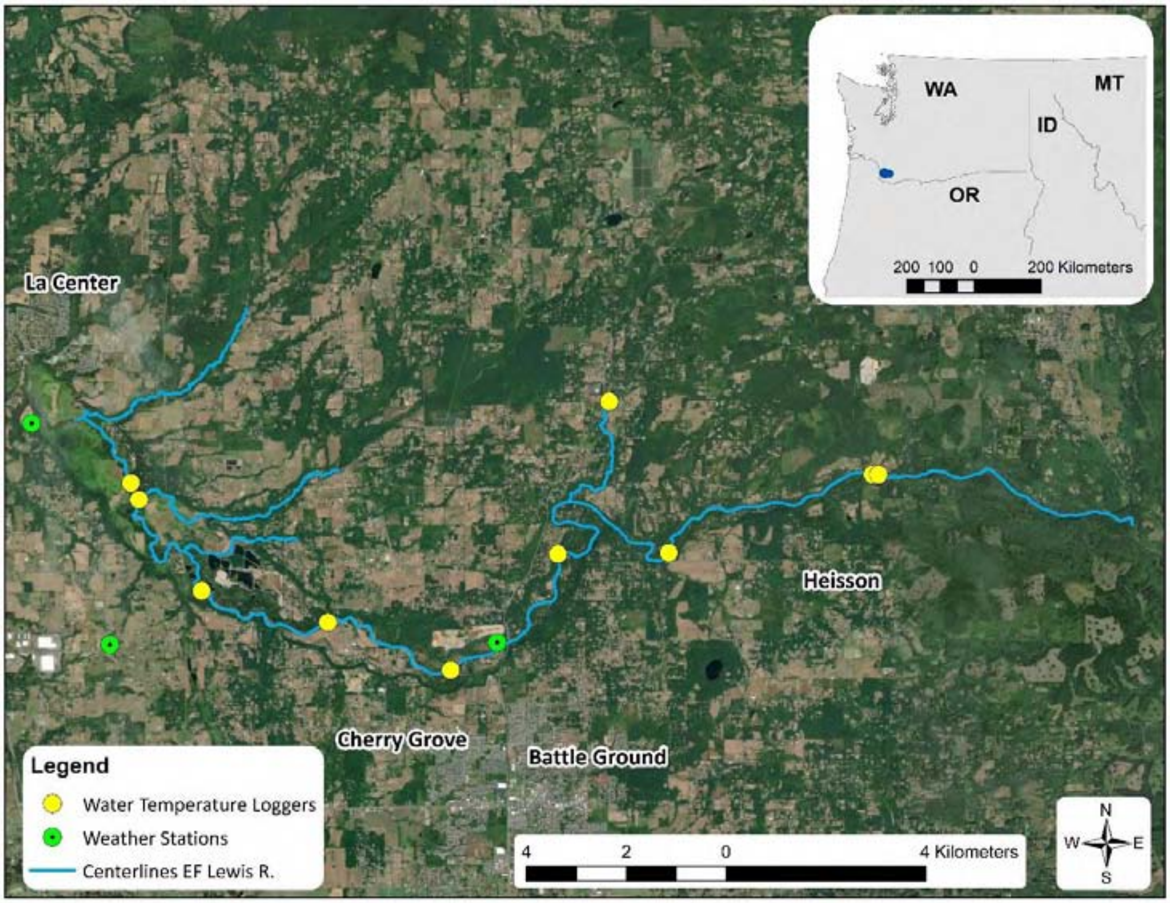

Figure 2: Map of survey area, location of water temperature data loggers and weather stations utilized in thermal calibration.

Airborne Survey Execution

The entire length of the East Fork Lewis River was successfully acquired in one lift on August 11, 2020 (Figure 3) with no coverage gaps identified during initial QAQC. The aircraft was flown in a channel-following pattern along sections that the active river channel fit within the sensor's frame. Multiple flight lines were required along sections where the channel meanders across the floodplain or was multithreaded. The executed flight pattern achieved the planned ranges of flight speed, altitude, and image acquisition rate for a >60% forward overlap between images (and >30 % side overlap where multiple flight lines were needed). The individual images were referenced with time, position, and heading information provided by a global positioning system (GPS).

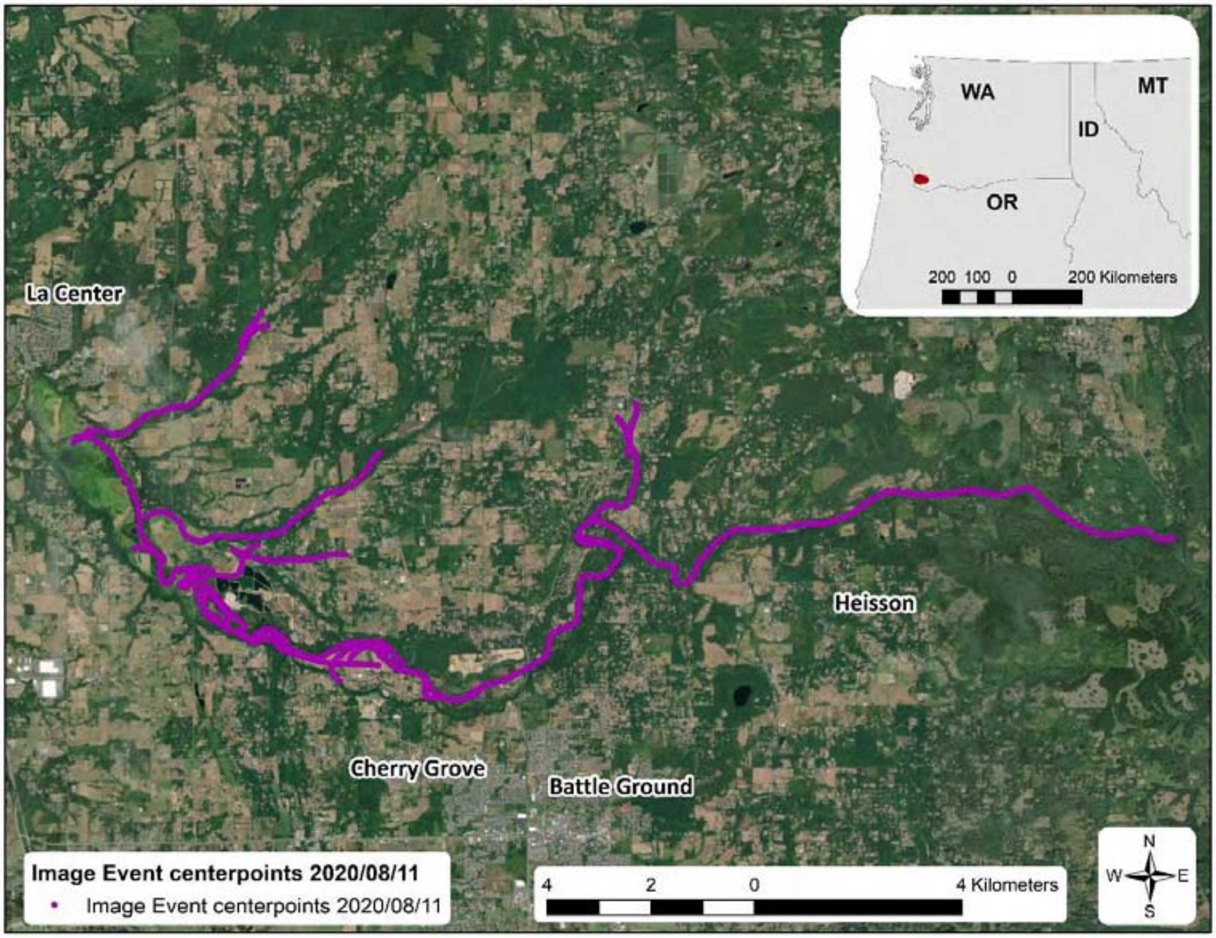

Figure 3: Flight line paths along the river channel's length.

Thermal Infrared Data Processing

Geo-Rectification

Initially, a series of corrections was applied to the aircraft trajectory and orientation using Applanix PPRTX data. Image timestamps were linked to the corrected trajectory to calculate the position and orientation of the sensor during each image event. Image location data and calibrated TIR images are input into Agisoft's Photoscan software and a mosaic is created using automatically generated tie-points and ground control data from reference base maps. No color balancing or seam feathering is used during the mosaic process to preserve the original temperature values of the TIR imagery.

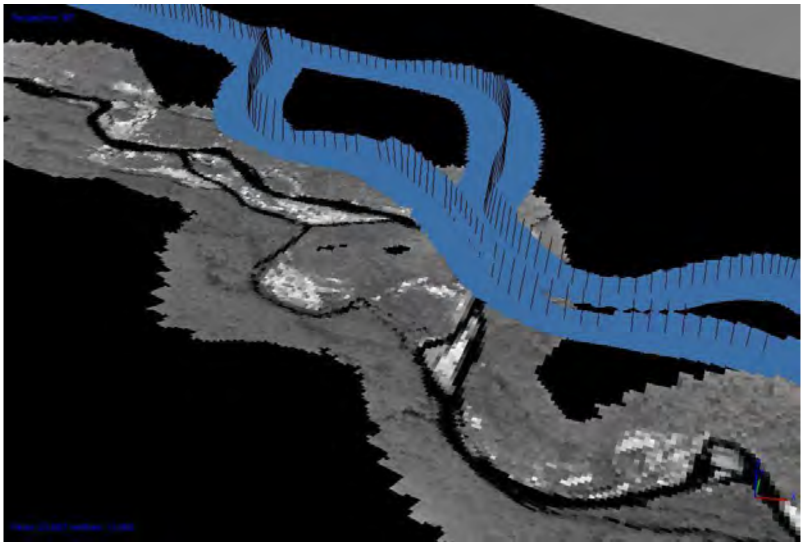

Figure 4: This figure shows an example of the TIR imagery mosaicking process inside Photoscan.

Thermal Infrared Imagery Calibration

Response characteristics of the TIR sensor are measured in a laboratory environment. Response curves relate the raw digital numbers recorded by the sensor to emitted radiance from a black body. The raw TIR images collected during the survey initially contain digital numbers which are then converted to radiance temperatures based on the factory calibration. Thermal infrared radiation received at the sensor is the sum of emitted radiation from the water's surface (e), reflected radiation (r), and transmitted radiation.

$$emissivity + reflectivity + transmisivity = 1$$

This adjustment is performed to correct for attenuation path and the emissivity of natural water which is 0.98[1], reflectivity is .02 and transmissivity is 0. The calculated radiant temperatures are adjusted based on the kinetic temperatures recorded at each ground control location (water temperature data logger). The in-stream water temperature data are assessed at the time of image acquisition, with radiant values representing the median of ten points sampled from the image at the data logger location.

Temperature and Color Ramps

The final TIR mosaic contains pixel values of degrees Celsius multiplied by 10, resulting in a 16bit unsigned raster format which is much smaller in file size than a float format raster.

Temperature values of the river occupy a relatively narrow range of the full 16bit histogram, thus visual representation of the imagery is enhanced by the application of a customized colorramp. Colorramps also highlight different features relevant to the analysis such as spatial variability of stream temperatures and inflows (Figure 5). The colorramps for the TIR mosaics were developed to maximize the contrast of the majority of the surface water features and are unique by tributary or mosaic. A QSI TIR specialist customized unique colorramp for each mosaicked reach of the river to improve visual presentation and exported the colorramp as ESRI *lyr file. Color ramps are an important product that is delivered to the end user.

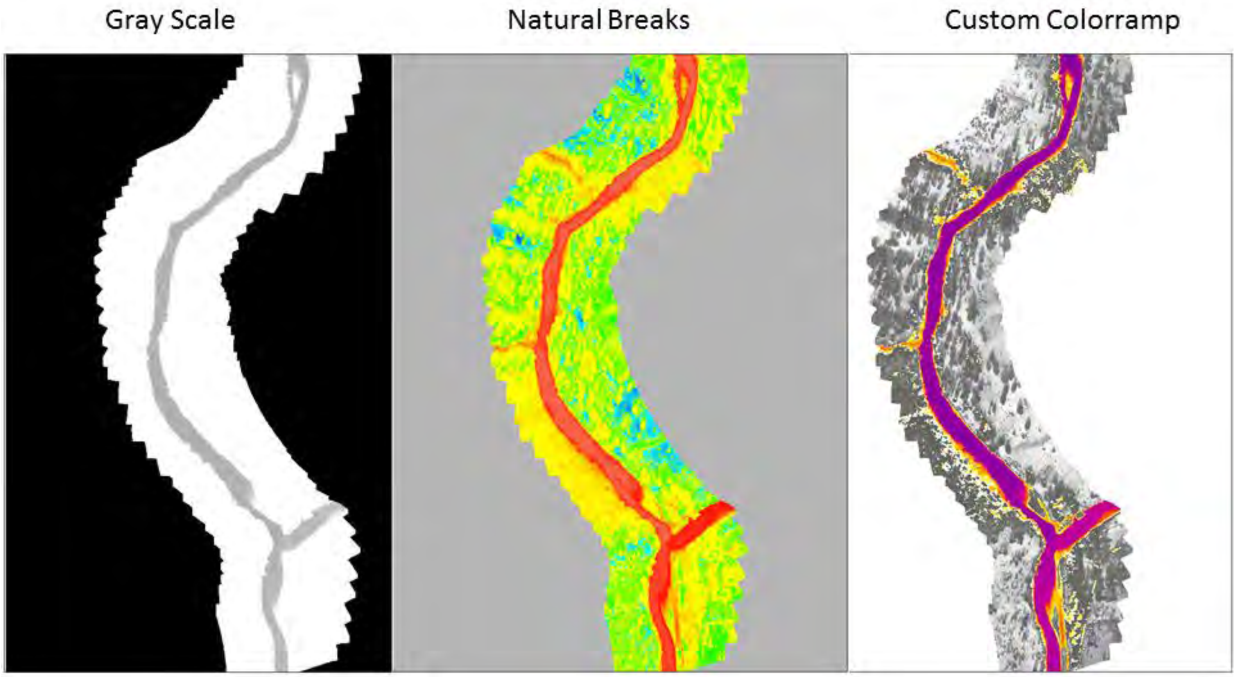

Figure 5: Examples of different colorramps applied to the same TIR image

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[1] Baldridge, A. M., S.J. Hook, C.I. Grove and G. Rivera, 2009. The ASTER Spectral Library Version 2.0. Remote Sensing of Environment, vol 113, pp. 711-715.

Accuracy Assessment Methodology

The final TIR mosaic's accuracy is assessed by comparing sampled pixels of the mosaic (where water features are present) at the data logger's location against the temperature recorded by the respective logger. Accepted temperature accuracy is less than ±0.5° C mean temperature difference between the mosaic and the logger-recorded values at the time of acquiring the TIR imagery. Since there are no temperature data recorded by loggers for each flight line in order to radiometrically calibrate it (initial calibration), and a line-to-line calibration step is required (between adjacent flight lines), minor deviation from the initial calibration might be needed to achieve the best possible seamless mosaic. The diurnal fluctuation of stream temperature dictates that acquiring the TIR data in the shortest time window possible to stay close to the values achieved by the initial calibration. This plays an important factor both during the phase of designing the flight plan ahead of time, as well as when making decisions during the flight. Furthermore, the mosaic's accuracy relies on the recorded temperatures and deployment conditions of the data logger. Deploying the loggers following the guidelines below assists in reaching a valid accuracy:

1) In flowing waters such as river or stream and not in pools or riffles sections.
2) In water column deeper than 0.5 m and shallower than 2 meters to allow for fully submerged data loggers and avoid stratified water column.
3) Within the channel's thalweg to measure a larger bulk of flowing water in the stream.
4) In water body with sufficiently exposed surface to the sky that can be detected by the sensor mounted to the aircraft.
5) Away from the bank where riparian vegetation may block the view from the aircraft.
6) In water stream reaches free from above-water surface features such as boulder and riparian and aquatic vegetation to allow for uniform water temperatures across the stream or the water body.

Positioning the data logger following above guidelines is essential factor to achieve the best mosaic possible because the TIR sensors only detect the heat signature at the surface of the object. In this case, water is also opaque to longwave radiation and the only thermal infrared signal emitted from the water body is at its surface. It scientifically sound to assume a thoroughly mixed water column in flowing stream and rivers no deeper than 3 meters. Additionally, deploying the sensor in shallow water, exposed to direct sun light has the potential to skew the recorded temperature by representing the temperature of the streambed, or the sensor itself, which has been absorbed heat throughout the day.

Assessing the mosaic's accuracy becomes challenging where the logger is positioned where there is no cluster of pixels with uniform temperatures in the mosaic. Such sites lead to generate "blended pixels" in the TIR mosaic. A blended pixel is one that represents two or more objects with varying temperatures, i.e. water and non-water features. Examples of such sites are narrow channels, water surfaces obscured by above surface boulders and vegetation (riparian or aquatic), and the mixing zone of entering tributaries or point-source inflow.

The logger's position in most cases is recorded using handheld GPS units with inherent positional uncertainty of a few meters. This error introduces another source of inaccuracy unless the logger's position is corrected based on the TIR imagery which is generated using survey grade positioning system. Adjusting the position relies on information from the field crew, or the client if the latter is providing the data, in order to position the logger in the stream (Figure 6).

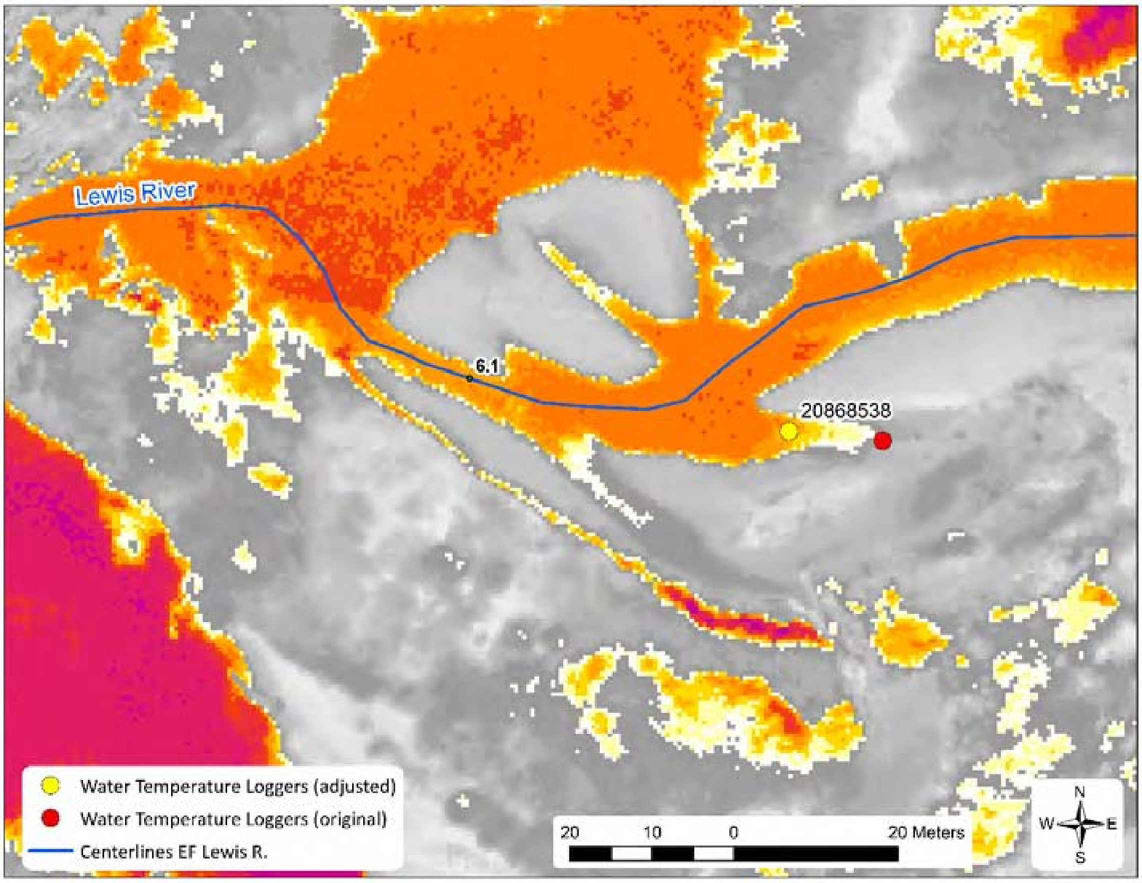

Figure 6: This image shows the original position of the data logger based on handheld GPS unit (red) and its adjusted position (yellow) near river km 6.1 of the EF Lewis River.

Interpretation and Feature Extraction

To begin the interpretation of thermal infrared data, a stream centerline was digitized using the TIR mosaics into a shapefile consisting of named streams (*at a scale of 1:5,000*). The goal is to digitize streams that are found in publicly available data (such as the National Hydrography layer – NHD). As the streams were digitized off the thermal imagery, care was taken to avoid as many non-water features as possible; however, due to the nature of the streams, aquatic vegetation, boulders, bridges, and other obstructions could not always be avoided in narrow passages. Variations in nomenclature might occur due to possible differences between information that is publicly available to QSI and local knowledge of named features. Additionally, river lengths are measured cumulatively from the downstream most point of the stream in the AOI towards the upstream most point. Therefore, the calculated length represents only the streams within the surveyed AOI and is not relative to the overall river network outside the AOI.

Thermal Infrared Mosaic Sampling and Interpretation

Two analysis techniques were used to interpret the TIR data: longitudinal temperature profile (LTP) and manual point source sampling.

Longitudinal Temperature Profile

Longitudinal temperature profile (LTP) is a technique in which the water temperature sampled (extracted from the TIR data mosaic) along the digitized centerline of stream. The LTP assists in identifying temperature gradient in the stream and changes due to potential influence of water inflows (tributaries, springs, effluents, etc.). Using a proprietary algorithm, water temperature is sampled at a specified interval along the centerline where each statistical data of temperatures is provided for each sample within a buffered distance (Figure 7). The statistical information includes average, mean, maximum, minimum, and standard deviation of the stream's temperature. Due to the nature of the automated sampling, some sample points inevitably fall on bridges or non-water features skewing the temperatures. These points can be identified as outliers by a high standard deviation and can be excluded from the final LTP. The resulting temperatures are plotted against river kilometers to develop the final LTP.

Significant Feature Sampling

Significant feature sampling (SFS) is a technique in which features of significant thermal anomalies in the TIR mosaic are identified and sampled to collect their statistical information. Such features may indicate to a potential inflow from tributaries, springs, or an expression of subsurface activity or hyporheic inflow. The features are manually identified across the floodplain and the riparian zone where a their thermal signature is higher or lower than the river's mainstem (Figure 8). The SFS is provided as a shapefile and in a tabular format where the point attributes include the associated tributary with the feature and temperature statistics calculated based on a specified buffer around each point location. Due to the nature of the springs and seeps and the scale at which the points were digitized, the statistics for smaller features inevitably include non-water pixels and might impact their statistical summaries. On the contrary, larger features will be undersampled. As such, the entirety of the statistical information should be considered in the analysis. The statistical information includes average, mean, maximum, minimum, and standard deviation of the feature's temperature. The findings were incorporated with the LTP plot to provide spatial context for interpreting temperature patterns.

Calculated Statistic Parameters

Each sampling point along the centerline holds information summarizing the statistical parameters of the 10 points within the defined buffer (Figure 7). The parameters are:

- Mean and median: define the mean and median temperature values of all 10 sampled points. The mean temperature is the value used in plots and figures. Median values can be used for further analyses by the end user.
- Minimum and maximum: define the minimum and maximum temperature values among all sampled points.
- Standard deviation: defines the standard deviation across all sampled points. This value is important to identify sample points where non-water features fall within the defined buffer. While low standard deviation values represent homogeneous thermal features, high standard deviation indicate that the sample point was too close to a feature at temperature significantly different than the water body. The value of standard deviation is important in selectig invalid sampling points.

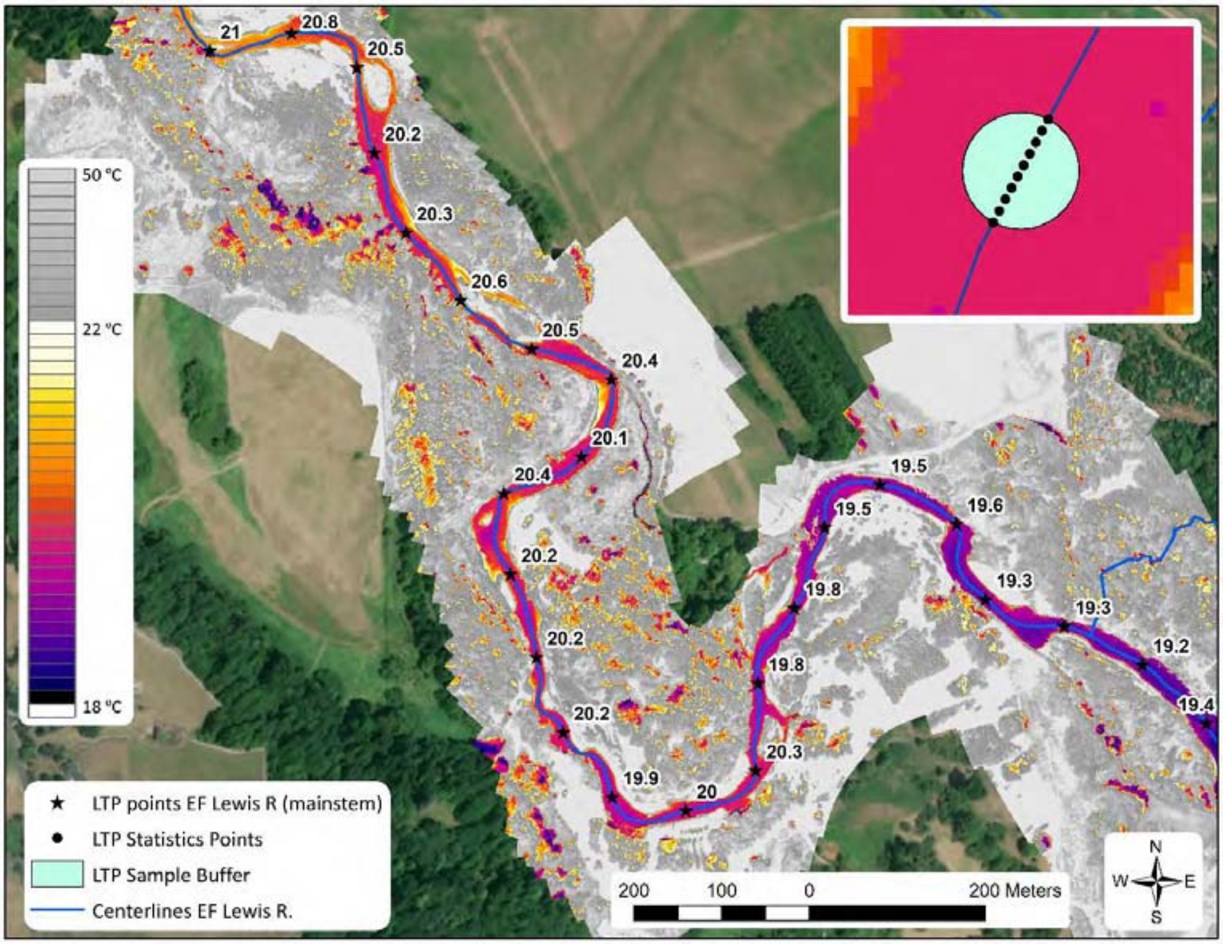

Figure 7: TIR image shows an example of the longitudinal temperatures along the stream's centerline. Mean water temperature is displayed along the stream's centerline (in ^{o}C).

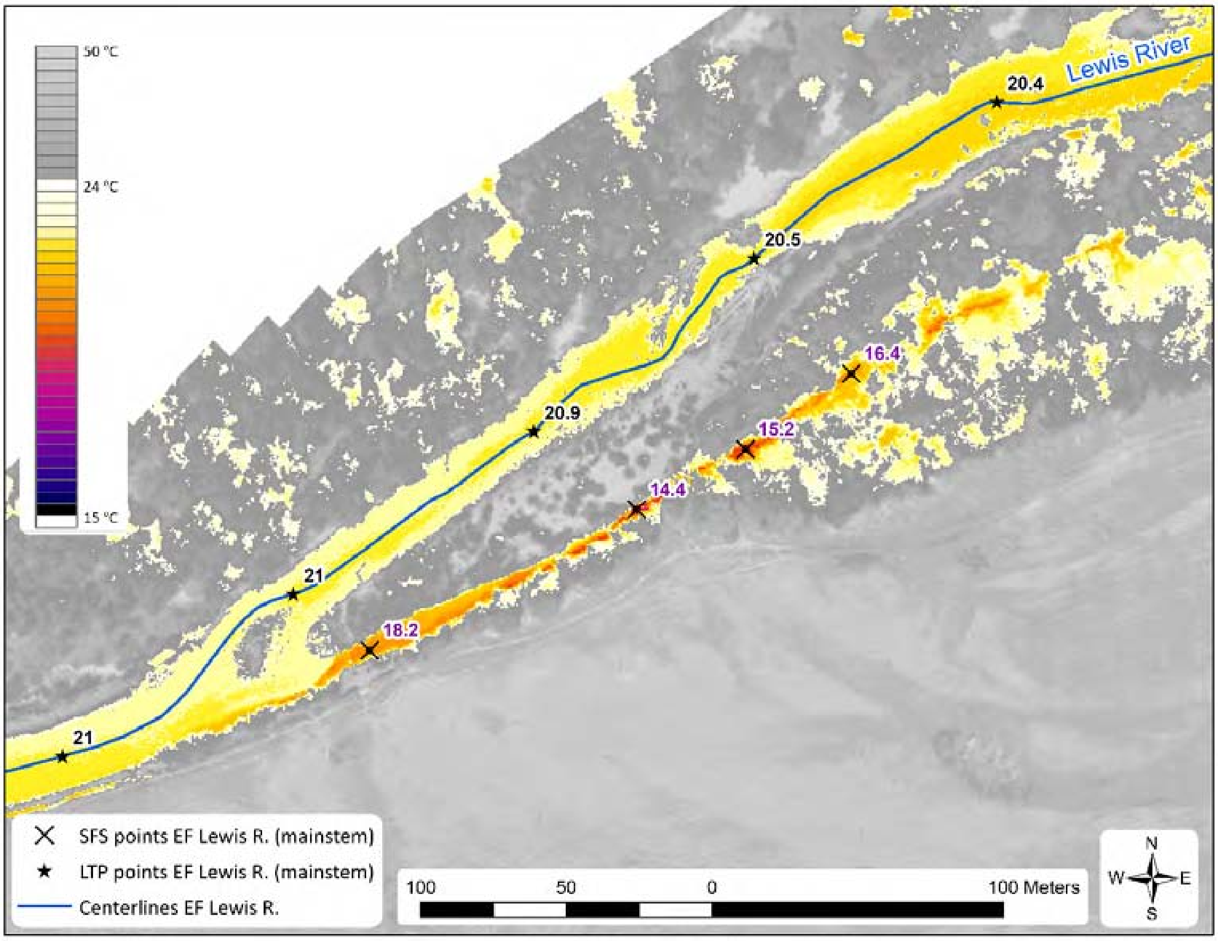

Figure 8: TIR image shows the location and temperature of significant feature sampling (SFS) of a potential inflow along a cold-water side channel into the mainstem. Also mean water temperature is displayed along the stream's centerline in °C.

Table 4: Summary of the processing and analyses steps used in the thermal analysis

Processing and Analyses Steps	Data File	Description	Software used
Calibrate thermal imagery	*<TIMESTAMP >.tif*	Convert raw TIR image digital number to radiance temperatures based on the sensor's factory calibration. Adjust radiant temperatures based on the ground control kinetic temperatures.	FLIR ResearchIR v. 1.50.3
Generate orthorectified imagery	*<TIMESTAMP >.tif*	Incorporate the spatial location and sensor's orientation into creating orthorectified imagery	OrthhoVista Or AgiSoft
colorramp	*<STREAM>_<SECTION>.lyr*	Develop a colorramp that highlights spatial variability of stream temperatures.	ArcMap v. 10.5
Digitize stream centerline along main flow path seen in TIR imagery	*Centerline_ <STREAM>.shp*	Streamlines were digitized and routed based on the final thermal mosaics in order to best represent the centerline/main flow path.	ArcMap v. 10.5
Longitudinal temperature Profile	*LTP_<STREAM>.shp*	Using automated QSI tools, a GIS point layer was generated from the stream center line layer at 100-meter intervals. Each point was assigned a river kilometer measure and the TIR radiant temperature was sampled based on an average of 2-meter sample buffer radiating out from the center point along the centerline.	ArcMap v. 10.5 QSI script
Identify and sample significant features	*SFS_<STREAM>.shp*	Manually digitize and sample significant features. The sampling utilizes QSI's customized tools.	ArcMap v. 10.5 QSI script
Longitudinal profiles plots	*LTP_SFS_<STREAM>.xlsx*	Plot temperature against river km for the longitudinal profile and the manually identified features.	Excel

Thermal Infrared Analysis

The TIR analysis focuses on utilizing the thermal signatures in the survey area to identify features that are relevant to the project's objectives. The analysis reviews the stream's longitudinal thermal gradient, features at the edge of the stream's channel, point source and non-point source inflows (tributaries, side channels, seepage, effluents, springs, hyporheic) in the floodplain. Identifying such features relies on automated algorithms and visual inspection by a trained professional analyst. The analysis is quantitative and the final TIR mosaic accuracy assessment is provided. Two datasets summarize the analysis: the longitudinal temperature profile (LTP) and the significant feature sampling (SFS). Both datasets are provided in shapefile and tabular formats. The LTP is generated by plotting mean stream temperatures at a specified interval against the stream's length. Significant features along the river and in the survey area are incorporated with the LTP plot to provide spatial context for interpreting temperature patterns.

Accuracy Assessment Results

TIR imagery was calibrated using in-stream temperature data from the loggers that were deployed. While the initial TIR imagery calibration was based on records from all loggers, temperature offset was observed at the lower section of the mainstem. Along this section, the data from three data loggers were used in the calibration (SN: 20733344, 20868531, 20868538) where two of which fell within the accuracy threshold and the third (SN: 20733344) didn't. A further review of this logger's records showed different temperature pattern than the other two. The plotted records showed that its daily maximum temperatures isn't as high as the adjacent loggers and it is unexpectedly divided into two maxima (Figure 9). Therefore, calibrating this section of the river was completed without the records from this logger. Nevertheless, the accuracy assessment table includes its relevant data point.

The accuracy assessment, a comparison between the water temperatures recorded by the in-stream data loggers and the radiant temperatures derived from the TIR mosaic, is summarized in Table 5. Data is considered within spec when the differences between TIR radiant and in-stream kinetic temperatures were within the target accuracy threshold of ±0.5 °C. The accuracy assessment is based on the data recorded by all data loggers highlighting the outlier data points. For the EF Lewis River project, all sections of the mosaic were within the accuracy threshold except to one (SN: 20733344) which was attributed to be a result of localized malfunction or a problematic deployment. Further invitation might be required by the end user of the recorded water temperature data and is beyond the scope of the thermal infrared survey project.

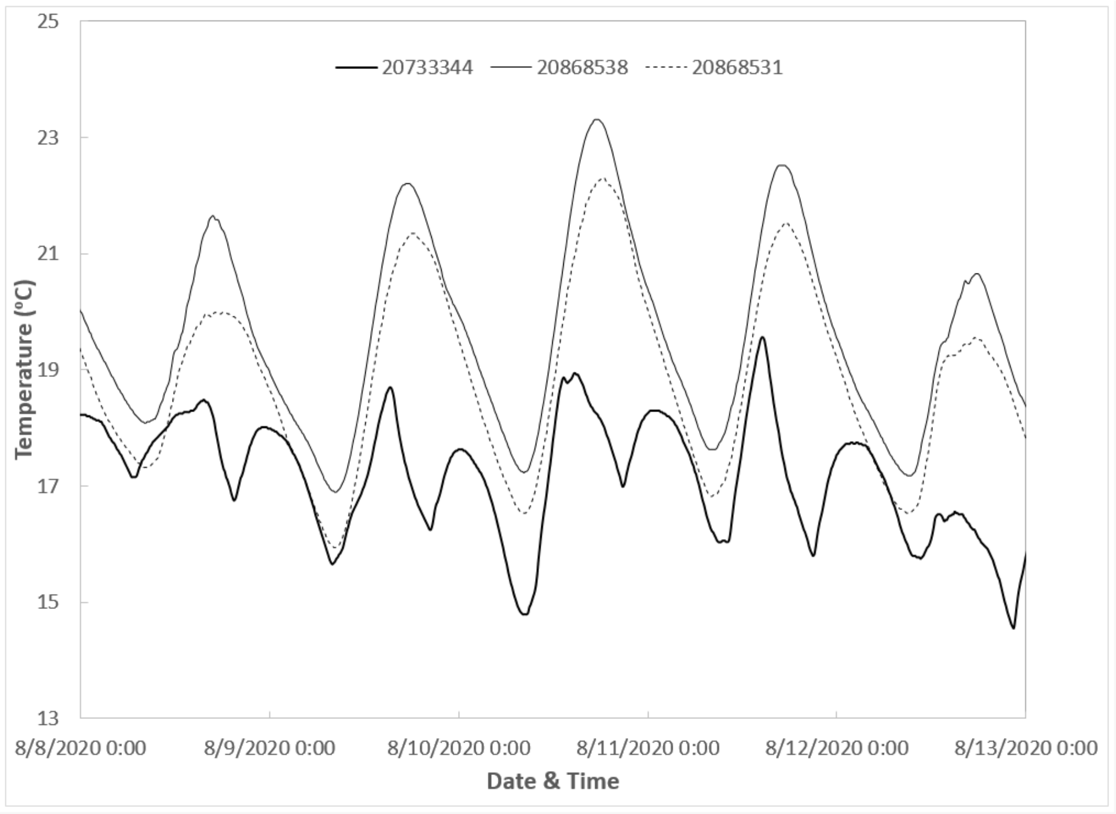

Figure 9: Water Temperature plot for three adjacent logger sites showing the unexpected pattern of logger SN20733344 which, in this case, is considered to be an outlier and shall be excluded from the final accuracy assessment.

Table 5: Comparison of radiant temperatures derived from the TIR images and selected temperatures from the in-stream sensors. Outliers are colored in red.

Serial Number	Stream	Calibration Temperature (°C)	Mean (°C)	Difference[2] (°C)
20868534	Rock Creek.	16.5	16.6	0.1
20868535	Mason Creek.	18.0	18.1	0.1
20868527	EF Lewis R.	20.4	20.8	0.4
20868529	EF Lewis R.	19.7	19.3	-0.4
20868526	EF Lewis R.	18.7	18.6	-0.1
20868524	EF Lewis R.	16.6	16.3	-0.3
20868543	EF Lewis R.	16.4	16.1	-0.3
20868531	EF Lewis R.	20.5	20.3	-0.2
20733344	EF Lewis R.	19.6	21.3	**1.7**
20868538	EF Lewis R.	21.4	21.8	0.4

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[2] Temperature difference is calculated by subtracted the temperature used for calibration from the mean temperature of sampled cells in the mosaic within a buffer of 1 meter from the location of the logger.

Longitudinal Temperature Profiles and Significant Features

The longitudinal temperature profile (LTP) of a stream is an informative tool to detect stream temperature gradients and the effect of water inflow sources. In the LTP, mean channel temperatures were plotted against river length for the East Fork Lewis River. A total of 50.2 km (30.2 miles) of stream centerlines were manually digitized and analyzed. Significant features of tributaries, side channel, or point sources/sinks were identified and plotted along with the LTP. The final LTP data excludes most of the non-water features that were sampled using the automated algorithm. However, further refinement might be required by the end user based on local information and familiarity with the survey area. The analysis divided the area into five mosaiced TIR imagery representing the mainstem and four tributaries. While the overall analysis focused on the mainstem's temperature gradient and major thermal signatures, at the tributaries level the emphasis was to identify water patches within the active channel and potential significant features within the floodplain.

EF Lewis River

The acquisition campaign successfully collected thermal infrared data along the EF Lewis River and its side channels. The analysis of extracting a longitudinal temperature profile (LTP) and the significant feature sites (SFS) was also successful. TIR mosaics and LTP analysis showed an overall downstream warming gradient throughout the course of the mainstem of the EF Lewis River (Figure 10). The mean temperature of the river water increased from 15.1 °C at the upstream section reaching 21.4 °C at the downstream section of the river. A downstream warming gradient occurs when water temperature increases while flowing downstream, mainly due to incoming solar loading, heat exchange with warm air, and potentially warmer inflow of water sources such as tributaries, springs, urban effluents, and agricultural backflow. Downstream warming is common in rivers under summer conditions, especially the ones fed by flow from springs and snowmelt.

The analysis also identified thermally significant features sites (SFS) across the river's floodplain to assist with explaining the thermal gradient. The focus is on locating tributaries entering the mainstem, hyporheic flow at the water's edge, side channels, and agricultural backflow. The water temperature relative to the mainstem, flow size, and density along the main channel has localized and downstream influence on the mainstem's water temperature. The majority of identified SFS were at temperatures colder than the mainstem mostly leading to a cooling gradient or a thermal stability. It is notable that localized temperature decreases were spatially correlated with cold inflow from tributaries especially from Dean Cr. between river km 6.3 and 5.3 and Mason Cr., and Lockwood Cr. Between river km 1.8 and 0. LTP results show that all three tributaries contribute cold water and have an important role in the mainstem's thermal regime. On the contrary, inflow from Rock Cr. shows to contribute to a slightly localized warming gradient or to have a minimal influence on the mainstem's water temperature.

There were 50 thermally identifiable significant feature sites across the mainstem's floodplain, most of which were colder than the mainstem (Figure 11). Most notable are an upstream sections (river km 31 to 23) and a downstream section (river km 15 to 6.3). The upstream section includes a section along which water temperature rapidly warmed and cooled and another section of gradual warming.

Along the section between river km 31 and 27, a rapid increase and decrease in water temperature were observed. Although all the identified SFS were colder than the mainstem all along this specific section, the rapid warming followed by yet a rapid cooling. This pattern can be the result of a variety of localized geomorphological characteristics. One explanation is that a low flow conditions and increased riverbed permeability may have caused a large percentage of the water to flow in the subsurface zone mostly between river km 31 and 28, and reemerging at river km 28.1 (near NE Hantwick Rd bridge) as a colder, hyporheic flow. A high density of boulders and rocks being exposed along the upper part of this section were visible in TIR imagery and support this explanation (Figure 12). A gradual downstream warming was observed thereafter.

River section 15 to 6.3 km was characterized by frequent side channels and cold, potentially hyporheic, inflow sites. Most of the identified SFS were also along the left-side bank and the north-facing slope. The combination of inflow temperature and slope aspect indicates that cold subsurface water or shallow groundwater might be seeping into the river along this section. The result to the mainstem is stabilizing stream temperature gradient by either lowering water temperature of preventing its downstream warming.

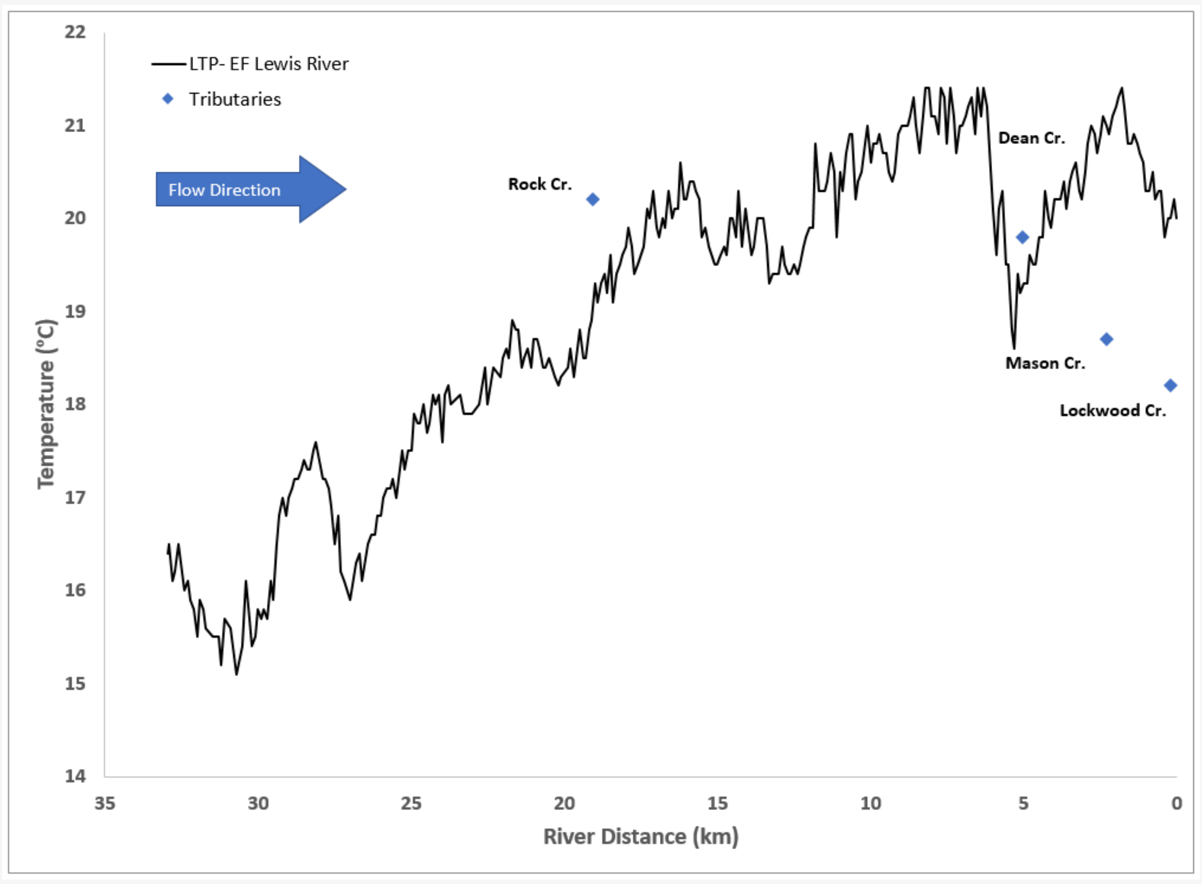

Figure 10: Longitudinal temperature profile (LTP) and inflow points from tributaries plotted against river length along the EF Lewis River. Both datasets represent mean sampled stream temperatures.

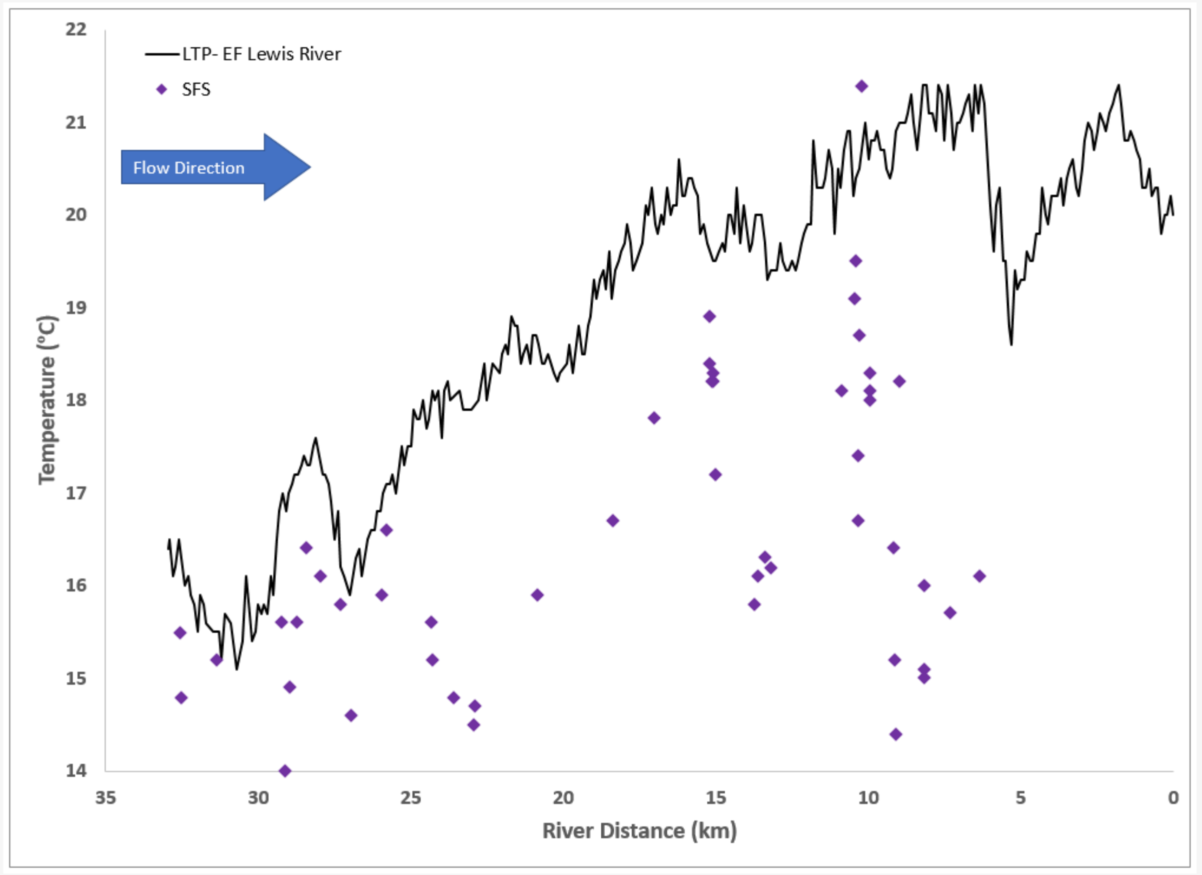

Figure 11: Longitudinal temperature profile (LTP) and significant feature sites (SFS) plotted against river length along the EF Lewis River. both datasets represent the mean sampled water temperature.

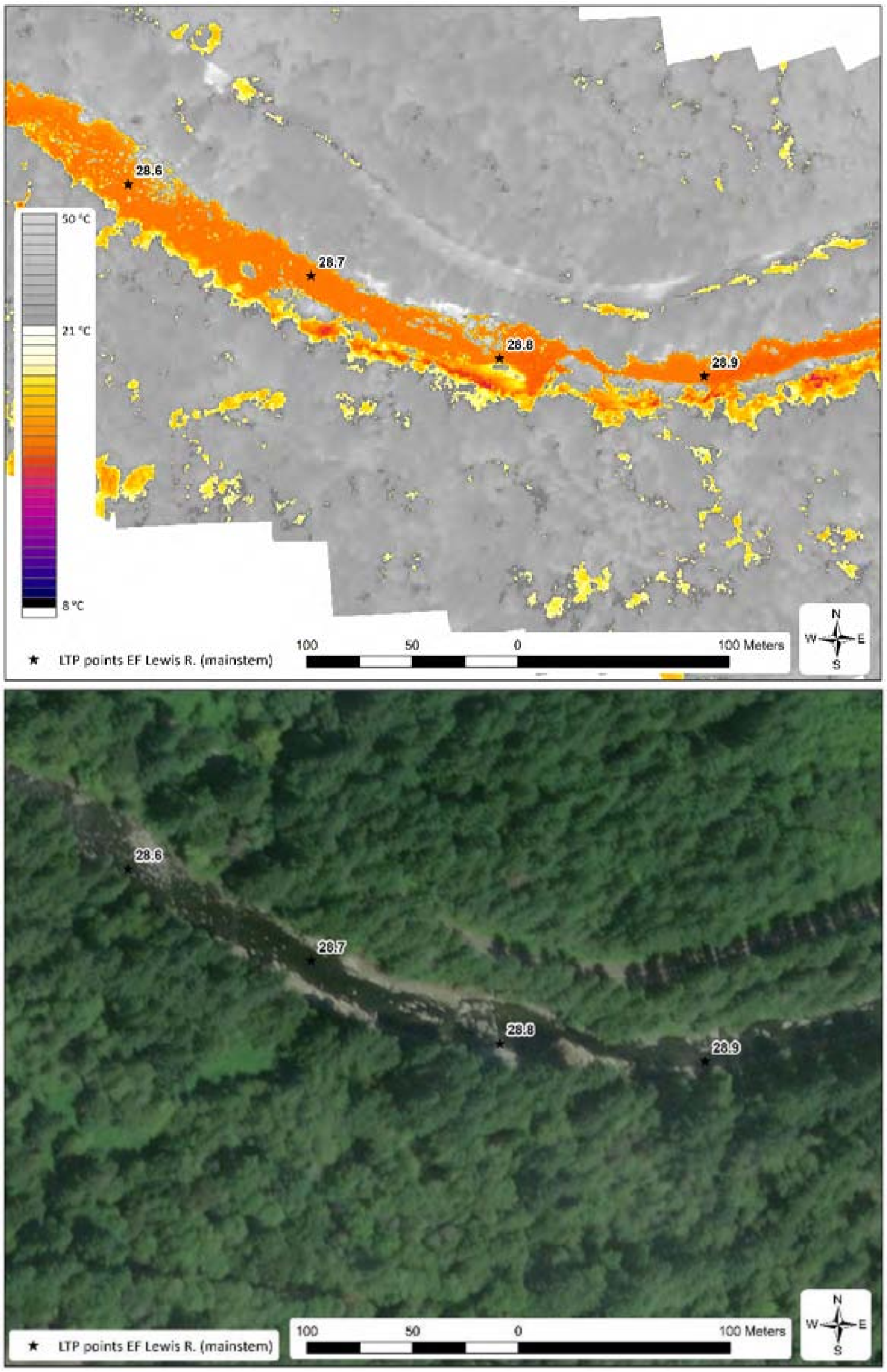

Figure 12: thermal infrared (top) and aerial natural color (bottom) imagery showing boulders and riverbed rocks exposed due to low flow conditions in the EF Lewis between river km 28.6 and 28.9. This could be one of the explanation behind rapid river temperature warming followed by a rapid cooling due to a high percentage of the water flowing in the subsurface zone.

Tributaries

Thermal infrared imagery was successfully collected for all four tributaries: Lockwood Cr., Mason Cr., Dean., and Rock Cr. Low water flow and dense canopy cover resulted in scattered thermal signatures representing water in the stream that otherwise would form a continuous, defined shape (Figure 13). With the help of customized color ramps to isolate the thermal signature of water and relevant features, a trained eye can identify the paths of stream's water along the active channel and digitize the centerlines. However, digitizing the centerlines was mostly tracking the potential paths between thermal features of water (Figure 14).

Generating longitudinal temperature profiles (LTPs) for the tributaries based on 100-meter intervals ended up sampling non-water features and missing a large portion of relevant water features. Therefore, a shorter interval sampling was applied (5-meter), resulting in a noisy temperature profile plot (Figure 15). To select only sampling points falling on water features, the range of temperatures recorded by the water loggers deployed in the tributaries (SN: 20868534 and 20868535) were reviewed. The review determined that water temperature didn't reach higher than 19 °C. However, the mosaic showed that potential upstream water features could have reached 22 °C.

Selecting relevant sampling points of the tributaries' LTPs required a temperature-based elimination procedure. The elimination procedure excluded sampling points higher than 22 °C to take into consideration features representing warmer portions of the stream (Figure 16). Additional selection parameters excluded sampling points of standard deviation higher than 0.5 ºC[3]. Unfortunately, the remaining points didn't provide an informative continuous temperature profile due to the lack of continuous water features and were plotted against river distance (Figure 17).

Following the standard procedure, which was implemented for EF Lewis River, significant feature sites were identified (Figure 18). Under the current conditions of disconnected water features, the LTP plot representing a 1-dimentional representation of stream temperature gradient was found to be uninformative and could not be used to draw conclusions. A 2-dimentional thermal infrared map has a higher potential in this case to provide an informative details especially as significant feature sites are incorporated.

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[3] Refer to "Calculated Statistic Parameters"

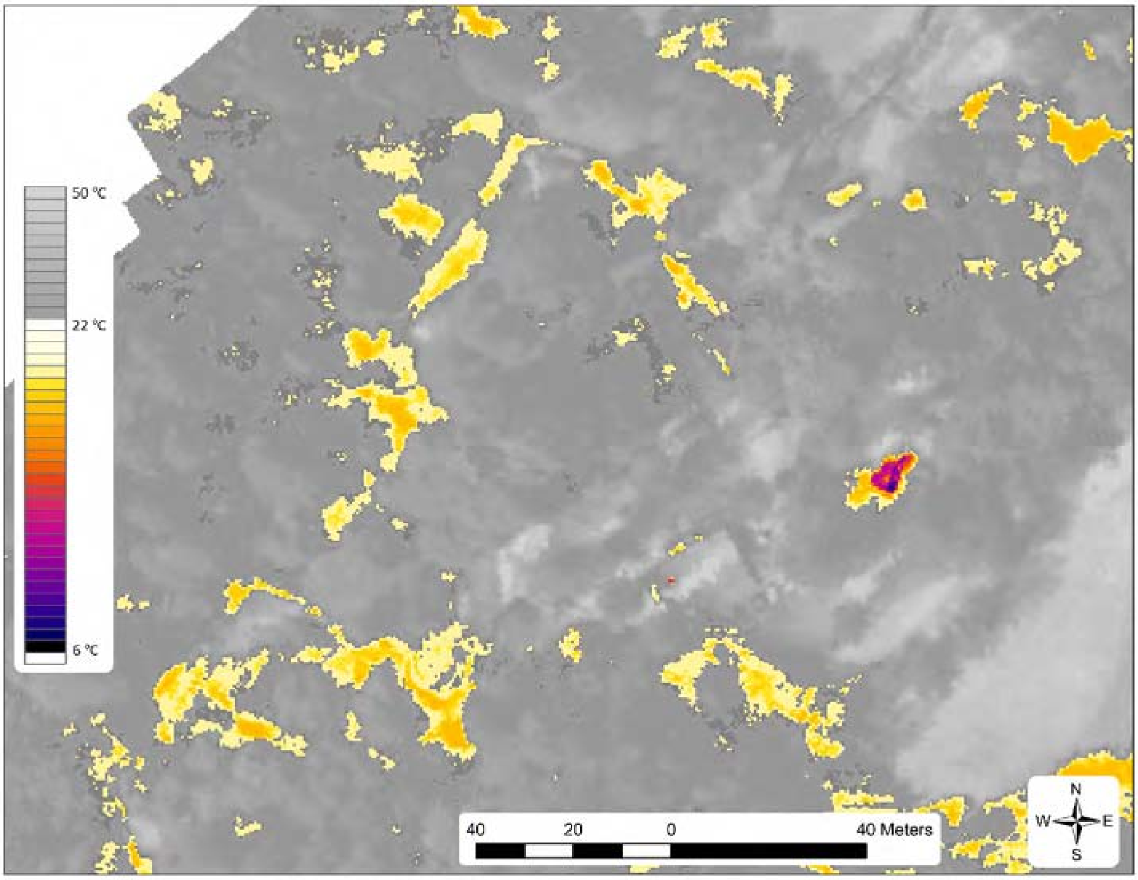

Figure 13: Thermal infrared map showing scattered signatures of potential water across the floodplain of Mason Creek. Customized color ramps and a trained analyst is required to identify the stream's path.

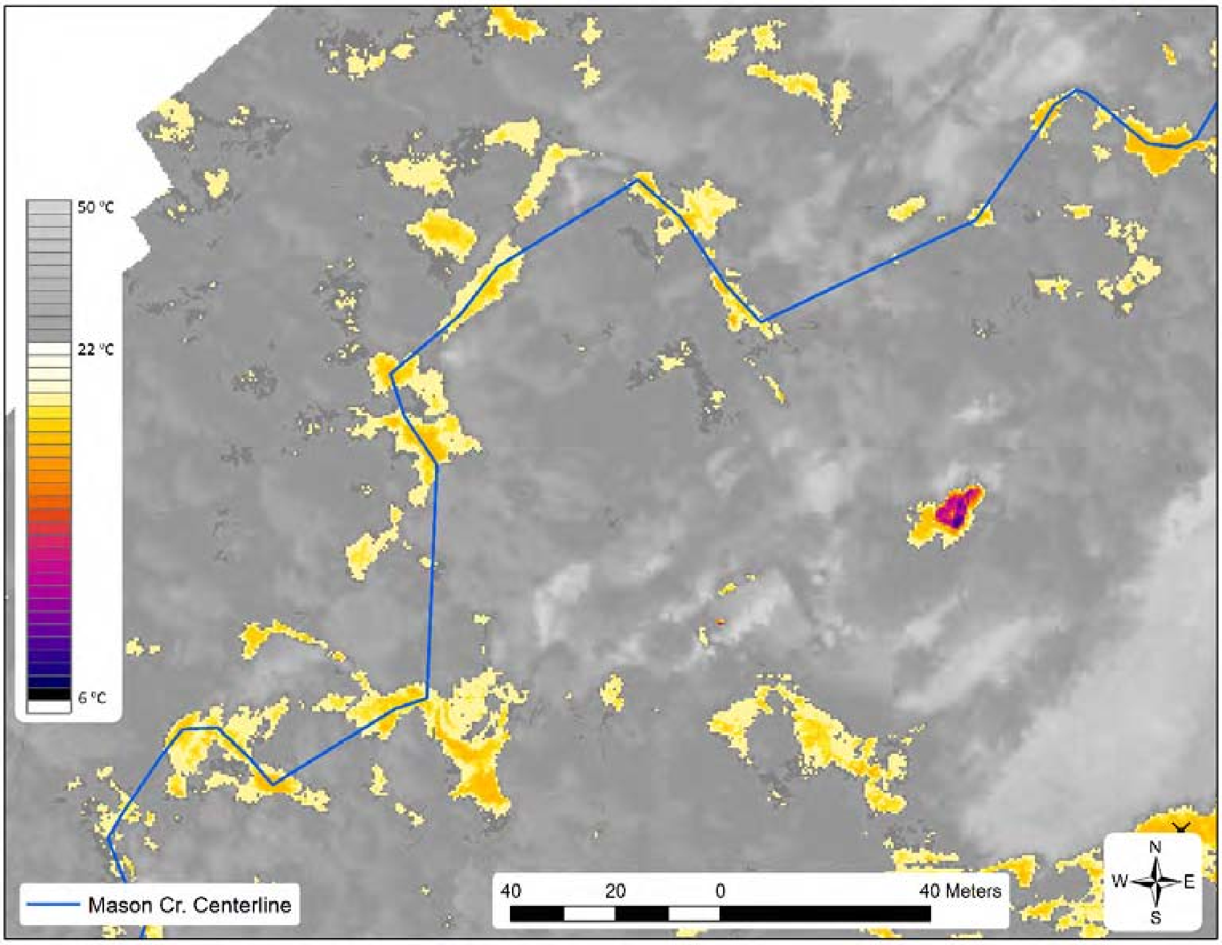

Figure 14: Thermal infrared map showing scattered signatures of potential water across the floodplain of Mason Creek and the digitized centerline.

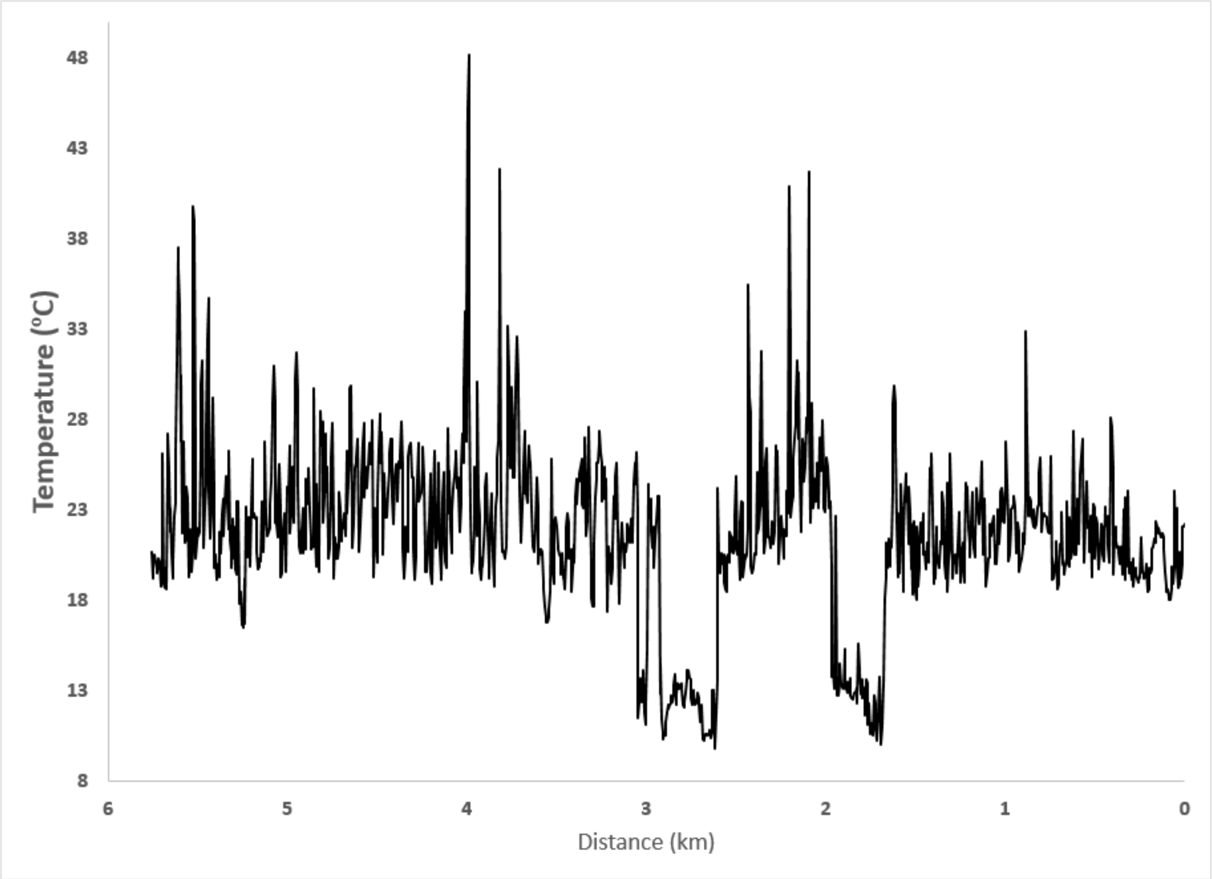

Figure 15: Plot of the longitudinal temperature profile along Mason Creek. It is uninformative plot due to the lack of continuous water body along the stream's centerline.

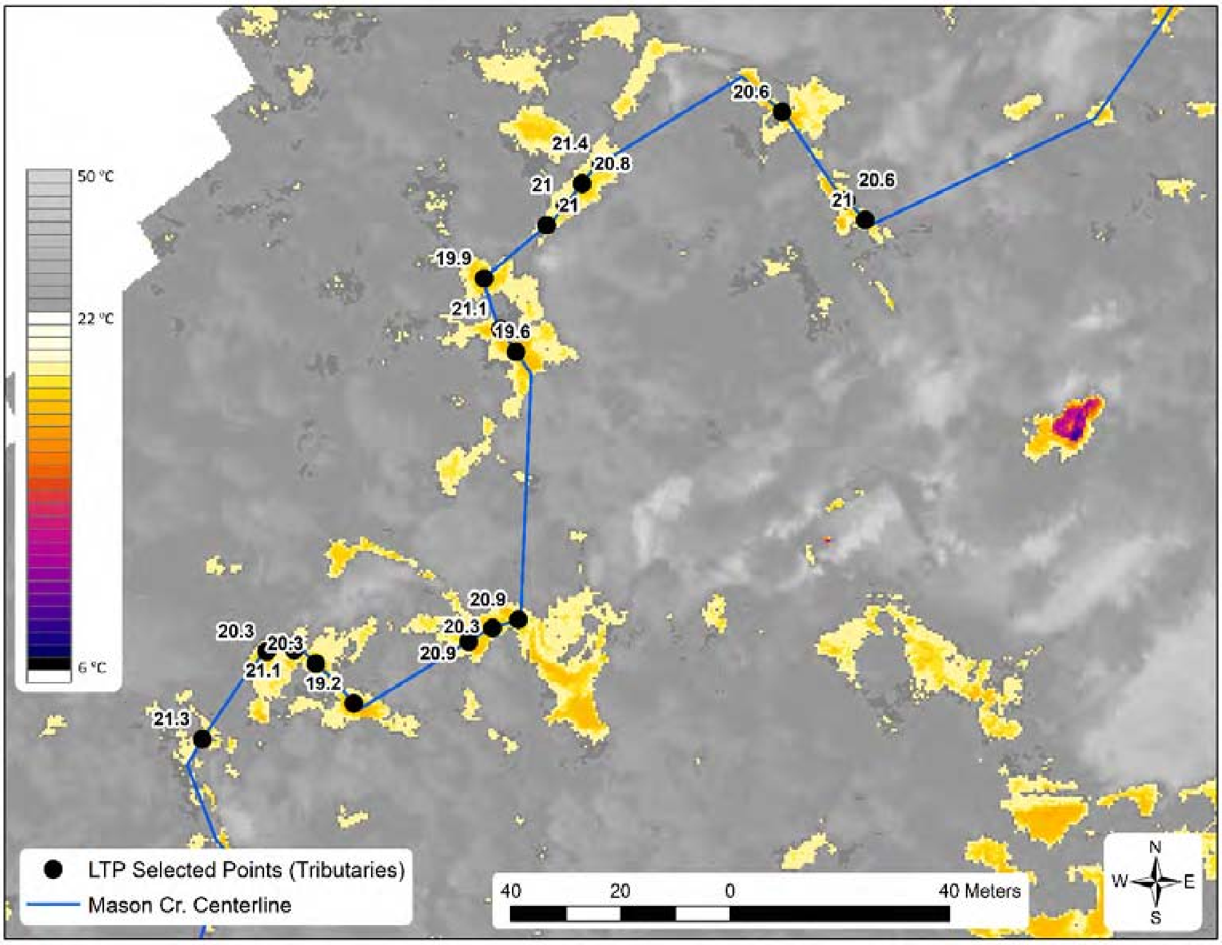

Figure 16: Thermal infrared map showing the selected LTP points falling on water features after eliminating sampling points warmer than 22 ^{o}C, Mason Creek.

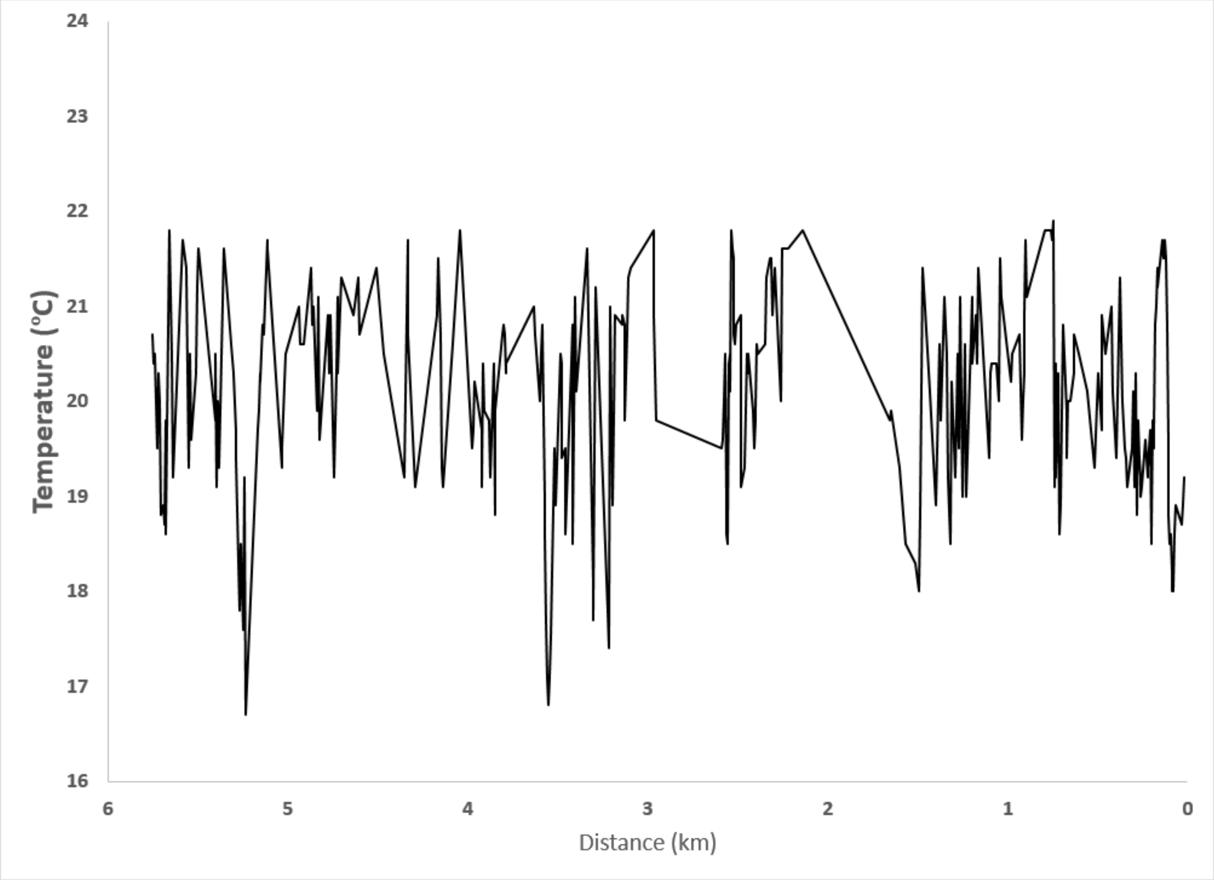

Figure 17: Plot of the filtered results of longitudinal temperature profile along Mason Creek. Despite eliminating results where the maximum temperature of sampled pixels is below 22 ^{o}C and a standard deviation is less than 0.5 ^{o}C, the data and plot uninformative due to the lack of continuous water body along the stream's centerline.

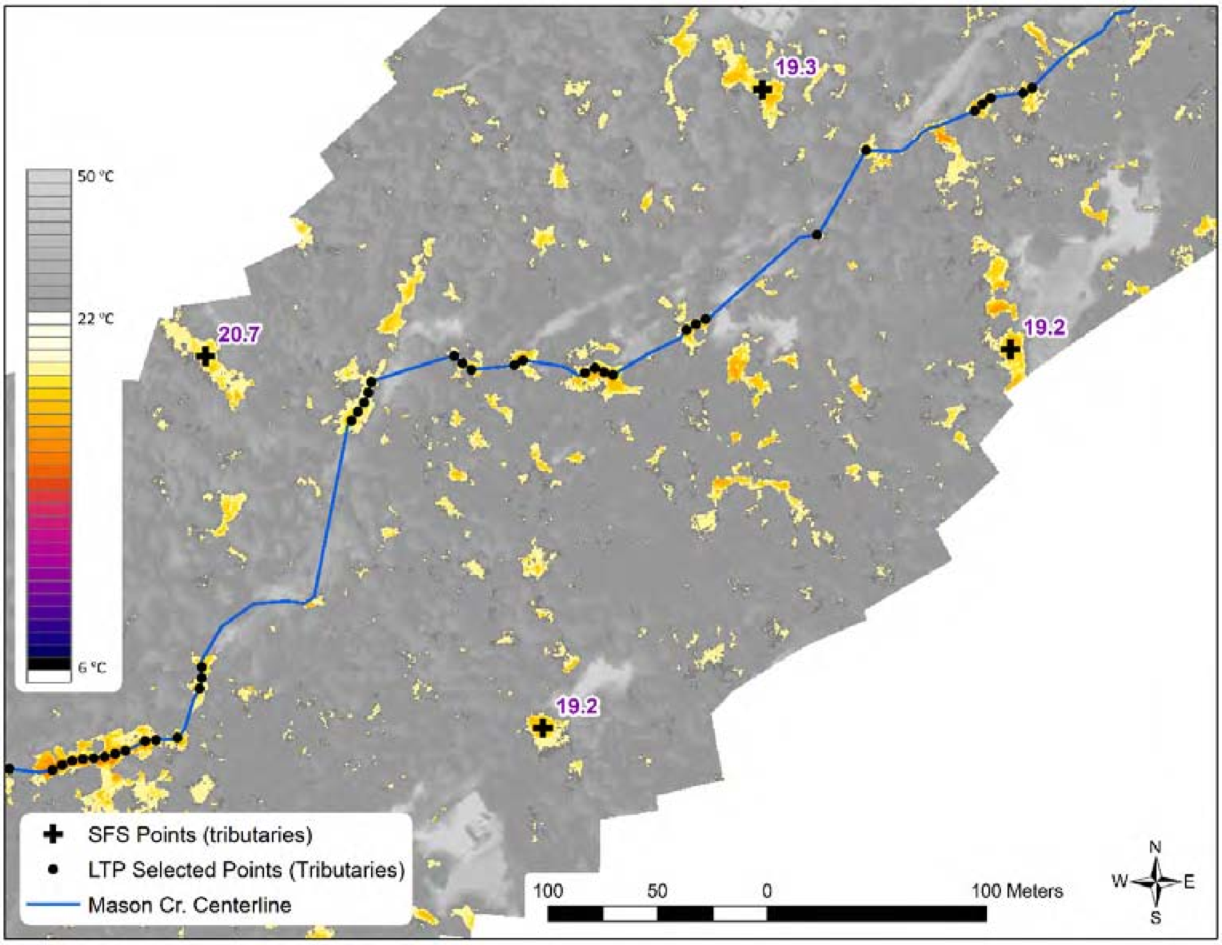

Figure 18: TIR map showing a sample of the identified significant feature sites adjacent to the digitized centerline and selected LTP points, Mason Creek.