# CHEHALIS THERMALSCAPE

## Study Goals and Objectives

The objectives of the Chehalis Thermalscape study are to 1) maintain a year-round temperature monitoring network across the Chehalis Basin, 2) use spatial stream network (SSN) models to develop and update basin wide stream temperature maps ("thermalscapes") used to track spatial and temporal trends in stream temperature, and 3) update climate change projections of stream temperature with the most up to date stream temperature data.

Additional objectives for 2022-2023 included developing thermalscapes for each month of the year. This information is some of the first to describe annual stream temperature patterns at the basin scale.

## Methods / Study Design

WDFW maintains temperature loggers continuously monitoring stream temperatures year-round throughout the Chehalis Basin (Figure 1). Each year, we attempt to place loggers in locations where previous data are lacking and thermalscape temperature predictions have relatively higher uncertainty. In 2022-2023, approximately 117 unique locations are actively being monitored for stream temperature.

Temperature data are collected at 30-minute intervals. At each of the fixed monitoring sites, loggers are positioned based on three criteria: well-mixed water, shade, and adequate depth to remain submerged for the summer low flow period. Loggers are anchored by cable or epoxy and secured in white perforated plastic vinyl chloride (PVC) housing which allows flowing water to contact the logger but shields the logger from sunlight. Monitoring sites are downloaded in spring, summer, and fall as streamflow allows. Loggers are typically replaced annually to ensure proper function; however, logger malfunctions can occur resulting in loss of data.

Prior to deployment, data loggers are calibrated with a National Institute of Standards and Technology (NIST) certified thermometer in cool and warm water baths over a 48 to 72 hour period to ensure measurement deviations on loggers do not exceed 0.5ºC.

We use three levels of screening to remove erroneous temperature data prior to modeling: 1) loggers are inspected in the field to ensure they are well positioned in the thalweg and submerged, 2) data are plotted by time and visually inspected for outliers (e.g., >30°C or <0°C) or abnormalities compared to neighboring loggers, and 3) data are deemed erroneous if the rate of hourly change exceeds 2.5ºC, which suggests that the logger was likely dewatered during that time.

New data were collected from 45 unique sites in 2021 and 67 unique sites in 2022 (Figure 1). These data were added to a dataset of previously collected stream temperature data from 241 unique sites resulting in 353 unique to develop SSN models. The totality of the dataset includes data collected by WDFW (n = 332), the Chehalis Tribe (n = 15), and Department of Ecology (n = 6). All month-year combinations with >80% of the month measured for stream temperature were used to develop thermalscapes.

Stream temperature modeling and development of basin wide thermalscapes was completed using a spatial stream network (SSN) modeling framework and universal kriging (Isaak et al. 2014, 2017). Spatial covariates in the modeling process included elevation, riparian canopy cover, slope, mean annual precipitation, cumulative drainage area, percentage of catchment considered open water or lake upstream, and base flow index. Models included a full mixture of spatial autocorrelation structures (e.g., tail up, tail down, and Euclidean distance) and random effects of year and site. The random effects of year and site were included to account for repeat measurements at sites across years and at many sites within years. Prior to inclusion in the models, spatial covariates were assessed for multicollinearity using variance inflation factors (VIFs). All VIFs were low (<2.5) prior to running SSN models.

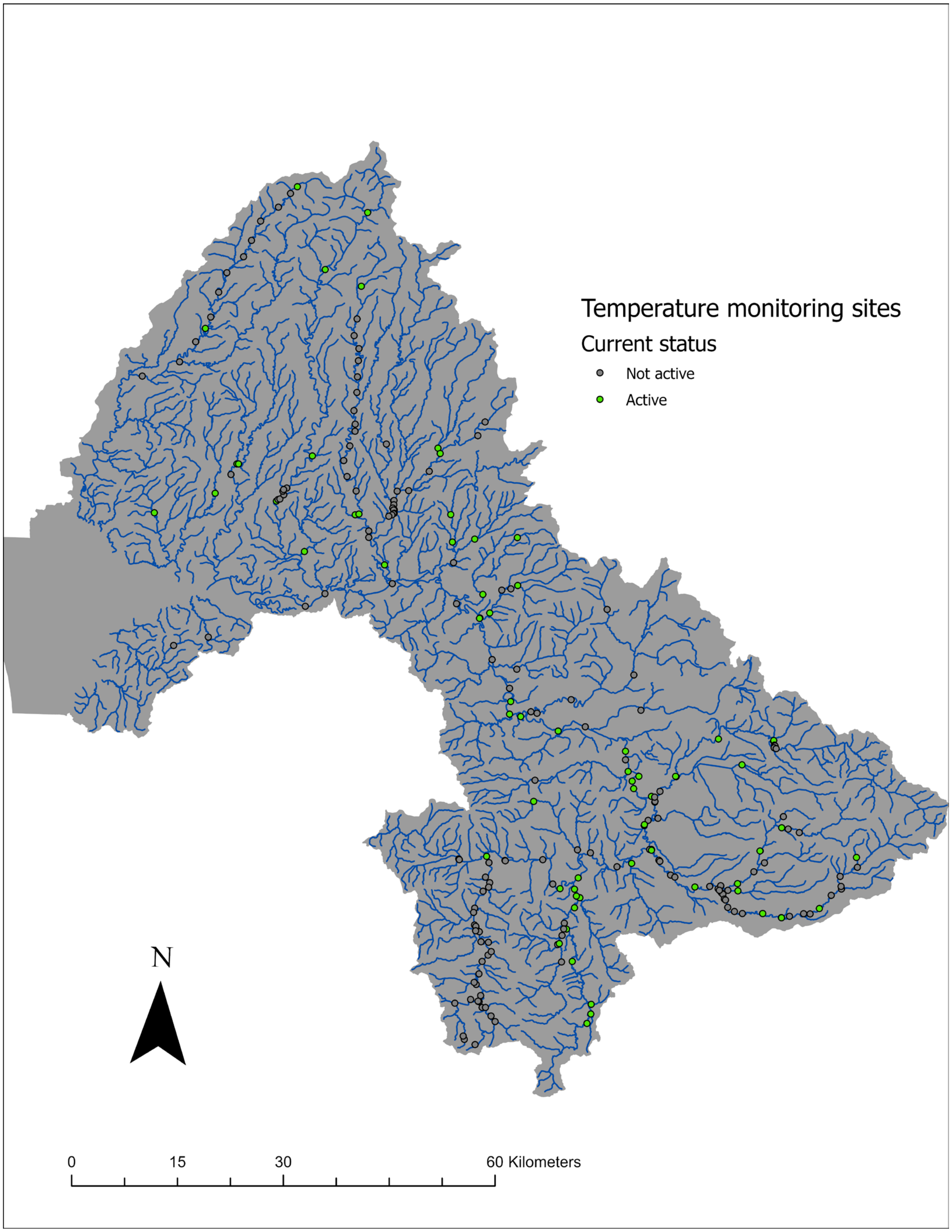


Figure 1. Temperature monitoring locations in Chehalis River. Green dots and gray dots indicate locations that are active as of 2022 (n = 67) and not active (n = 158), respectively.

## Summary of Results

Figures 1 and 2 display preliminary thermalscapes representing mean monthly temperature for all 12 months of the year. All models performed well with root mean square predictions errors (RMSPE) of ≤1.1°C and mean absolute prediction errors (MAPE) of <0.03°C.

Preliminary modeling presented here suggests covariates explaining variation in stream temperatures vary across the year (Table 1). However, it is important to note additional work is needed to account for temporal covariates of stream flow and air temperature in models. Interannual variability of air temperatures and stream flows will likely explain a significant proportion of variation in mean monthly stream temperatures because stream temperatures are sensitive to these temporal variables (Isaak and Hubert 2001). . Models presented here include a "year" covariate which can account for annual variation of stream temperatures and tended to explain a significant amount of intra-annual variation (12-70%) in stream temperature (Table 2). This underscores the importance of including air temperature and stream flow in the models. Additionally, including air temperature and stream flow in the models allows for predicting monthly stream temperatures under climate change scenarios by utilizing downscaled future air temperature projections from global climate models and predicted stream flow changes from the 2022 VIC model update.

KEY FINDINGS:

Warm stream temperatures, generally stressful for salmon (>20°C), are most widespread in July and August in the mainstem Chehalis and lower mainstem of major tributaries including the Black, Skookumchuck, Newaukum, and South Fork Chehalis rivers (Figures 1 and 2). Warm stream temperatures (>20°C) appear to be sustained in the mainstem Chehalis between the confluences of the Newaukum and Skookumchuck River for the most prolonged period relative to other areas in the basin (June – August). In spring and fall months of April, May, and September, mean monthly temperatures are generally <20°C across the basin.

Notable basin wide increases and decreases in stream temperatures are apparent during transitions from March to April and from September to October, respectively (Figures 1 and 2).

An interesting finding included heterogeneity in stream temperatures during winter months. For example, in January relatively warmer mean stream temperatures were observed in Olympic Mountain tributaries in the East Fork Satsop River and southern Grays Harbor (Figure 2). Such heterogeneity in winter stream temperatures across the basin could influence biological processes including, but not limited to, overwinter survival and incubation of salmon and recruitment of non-native predators, which may warrant additional investigations. Finer resolution maps (e.g. displaying temperature categories at <2°C scales) may reveal additional heterogeneity not shown in Figure 1 and 2.

Table 1. Preliminary results of relationships between mean monthly stream temperature and spatial covariates. Significant relationships (*p<0.05*) are indicated with a presence of "+" for positive and "-" for negative associations, respectively.

| Model | Elevation (m) | Riparian Canopy Cover (%) | Slope (m/m) | Mean annual precipitation (mm) | Cumulative drainage area ($km^2$) | Lake % | Base flow index |
|---|---|---|---|---|---|---|---|
| Jan | - | | | | | | |
| Feb | - | | | | | | |
| Mar | - | | | | + | + | |
| Apr | - | | | | | | |
| May | - | - | | | | + | |
| Jun | - | - | | | | + | |
| Jul | - | | | | | | |
| Aug | - | | | | | | |
| Sep | - | | | | | | |
| Oct | | | | | + | | |
| Nov | - | | | | | + | |
| Dec | - | | | | | | |

Table 2. Preliminary results of total variance explained by spatial covariates, spatial autocorrelation (tail-up, tail-down, Euclidean), and random effects (Site ID, year, nugget effect, or fine scale spatial error).

| Model | Spatial covariates | Tail-up | Tail-down | Euclidean | Site ID | Year | Nugget |
|---|---|---|---|---|---|---|---|
| Jan | 0.03 | 0.00 | 0.08 | 0.05 | NA* | 0.70 | 0.14 |
| Feb | 0.06 | 0.01 | 0.00 | 0.42 | 0.00 | NA* | 0.51 |
| Mar | 0.20 | 0.00 | 0.02 | 0.36 | 0.02 | NA* | 0.40 |
| Apr | 0.18 | 0.07 | 0.02 | 0.26 | 0.01 | 0.39 | 0.07 |
| May | 0.21 | 0.11 | 0.01 | 0.28 | 0.00 | 0.33 | 0.05 |
| Jun | 0.15 | 0.13 | 0.00 | 0.29 | 0.00 | 0.38 | 0.05 |
| Jul | 0.17 | 0.27 | 0.11 | 0.15 | 0.00 | 0.25 | 0.06 |
| Aug | 0.11 | 0.26 | 0.45 | 0.02 | 0.00 | 0.12 | 0.04 |
| Sep | 0.14 | 0.25 | 0.18 | 0.22 | 0.00 | 0.16 | 0.04 |
| Oct | 0.20 | 0.04 | 0.26 | 0.02 | 0.02 | NA* | 0.46 |
| Nov | 0.08 | 0.00 | 0.13 | 0.02 | 0.00 | 0.50 | 0.27 |
| Dec | 0.05 | 0.00 | 0.00 | 0.13 | 0.00 | 0.56 | 0.26 |

*Inclusion resulted in a singular matrix likely due to interdependencies among predictor variables not identified with VIFs. Therefore, it was not included in the final model.

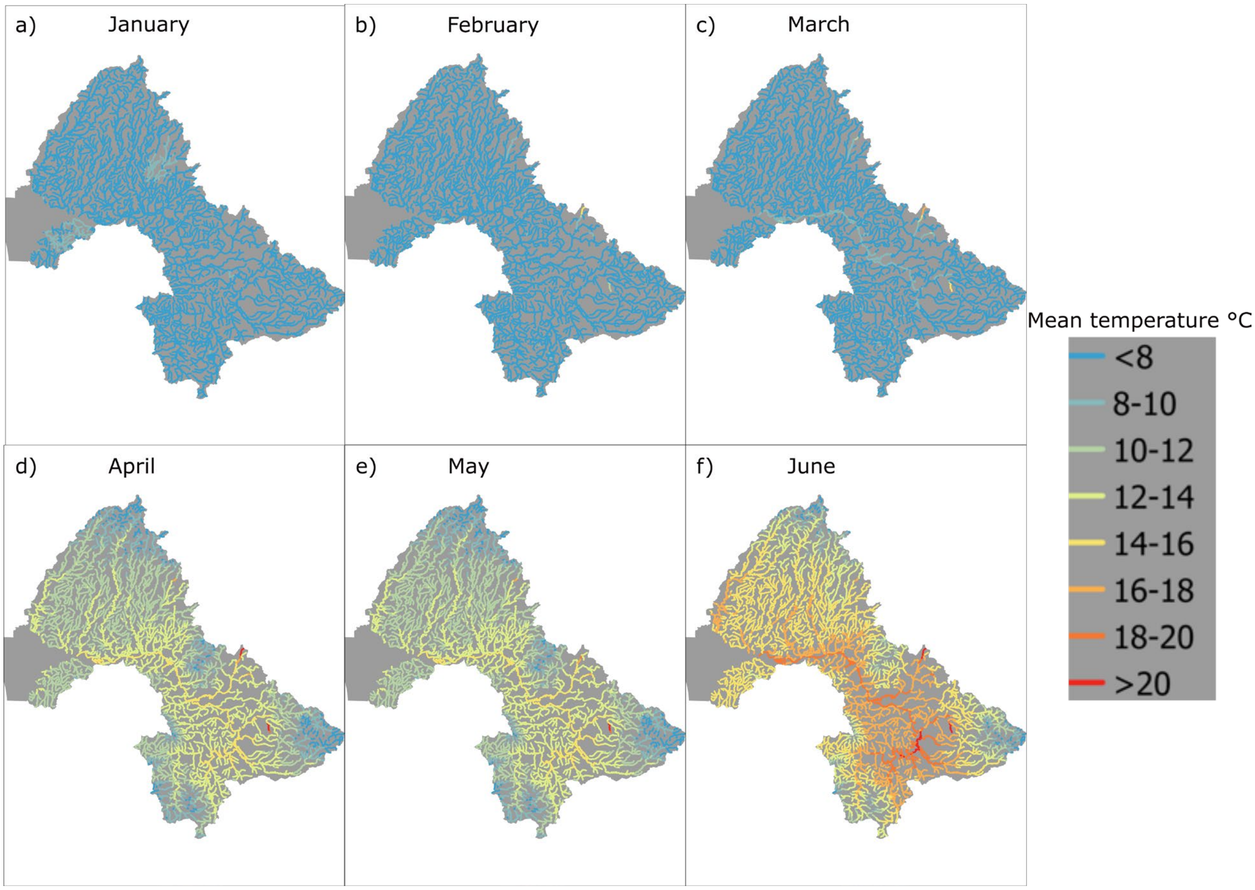


Figure 2. Thermalscapes of mean monthly temperatures for January through June.

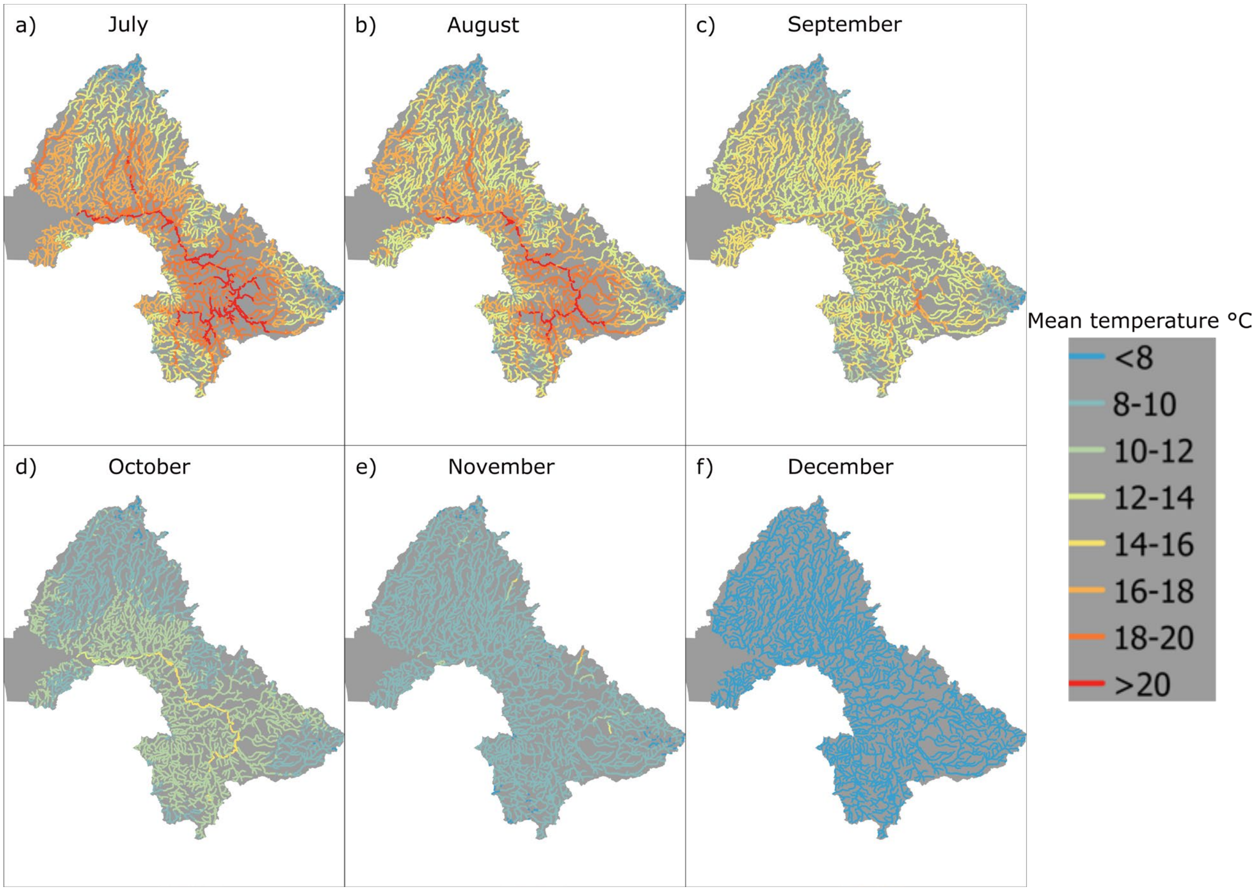


Figure 3. Thermalscapes of mean monthly temperatures from July through December.

## Discussion

Because stream temperature controls biological processes of ectothermic species, thermalscapes provide critical information for species of interest or indicator species including salmon, native fish, and non-native fish predators. Thermalscapes figure prominently for defining spatial distributions, quantifying habitat capacity, and therefore spatially prioritizing restoration and protection planning. Typically, restoration and protection planning for salmon in riverine ecosystems emphasizes the exposure and sensitivity of species during summer when habitat is constricted due to warm temperatures. While this is critical, especially in rain-dominant rivers like the Chehalis, it has also led to misguided conclusions that warm water habitats are not as important for salmon (Armstrong et al. 2021). Monthly thermalscapes show that thermally suitable habitat tracks spatiotemporal seasonal shifts across the Chehalis riverscape. For example, the most widespread warm thermal conditions that are typically not optimal for rearing salmon (>20°C) were present in July and August. However, these habitats were generally within optimal rearing temperatures for the rest of the spring and fall, highlighting the potential importance of these habitats. Previous snorkel surveys in the South Fork Newaukum River revealed expansions and contractions of rearing salmon spatial distributions from May through September correlating with spatiotemporal thermal shifts presented here (Winkowski et al. 2018).

It's important to note that the thermalscapes presented here represent mean temperatures. Modeling metrics of stream temperatures representing magnitude, such as maximum and minimum temperatures, may yield different results and interpretation.

## Adaptive Management

Stream temperature is often referred to as a master variable in riverine ecosystems. Information developed by the thermalscape analysis is critical for understanding the environment that supports aquatic species in the Chehalis Basin and is subsequently highly relevant for restoration and protection planning. This study provides more thermal information that is relevant to biological processes than was previously available when ASRP conservation and restoration projects were developed. While further research is needed, these results provide insight into the seasonality of river temperatures in the Chehalis Basin. This new information could be a valuable spatially explicit tool for understanding  overwinter habitat for rearing salmon, incubation conditions for salmon eggs, predicting spatial distributions, recruitment dynamics, and consumption levels of non-native predators, or characterizing seasonal variability of thermal regimes of impounded rivers such as the Skookumchuck and Wynoochee. On a larger scale, thermalscapes may also be a tool to identify locations of which stream temperature cooling restoration projects could be applied to reduce the overall quantity of warm water habitat during summer months when stream temperatures are at their peak.