TASK 2.11 SUMMARY REPORT: SCIENTIFIC STUDIES OF SUISUN CREEK TO ENHANCE STREAM FLOWS

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INTRODUCTION

This report summarizes the results of the following tasks:

- Task 2.1 Coordination with Creek Landowners
- Task 2.2 Establish Creek Reaches
- Task 2.3 Calibration and Deployment of Air/Water Temperature Data Loggers
- Task 2.4 Installation of Stream Flow Gages
- Task 2.5 Dissolved Oxygen Monitoring
- Task 2.7 Riparian Corridor Surveys
- Task 2.8 Fish Surveys

Ca. Land Stewardship Institute (CLSI) carried out several different types of monitoring from 2017-2021 along Suisun Creek. Monitoring included streamflow, water temperature, canopy cover, dissolved oxygen, pH and specific conductance. A survey and mapping of the riparian corridor was completed in 2018. Cramer Fish Sciences completed fish surveys between 2017-2020.

Creek reaches (Figure 1) were established based on geomorphic features of Suisun Creek. CLSI contacted all of the landowners along Suisun Creek and requested access for the monitoring and fish and riparian surveys. As can be seen on Figure 1 most landowners were interested in the studies and provided access while those areas marked as no access indicate where the landowner who would not grant access. A series of monitoring stations were established along the creek (Figure 2).

GIS was used to determine distance of each station from a location in the Suisun Marsh (the downstream terminus of channelized flow (38° 12' 8.259" N, 122° 6' 12.751"). The stations are shown from downstream to upstream in Table 1. The column labeled Upstream Reach Length gives the distance to the next station upstream. This study uses the cumulative distance from the Gordon Valley Dam to locate stations or to calculate the distance between stations.

Table 1. River Mile of Each Station on Suisun Creek.

STATION	Cumulative Distance from Suisun Marsh miles	Cumulative Distance from Suisun Marsh feet	Upstream Reach Length feet	Cumulative Distance from Gordon Valley Dam feet	Cumulative Distance from Gordon Valley Dam miles
Suisun Marsh	0.00	0	45,912	76,053	14.4
SC-5.0	8.70	45,912	1,305	30,141	5.7
SC-5.5	8.94	47,217	806	28,836	5.5
SC-5.6	9.10	48,023	6,029	28,030	5.3
SC-6.0	10.24	54,052	860	22,001	4.2
SC-6.2	10.40	54,912	579	21,141	4.0
SC-7.0	10.51	55,491	2,353	20,562	3.9
SC-7.5	10.96	57,844	1,609	18,209	3.4
SC-7.8	11.26	59,453	135	16,600	3.1
SC-8.0	11.29	59,588	5,303	16,465	3.0
SC-8.4	12.29	64,891	90	11,162	2.1
SC-8.5	12.31	64,981	540	11,071	2.15

STATION	Cumulative Distance from Suisun Marsh miles	Cumulative Distance from Suisun Marsh feet	Upstream Reach Length feet	Cumulative Distance from Gordon Valley Dam feet	Cumulative Distance from Gordon Valley Dam Miles
SC-8.6	12.41	65,521	796	10,532	2.0
SC-8.7	12.56	66,317	581	9,736	1.8
SC-8.8	12.67	66,898	615	9,155	1.7
SC-9.0	12.79	67,513	2,447	8,540	1.6
SC-9.4	13.25	69,960	375	6,093	1.2
SC-9.5	13.32	70,335	681	5,718	1.1
SC-9.6	13.45	71,016	4,179	5,037	1.0
SC 10.0	14.24	75,195	858	858	0.2
SC 10.1	14.40	76,053	0	0	0.0

Stations are listed in upstream-to-downstream order in Table 2. The total number-of-days-of-record shown in this table includes an unknown number of days when the dataloggers, at various stations each year, were out of the water or in a dry channel. Estimates of when the channel became dry were made by examining the temperature records.

Table 2. Total Number of Days of Water Temperature Records for Each Station

Station	2017 Total Days	2018 Total Days	2019 Total Days	2020 Total Days	2021 Total Days	Total Days of Record
SC-10 Air	94	141	120	131	0	486
SC 10.1	129	148	0	0	0	277
SC-10.0	88	105	105	152	141	591
SC-9.6	137	148	131	119	0	535
SC-9.5	96	105	105	152	119	577
SC-9.4	137	148	144	119	0	548
SC-9.0	137	148	144	114	0	543
SC-8.8	137	148	0	0	0	285
SC-8.7	137	148	0	0	0	285
SC-8.6	137	148	133	114	0	532
SC-8.5	137	148	133	114	0	532
SC-8.4	95	148	105	152	119	619
SC-8.0	137	66	131	114	0	448
SC-7.8	137	148	144	10	0	439
SC-7.8 Air	137	138	146	131	0	552
SC-7.5	137	148	131	115	0	531
SC-7.0	103	134	105	152	119	613
SC-6.5	137	148	131	43	0	459
SC-6.2	137	148	144	43	0	472
SC-6.0	75	0	151	70	119	415
SC-5.6	97	96	74	61	119	447
SC-5.5	137	148	131	50	0	466
SC-5.0	137	41	131	25	0	334

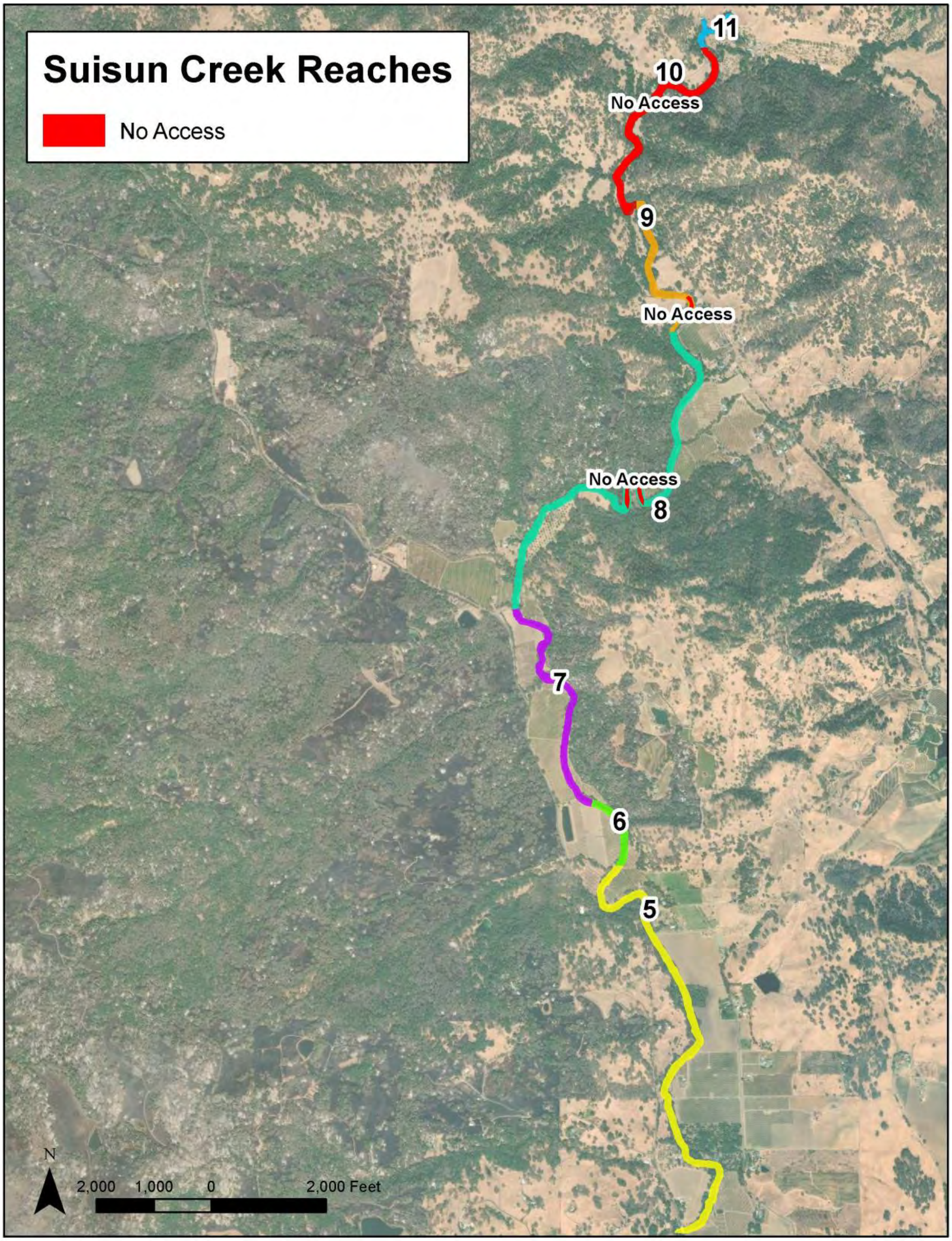


Figure 1. Stream reaches along study area of Suisun Creek.

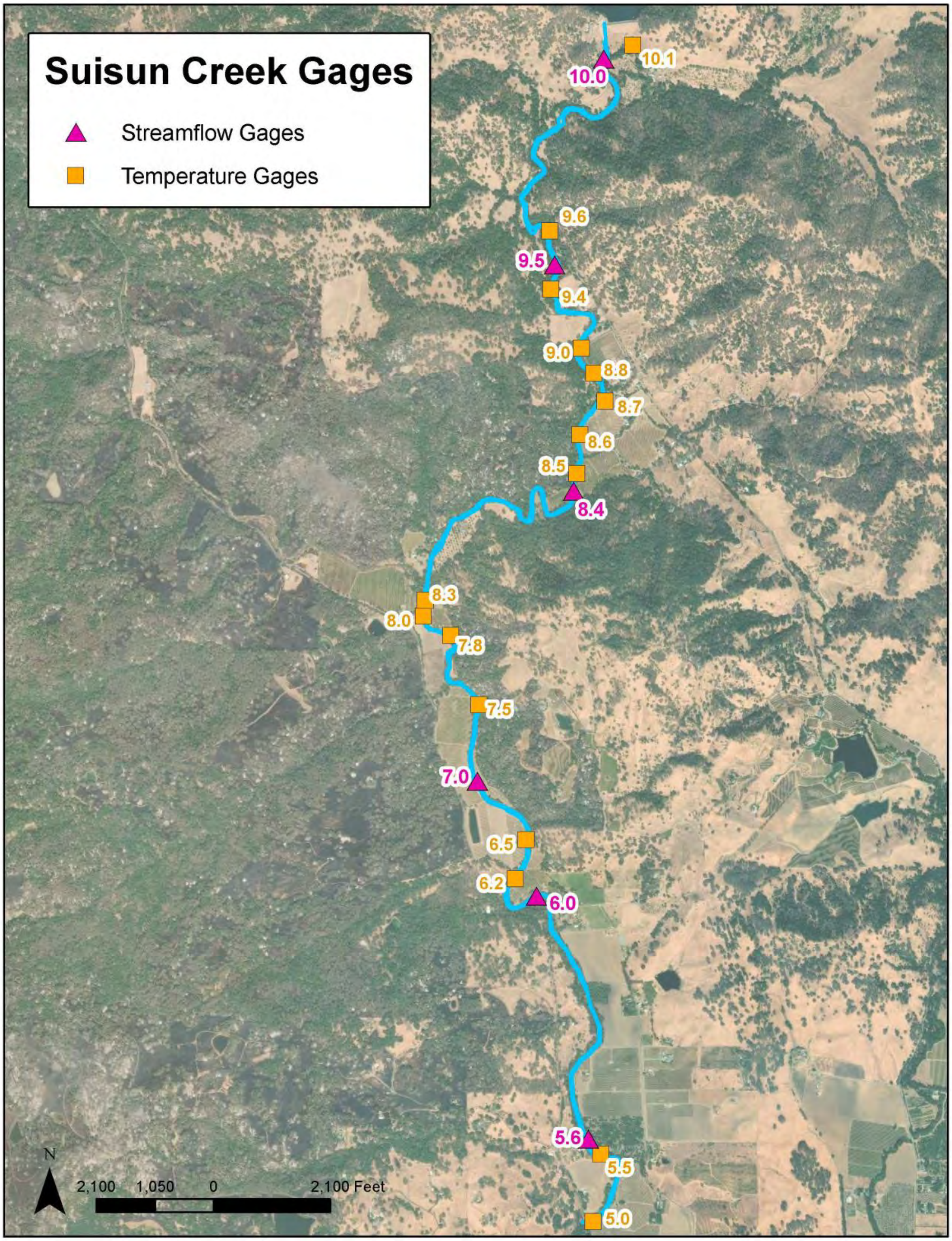


Figure 2: Map of upper Suisun Creek watershed showing locations of monitoring stations

Table 3 provides data from the Department of Water Resources, California Data Exchange Center for the amount of precipitation for each year of the study.

Table 3. Water-Year Precipitation at the Napa Fire Station.

Water-Year Oct 1- Sept 30	Precipitation inches	Percent of Long-Term Average	Dry. Normal or Wet year
2016-17	45.00	186%	Wet
2017-18	19.22	79%	Dry
2018-19	33.29	138%	Wet
2019-20	14.26	59%	Dry
2020-21	10.26	42%	Dry

METHODS

STREAMFLOW

Pressure transducers were installed at six locations along Suisun Creek where channel conditions were best for streamflow measurement. Gages recorded year-round for the 2017-2021 period. Initially, vented pressure transducers were used to measure stream stage at six stations. These vented transducers malfunctioned apparently due to problems with the venting tubes. As a result, some data collected in 2017 and 2018 were not useful for determination of streamflow. The vented transducers were replaced in Spring 2019 with non-vented transducers. Records for the non-vented transducers were compensated using barometric data collected at SC 10.0 and SC 5.6. For both types of transducers, recording interval was 15 minutes.

Periodically, discharge measurements were made using a vertical-axis minimeter and were used to develop arithmetic ratings for each gage. Ratings were limited to relatively low flows owing to limitations in measuring high flows. Points of zero flow were measured annually with a graduated wading rod and used for rating development.

Methods for selecting stations, collecting and evaluating data followed U.S. Geological Survey protocols (Rantz 1982a and b).

WATER TEMPERATURE AND WATER QUALITY

Water temperatures in Suisun Creek were monitored with two networks of sensors. One network was comprised of the transducers used at stream flow gages, which measure water temperature in addition to stage. The other network consisted of HOBO temperature sensors (Hobo Water Temp Pro v.2) installed at locations between gaging stations (Figure 2). Monitoring stations were selected to provide for a series of instruments along most of the creek. Several of the HOBO sensors were lost or damaged during the study, so the number of sensors is not the same for all years of the study.

Water temperature dataloggers were checked for accuracy prior to deployment. The HOBO sensors were calibrated at room temperature and in an ice bath annually using a NIST mercury thermometer (Forest Science Project 1997). Each logger was also checked for battery status and launched by computer to record at 30-minute intervals. The instruments were deployed in deeper areas of the channel—pools and glides—to monitor water temperatures for rearing salmonids. Sensors were deployed in the Spring and removed in the Fall 2017-2020. At the time of Hobo sensor deployment, the

Figure 3. Stream flow gage with pressure transducer and outside staff gage

Figure 4. YSI sonde in creek measures water temperature, pH, dissolved oxygen, specific conductance and depth.

depth and width of the water is measured. A sketch of the site is done and photos are taken. Riparian canopy cover is measured on a transect across the creek at the station. A spherical densiometer is used with a 4-corner measurement at each point on the transect. The transect will have at least 3 points that are generally 5-7 ft. apart. Canopy cover is reported as an average of all the measurements. Water depth and width are also measured at retrieval of the instrument.

A YSI multi-parameter submersible sonde was used to monitor water temperature, dissolved oxygen, pH, specific conductance, and water depth. Each probe used for the sonde was calibrated using standard solutions as described in the YSI manual, and batteries were replaced prior to each deployment. The sonde batteries last for two to three weeks. Similar to the hobo dataloggers the sondes were placed in pools and glides where salmonids rear in summer. Canopy cover, width and depth of flow, and overall station conditions were recorded at deployment. The sonde was deployed at gaging stations or temperature monitoring stations (Figure 2). One to three locations were monitored each summer of the study.

QUALITY ASSURANCE/QUALITY CONTROL (QA/QC)

As part of prior monitoring programs completed on Suisun Creek a Monitoring Plan (MP) and Quality Assurance Project Plan (QAPP) were completed and approved by the Regional Water Quality Control Board (LMA 2005). These plans were utilized in this study as well. Data quality objectives included: accuracy, precision, completeness, and representativeness. Table 4 lists the data quality objectives for water temperature and water quality parameters. These objectives were carried out for water temperature/quality monitoring through the following procedures:

- The accuracy of the Hobotemp dataloggers was checked by performing a comparison of each datalogger to a NIST thermometer for a room temperature water bath and an ice bath. Precision was checked before and after deployment. Completeness was evaluated by the number of days of the May to October period that data was collected. Representativeness was achieved by monitoring in numerous locations.

- The accuracy for the YSI sondes was determined by measuring known standards for dissolved oxygen and pH and calibrating the instrument for any difference from the standard. Precision was checked before and after deployment. Completeness was determined by data collection over the deployment period per station. Representativeness was achieved by deploying the sondes in a number of stations.

Table 4. Data Quality Objectives for Water Temperature and Water Quality Parameter

Parameter	Method / Range	Units	Detection Limit	Sensitivity	Accuracy	Precision	Complete-ness
Temperature	Hobotemp datalogger	°C	.01	0.01	± 0.5	± 0.2	90%
Dissolved oxygen	YSI sonde	mg/L	0.01	0.01	± 0.5	± 0.2	90%
pH	YSI sonde	pH	0.5	0.5	+/- 0.5	20%	90%
Specific conductance	YSI sonde	mS/cm	N/A	+/-0.2	+/-0.2	+/-0.2	90%

MONITORING RESULTS

STREAMFLOW

For this study, flows were monitored at 6 stream gages between Lake Curry and Station 5.6 about 5 miles downstream (Figure 2). The gage furthest upstream is SC 10.0, which monitors lake releases about 500 feet downstream of the outlet from the lake. Gage numbers decrease downstream to the furthest downstream gage, SC 5.6.

Streamflow records (Figures 5-10) show that flows generally increased between SC 10.0 and SC 8.4, and then decreased from that point to SC 5.6. Flows decreased to zero at downstream stations when releases from the lake were reduced below 1 CFS (Figures 6-10). Field observations indicated that tributary streams, including Wooden Valley Creek, ran dry by early summer and did not provide flow to Suisun Creek beyond the end of June. Appendix A contains hydrographs from all the stations.

The stream flow monitoring was completed to provide data to answer the following questions:

- **How do Lake Curry releases change flow on Suisun Creek in the dry season?**
- **Are diversions of the released water occurring along Suisun Creek?**
- **How do Lake Curry releases change flow on Suisun Creek in the wet season?**

Downstream Changes in Streamflow in the Dry Season

Increases in flow

Flow increases between SC 10.0 and SC 8.4 may result from shallow hillslope groundwater seepage. Throughout the study, small amounts of seepage were observed entering the channel downstream of SC 10.0 near the Lake Curry spillway. This seepage may have been water from the lake or groundwater from local aquifers. Data from winter and spring of 2021 indicate persistent influent groundwater between the lake and SC 8.4, which may be a result of the 2020 LNU wildfire that killed many trees in the watershed and may therefore have reduced transpiration.

During periods when the channel at SC 5.6 was dry, water was observed seeping into the channel downstream of the gage. This seepage may have been related to irrigation of vegetation near the channel. This seepage is not reflected in our streamflow records as it occurred downstream of our gages.

From Dec 2017-June 2018 the City of Vallejo released no water from Lake Curry resulting in Suisun Creek drying up in almost all areas (Figures 6-8). During the fall of 2019, releases from the lake outlet were stopped to allow repairs to be made. The City of Vallejo pumped water over the spillway during the repairs, increasing flows at downstream stations in September 2019 (Figure 9).

Decreases in flow

After cessation of seasonal flow from Wooden Valley Creek, streamflow decreased each year between SC 8.4 and SC 5.6 (Figures 5-10). Flow decreases downstream of SC 8.4 might have resulted from diversions, evaporation, and seepage to groundwater.

Diversions

Water rights held on Suisun Creek do not provide for legal diversions during summer low-flow conditions. Appropriative rights have required bypass flows that prohibit diversions when streamflow is less than 3 cfs. Riparian rights do not allow diversion of water released from storage, which is almost all of the flow in Suisun Creek during summer. Figure 11 shows an example of the effect of diversion on flow in a hydrograph form the Russian River. The streamflow records at each gage were reviewed for sudden drops in flow level coincident with a pump form a direct diversion being turned on. Our streamflow records do not provide any clear evidence of such diversions during summers.

Evaporation

Streamflow measurements made in late July 2020 at SC 10.0 and SC 5.6 were used to estimate evaporative losses between the stations. Streamflow at SC 10.0 was measured as 0.8 cfs and streamflow at SC 5.6 was measured as 0.1 cfs. Evaporation from open water surfaces on small streams in central California can be equivalent to roughly 0.03 ft/day (Blaney, 1960). Based on this evaporation rate, the estimated average width of the wetted channel (30 ft), and the length of the stream between the two gages (25,000 ft), evaporative loss would amount to 22,500 ft^3/day, equivalent to 0.3 cfs. This would represent roughly 40% of the streamflow loss observed between the two stations.

Seepage to groundwater

The limited available groundwater level data from wells along the creek (USGS 2021) near the Solano-Napa County line indicate that groundwater levels have generally remained 17 to 42 feet below land surface. As the stream is generally not incised as deeply as 17 feet, the elevation of the channel bed is higher than the local water table. Seepage is therefore likely to be directed from the stream to the aquifer. Seepage losses would be consistent with the estimates of evaporative losses discussed above, which indicated that not all of the decrease in streamflow could be attributed to evaporation alone.

Winter flows

Releases from Lake Curry can maintain fish habitats in Suisun Creek when winters rainfall is not sufficient. As shown in Figure 12, when releases from the lake were stopped during a dry winter, downstream flows also rapidly ceased. More recent data shown in Figure 14 indicate some increases in flow downstream of the lake during a dry winter. However, this period followed a major wildfire in the summer of 2020 that killed most of the trees in the upstream watershed. The destruction of woody vegetation may have resulted in reduced evapotranspiration and therefore increased groundwater seepage (Bart, 2014; Wine and Cadol, 2016) during the winter of 2020-2021. If so, this effect will be transitory, and groundwater seepage to the stream will likely be reduced in the future.

Summary

In summary, almost all of the flow in Suisun Creek during summers was water released from Lake Curry. Streamflow decreased downstream of the lake due to evaporation and seepage. During periods when lake releases were reduced below 1 CFS, connected flows throughout the study reach were not maintained. A release of 2-2.5 is required to maintain connected flow. Clear examples of the effects of decreased lake releases on downstream flows can be seen in Figures 6-10, which show flow at downstream gages decreasing to zero. During winters when rainfall is limited, releases from the lake will be the only reliable source of water to maintain the connected flow needed for steelhead migration. Although streamflow data for the dry winter of 2020-2021 indicate some groundwater seepage to the stream, this seepage may have resulted from the loss of woody vegetation following a major wildfire. Seepage to the stream is likely to decrease as vegetation recovers.

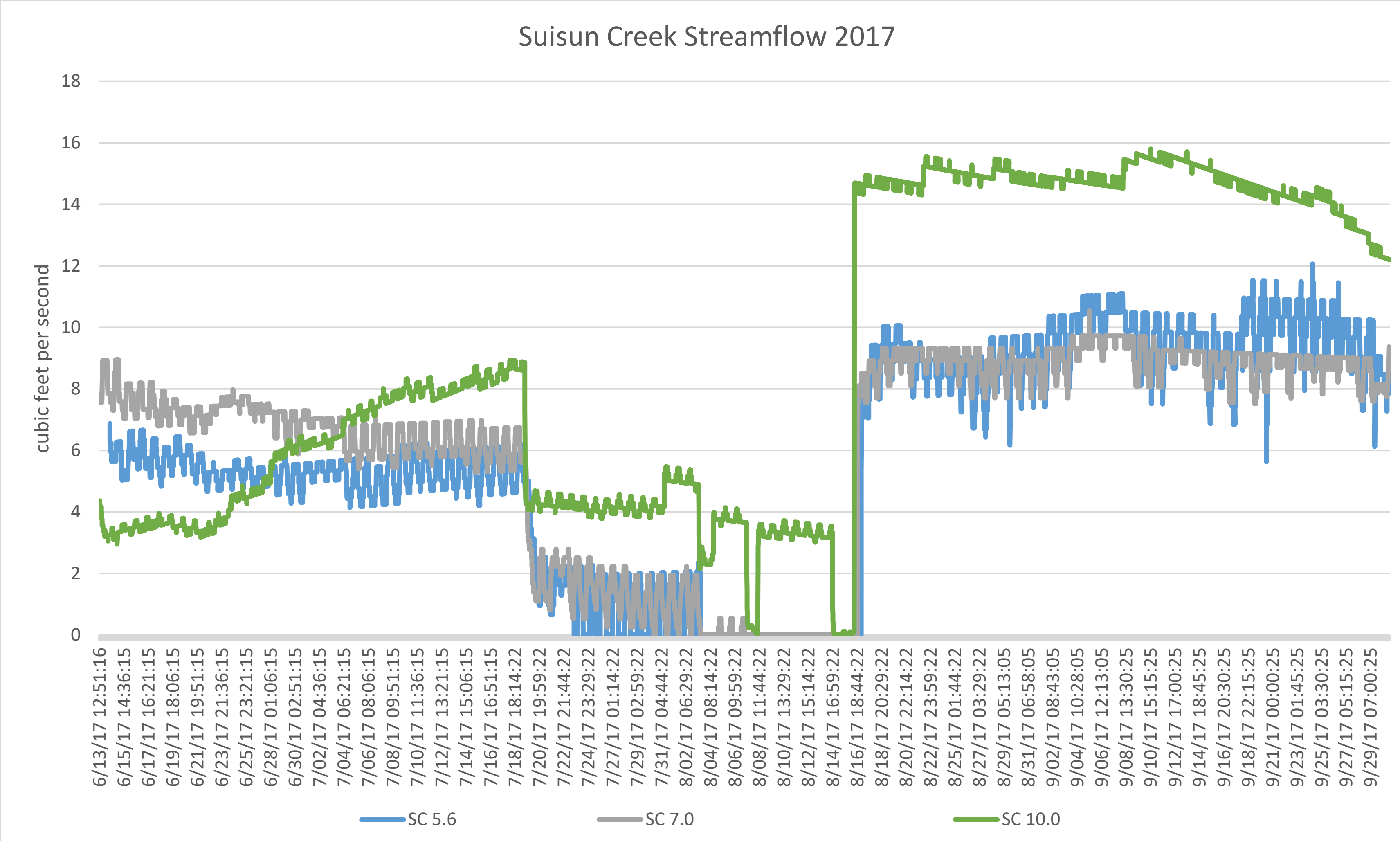
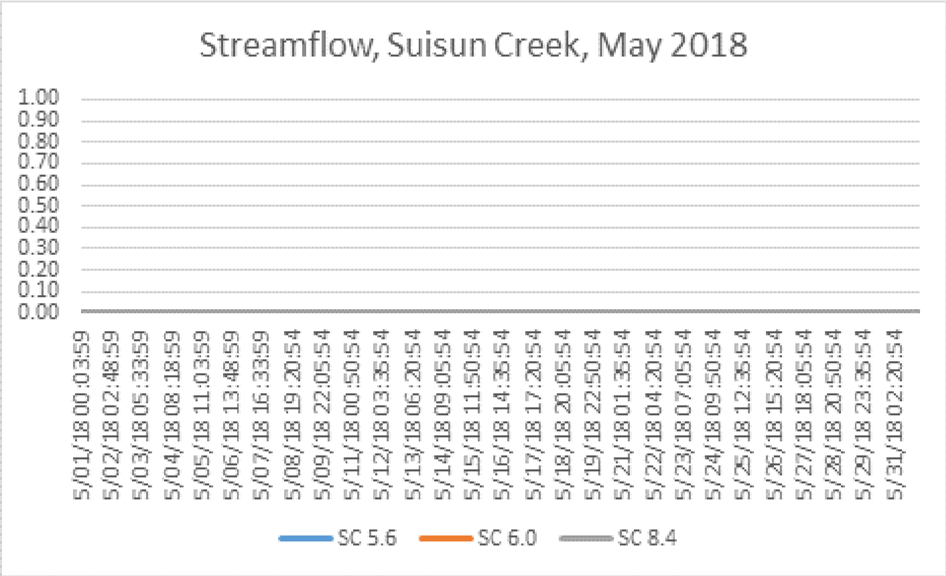
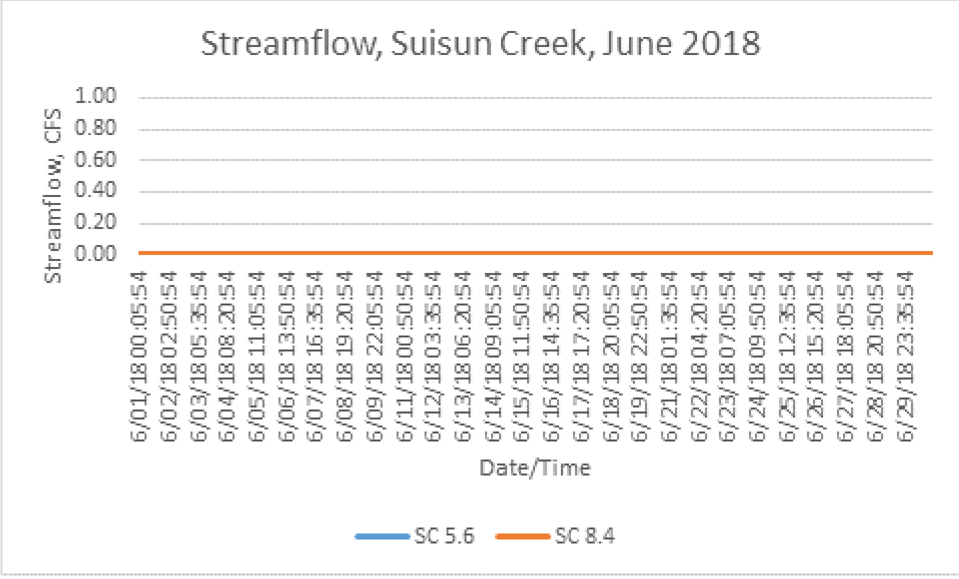


Figure 5. Summer streamflow, Suisun Creek, 2017. Green line (station 10) shows the release from Lake Curry; silver line (station 7) is 3.9 miles downstream from dam; blue line (station 5.6) is 5.3 miles downstream from dam. Flow at downstream stations shows changes of releases from Lake Curry.





Figures 6-8. Summer streamflow, Suisun Creek, 2018. Releases from Lake Curry were shut off by the City of Vallejo for over 6 months of 2018. This resulted in flows 2 miles downstream (station 8.4) of 0 and flows downstream at 4.2 miles (station 6.0) and 5.3 miles (station 5.6) of 0.

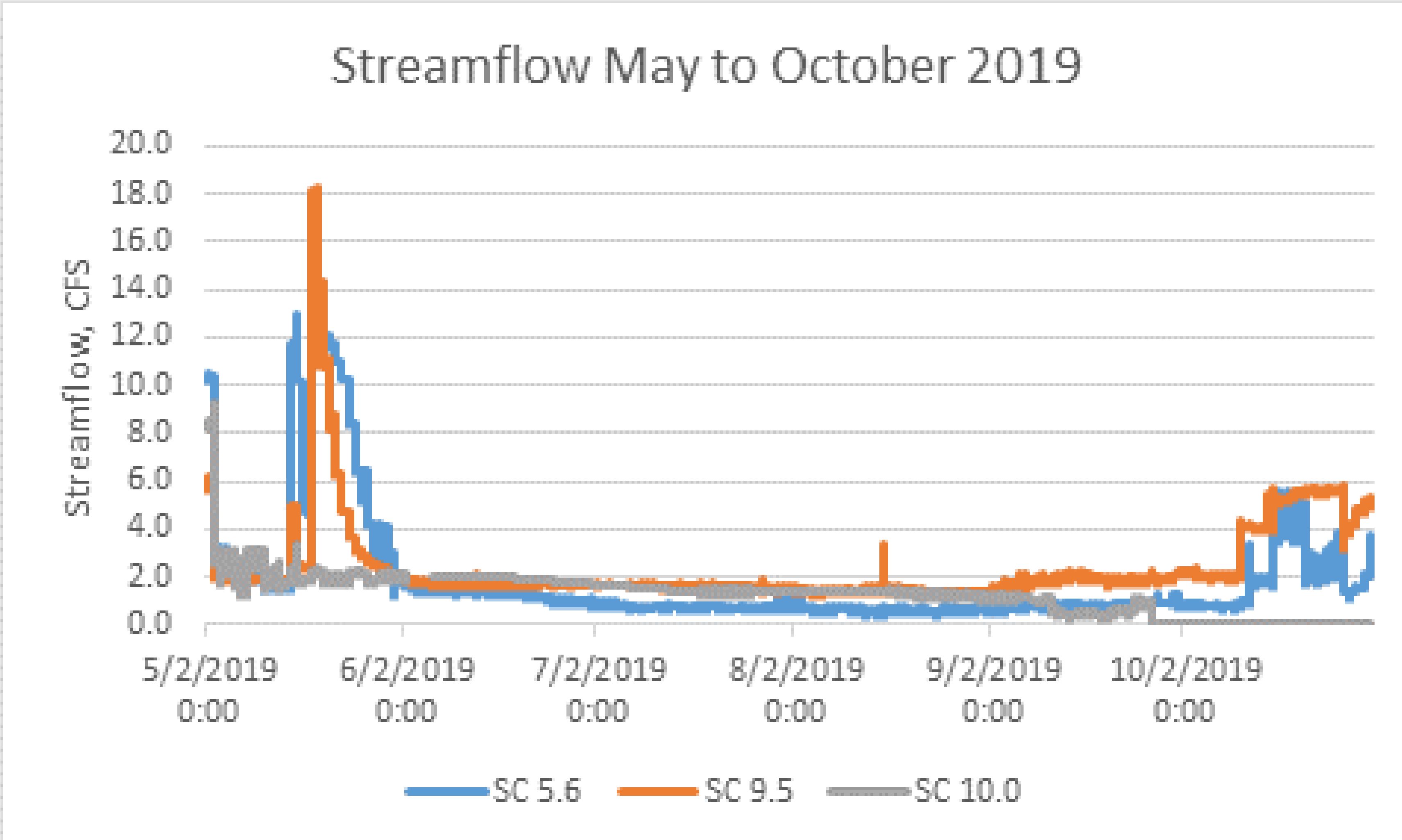


Figure 9. Summer streamflow, Suisun Creek, 2019. Releases from Lake Curry (silver line) vary between 0-2 cfs. May to Sept. Flows at station 9.5 (orange line) 1.1 miles downstream of dam are similar. Flows at station 5.6 located 5.3 miles downstream of dam (blue line) are close to 0. Hydrograph shows effect of water pumped over spillway in October as a result of National Marine Fisheries Service request to avoid impacts to threatened steelhead trout.

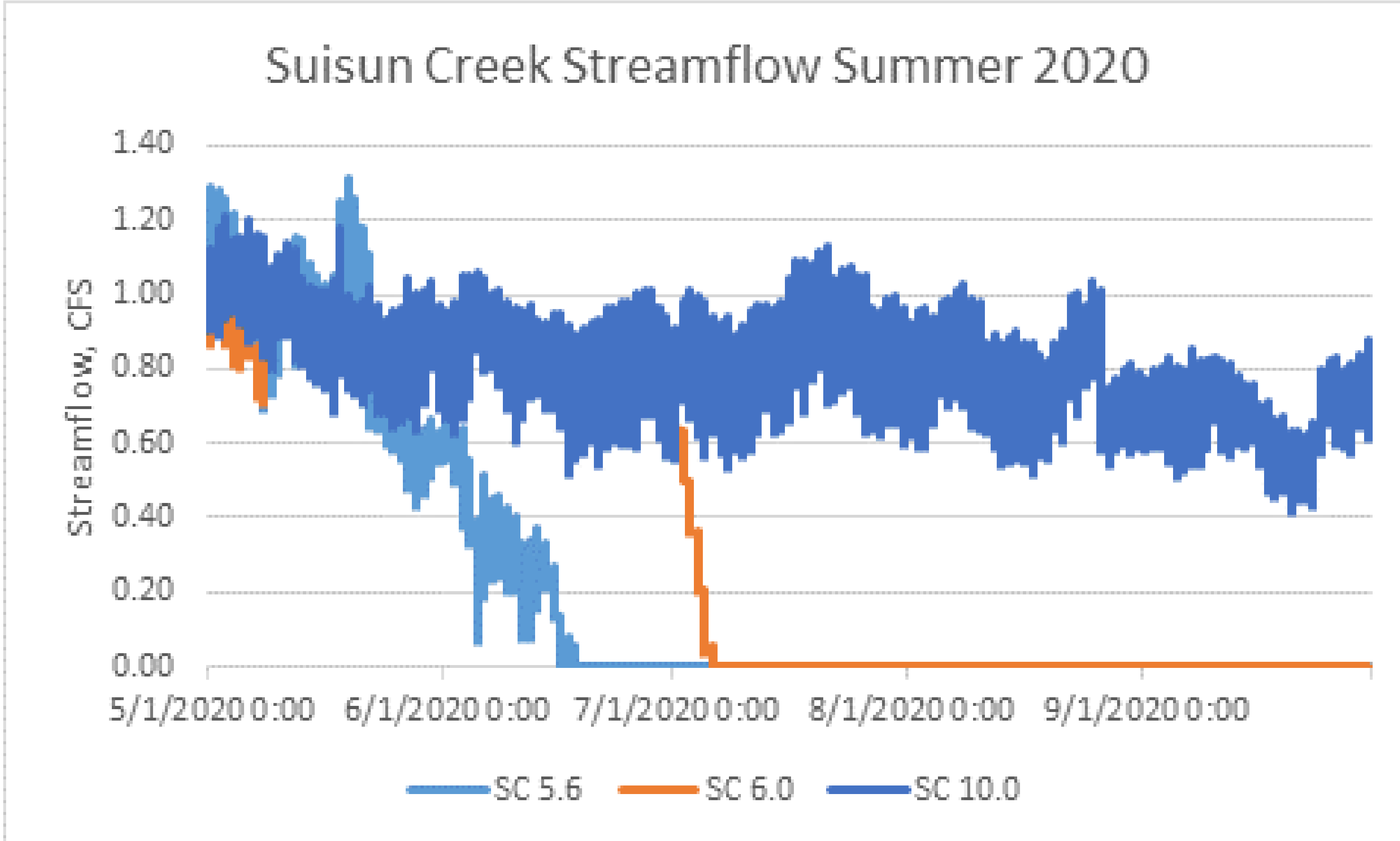


Figure 10. Summer streamflow, Suisun Creek, 2020. Releases from Lake Curry (dark blue line) vary between 0.5-1.25 cfs from May to Sept. Flows at station 6.0 located 4.2 miles downstream of dam (orange line) go to 0 in July. Flows at station 5.6 located 5.3 miles downstream of dam (light blue line) go to 0 in July. 2020 was a dry year showing that a release of 1.0 cfs will not maintain connected flow.

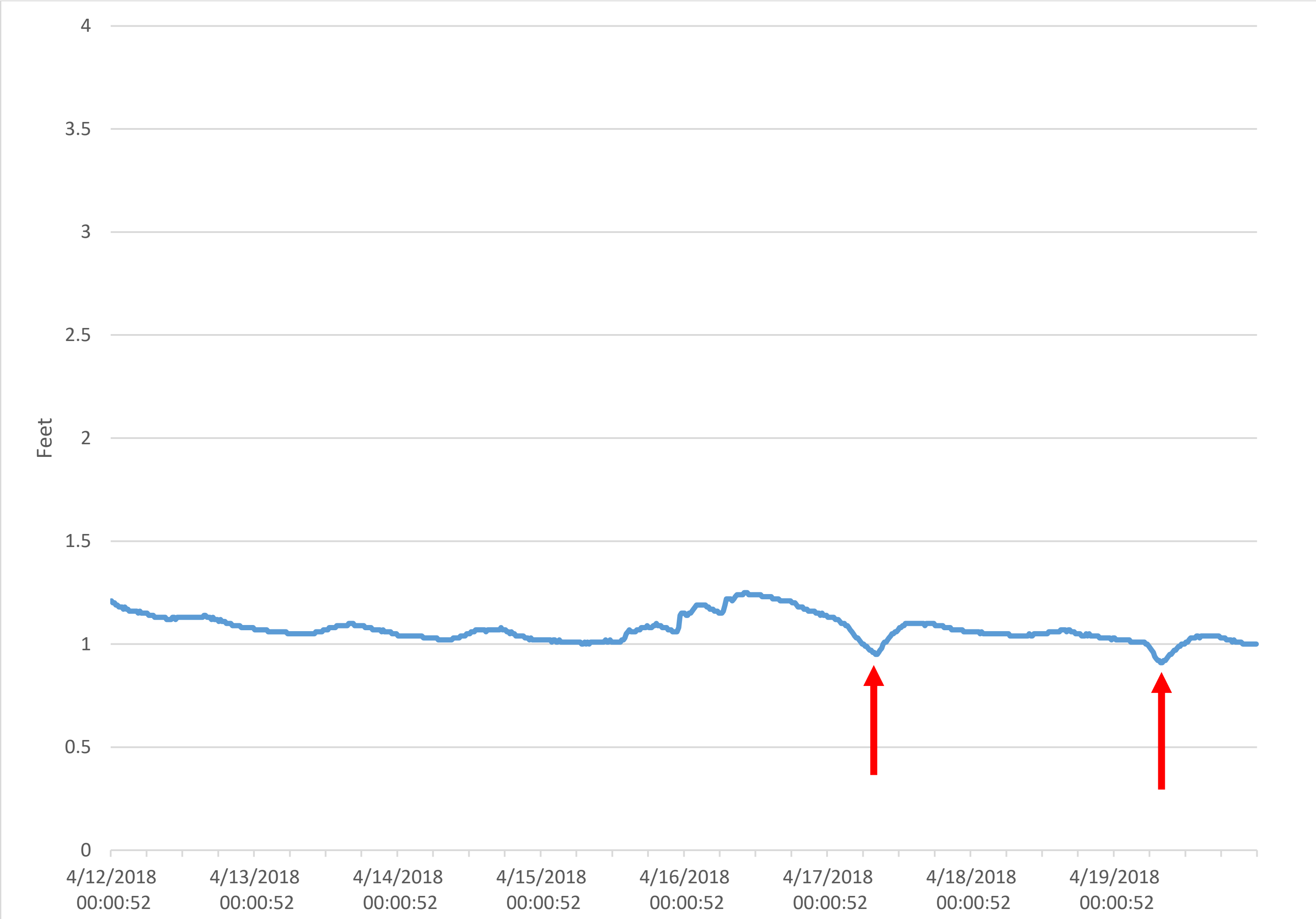
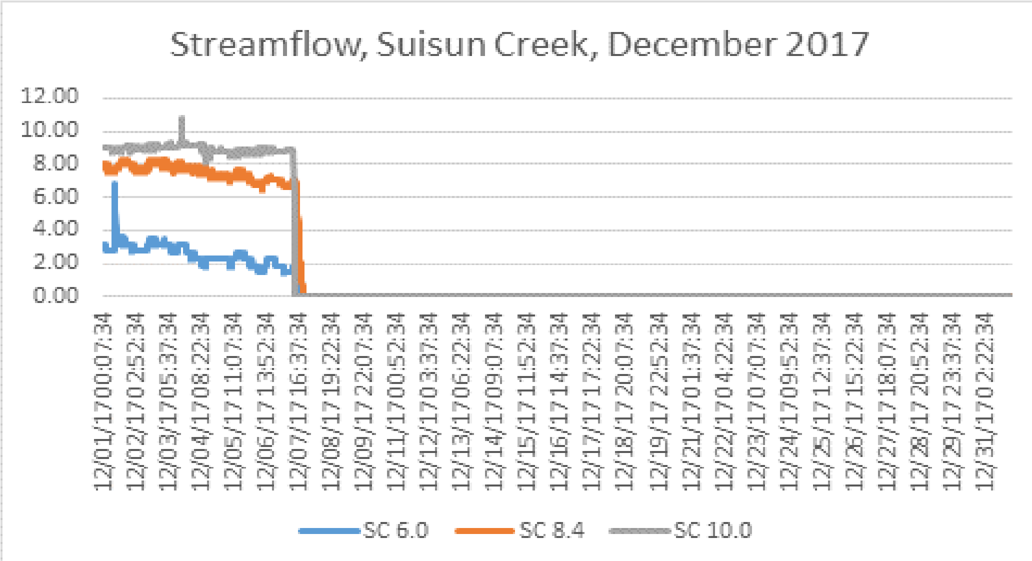
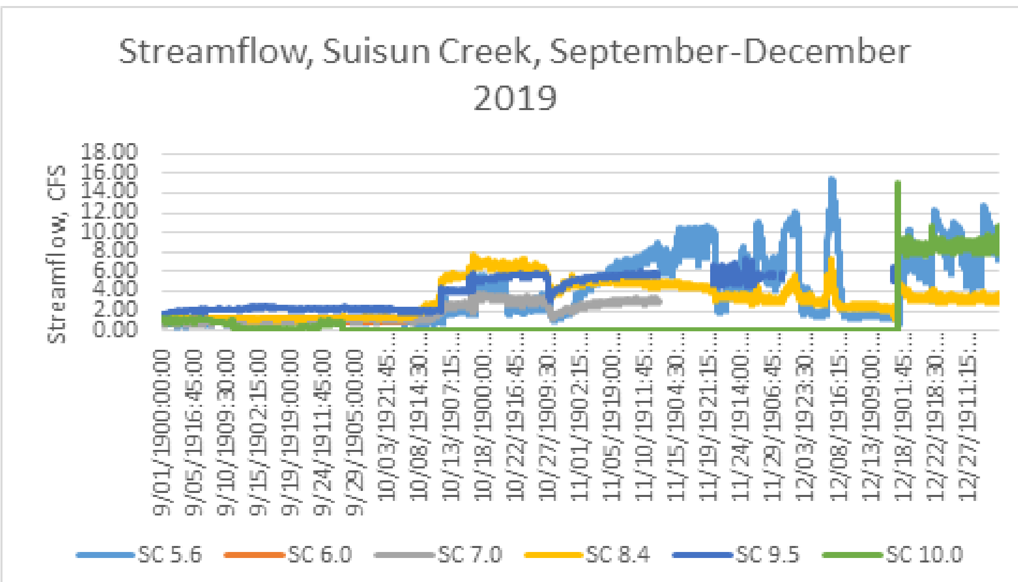


Figure 11. Example hydrograph showing abrupt changes in flow indicative of diversion of flow. The data from the six stream flow gages on Suisun Creek were analyzed for this type of change during summer months and none were found.





Figures 12-13. Effects of releases from Lake Curry on winter flows. With no release out of Lake Curry in December 2017 flows on Suisun Creek go to zero between storms. Releases were also stopped in 2018 between Sept and Dec but rainfall provided base flows for a portion of this time. Releases could maintain creek habitats between storms

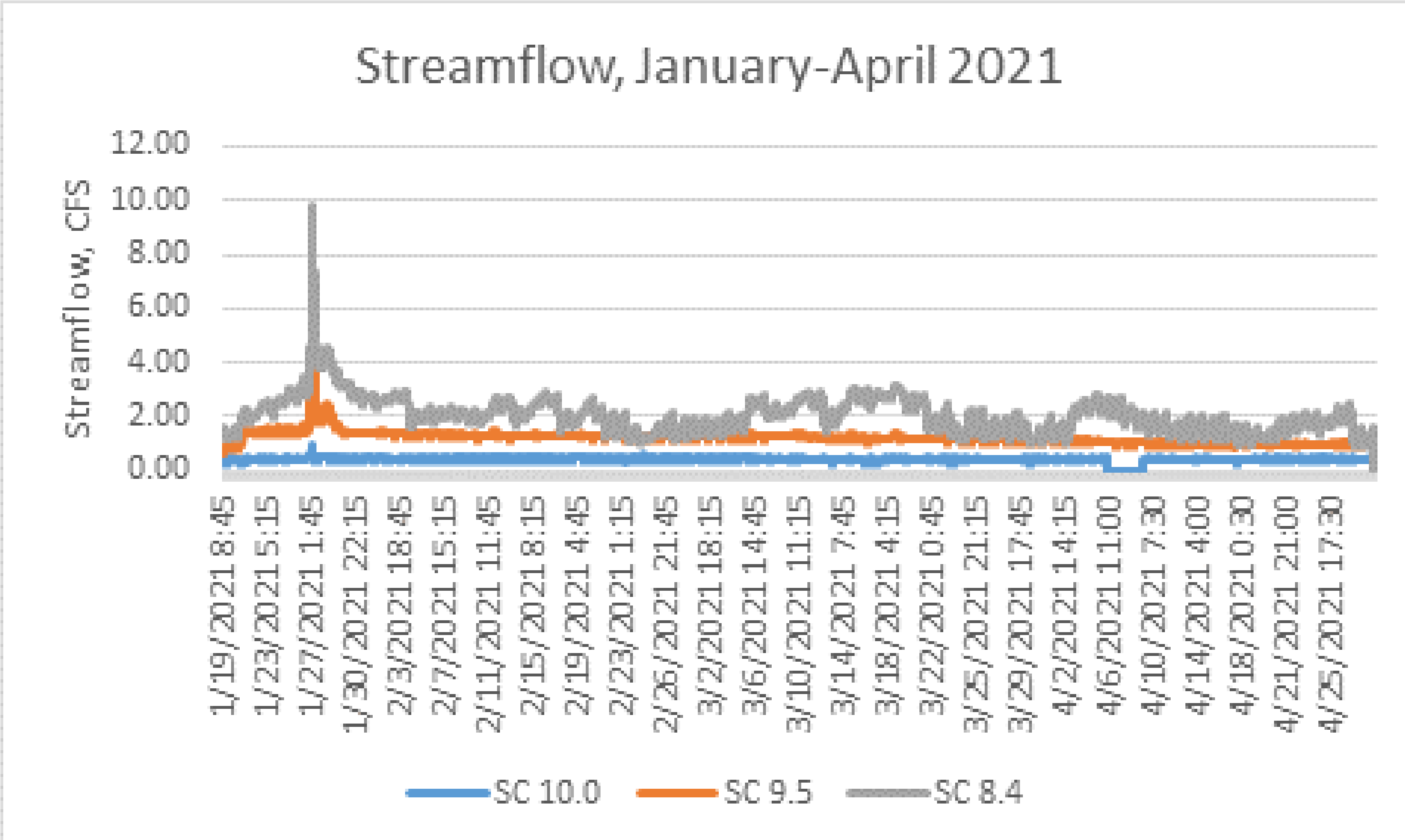


Figure 14. Releases from Lake Curry are around 1 cfs with rainfall providing most of baseflow in the upper portion of the creek

WATER TEMPERATURES

The objective of the water temperature monitoring is to assess habitat suitability for steelhead trout and to identify projects needed to increase habitat values. The effects of warm water on steelhead trout are complex. We identified criteria to determine when stream water is too hot for fish based on information in the literature. Sullivan et al. 2002 report that growth of juvenile steelhead trout declines when water temperatures exceed 70^{o} F or if water temperatures fall below 58.1^{o} F. Growth of juvenile steelhead trout is an important factor in determining the probability of whether a young steelhead trout will survive in the ocean and eventually return to spawn. Larger juveniles have a higher probability of returning to spawn. For this study, we selected 70^{o}F as the threshold for the onset of chronic stress on juvenile steelhead trout, due to elevated water temperature. Extended exposure to water temperatures above 75.2^{o} F can result in mortality for steelhead trout. For example, 77.7^{o} F water can pose a threat of mortality if fish are exposed to it for more than 9.6 hours. Appendix B contains all the water temperature data for the 2017-2020.

The water temperature monitoring was completed to provide data to answer the following questions:

- **How do water temperatures change from upstream to downstream?**
- **How do water temperatures change with a change in releases from Lake Curry?**
- **How does canopy cover change water temperatures?**

Temperatures change from upstream to downstream

As shown by the HOBO sensor data in Figures 15 to 18, water temperatures in Suisun Creek show two subtle trends during summers: temperatures generally increase downstream and water temperatures at each station increase over the summer. Water temperatures downstream of SC 8.0 exceeded the 70^{o} F threshold that is considered stressful to steelhead. Temperatures at downstream stations occasionally exceed 80^{o} F, a temperature considered lethal for steelhead. Temperatures at the stations upstream of SC 8.0 remained below 70^{o} F. Figure 19 compares the water temperature measured at SC 9.6 and SC 5.0 which are separated by 4.7 stream miles. Appendix B has water temperature graphs for each station for each year.

Water temperatures at the lake outlet were not constant during the study, and variations in temperatures of water released from the lake may have affected downstream temperatures. Records for SC 10.0 showed seasonal and diurnal changes, as well as temperature changes that may have been related to outlet valve configurations. For example, the temperatures of water released from the lake in the wet year of 2019, when the lake was full in June, never exceeded 60 ^{o} F (Figure 20). However, in the dry year of 2020, when the lake level was well below the spillway in June, exceeded 70^{o} F from July 24 to the end of September (Figure 21).

In order to better understand the relative contributions of downstream warming and diurnal changes in lake outlet temperatures to temperature increases downstream of the lake, we compared diurnal temperature ranges at SC 10.1 with temperature ranges at all downstream stations in 2017, the year with the most complete data set (Figure 22). Diurnal range is the difference between daily temperature minima and maxima, and indicate the amount of warming each day. The diurnal range for SC 10 at the lake outlet was small (about 1 degree F) because the large volume of water in the lake as well as evaporation from the lake surface buffered changes due to solar radiation. From SC 9.6 to 7.8, the diurnal temperature range increases to 5-6 degrees F. From SC 7.5 to SC 6.2, the diurnal temperature range increases, approaching 8 degrees F at SC 6.2. Then from SC 5.6 to SC 5.0, the diurnal temperature range decreases to roughly 5 degrees F, possibly due to groundwater seepage as described previously.

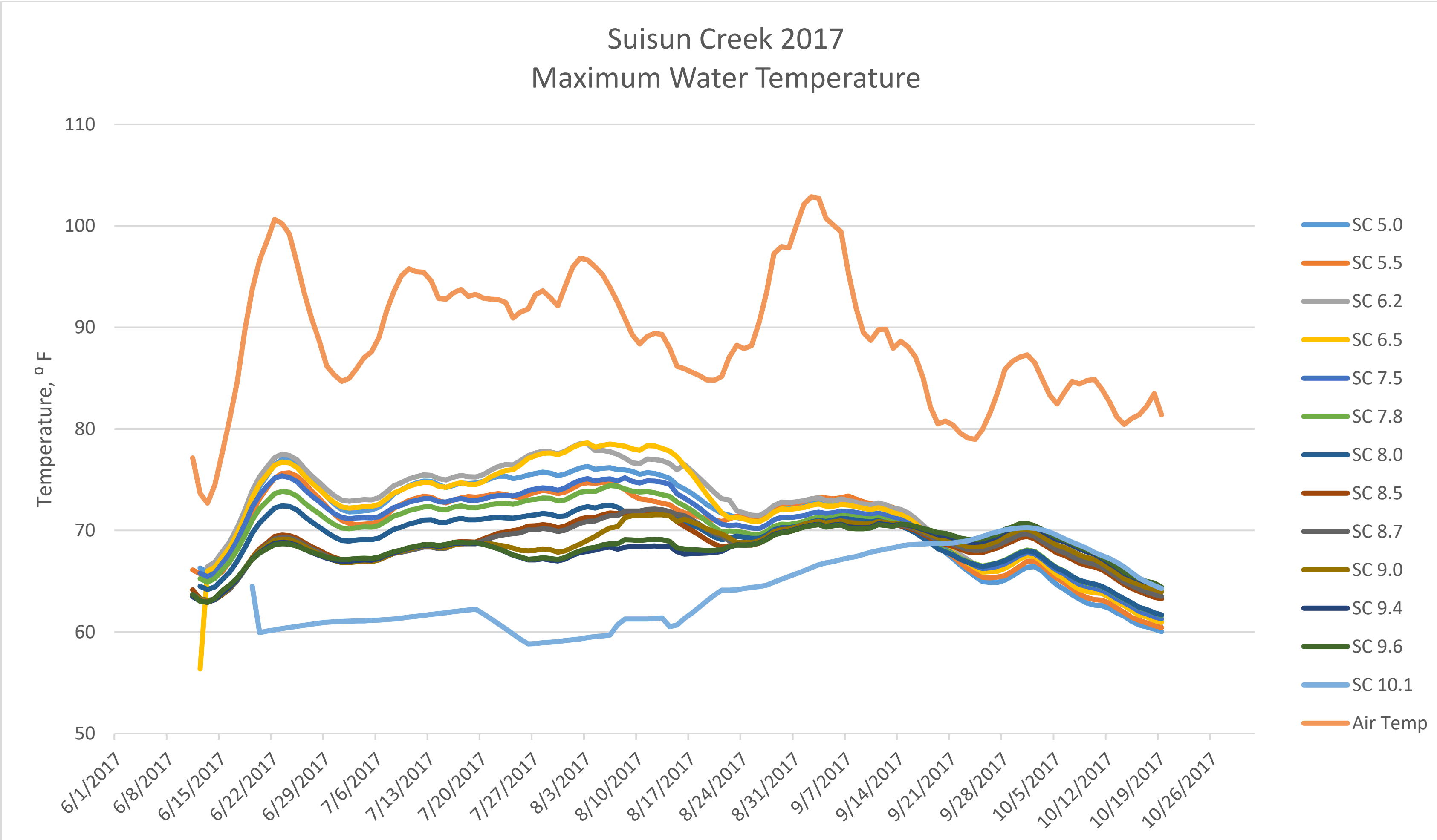


Figure 15. Suisun Creek daily maximum water temperatures for 2017 at selected stations. Air temperature data is from station 7.8 located about 3 miles downstream of Lake Curry. Rainfall for the 2017 water year was 45.0 inches in Napa.

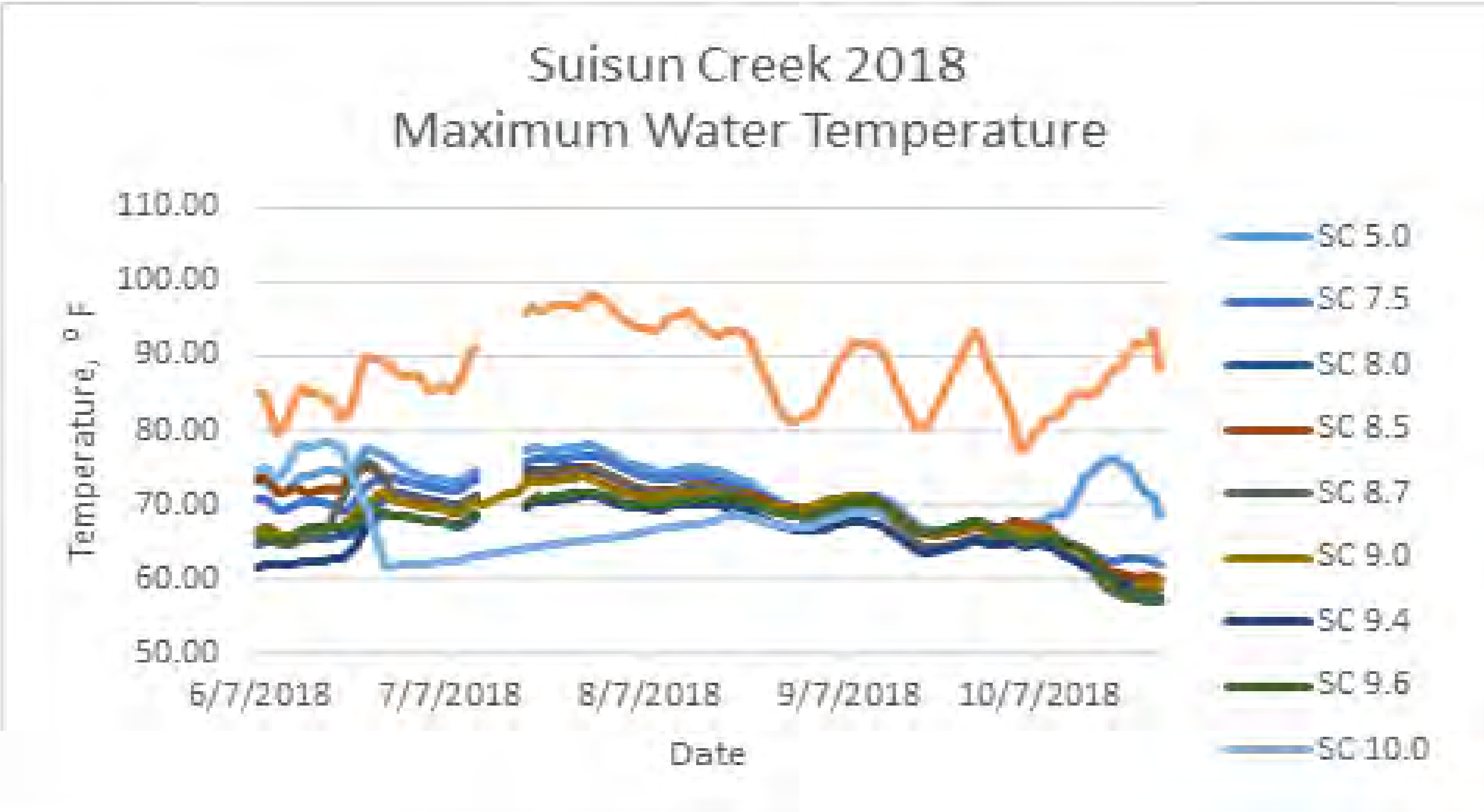


Figure 16. Suisun Creek daily maximum water temperatures for 2018 at selected stations. The gap in data in July represents a time when temperature sensors were removed and not redeployed for a few days to allow maintenance. Air temperature data is from station 7.8 located about 3 miles downstream of Lake Curry. Rainfall for the 2018 water year was 19.22 inches in Napa.

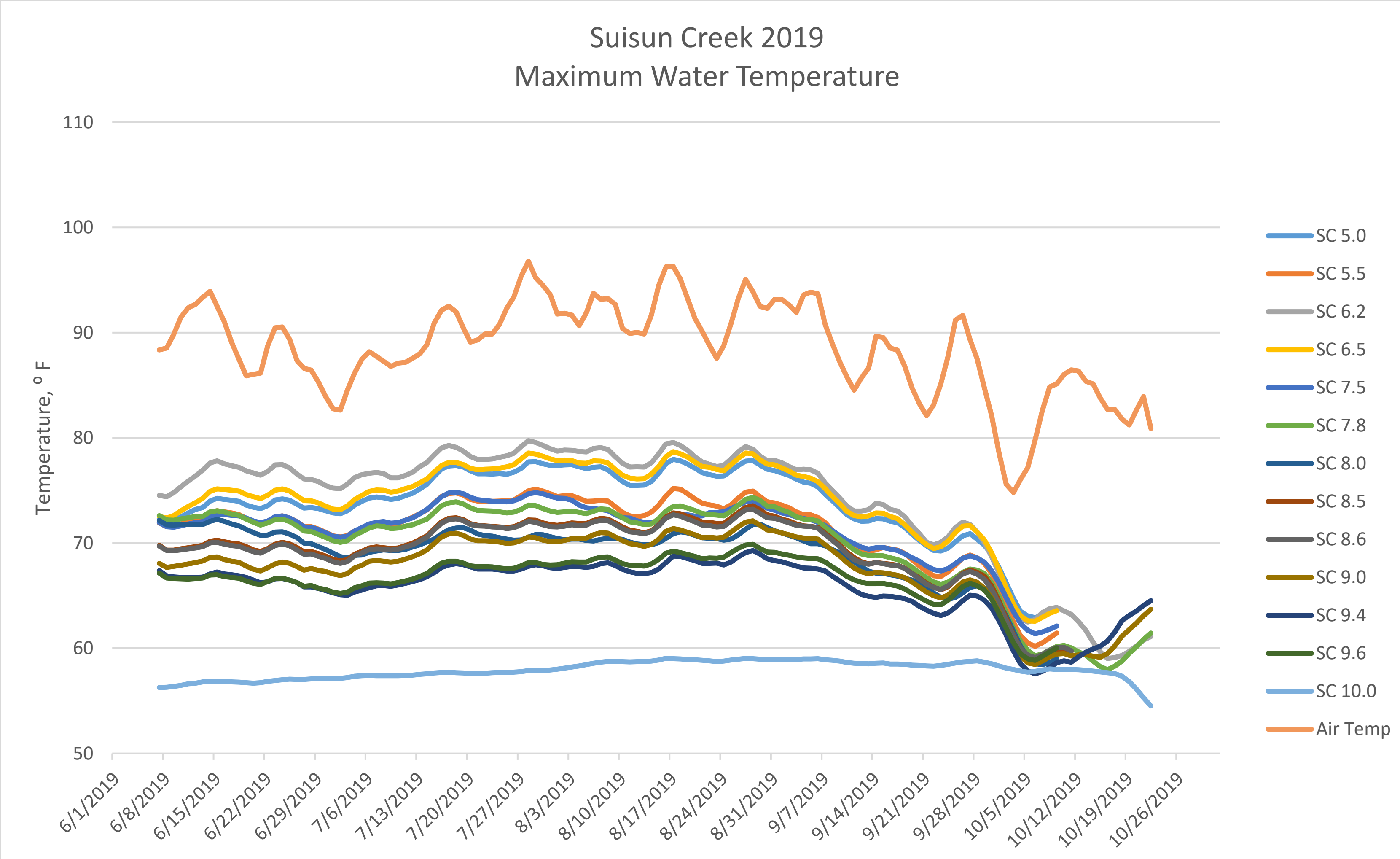


Figure 17. Suisun Creek daily maximum water temperatures for 2019 at selected stations. Air temperature data is from station 7.8 located about 3 miles downstream of Lake Curry. Rainfall for the 2019 water year was 33.29 inches in Napa.

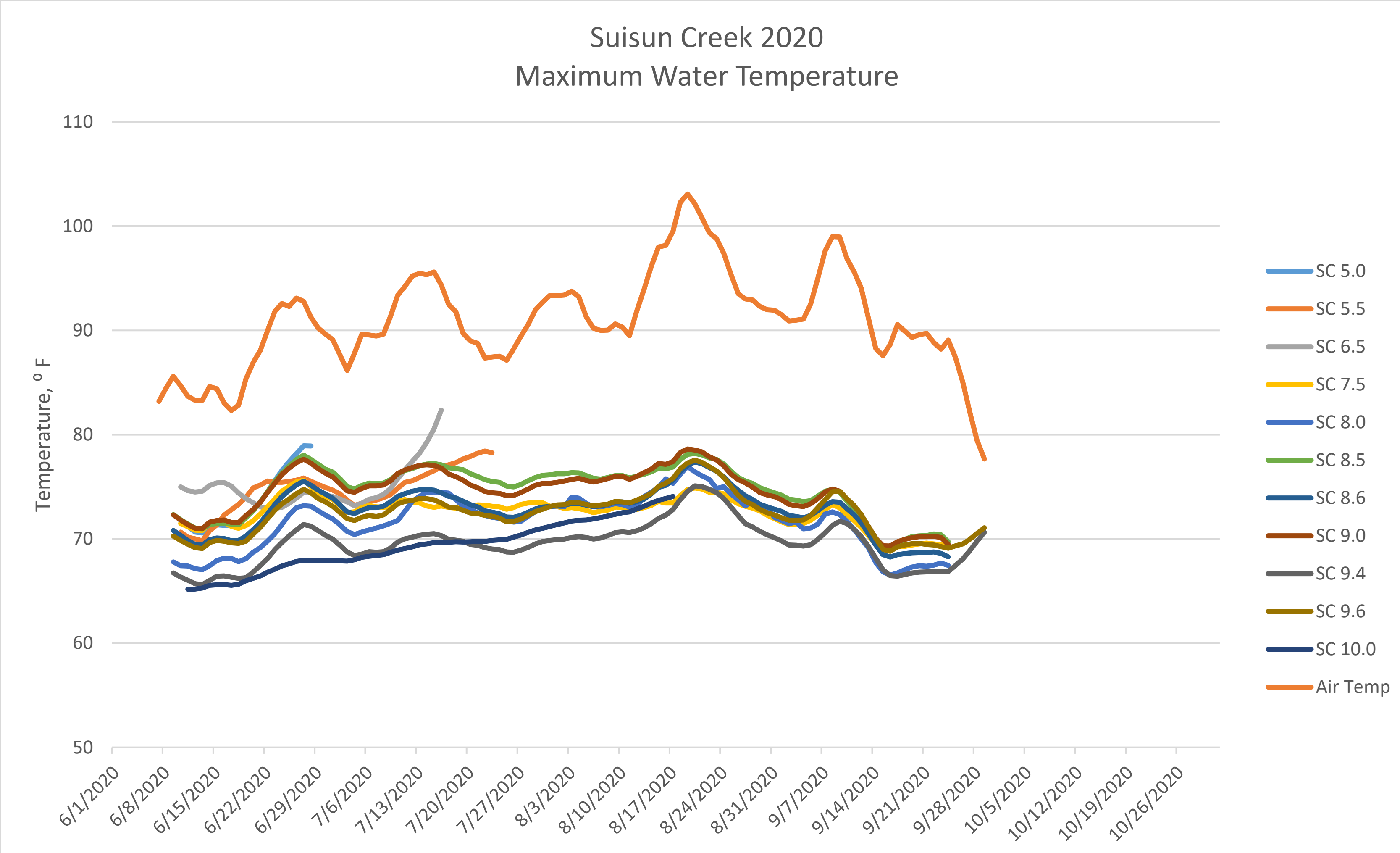
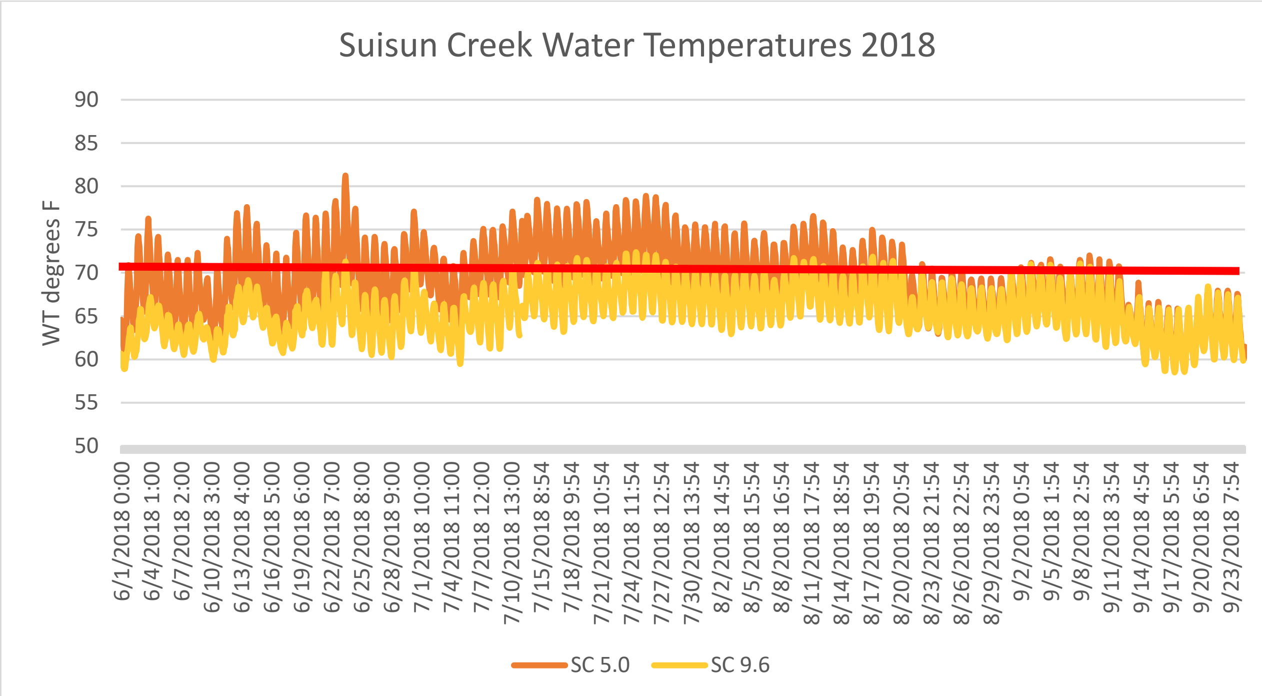


Figure 18. Suisun Creek daily maximum water temperatures for 2020 at selected stations. Air temperature data is from station 7.8 located about 3 miles downstream of Lake Curry. Rainfall for the 2020 water year was 14.26 inches in Napa. Incomplete lines are due to the creek drying up.



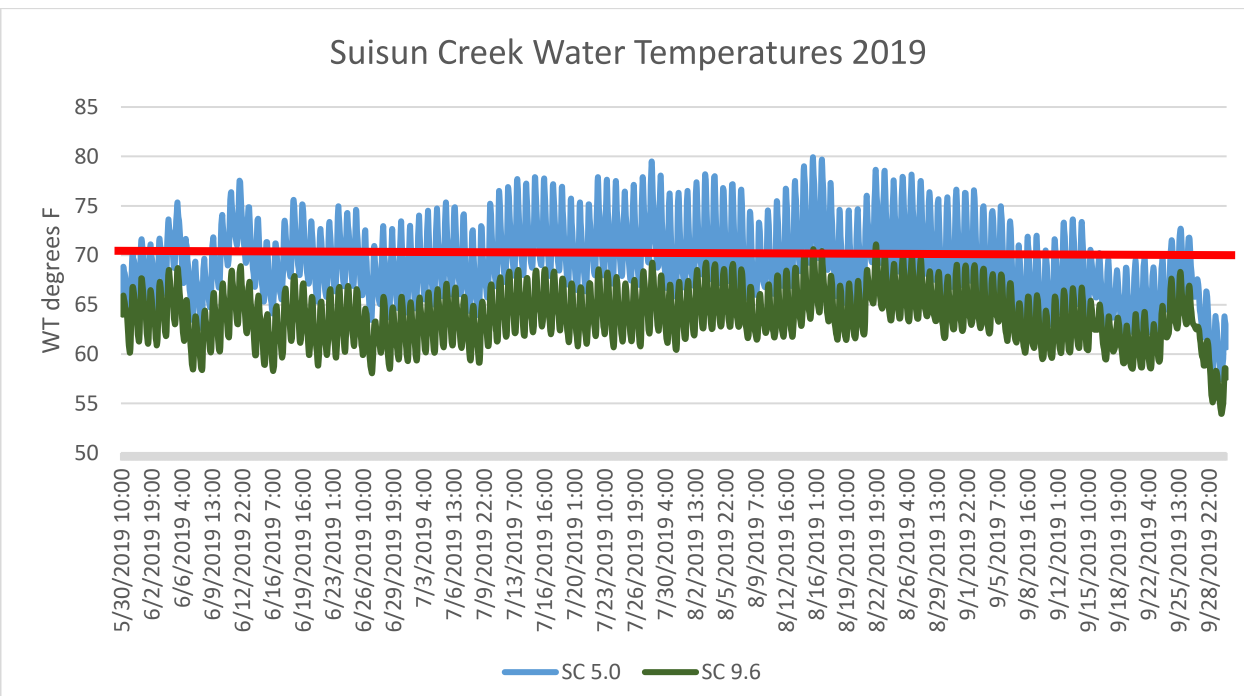


Figure 19. Comparison of station 9.6 located 1.0 miles downstream of Lake Curry and station 5.0 located 5.7 miles downstream of Lake Curry in 2018 and 2019

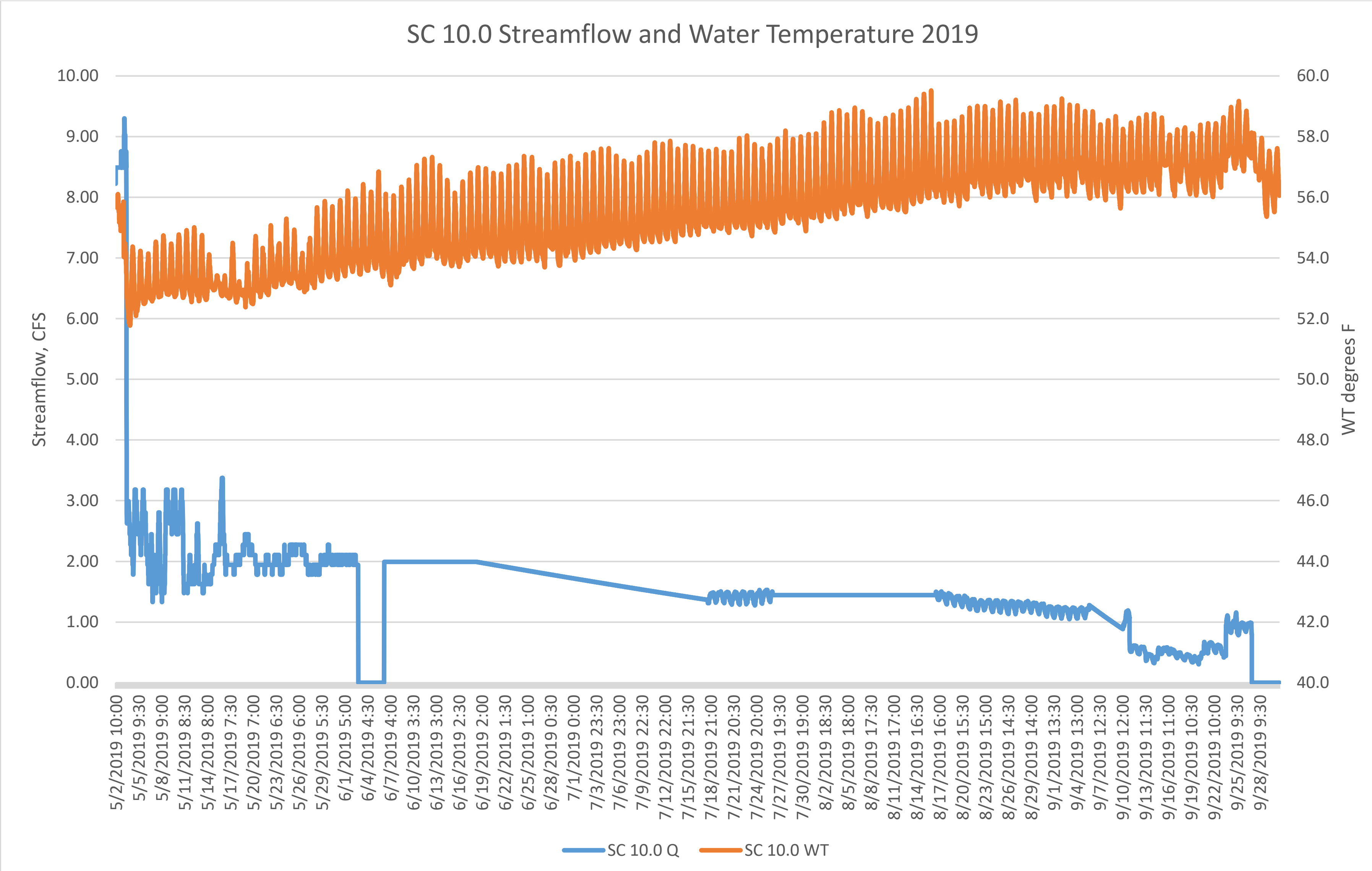


Figure 20. Streamflow and water temperature at station 10.0 in summer 2019.

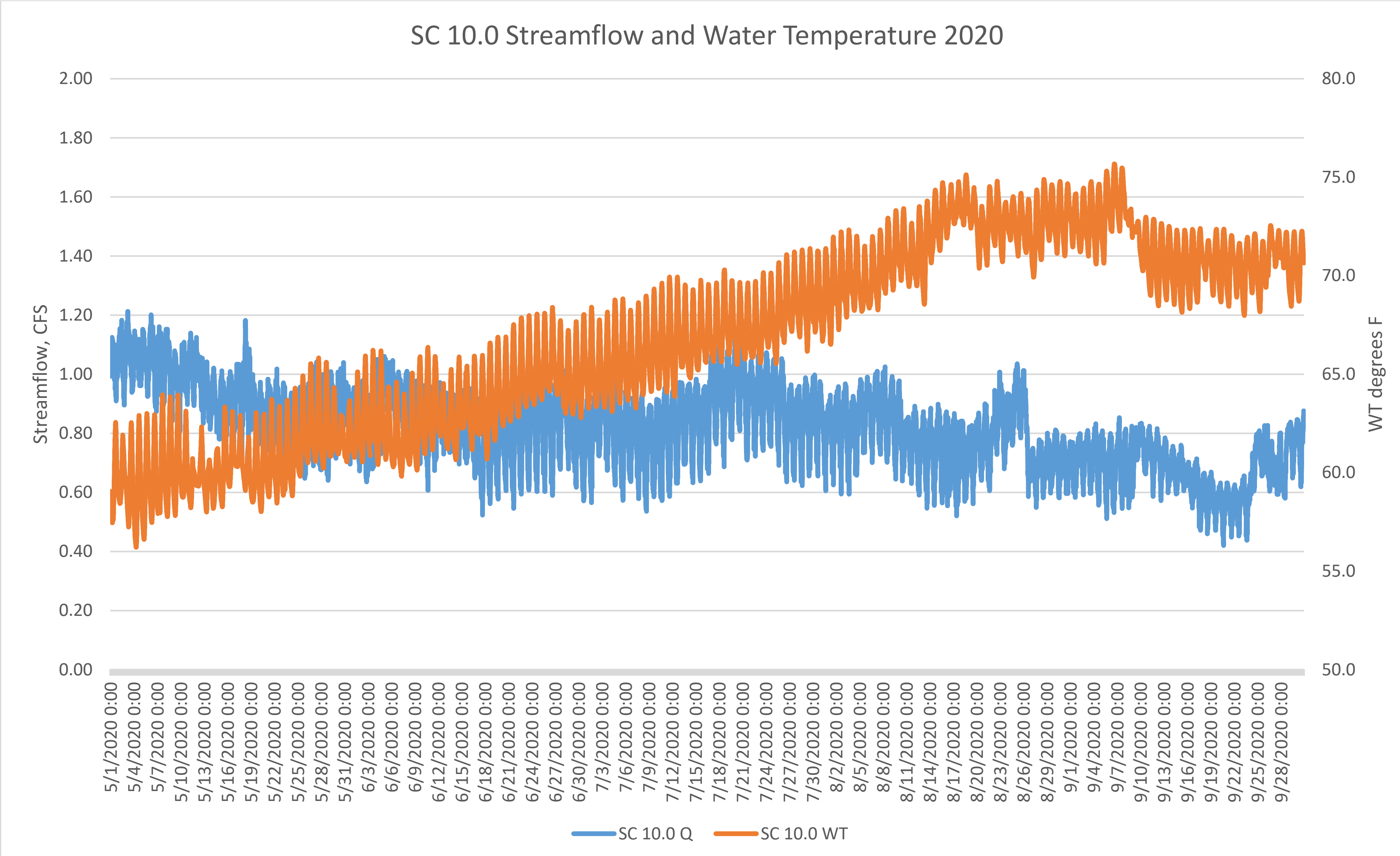


Figure 21. Streamflow and water temperature at station 10.0 in the summer 2020.

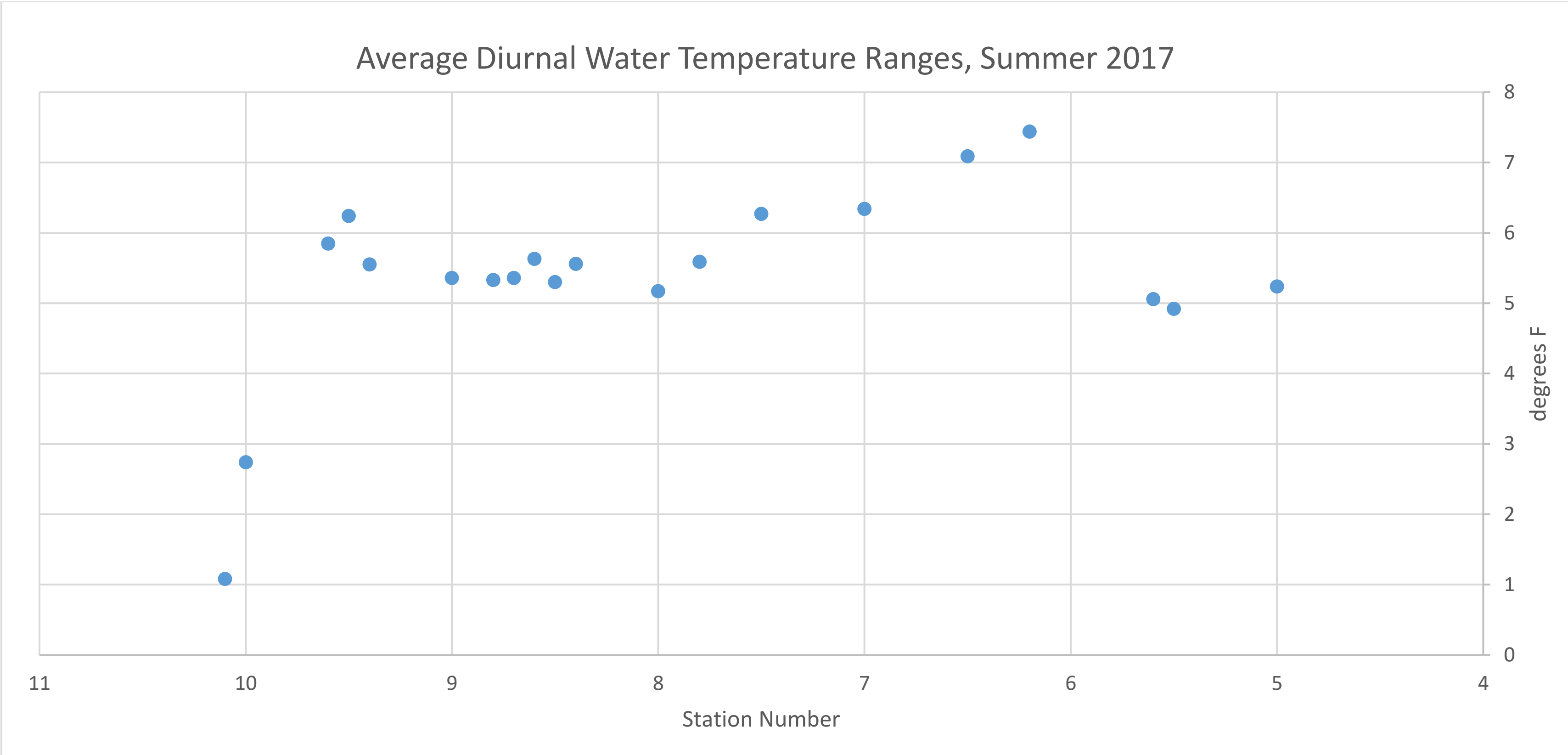


Figure 22. Average diurnal water temperature ranges in summer 2017.

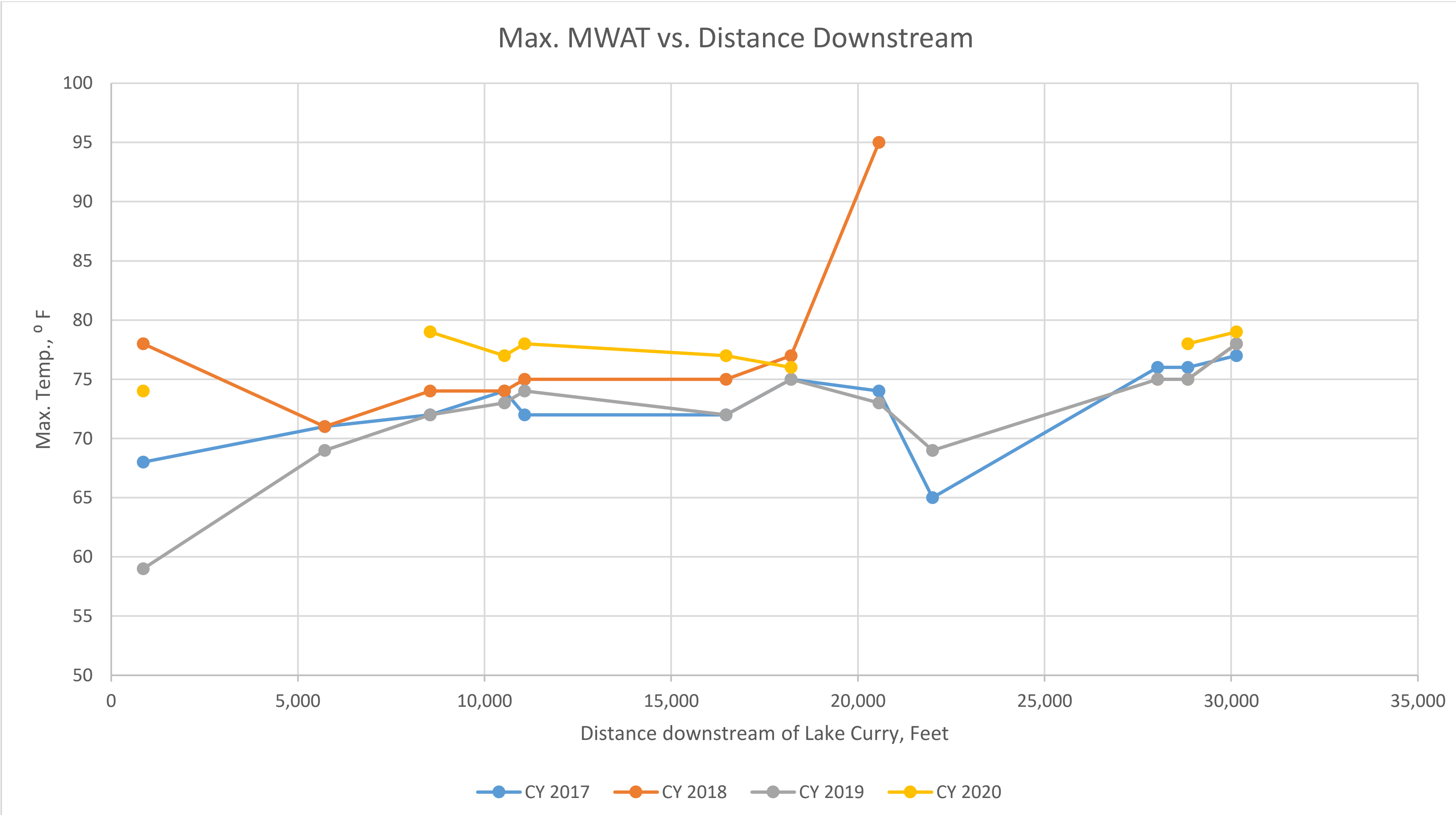


Figure 23. The Maximum Annual MMWAT (7-day moving average of maximum water temperatures) versus Distance Downstream from Gordon Valley Dam. The line for 2020 has a large gap due to dry conditions in the creek. In 2018 the creek had low flows and high temperatures.

__Changes in Water Temperature with Changes in Releases from Lake Curry__
We evaluated this question using both a model and an analysis of monitoring data.

Spatial Stream Network (SSN) Model
Water temperatures downstream of Lake Curry are affected by a number of factors other than the temperature of the water released from the lake. These include flow rates, air temperatures, and the level of riparian canopy cover. To evaluate these factors CLSI worked with Cramer Fish Sciences to create a spatial stream network (SSN) model (Appendix C). There are two primary benefits of developing an SSN model for Suisun Creek. First, by accounting for spatial autocorrelation and the nested nature of rivers, an SSN model allowed us to predict and evaluate habitat conditions (i.e., water temperatures) in areas of Suisun Creek that are inaccessible (e.g., landowner restrictions) or haven't previously been monitored. Second, the SSN model improved our understanding of how the surrounding landscape, flow conditions, and climate impact instream temperatures because the model allows us to spatially link characteristics of the drainage basin (e.g., aspect, canopy cover, geology) to instream habitat conditions.

We built an SSN model (Peterson and Ver Hoef 2010, Ver Hoef et al. 2012), for Suisun Creek using stream temperature data collected by CLSI in 2006 and 2017. We developed a spatial generalized linear model using the SSN model framework to test the collective effects of air temperature, canopy cover, and Lake Curry discharge on stream temperatures in Suisun Creek. This modelling framework also allowed us to consider the spatial autocorrelation inherent in these data. Our approach allowed us to conduct a robust evaluation of how altering discharge from Lake Curry changes downstream temperatures in Suisun Creek while accounting for other key factors.

Water temperature data collected in 2006 and 2017 coincide with records of mean daily discharge from Lake Curry. Collectively these data represent 3,388 daily maximum temperature records (°F) collected from 30 unique monitoring locations. We obtained spatially explicit mean daily air temperature records from the PRISM Climate Group that is based out of Oregon State University (http://prism.oregonstate.edu/). Estimates of canopy cover throughout the Suisun Creek watershed were either obtained from point measurements taken at the time of water temperature logger deployment or from professional judgement of areal imagery. Discharge data from Lake Curry was provided by the City of Vallejo lake operations management staff.

One of the key benefits of modelling these temperature data in the SSN framework is that it provides a mechanism for predicting water temperatures throughout the stream network. Furthermore, this framework allows us to make these predictions of how altering air temperature, canopy cover, and/or discharge rate from Lake Curry will impact stream temperatures. We examined how daily maximum water temperatures would change at approximately 70 sites stratified uniformly along the mainstem of Suisun Creek under several different scenarios. These scenarios are described below and include variations in air temperature, canopy cover, and discharge rate from Lake Curry.

The following scenarios were modeled. Table 5 shows the model results.
1. Current conditions; mean daily air temperatures in July, current canopy cover, and 2 CFS discharge.
2. Increase in mean daily air temperatures by 2.8°C from July mean (estimated A1B impact from climate warming), current canopy cover, and 2 CFS discharge.
3. Decrease in canopy cover; mean daily air temperatures in July, 0% canopy cover, and 2 cfs discharge.
4. Increase in canopy cover; mean daily air temperatures in July, 100% canopy cover, and 2 cfs discharge.
5. Lake discharge at 1 cfs; mean daily air temperatures in July, current canopy cover.

6. Lake discharge at 4 cfs; mean daily air temperatures in July, current canopy cover.
7. Lake discharge at 6 cfs; mean daily air temperatures in July, current canopy cover.

Table 5 Generalized results across prediction sites from each modeled scenario for the upper watershed model. Values reported are of predicted daily maximum water temperature. Scenarios are ranked from coolest to warmest average temperature.

Rank	Scenario	Average (°F)	SD (°F)	Max (°F)	Δ From Baseline (°F)
1	4	68.70	0.42	69.33	-5.02
2	7	72.18	4.68	84.26	-1.55
3	6	72.95	4.67	85.01	-0.77
4	1	73.73	4.67	85.75	0.00
5	5	74.11	4.66	86.12	1.16
6	2	74.83	4.67	86.86	1.88
7	3	85.21	0.42	85.84	10.38

There is broad agreement within the scientific community that air temperature is considered a very good predictor of water temperature (Stefan and Preud'homme 1993, Caissie 2006, Webb and Nobilis 2007, Webb et al. 2008, Kaushal et al. 2010). In fact, some biological and water quality research of streams often use air temperature as a surrogate for water temperature because water temperature data are sometime scarce or are relatively difficult to obtain (Smith 1981, Stefan and Preud'homme 1993, Webb et al. 2008). It is therefore reasonable to assume that climate warming over the next century will invariably warm stream temperatures in Suisun Creek as the model predicted.

It is important to highlight that we identified a significant interaction between air temperature and lake discharge. This significant interaction means that increasing discharge rate from Lake Curry, even for short periods of time (e.g., pulse flow), will decrease stream temperatures and the relative benefit of this elevated discharge rate will increase as air temperatures increase. Therefore, pulses during very hot periods could provide the greatest cooling benefit to the stream.

Shading provided by riparian vegetation, tall trees, and steep terrain may control the amount of shortwave radiation that reaches streams and rivers, which influences stream temperatures (Allen 2008). Riparian restoration is a potential tool that can be applied in Suisun Creek to decrease stream temperatures and/or mitigate for the expected impacts from climate warming. Small streams, such as Suisun Creek, are considered more vulnerable to the thermal effects of increasing solar radiation because they have a low thermal capacity relative to larger systems (Moore et al. 2005, Caissie 2006). Increasing the water volume in small tributaries will increase their thermal mass and therefore reduce their vulnerability to warming temperatures.

Monitoring Data

The water at the bottom of Lake Curry is usually cooler than the water in Suisun Creek, so larger releases of cool lake water should reduce downstream temperatures. Conversely, reduced releases would be expected to result in higher downstream temperatures. Water temperatures in 2019 and 2020 at station 9.6 located 1 mile downstream of the lake (Figures 24 and 25) show temperatures did not exceed 70^{o} F with release of 2.0 cfs. However, in 2020 when releases were below 1.0 cfs temperatures exceeded 70^{o} F.

Figures 26-29 show flows and temperatures at Station 8.4 located 2.2 miles downstream from Lake Curry. In 2017 when releases from Lake Curry varied from 2 to 15 cfs water temperatures at Station 8.4 exceed 70^{o} F a few times when flows are low. Flows in 2019 and 2020 where 1.5-2.0 cfs and temperatures exceeded 70^{o} F a number of times. Figures 30-31 show flows and temperatures in 2017 and 2020 at Station 5.6 located 5.3 miles downstream of Lake Curry. In the wet year 2017 where flows varied greatly temperatures ranged from 70-75^{o} F. In 2020 releases from Lake Curry were less than 1.0 cfs and the creek went dry. These data demonstrate that flow levels, as defined by releases from Lake Curry, affect temperatures of aquatic habitat particularly in upper Suisun Creek between stations 10 and 8. Downstream of station 8 the releases are less effective in creating cooler water temperatures. Additionally, releases below 2.5 cfs result in disconnected flow on Suisun Creek.

Figures 32-37 depict the water temperature data as daily maximum, daily minimum, daily median and the moving 7-day average of maximum temperatures. This type of analysis shows us how often high-water temperatures occur and may affect steelhead habitats. For station 9.6 flow releases of 0.5-1.5 cfs in 2020 show temperatures that frequently exceed 70^{o} F compared to 2017 that had higher flows. For station 8.5 the pattern is very similar to station 9.6 with excessive temperatures in 2020 with very low releases. At station 6.5 water temperatures exceeded 70^{o} F in both 2017 and 2020. This data is consistently shows the creek downstream of station 8 have higher summer water temperatures. Tables 7-10 summarize the temperature data which is also included as graphs in Appendix B.

Air Temperatures

Air temperatures were monitored with HOBO sensors at station 10.0 (Dam Air) and at station 7.8 (7.8 Air). Air temperatures at both stations exceeded 90^{o} F for much of each summer, and frequently exceeded 100 ^{o}F (Figure 38). These daytime high temperatures greatly exceeded temperatures measured in the stream. Nighttime air temperatures generally fell to temperatures cooler than stream temperatures (Figure 38).

Stream temperatures were positively correlated with air temperatures (Table 6). Correlation coefficients indicate the degree of association between two variables, and can range from 0 (no association) to 1.00 (all of the variation in one variable can be explained by variation in the other variable). Correlation coefficients ranged from 0.38 for SC 9.6 to 0.82 for SC 6.2. These results indicate that variations in air temperature are associated to a degree with variations in stream temperatures, but that other factors also affect stream temperatures.

Table 6. Correlation Coefficients for Air and Water Temperatures, Summer 2019

Air Temperature Station	Water Temperature Station	Correlation Coefficient
Dam	9.6	0.38
Dam	9.4	0.52
Dam	9.0	0.70
Dam	8.6	0.63
Dam	8.5	0.64
7.8	8.0	0.60
7.8	7.5	0.71
7.8	6.5	0.58
7.8	6.2	0.82
7.8	5.5	0.60
7.8	5.0	0.45

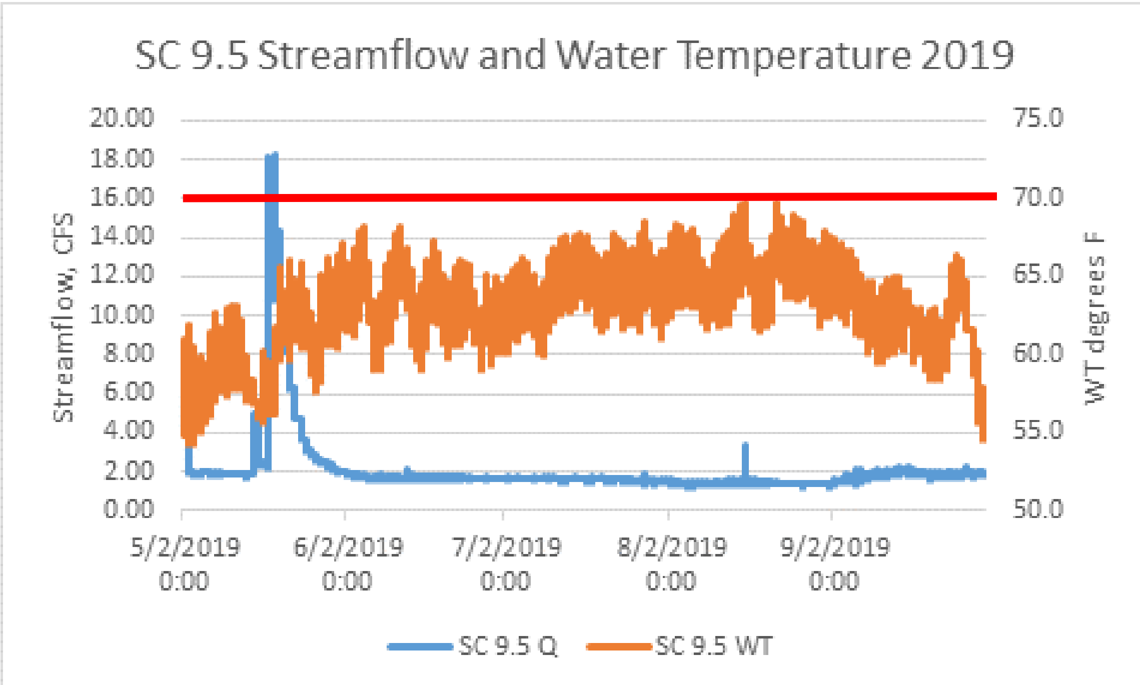


Figure 24. Temperatures at station 9.5 with a flow of 2 cfs are below 70^{o} F

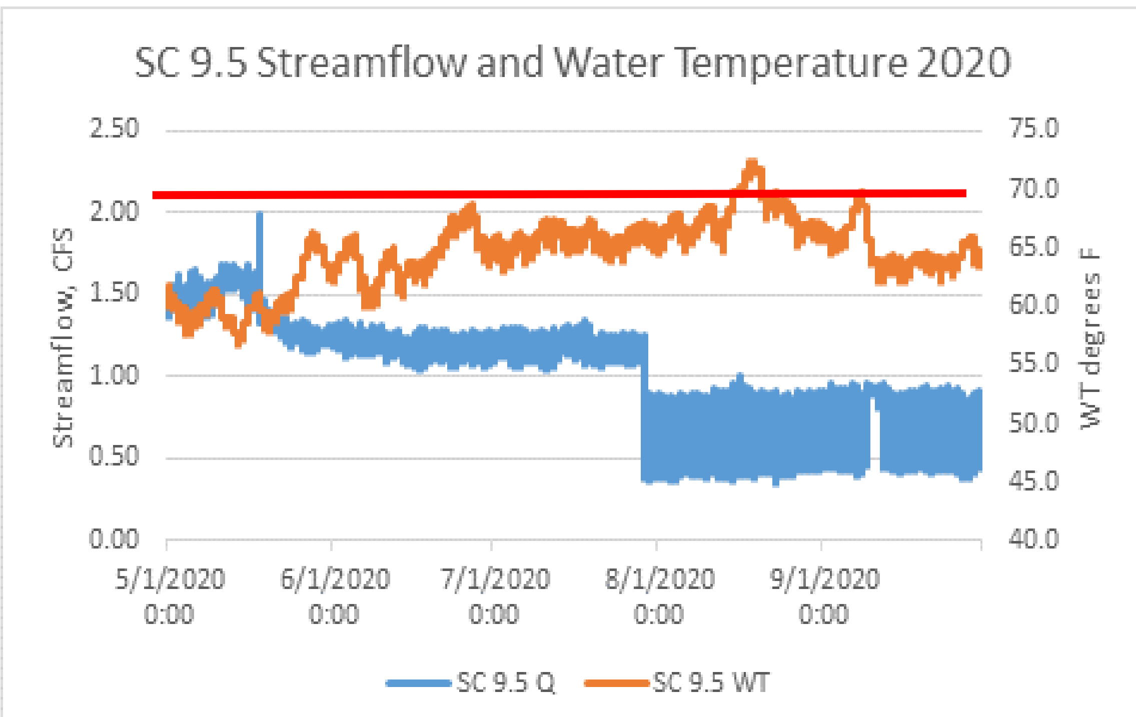
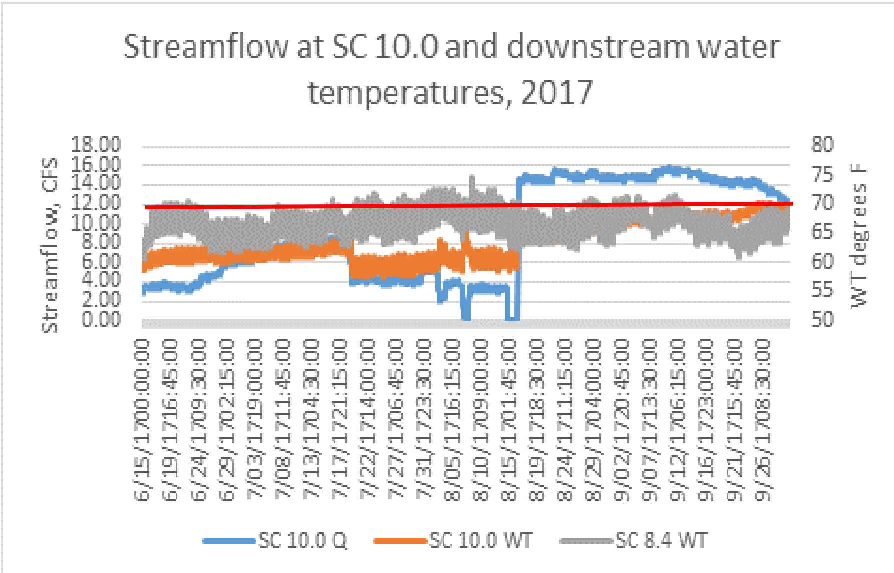
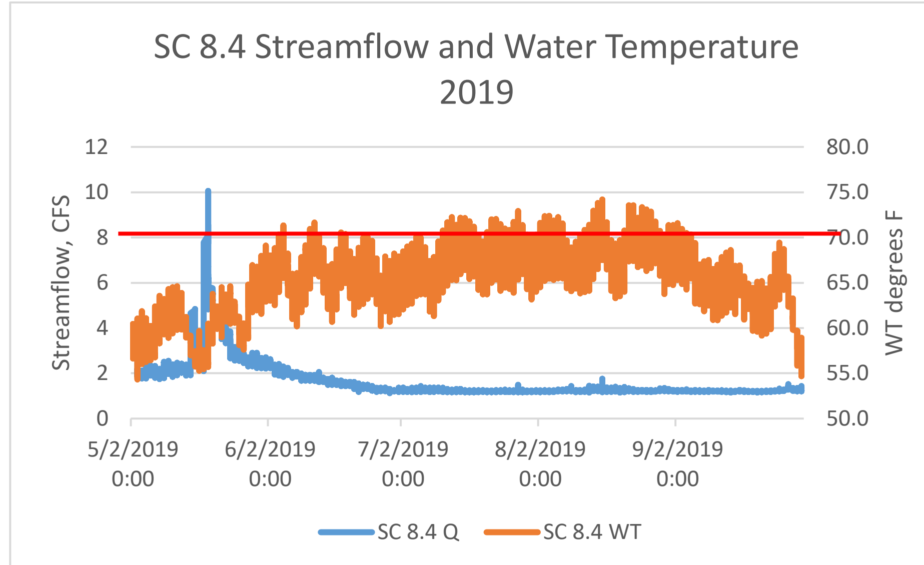
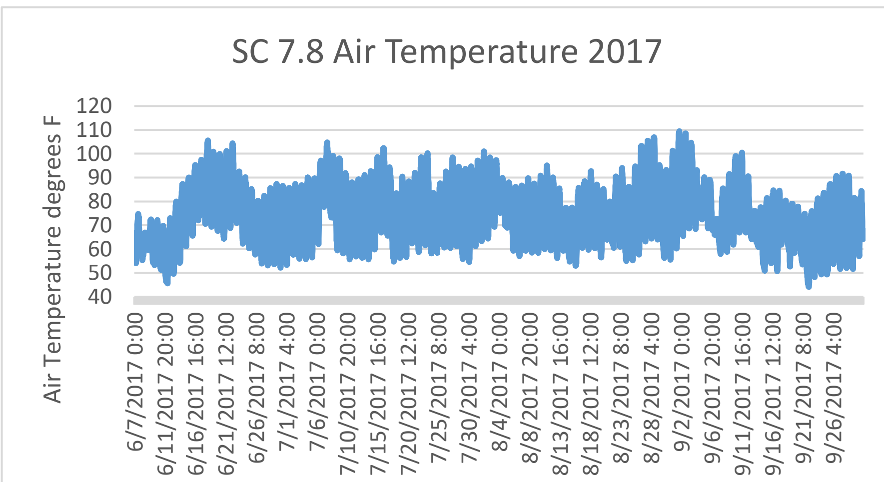
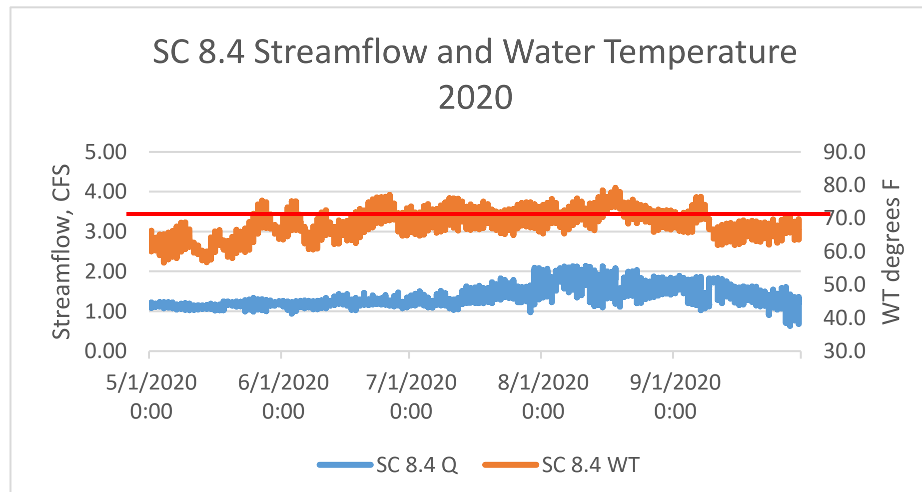


Figure 25. Temperatures at station 9.5 with a flow of 1.5-1.0-.5 cfs and temperatures exceed 70^{o} F for a short period as flows are reduced.

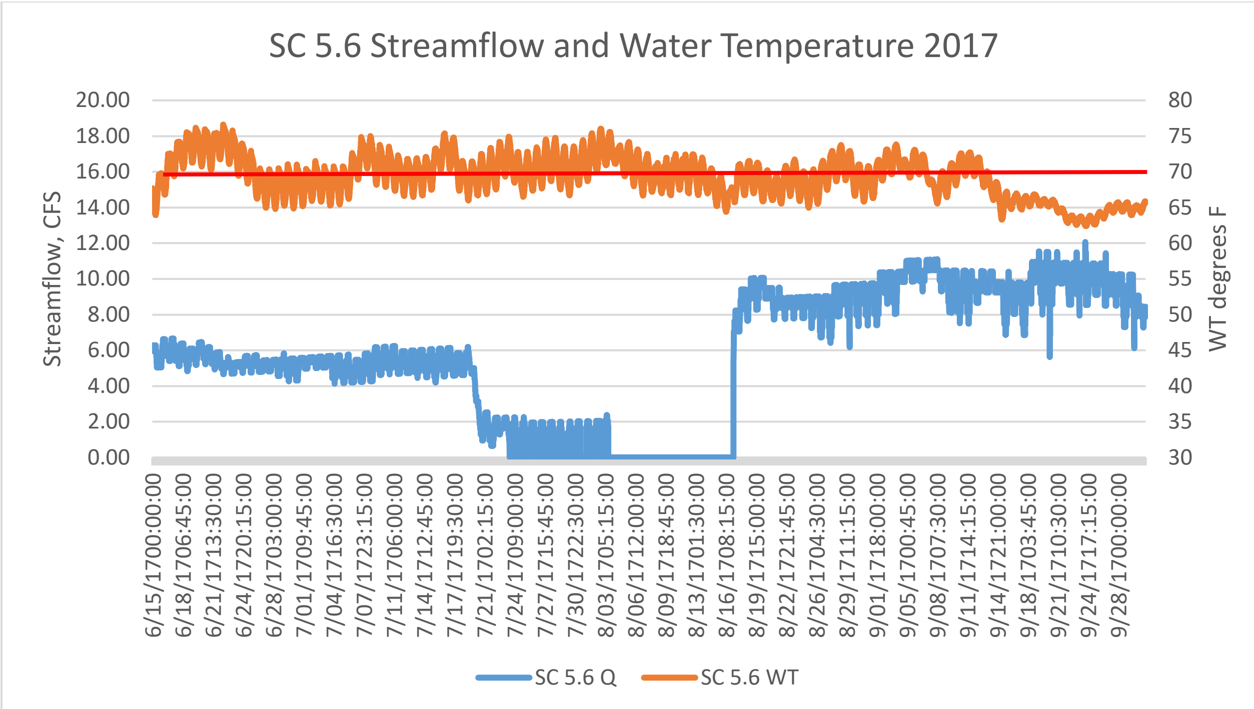


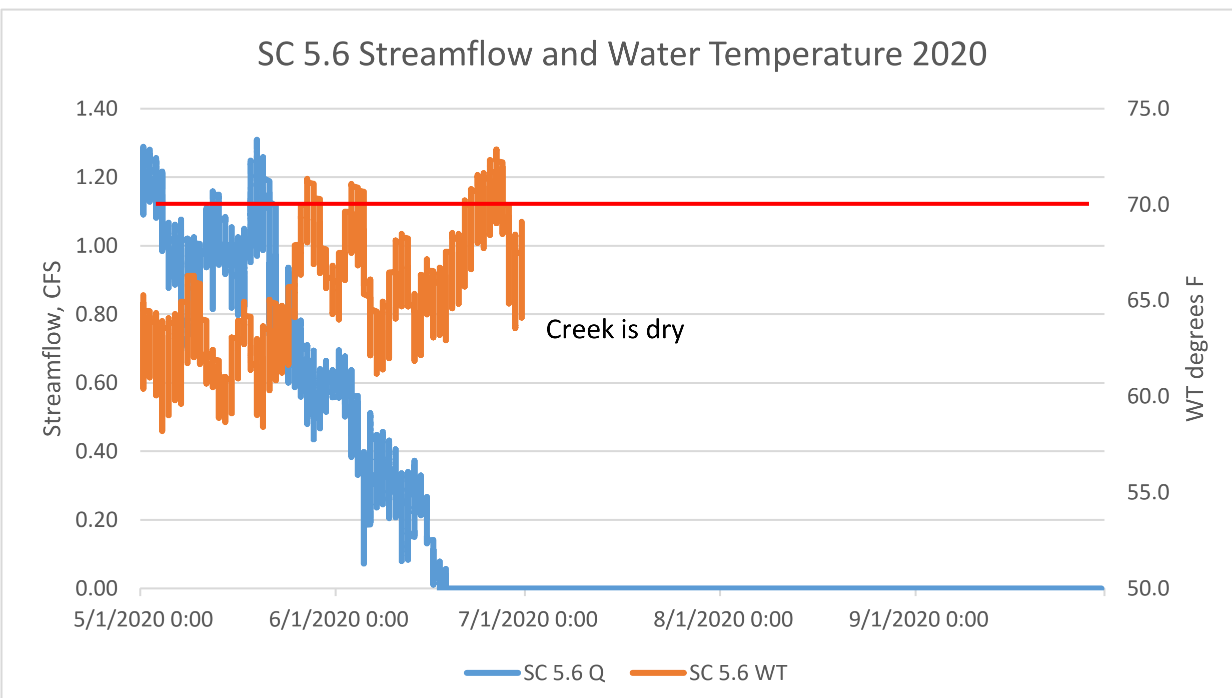




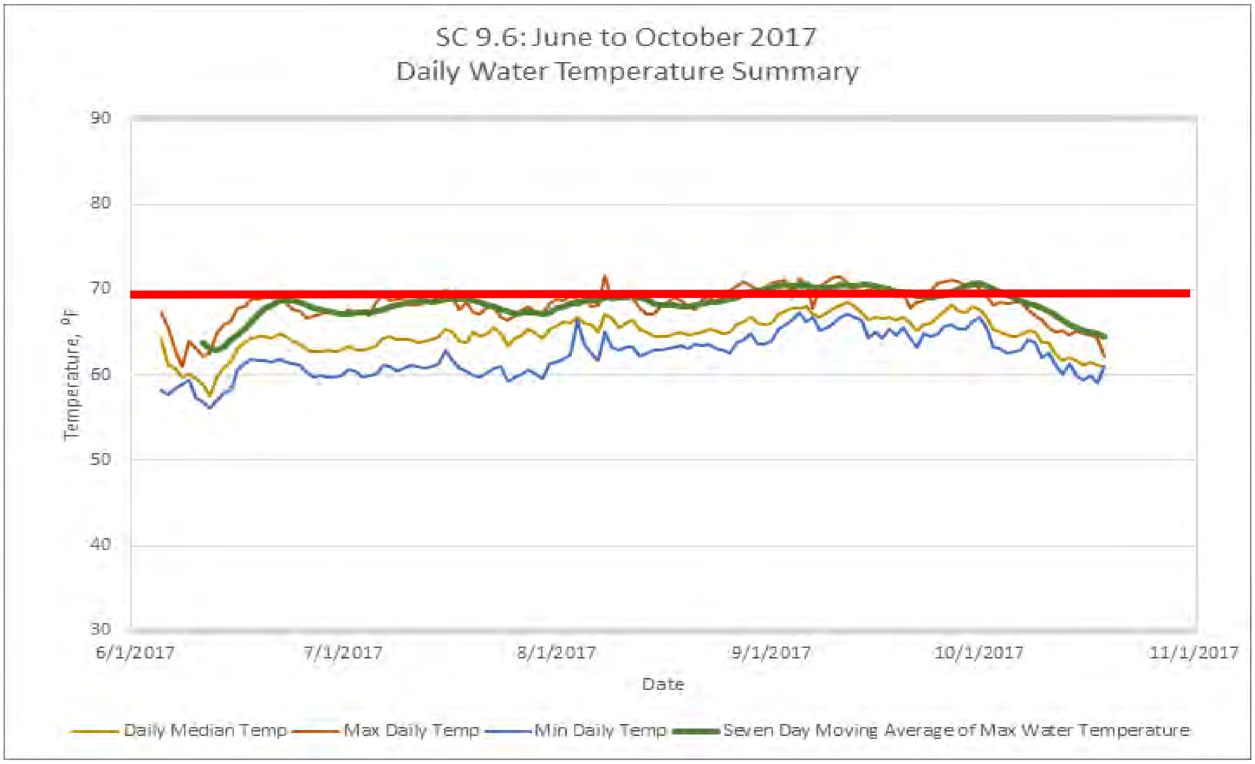


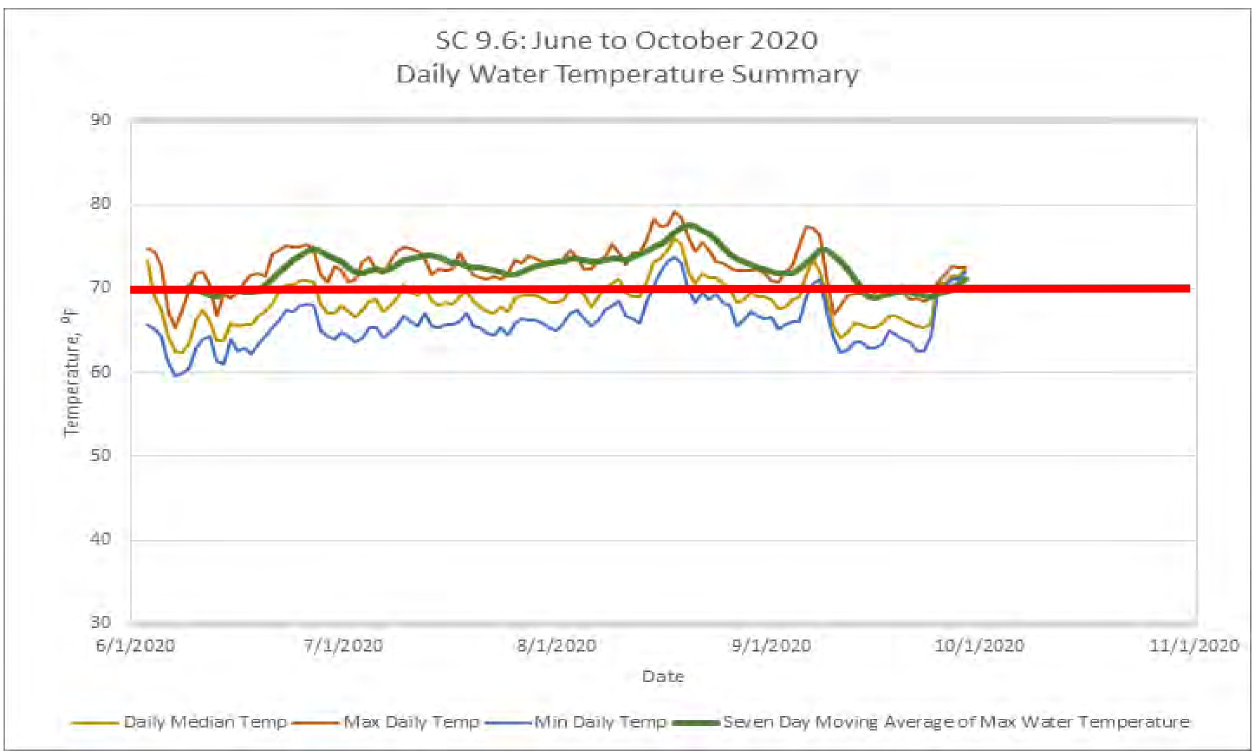
Figures 26-29. Flows and water temperatures at station 8.4 show that low releases of less than 2 cfs result in high water temperatures



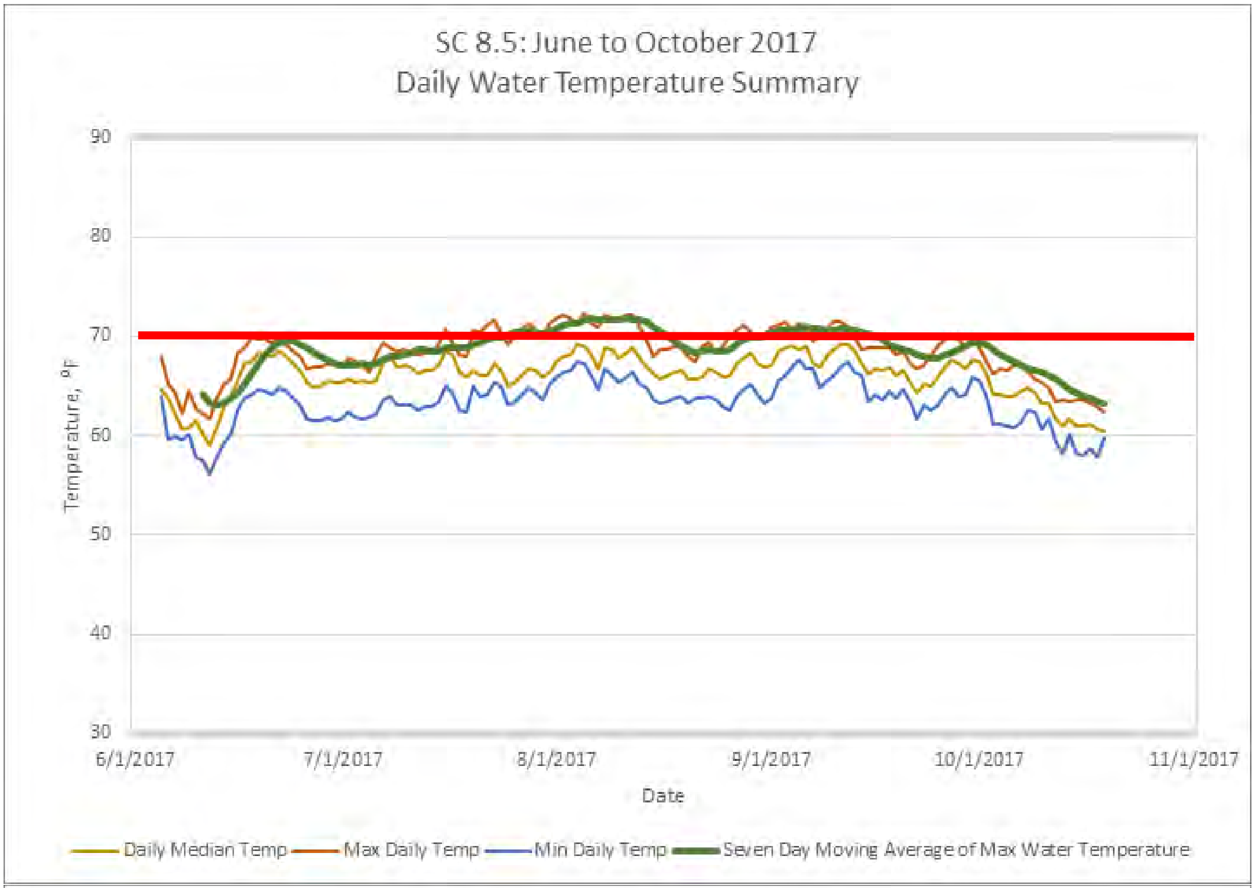


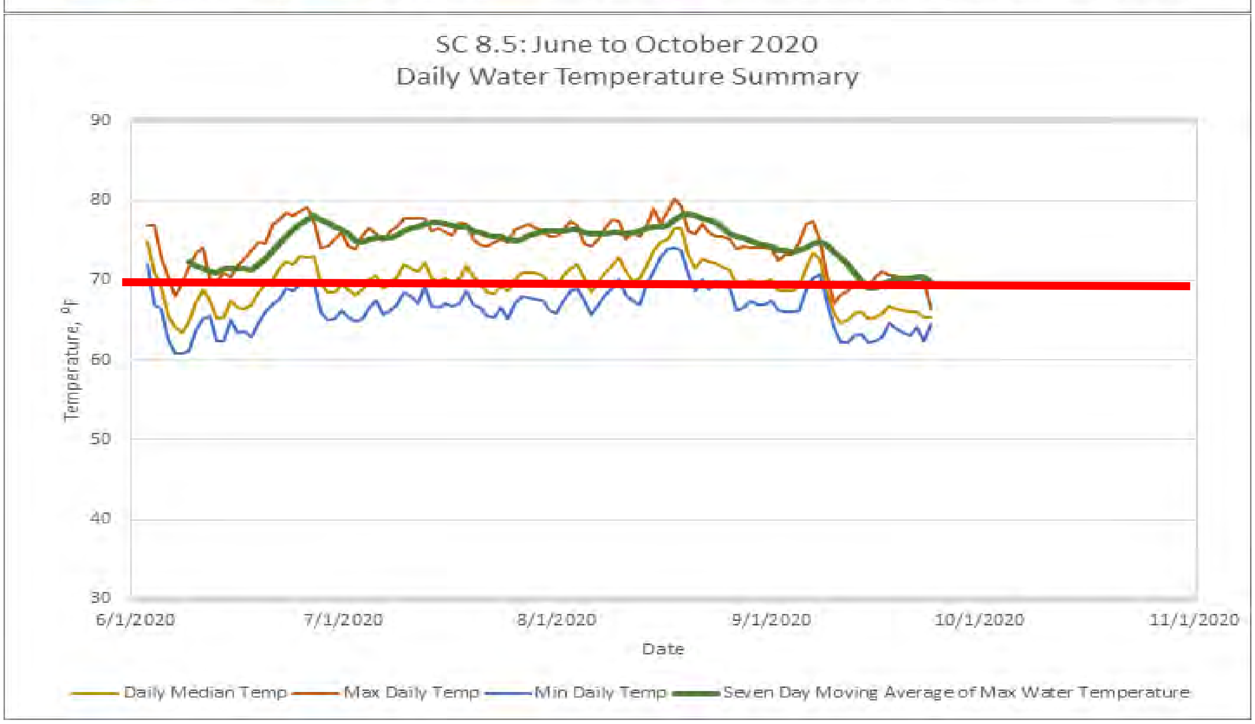
Figures 30-31 Releases from Lake Curry maintain fairly cool water temperatures in the upper Suisun Creek but temperatures can become too hot for steelhead downstream of station 8.0. Releases less than 2.5 cfs result in intermittent flow downstream of station 8.



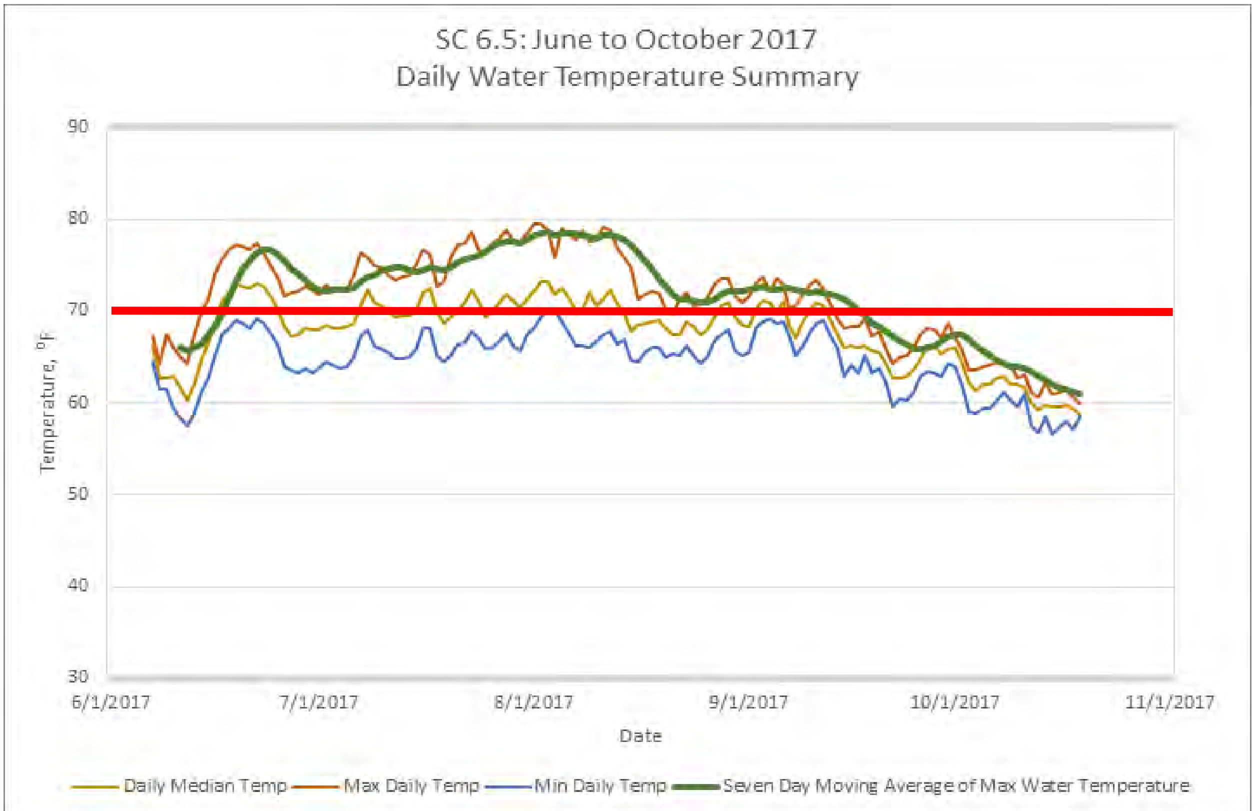


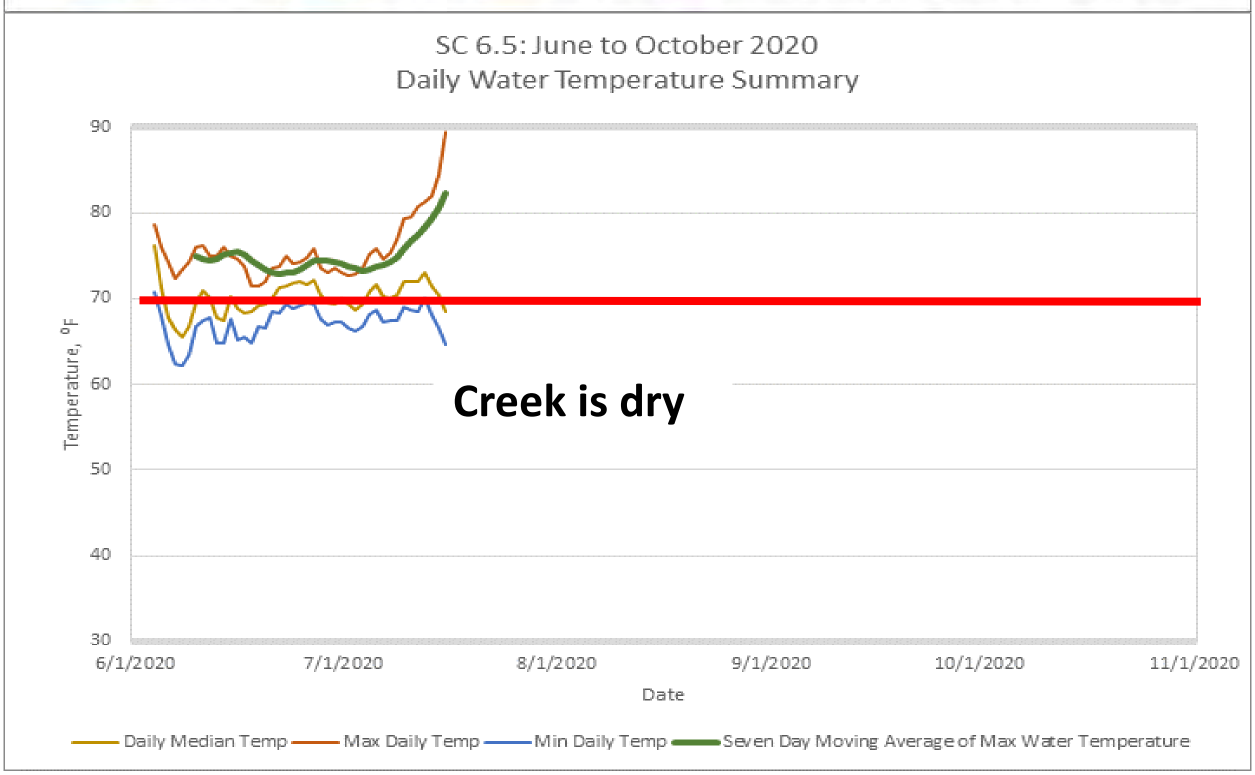
Figures 32-33. Releases from Lake Curry in 2017 ranged from 1-15 cfs and was a wet year. In 2020 releases were 0.5-1.5 and was a dry year. Temperatures at station 9.6 averaged much higher with lower releases.





Figures 34-35. Releases from Lake Curry in 2017 ranged from 1-15 cfs and was a wet year. In 2020 releases were 0.5-1.5 and was a dry year. Temperatures at station 8.5 averaged much higher with lower releases.





Figures 36-37. Releases from Lake Curry in 2017 ranged from 1-15 cfs and was a wet year. In 2020 releases were 0.5-1.5 and was a dry year. Flows at station 6.5 dried up in 2020 and averaged much higher in 2017 than upstream stations.

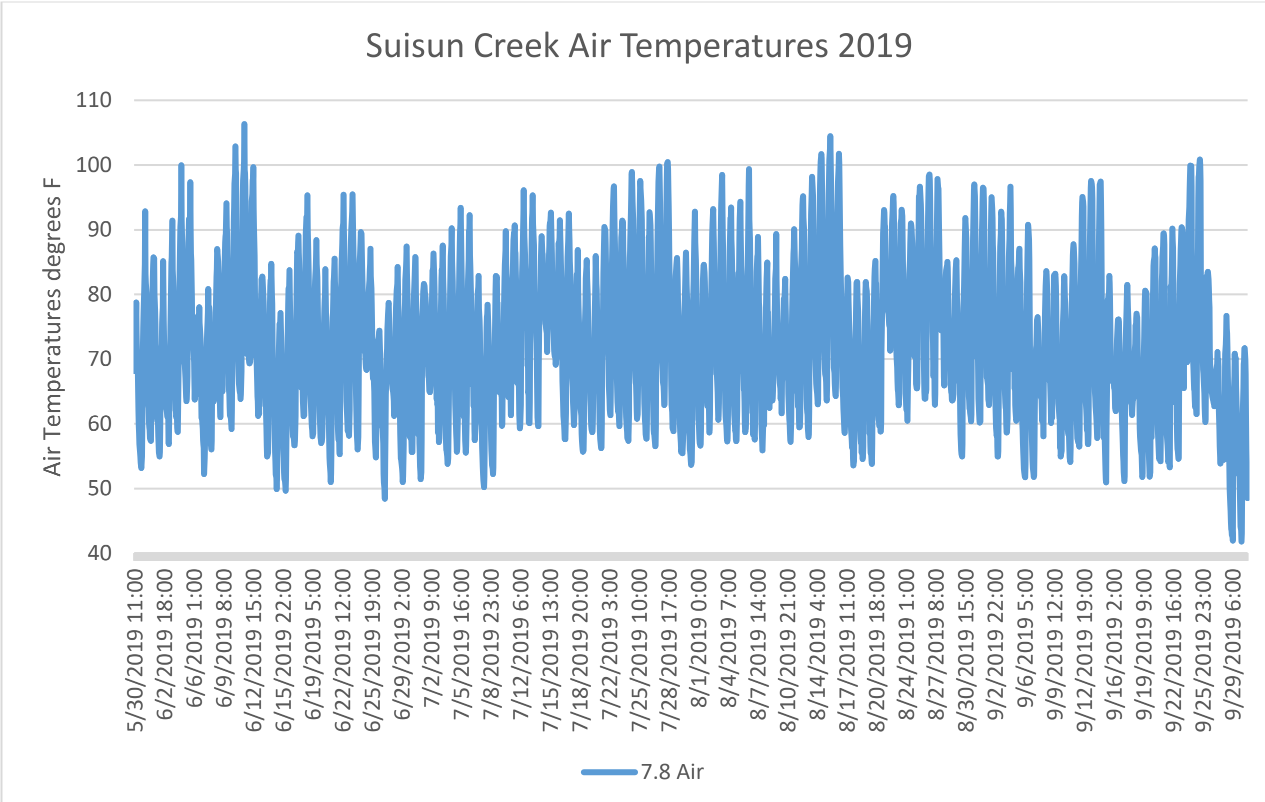


Figure 38. Example air temperature graph for station 7.8.

Table 7. Suisun Creek Water Temperature (℉) Monitoring Summary, 2017

Station	Month	7-Day Moving Average of Daily Average Temperature		7-Day Moving Average of Daily Maximum Temperature		Daily Range of Temperature		Number of Hours per Day > 70℉	
		Min	Max	Min	Max	Min	Max	Min	Max
5.0	Jun - Jul	63.4	74.2	65.9	77.0	1.9	8.6	4	24
	Aug - Sep	63.2	72.6	63.2	76.3	2.5	9.2	2	24
5.5	Jun - Jul	63.0	73.7	65.3	75.7	1.7	6.5	3	24
	Aug - Sep	63.2	72.2	63.2	74.7	2.9	6.4	1	24
5.6	Jun - Jul	62.8	73.5	65.2	75.7	3.3	6.8	1	24
	Aug - Sep	68.1	72.0	68.1	74.8	2.5	6.7	3	24
6.0	Jun - Jul	59.4	63.1	60.3	64.4	0.3	2.5	0	0
	Aug - Sep	63.2	67.5	63.2	69.8	0.9	5.5	0	4
6.2	Jun - Jul	62.7	72.7	66.2	77.8	3.0	11.5	3	20
	Aug - Sep	63.7	72.9	63.7	78.6	3.1	17.6	2	24
6.5	Jun - Jul	62.8	72.5	65.7	77.7	2.7	11.9	6	20
	Aug - Sep	63.8	73.0	63.8	78.6	2.9	12.4	2	24
7.0	Jun - Jul	61.8	71.0	64.5	74.5	2.3	8.6	1	17
	Aug - Sep	67.0	71.4	67.0	74.3	2.2	9.2	0	24
7.5	Jun - Jul	62.4	71.3	65.4	75.4	2.4	8.5	2	17
	Aug - Sep	64.2	72.1	64.2	75.2	2.7	11.0	1	24
7.8	Jun - Jul	62.1	70.4	64.9	73.8	2.0	7.9	1	15
	Aug - Sep	64.3	71.4	64.3	74.4	2.4	6.7	1	24
8.0	Jun - Jul	61.7	69.7	64.2	72.4	2.0	6.6	1	13
	Aug - Sep	64.3	70.3	64.3	72.5	1.8	6.5	1	16
8.4	Jun - Jul	60.8	67.8	63.0	70.8	2.4	7.1	2	8
	Aug - Sep	66.2	69.1	66.2	72.5	2.3	8.8	0	11
8.5	Jun - Jul	60.7	67.4	63.1	70.6	2.6	6.9	1	5
	Aug - Sep	65.4	68.7	65.4	71.7	2.7	7.5	1	10
8.6	Jun - Jul	60.8	67.8	63.2	71.0	2.4	7.0	2	8
	Aug - Sep	65.3	69.3	65.3	73.9	2.7	23.0	1	12
8.7	Jun - Jul	60.7	67.3	63.1	70.2	2.7	6.4	1	4
	Aug - Sep	65.6	68.7	65.6	72.1	2.6	8.5	1	10
8.8	Jun - Jul	60.5	66.7	63.0	69.0	2.9	6.7	0	0
	Aug - Sep	65.7	68.3	65.7	71.6	2.5	7.8	1	9
9.0	Jun - Jul	60.5	66.6	63.1	69.1	2.9	6.9	0	0
	Aug - Sep	65.9	68.4	65.9	71.5	2.3	10.7	1	9
9.4	Jun - Jul	60.0	65.2	62.9	68.8	2.7	8.1	0	0
	Aug - Sep	64.7	68.1	64.7	70.7	1.5	7.5	1	8
9.5	Jun - Jul	60.4	65.5	63.2	69.3	2.1	8.5	1	4
	Aug – Sep	65.0	68.2	65.0	71.0	1.2	7.7	3	7

Station	Month	7-Day Moving Average of Daily Average Temperature		7-Day Moving Average of Daily Maximum Temperature		Daily Range of Temperature		Number of Hours per Day > 70℉	
		Min	Max	Min	Max	Min	Max	Min	Max
9.6	Jun - Jul	60.0	64.8	62.9	68.8	2.1	8.3	0	0
	Aug - Sep	64.4	68.1	64.4	70.7	1.1	7.4	1	7
10.0	Jun - Jul	59.2	62.4	61.0	65.4	1.8	5.4	0	0
	Aug - Sep	59.5	67.1	59.5	67.6	0.3	8.3	0	0
10.1	Jun - Jul	58.4	61.9	58.8	64.5	0.4	4.3	0	0
	Aug - Sep	58.9	69.9	58.9	70.2	0.2	7.7	1	13

Table 8. Suisun Creek Water Temperature (℉) Monitoring Summary, 2018

Station	Months	7-Day Moving Average of Average Temperature		7-Day Moving Average of Daily Maximum Temperature		Daily Range of Temperature		Number of Hours per Day > 70℉	
		Min	Max	Min	Max	Min	Max	Min	Max
5.0	Jun - Jul	66.8	73.6	71.7	78.1	5.5	12.7	1	24
	Aug - Sep	62.9	72.5	62.9	76.9	3.6	9.3	1	18
5.5	Jun - Jul	64.4	72.8	67.0	75.3	2.8	8.0	1	24
	Aug - Sep	60.9	71.8	60.9	74.5	2.0	6.9	4	24
5.6	Jun - Jul	62.4	71.9	64.1	74.7	2.2	8.1	0	24
	Aug - Sep	64.3	70.7	64.3	73.4	2.5	6.5	2	20
6.2	Jun - Jul	66.7	74.1	74.7	120.2	4.7	76.9	5	24
	Aug - Sep	62.6	73.3	62.6	78.8	3.6	11.3	1	20
6.5	Jun - Jul	66.2	74.3	70.1	80.8	4.6	14.4	3	24
	Aug - Sep	63.6	73.4	63.6	79.7	3.4	12.2	1	19
7.0	Jun - Jul	66.2	72.2	70.4	75.5	4.5	12.5	1	24
	Aug - Sep	61.5	71.2	61.5	74.2	3.6	7.4	2	18
7.5	Jun - Jul	65.5	73.3	69.3	76.7	3.9	12.6	1	24
	Aug - Sep	63.2	72.6	63.2	75.9	3.0	7.8	1	20
7.8	Jun - Jul	66.3	73.0	68.4	76.3	1.9	8.3	1	24
	Aug - Sep	62.4	72.2	62.4	75.3	2.8	7.2	1	21
8.0	Jun - Jul	62.6	72.0	64.7	75.2	3.0	9.1	1	15
	Aug - Sep	63.1	70.9	63.1	73.9	1.3	6.7	3	8
8.4	Jun - Jul	64.2	72.4	67.4	75.0	4.1	8.3	1	24
	Aug - Sep	61.8	71.6	61.8	74.2	2.8	7.3	3	21
8.5	Jun - Jul	63.6	71.3	69.7	75.2	4.8	23.7	1	17
	Aug - Sep	61.8	70.6	61.8	74.0	4.2	9.0	1	14
8.6	Jun - Jul	62.4	70.9	63.8	74.4	1.1	12.9	1	15
	Aug - Sep	61.7	70.2	61.7	73.7	2.6	7.5	3	12
8.7	Jun - Jul	61.9	70.7	64.8	75.8	4.3	30.7	1	15
	Aug - Sep	61.8	70.0	61.8	73.7	2.8	7.7	1	11

Station	Months	7-Day Moving Average of Average Temperature		7-Day Moving Average of Daily Maximum Temperature		Daily Range of Temperature		Number of Hours per Day > 70°F	
		Min	Max	Min	Max	Min	Max	Min	Max
8.8	Jun - Jul	63.4	70.2	64.8	74.3	1.4	11.3	1	13
	Aug - Sep	61.8	69.6	61.8	73.4	2.5	8.5	1	9
9.0	Jun - Jul	64.4	70.2	65.9	73.7	1.6	11.5	1	15
	Aug - Sep	61.9	69.2	61.9	72.5	4.0	8.4	1	9
9.4	Jun - Jul	61.0	68.6	61.7	71.2	0.8	8.4	1	8
	Aug - Sep	62.0	68.0	62.0	70.6	1.2	6.6	1	6
9.5	Jun - Jul	63.5	68.8	64.7	70.8	1.9	5.8	0	9
	Aug - Sep	65.5	68.2	65.5	70.0	0.4	5.1	1	6
9.6	Jun - Jul	62.7	68.3	64.9	71.7	3.0	8.6	3	8
	Aug - Sep	62.5	67.7	62.5	71.0	1.9	8.7	1	7
10.0	Jun - Jul	59.7	65.3	61.8	78.5	2.2	27.7	5	10
	Aug - Sep	63.8	66.8	63.8	69.0	0.3	5.3	1	1

Table 9. Suisun Creek Water Temperature (°F) Monitoring Summary, 2019

Station	Months	7-Day Moving Average of Average Temperature		7-Day Moving Average of Daily Maximum Temperature		Daily Range of Temperature		Number of Hours per Day > 70°F	
		Min	Max	Min	Max	Min	Max	Min	Max
5.0	Jun - Jul	67.9	71.9	72.0	77.7	5.6	10.9	3	24
	Aug - Sep	65.2	72.1	65.2	77.9	4.5	10.7	2	21
5.5	Jun - Jul	67.6	71.7	70.6	75.1	4.7	8.2	1	24
	Aug - Sep	65.2	72.3	65.2	75.2	1.7	7.4	1	24
5.6	Jun - Jul	67.2	71.2	70.2	74.9	3.9	8.3	1	24
	Aug - Sep	68.9	70.5	68.9	74.0	4.7	6.7	3	14
6.0	Jun - Jul	61.8	65.8	64.1	68.7	2.2	7.0	0	0
	Aug - Sep	62.7	65.4	62.7	67.2	0.0	4.7	0	0
6.2	Jun - Jul	67.9	72.4	74.4	79.7	7.3	14.2	4	22
	Aug - Sep	64.7	73.1	64.7	79.6	3.6	12.6	1	24
6.5	Jun - Jul	68.0	72.4	72.4	78.6	6.2	12.8	1	22
	Aug - Sep	65.2	73.2	65.2	78.7	3.9	11.7	1	24
7.0	Jun - Jul	65.4	70.6	66.4	72.4	1.3	5.2	2	21
	Aug - Sep	67.2	71.9	67.2	73.5	2.8	4.8	0	24
7.5	Jun - Jul	67.6	71.7	70.5	74.8	5.1	7.6	1	20
	Aug - Sep	65.3	71.5	65.3	74.3	1.9	6.3	1	24
7.8	Jun - Jul	67.2	71.3	70.1	73.9	4.0	8.7	1	22
	Aug - Sep	64.5	72.2	64.5	74.3	1.9	5.2	3	24
8.0	Jun - Jul	66.0	69.5	68.6	72.2	2.6	8.8	1	15
	Aug - Sep	63.5	70.4	63.5	71.8	1.3	4.8	1	20

Station	Months	7-Day Moving Average of Average Temperature		7-Day Moving Average of Daily Maximum Temperature		Daily Range of Temperature		Number of Hours per Day > 70°F	
		Min	Max	Min	Max	Min	Max	Min	Max
8.4	Jun - Jul	64.7	68.9	67.6	71.8	4.4	7.8	1	10
	Aug - Sep	64.7	69.9	64.7	72.9	4.5	7.5	2	15
8.5	Jun - Jul	65.0	69.1	68.3	72.4	5.2	8.1	1	12
	Aug - Sep	62.9	70.1	62.9	73.5	3.2	7.9	1	15
8.6	Jun - Jul	64.6	68.5	68.1	72.3	4.9	8.1	1	9
	Aug - Sep	62.6	69.5	62.6	73.2	3.0	8.2	2	13
9.0	Jun - Jul	63.9	67.6	66.9	70.9	3.7	6.6	1	6
	Aug - Sep	62.1	68.7	62.1	72.1	2.6	6.6	1	9
9.4	Jun - Jul	62.3	65.6	65.0	68.0	3.6	5.7	0	0
	Aug - Sep	61.3	66.9	61.3	69.3	2.1	5.3	1	3
9.5	Jun - Jul	63.5	68.8	64.7	70.8	1.9	5.8	0	9
	Aug - Sep	65.5	68.2	65.5	70.0	0.4	5.1	1	6
9.6	Jun - Jul	62.7	68.3	64.9	71.7	3.0	8.6	3	8
	Aug - Sep	62.5	67.7	62.5	71.0	1.9	8.7	1	7
10.0	Jun - Jul	59.7	65.3	61.8	78.5	2.2	27.7	5	10
	Aug - Sep	63.8	66.8	63.8	69.0	0.3	5.3	1	1

Table 10. Suisun Creek Water Temperature (°F) Monitoring Summary, 2020

Station	Months	7-Day Moving Average of Average Temperature		7-Day Moving Average of Daily Maximum Temperature		Daily Range of Temperature		Number of Hours per Day > 70°F	
		Min	Max	Min	Max	Min	Max	Min	Max
5.0	Jun	66.5	72.7	70.6	78.9	5.1	12.4	4	18
	No data after June 28								
5.5	Jun - Jul	65.3	70.1	69.8	78.4	5.1	14.0	1	13
	No data after June 28								
6.2	Jun	67.5	67.5	78.5	78.5	9.9	27.5	1	9
	No data after June 10.								
6.5	Jun - Jul	68.8	72.7	72.9	82.4	4.7	24.7	4	24
	No data after July 16.								
7.5	Jun - Jul	67.3	72.2	70.8	75.6	4.2	8.8	3	23
	Aug - Sep	66.2	72.3	66.2	74.9	2.4	8.1	2	24
8.0	Jun - Jul	64.7	70.1	67.0	74.5	3.2	13.2	1	16
	Aug - Sep	64.7	72.8	64.7	76.9	1.3	12.2	1	24
8.5	Jun - Jul	66.2	72.6	71.0	78.0	4.6	10.9	1	23
	Aug - Sep	65.6	74.8	65.6	78.2	1.8	9.6	1	24
8.6	Jun - Jul	66.0	71.9	69.4	75.5	3.8	9.0	3	22
	Aug - Sep	65.6	74.6	65.6	77.4	1.8	7.7	5	24

Station	Months	7-Day Moving Average of Average Temperature		7-Day Moving Average of Daily Maximum Temperature		Daily Range of Temperature		Number of Hours per Day > 70°F	
		Min	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**
9.0	Jun - Jul	66.1	72.0	71.0	77.6	5.1	11.8	1	17
	Aug - Sep	65.8	74.8	65.8	78.6	1.7	10.5	1	24
9.4	Jun - Jul	64.3	69.8	65.6	71.4	1.6	5.1	1	16
	Aug - Sep	65.3	73.5	65.3	75.1	0.8	4.1	1	24
9.6	Jun - Jul	64.9	70.6	69.1	74.8	4.9	9.5	1	15
	Aug - Sep	65.5	73.9	65.5	77.5	0.5	9.1	2	24
10.0	Jun - Jul	62.4	68.6	65.2	71.2	2.7	6.1	2	8
	Aug - Sep	68.8	73.2	68.8	74.9	1.4	5.5	2	24

Changes in Canopy Cover and Water Temperatures

Canopy cover was measured using a solar densiometer annually at all locations where HOBO temperature sensors were deployed to determine how the level of shading on the creek affects water temperatures. The solar densiometer measures the percent of tree canopy cover. Measurements were taken at both banks and at mid-stream, with the observer facing upstream, downstream, toward the right bank, and toward the left bank.

During the 2017 to 2021 study period, riparian vegetation in the Suisun watershed was affected by major wildfires in 2017 and 2020. The riparian corridor was also affected by drought conditions in 2014 to 2016 and in 2020. In addition to trees lost to the fires, a large number of trees, mostly white alders, died from drought-related stress, and riparian cover was mechanically removed near station 7.0 in 2020. Average stream temperatures generally increase with distance downstream of Lake Curry, and show a reasonably consistent inverse relation to canopy cover (Figures 39 to 42). This relation is most clearly seen in the data for 2017, prior to the large wildfires (Figure 39). In subsequent years, both stream temperatures and canopy cover showed a less consistent downstream pattern except at the upstream 3 stations where cover remained high and temperatures remained low (Figures 40 to 42).

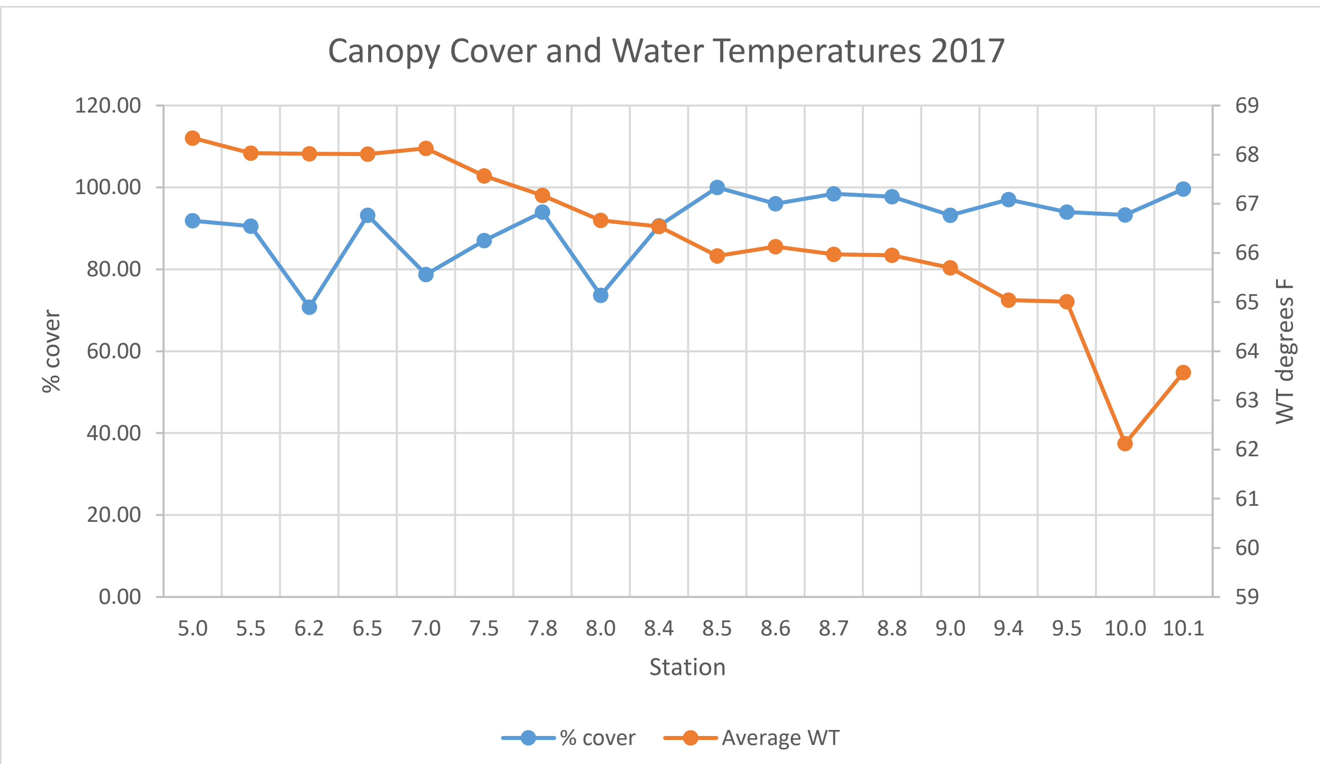


Figure 39. Canopy cover and average summer water temperatures at all stations in 2017

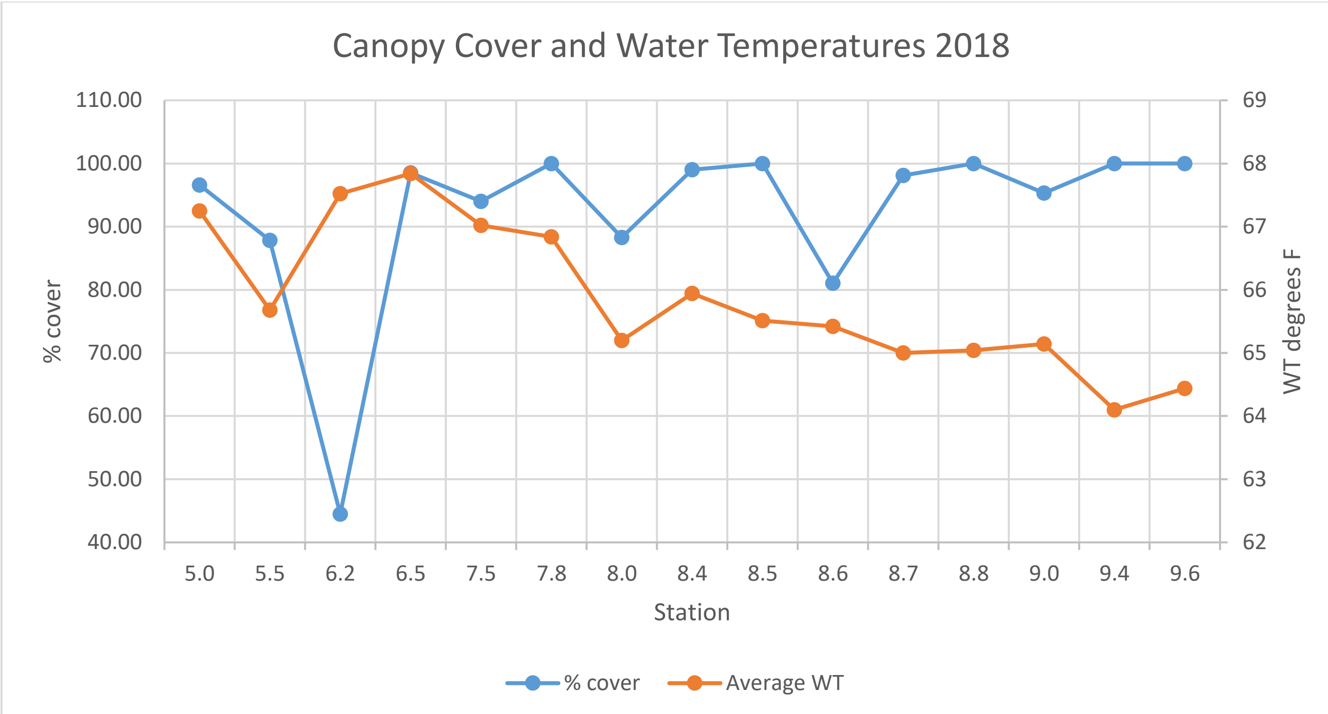


Figure 40. Canopy cover and average water temperatures at all stations in 2018

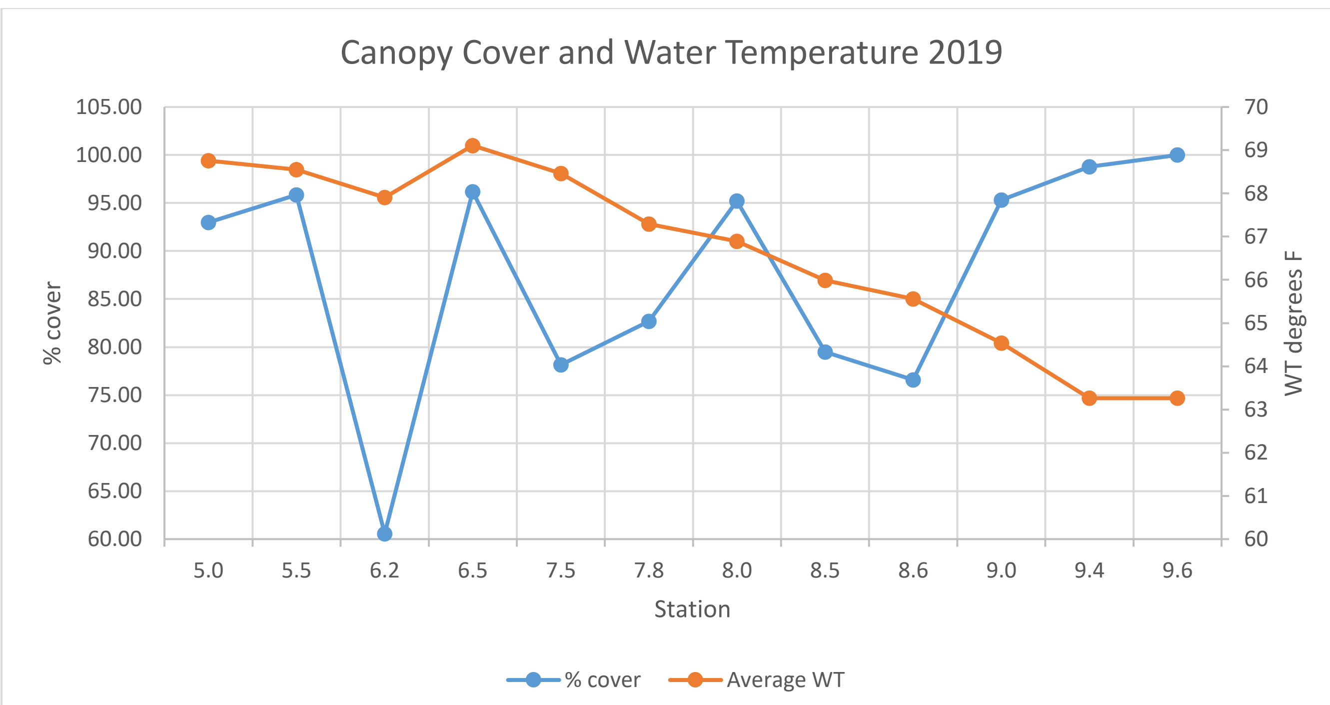


Figure 41 Canopy cover and average water temperatures at all stations in 2019

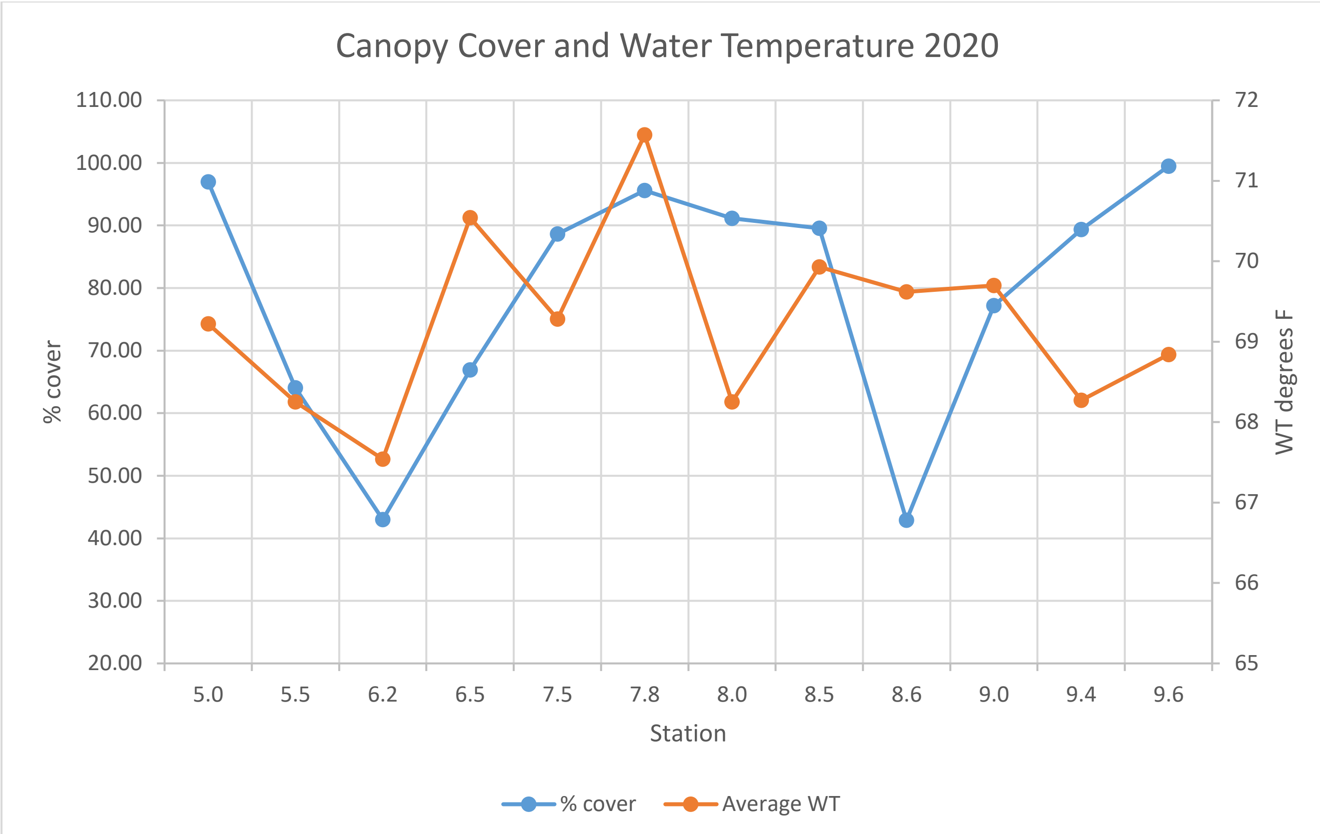


Figure 42. Canopy cover and average water temperatures at all stations in 2020

Correlation coefficients for canopy cover and water temperature for all stations were -0.48 in 2017, -0.36 in 2018, -0.30 in 2019, and 0.24 in 2020. These results indicate that the relation between canopy cover and water temperature became weaker and shifted from negative to positive between 2017 and 2020, probably as a result of reduced canopy cover.

To better understand the role of canopy cover in maintaining stream temperatures, we plotted average annual values of canopy cover and stream temperature at each station for the 4 years of the study (2017 to 2020). An example is shown below in Figure 43. Of the 11 stations analyzed, 8 showed the pattern depicted in Figure 43, in which canopy cover decreased and water temperature increased. These results indicate that reduced canopy cover and increased solar radiation were responsible in part for observed increases in stream temperatures downstream of Lake Curry between 2017 and 2020.

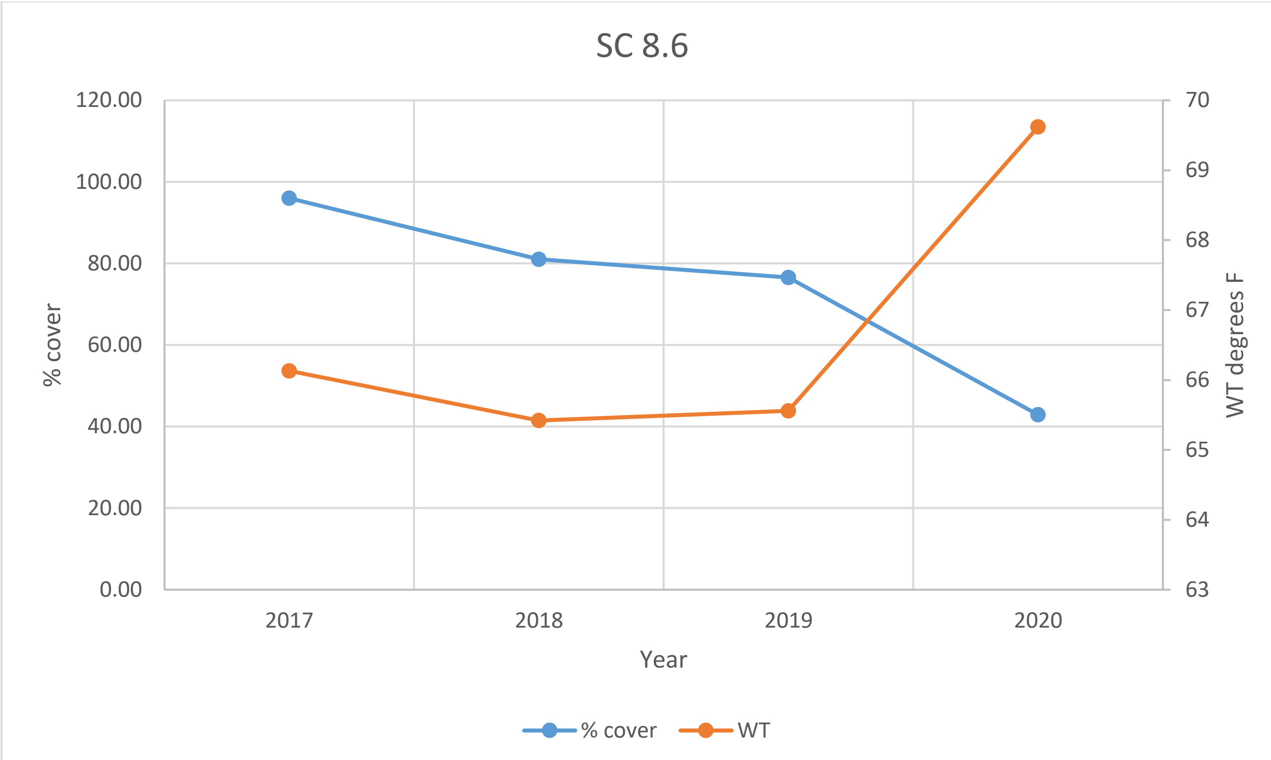


Figure 43. Canopy cover and water temperature at station 8.6 from 2017 to 2020.

DISSOLVED OXYGEN

Dissolved oxygen (DO) concentrations were measured at selected locations on upper Suisun Creek using a YSI multi-parameter submersible sonde that also monitored water temperature, specific conductance, and pH. The water quality monitoring was done to answer the following questions:

- **How do flows affect dissolved oxygen levels?**
- **How do water temperatures affect dissolved oxygen levels?**

We focus here on the monitoring results for DO and water temperature as the most critical determinants of water quality for steelhead habitat. DO concentrations below 4 mg/L are considered lethal for steelhead while DO concentrations of 7 mg/L will sustain steelhead (San Francisco Bay Regional Water Quality Control Board 2017).

Results for selected stations are shown in Figures 44 to 47 to illustrate the range of DO concentrations in the creek. Appendix D contains graphs of all the water quality monitoring completed. Generally, dissolved oxygen concentrations were high but showed pronounced diurnal fluctuations. These fluctuations were probably driven by daily cycles of photosynthesis and respiration by algae (Figures 44 and 45). Daytime peaks in DO were markedly lower in 2019 at station 6.0 during a low-flow period (Figure 46). DO concentrations in an isolated pool with no surface water flowing in or out of the pool reached typical daytime highs, but plunged at night to near 0 mg/L without aeration from surface flows. These results indicate that DO concentrations in Suisun Creek are generally adequate to support steelhead during summers. However, long periods of low or no flow can result in DO concentrations lethal to steelhead trout.

Table 11. The Dissolved Oxygen Concentration and Temperature Measured at Selected Stations on Suisun Creek, 2017 to 2020.

	SC-9.5 9/14 to 10/20/17	**SC-7.0** 9/12 to 9/18/18	**SC-6.0** 8/30 to 9/11/19	**SC-9.5** 7/29to 8/19/20
Temp $\leq$ 68° - DO $\geq$ 7 mg/l	79.7%	81.2%	47.5%	2.5%
Temp $\leq$ 68° - DO < 7 mg/l	0.0%	2.4%	7.0%	13.7%
68° < Temp < 77° - DO $\geq$ 7 mg/l	20.3%	15.4%	0.0%	33.3%
68° < Temp < 77° - DO < 7 mg/l	0.0%	0.0%	43.4%	48.9%
Temp $\geq$ 77° - DO $\geq$ 7 mg/l	0.0%	0.9%	0.0%	0.4%
Temp $\geq$ 77° - DO < 7 mg/l	0.0%	0.0%	1.8%	1.1%

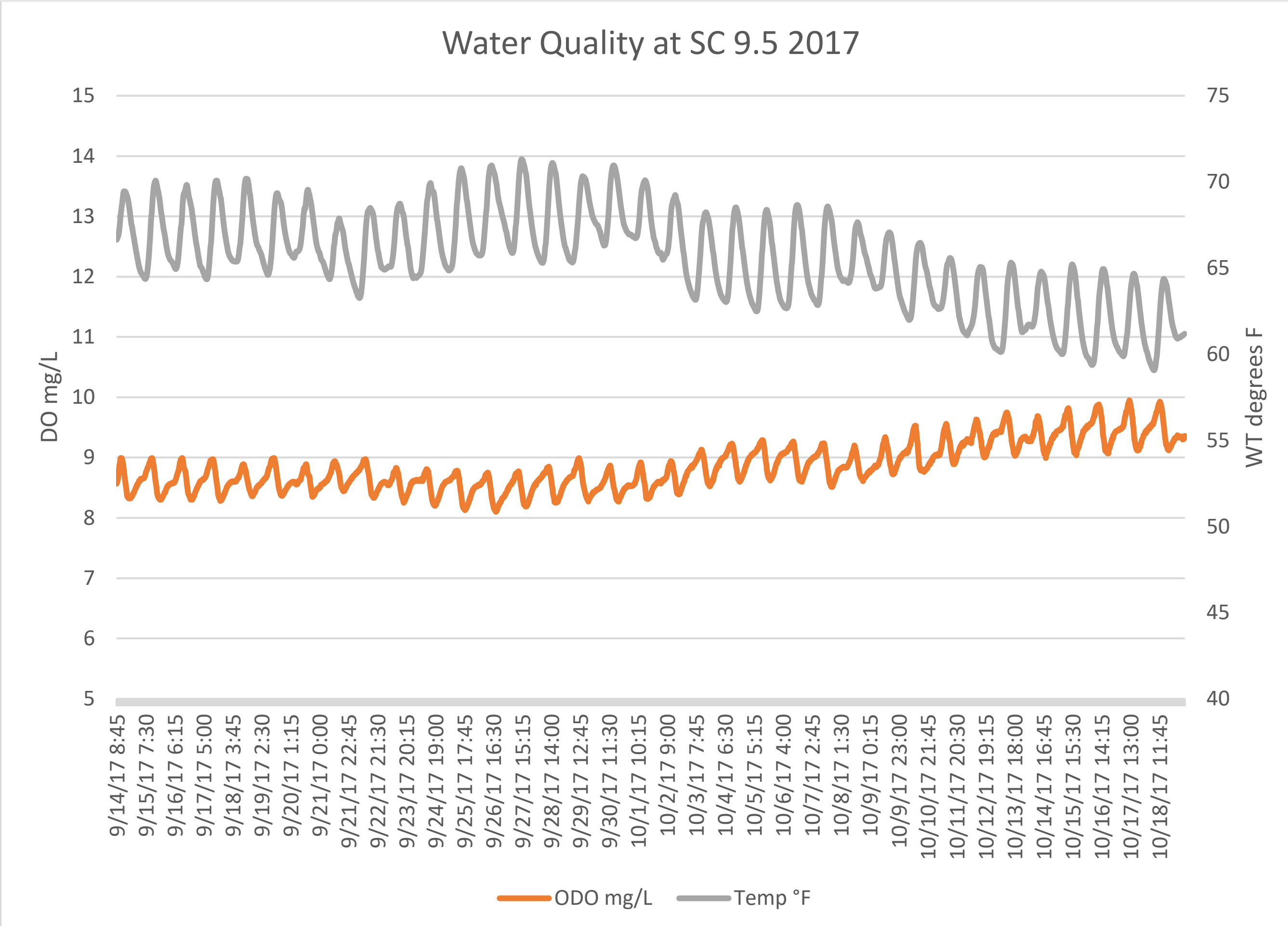


Figure 44. Water temperature and dissolved oxygen at station 9.5, 2017

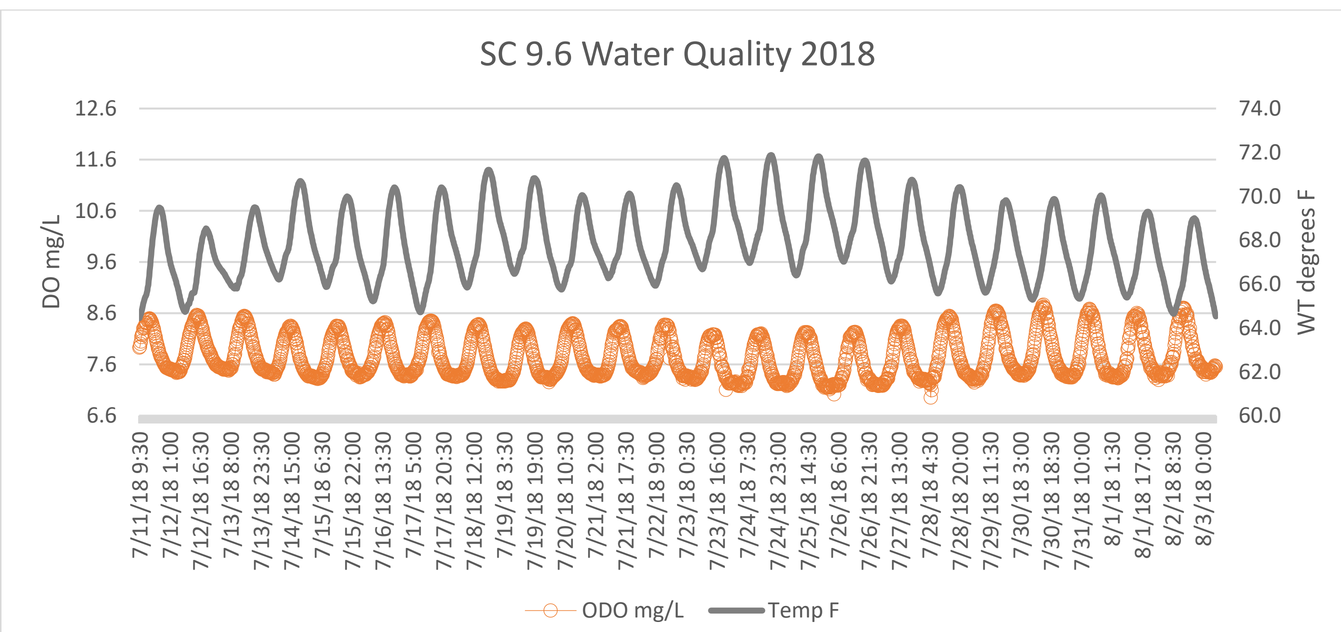


Figure 45. Water temperature and dissolved oxygen at station 9.6, 2018

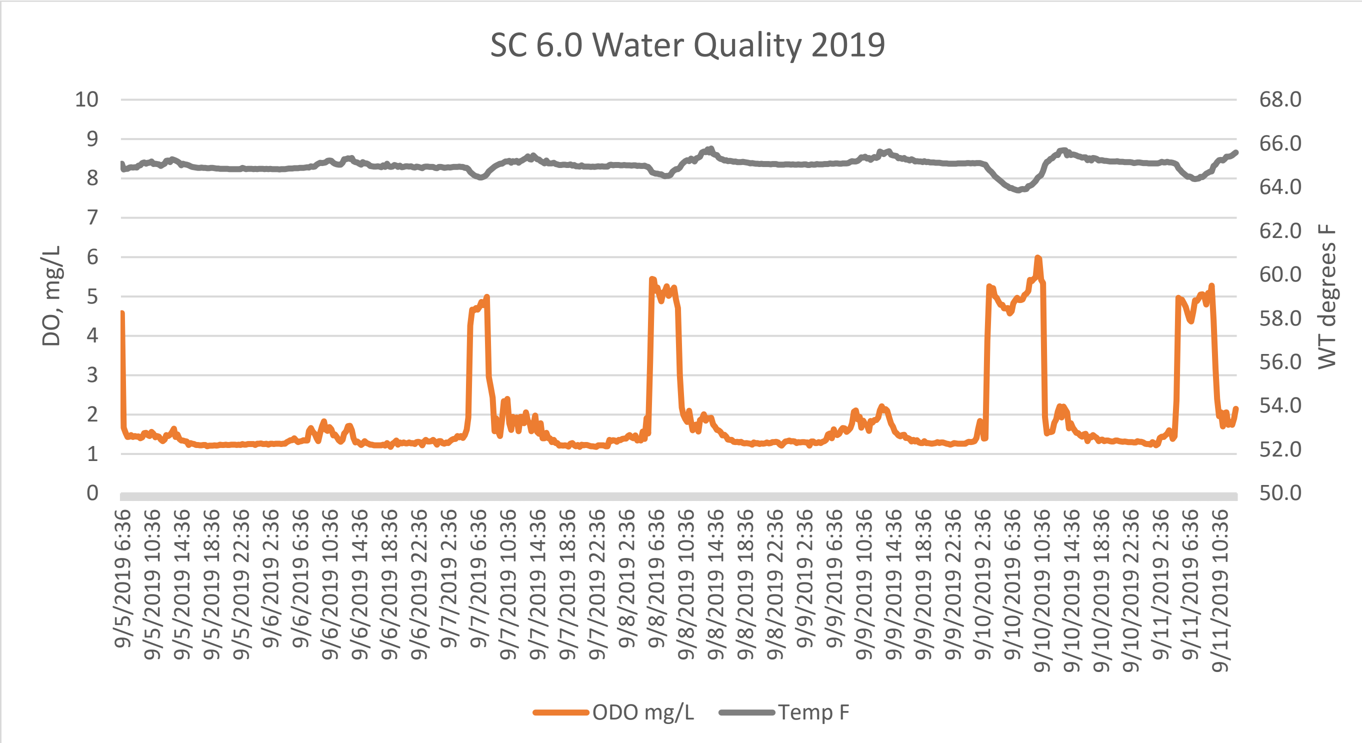


Figure 46. Water temperature and dissolved oxygen at station 6.0, 2019

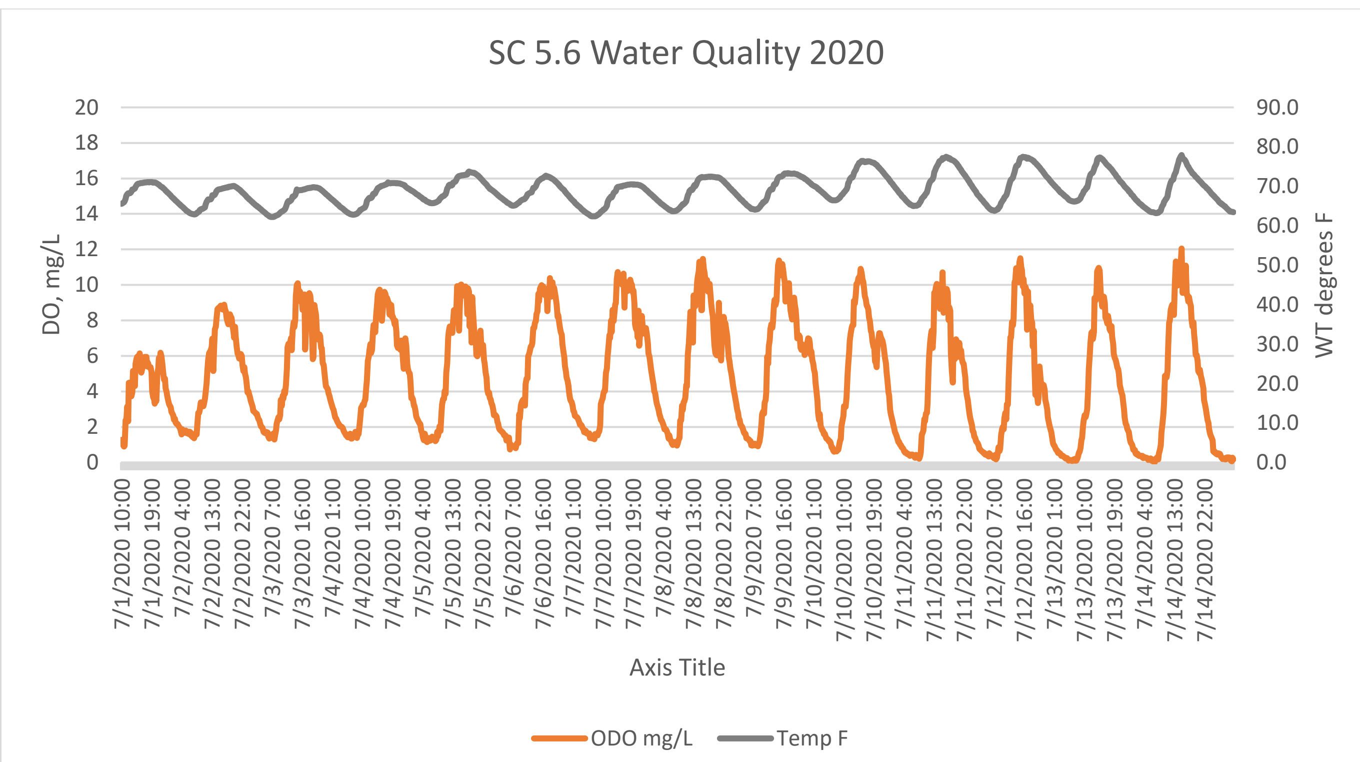


Figure 47. Water temperature and dissolved oxygen at station 5.6, 2020

Table 12. Dissolved Oxygen Concentrations for Selected Sonde Deployments in Suisun Creek, 2017 to 2020

Impairment Level	**Level of Effect Water Column DO (mg/L)**	**SC-9.5** 9/14 to 10/20/17 Dissolved Oxygen Percentile	**SC-7.0** 9/12 to 9/18/18 Dissolved Oxygen Percentile	**SC-6.0** 8/30 to 9/11/19 Dissolved Oxygen Percentile	**SC-9.5** 7/29 to 8/19/20 Dissolved Oxygen Percentile
No Production Impairment	8	none	67%	54%	87%
Slight Production Impairment	6	none	0.2%	52%	31%
Moderate Production Impairment	5	none	none	49%	1.2%
Severe Production Impairment	4	none	none	45%	none
Limit to Avoid Acute Mortality	3	none	none	45%	none
Maximum Oxygen Conc. mg/l		11.9	9.7	9.3	9.1
Median Oxygen Conc. mg/l		8.8	7.2	5.1	6.4
Minimum Oxygen Conc. mg/l		8.1	5.8	1.2	4.1

As shown in Table 12, dissolved oxygen concentrations were frequently low enough to be harmful to steelhead in Suisun Creek at station 6. The most deleterious oxygen levels were observed in 2019 during low-flow conditions, when 45% of the observations were below the threshold for avoiding acute mortality.

Summary

Summer streamflow in upper Suisun Creek results almost entirely from releases from Lake Curry. Tributaries run dry in early summer, and groundwater inflows are not a significant source of streamflow except immediately downstream of the lake. Streamflow diminishes with distance downstream of the lake owing to evaporation and seepage. Streamflow data do not show summer diversions occurring along Suisun Creek. Water released from the lake varied in temperature during the study owing to variations in lake level management. Released water remains relatively cool in the first three miles downstream of the lake, but warms as it flows down the stream below station 8.0. Data demonstrate that flow levels, as defined by releases from Lake Curry, affect temperatures of aquatic habitat particularly in upper Suisun Creek between stations 10 and 8. Downstream of station 8 the releases are less effective in creating cooler water temperatures. Water temperatures at upstream stations are generally below 70^{o} F, but at the stations farthest downstream (station 7.0 to 5.0), water temperatures often exceed 70^{o} F. Riparian shading is an important control on stream warming. Loss of canopy cover due to wildfires and drought have resulted in higher water temperatures. Dissolved oxygen levels remain near 10 mg/L when flows are high enough to provide aeration. In disconnected pools, DO levels decline to near zero at night. Releases below 2.5 cfs result in disconnected flows on Suisun Creek with low DO levels and high water temperatures not supportive of steelhead trout.

RIPARIAN CORRIDOR SURVEYS

Riparian vegetation was mapped by species and size class along all areas of Suisun Creek where access was available (Appendix E). The mapping was done in August 2018 to define the ecological status of the riparian corridor and to measure canopy cover or shading of the creek. Polygons were delineated along the Suisun Creek channel (Figure 48). Within each polygon we recorded the condition of the channel and banks, presence of erosion, number and location of bank revetments and invasive species, the number and size class of each tree species, understory species and density and any other conditions of note.

Surveys of open water or unshaded areas were completed in 1999 and 2010 (Figures 49 and 50). These surveys show an increase in canopy cover between these two dates. Figure 51 shows the widespread loss of mature white alders along the creek due to the drought in 2014-15. The 2018 survey found this species along with Fremont cottonwoods were actively regenerating with numerous seedlings along the creek.

Figure 52 depicts the biodiversity of tree species surveyed on Suisun Creek in 2018. Over 11 native species were recorded as were a number of non-native species.

Size class – seeding, sapling. small/medium tree and large tree, were recorded for each native tree species. The most common pioneer species, or species that rapidly germinate and grow into channel areas, were cottonwood and white alder; willow is much less common. Fremont cottonwood has a high number of seedlings compared to other size classes (Figure 53).

Most common mid and upper bank species were Ca. bay laurel and live oak. Live oak, Ca. bay laurel, Ca. black walnut and Oregon ash had the highest number of seedlings for the mid and upper bank species (Figure 54).

The 2018 survey also documented the locations of invasive non-native trees such as Acacia, Eucalyptus, fig and tree of heaven (Figure 55). Other invasive plants species that were mapped include Arundo, Himalayan blackberry, blue periwinkle, poke weed, cape ivy and English ivy (Figure 55). Figure 56 is an example of the maps of the locations of invasive species produced by the survey. Additional maps are in Appendix D.

Summary

There is a fairly good level of biodiversity with regeneration in both pioneer and mid and upper bank species along upper Suisun Creek. The most recent drought killed many white alders but both alder and cottonwood seedlings are abundant to replace these dead trees.

The thin riparian corridor along the top of the bank is being undercut by bank failures in many locations. The base of hillslopes in semi-confined channel areas also has many erosion sites.

Invasive non-native trees (fig is most common) and invasive understory species interfere with native tree seedling germination and growth. An invasive species eradication program in collaboration with landowners is needed.

Only half of the canopy cover readings along the creek are in the 80-100% range indicating a need for additional revegetation and large trees on top of bank completed in collaboration with landowners. CLSI completed several revegetation plans with landowners.

Figure 48. Polygons defined along Suisun Creek for riparian mapping

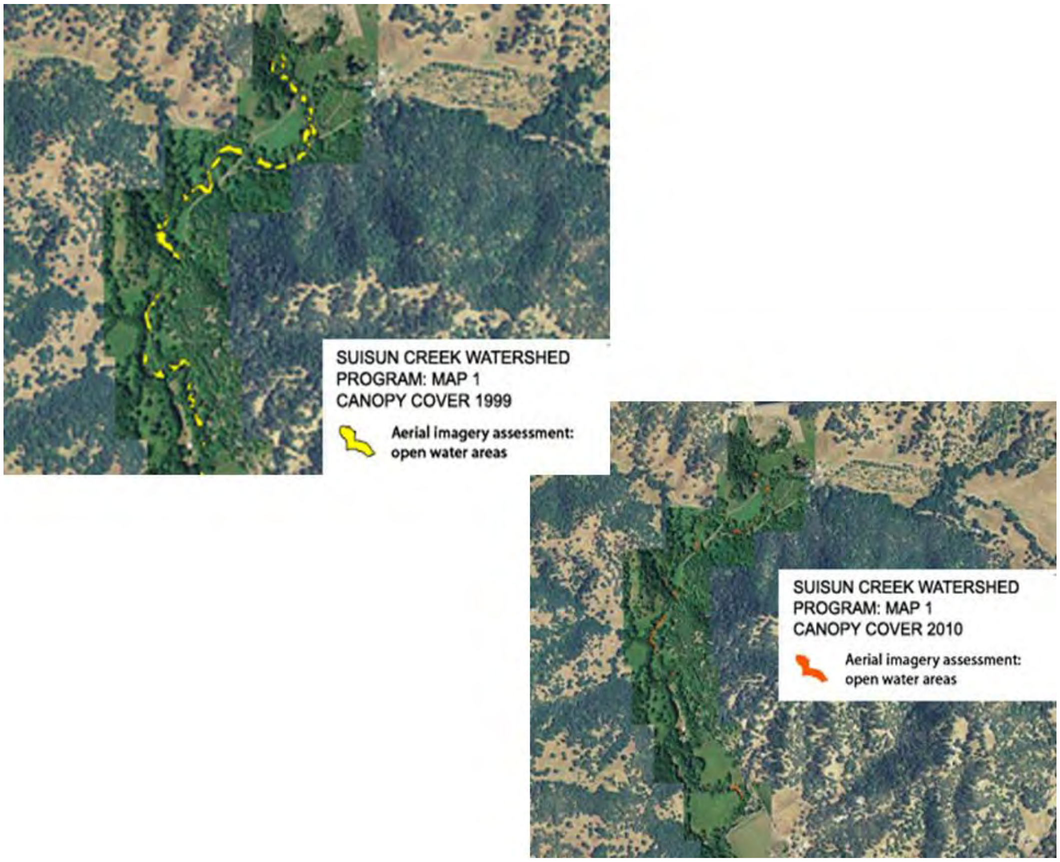


Figure 49. Comparison of canopy cover on upper Suisun Creek between 1999 and 2010.

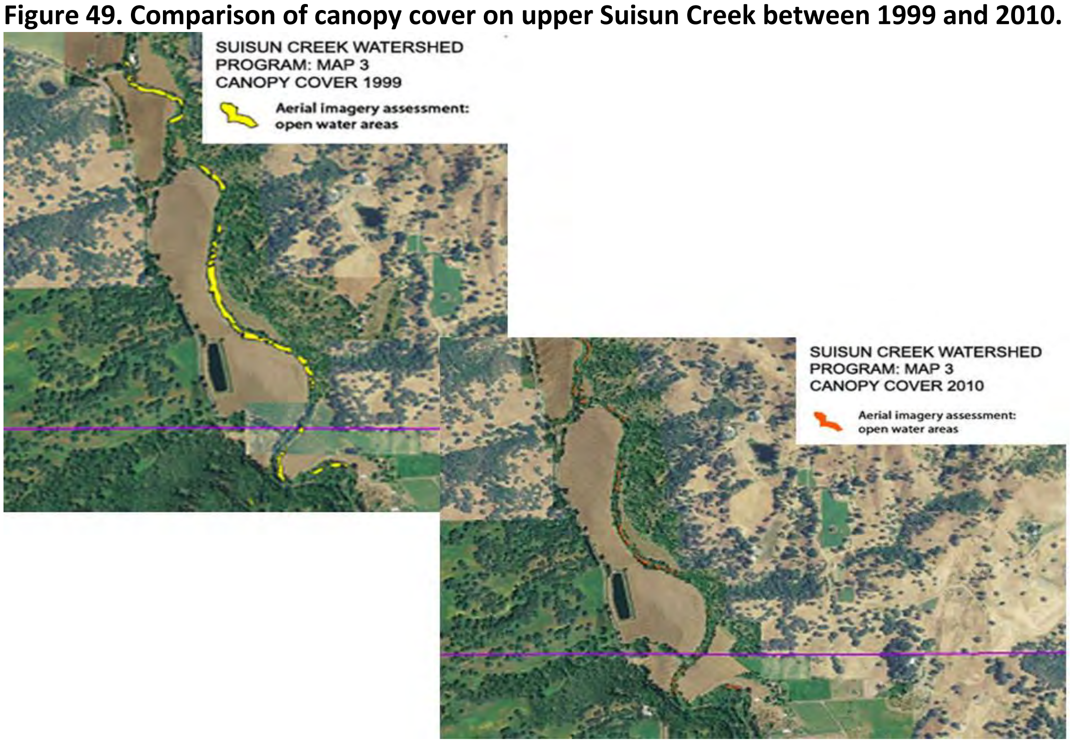


Figure 50. Comparison of canopy cover on Suisun Creek between 1999 and 2010. Cover generally increased along the creek.

Figure 51. Examples of dead alders along Suisun Creek following the 2014-15 drought

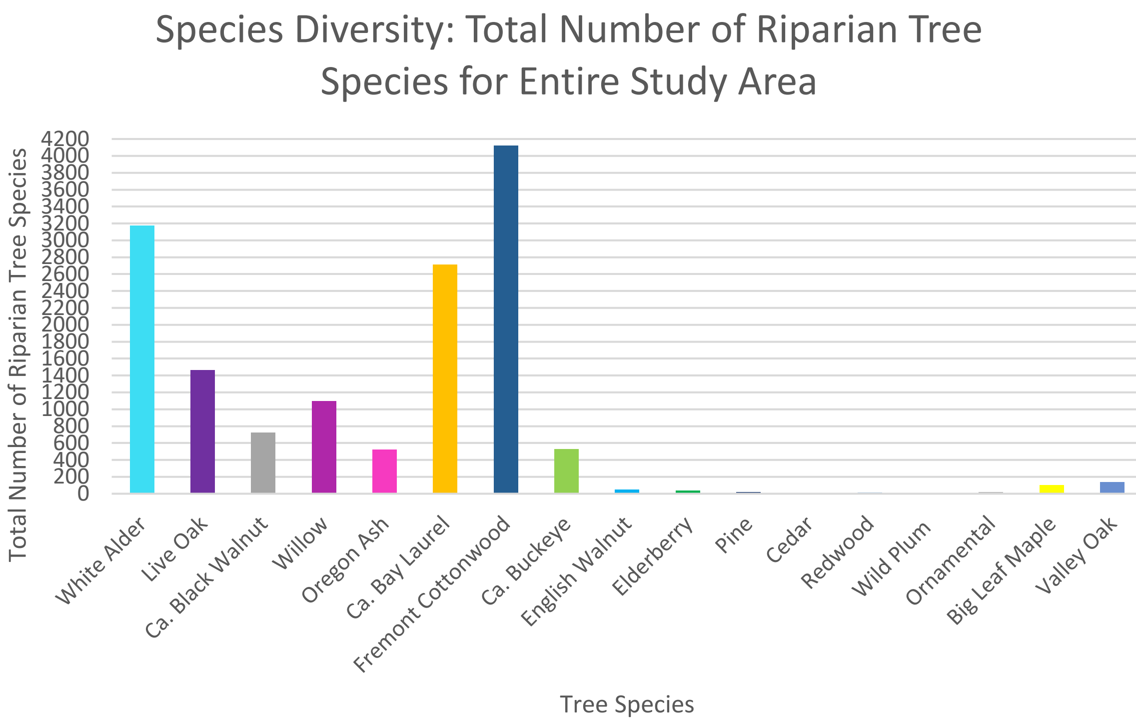
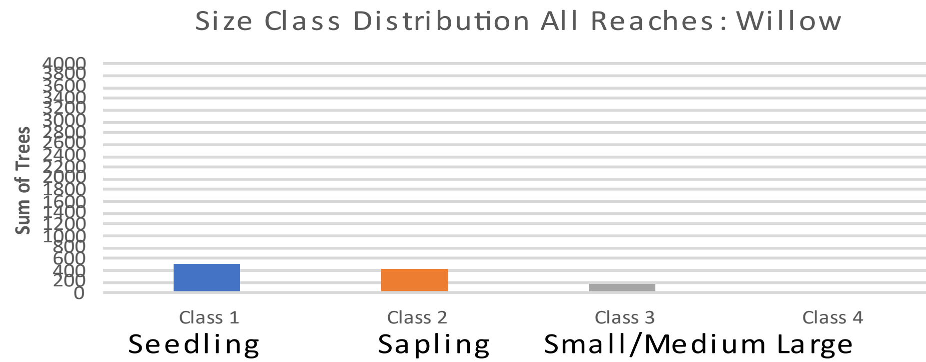
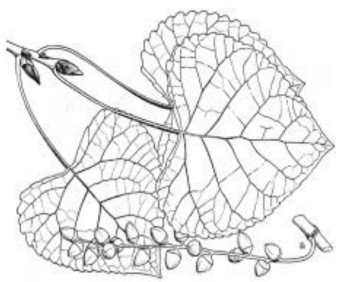


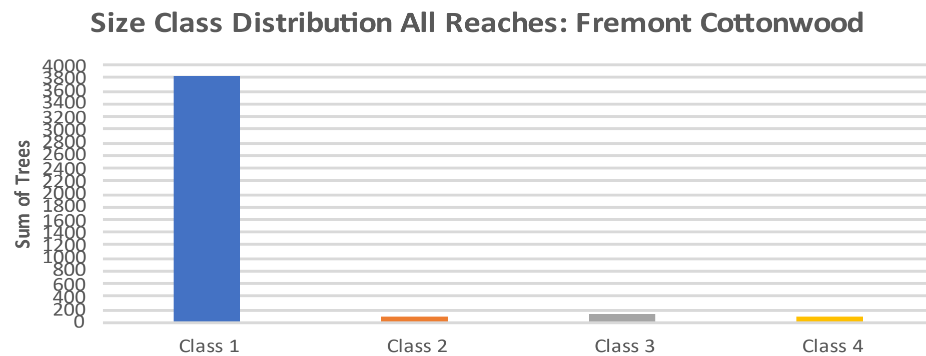
Figure 52. Biodiversity of riparian trees surveyed along Suisun Creek in August 2018.

Willow (Salix sp.)

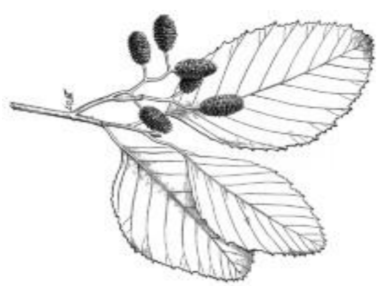


Fremont Cottonwood (Populus fremontii)





White Alder (Alnus rhombifolia)



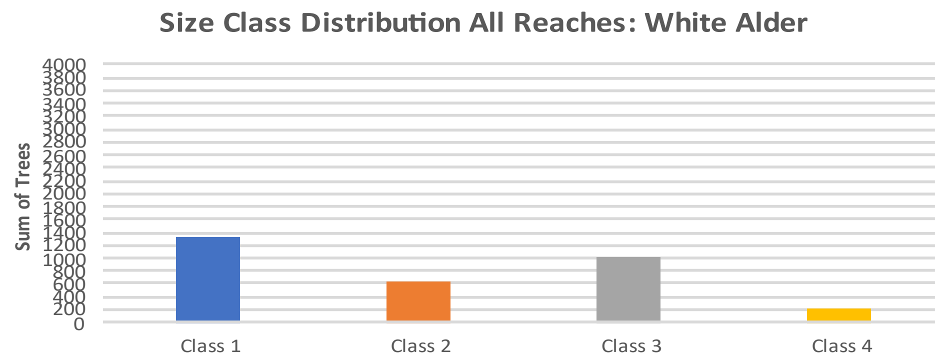
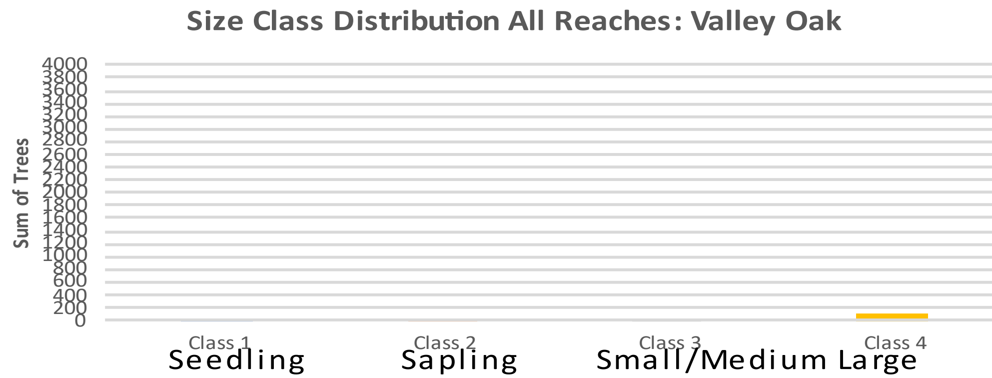
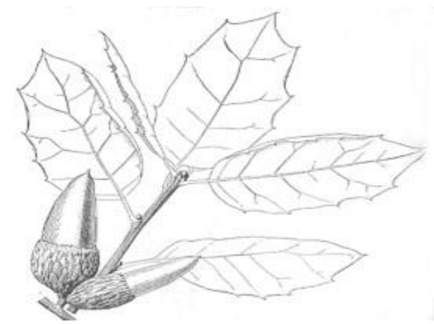


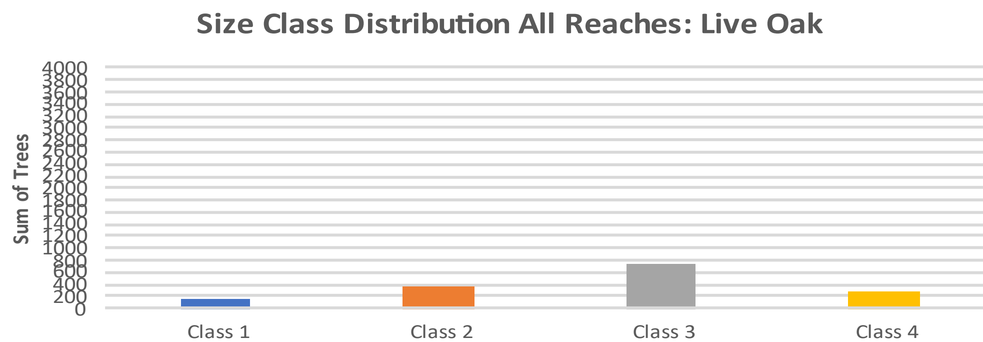
Figure 53. Size class distribution of three pioneer species recorded in riparian corridor of Suisun Creek in 2018. Fremont cottonwood and white alder are actively regenerating following the effects of drought and fire.

Valley Oak (Quercus lobata)



Live Oak (Quercus agrifolia)





California Bay Laurel (Umbellularia californica)

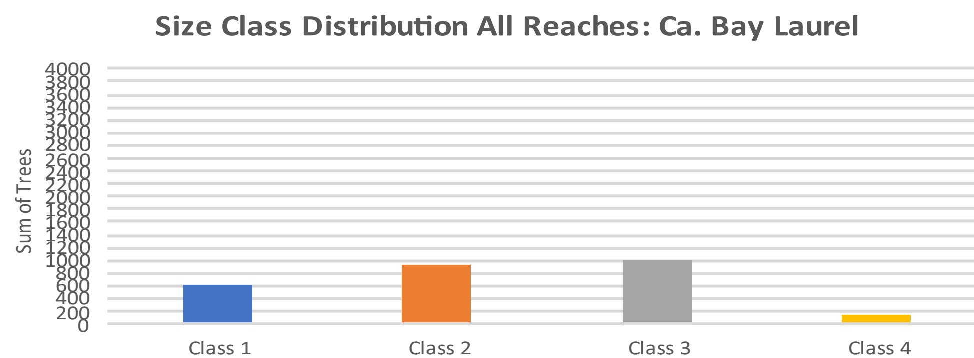


Figure 54. Size class distribution of three mid and upper streambank species recorded in riparian corridor of Suisun Creek in 2018. Both Ca. Bay laurel and live oak show a stable relationship between seedling, sapling and mature trees.

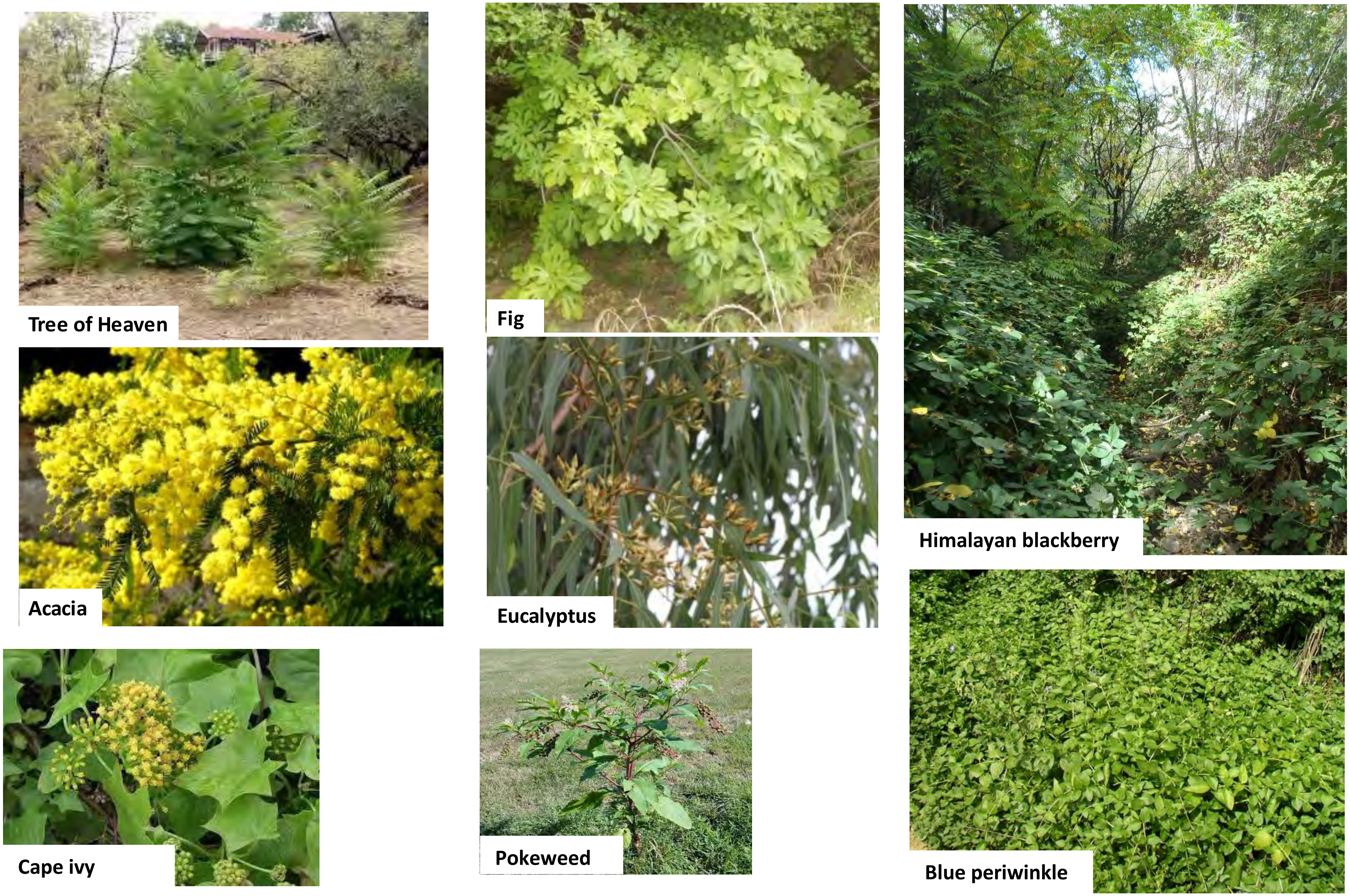


Figure 55. Invasive non-native species found in 2018 survey of Suisun Creek.

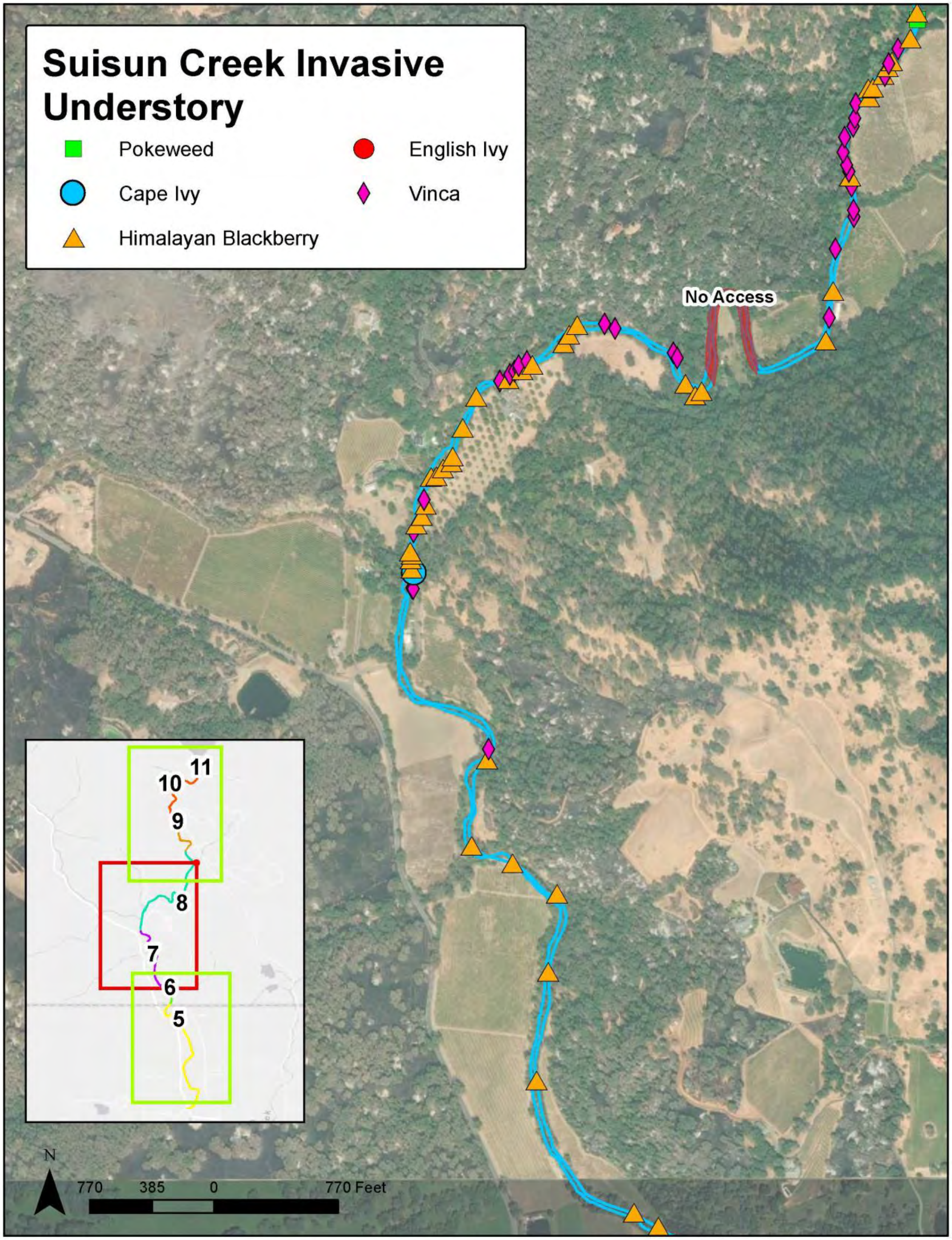


Figure 56. Example map of invasive species along Suisun Creek

FISH SURVEYS

Snorkel Surveys

Snorkel surveys were performed in 2017, 2019 and 2020 from station 10 to 5. Appendix E contains the complete results of these surveys. Snorkel surveys were conducted from Lake Curry dam downstream approximately six miles. A total of nine species were observed including Central California Coast DPS steelhead listed as threatened under the Endangered Species Act 1973 (Table 13). Survey followed guidelines described in an American Fisheries Society publication of best practices in fisheries science (Johnson et al. 2007). Steelhead were primarily found in reaches 11, 9 and 8 (Figure 1).

Table 13. Summary of Total Abundance of Each Species Identified During 2017 Suisun Creek Snorkel Surveys Between Stations 10-5.

Common & Scientific Names	Total Abundance
Bluegill Sunfish (*Lepomis macrochirus*)	1
California Roach (*Hesperoleucus symmetricus*)	8179
Inland Silverside (*Menidia beryllina*)	1
Prickly Sculpin (*Cottus asper*)	1
Sacramento Pikeminnow (*Ptychocheilus grandis*)	1736
Sacramento Sucker (*Catostomus occidentalis*)	2005
Steelhead (*Oncorhynchus mykiss*)	46

Snorkel surveys of Suisun Creek were conducted on June 7 & 8, 2018. Surveys were planned to cover stations 6.5-9.0 and 9.4-9.6). Upon reaching the creek the crew noted that the stream was dry and did not have open channel flow (Figure 57). The crew proceeded to walk the creek to determine if there were isolated pools with fish. No steelhead trout were observed during the surveys. Two known locations that had previously had steelhead trout were dry. Intermittent isolated pools occurred upstream of station 8.0. Three-spine stickleback (*Gasterosteus aculeatus*), Sacramento pikeminnow (*Ptychocheilus grandis*), Sacramento sucker (*Catostomus occidentalis)* and California roach (*Hesperoleucus symmetricus*) were observed, but they appeared to be in poor health, with significant fungus covering their scales. Appendix F contains a summary of each survey.

The June 2020 snorkel surveys found a total of 150 habitat units including pools, riffles, and flatwater; a total of 41,951 fish were observed and identified to species and additional 1,000 fish that could not be confidently identified to species were identified to family Cyprinidae and a total of 8 species were observed (Table 14).

Table 14. Total Abundance of Each Species Identified During Suisun Creek Snorkel Surveys, June 2020.

Common & Scientific Names	Total Abundance
Bluegill Sunfish (*Lepomis macrochirus*)	565
California Roach (*Hesperoleucus symmetricus*)	23,943
Prickly Sculpin (*Cottus asper*)	21
Sacramento Pikeminnow (*Ptychocheilus grandis*)	2,247
Sacramento Sucker (*Catostomus occidentalis*)	4,419
Tule Perch (*Hysterocarpus traskii*)	255
Steelhead Trout (*Oncorhynchus mykiss*)	51
Three spine Stickleback (*Gasterosteus aculeatus)*	10,450

Figure 57. In 2018 with Lake Curry releases stopped Suisun Creek is dry where steelhead were recorded the prior year.

Figure 58. Small intermittent pool upstream of station 8.0 in Suisun Creek in 2018 when no releases were made from Lake Curry.

Lifecycle model
Cramer Fish Sciences developed a life cycle model to estimate spawning and rearing habitat needed to support anadromous steelhead in Suisun Creek. The primary objective of this effort is to provide tools and information to support planning and assessment of steelhead habitat management goals that will allow stakeholders to:

- identify measurable goals that relate to federal and state laws and helps determine when "enough is enough"
- identify gaps in understanding and provide an iterative and transparent process whereby new information can fill knowledge gaps; and
- "game" habitat quantity and available water to wisely and adaptively manage flow and non-flow actions that support steelhead population targets.

The overall process to determine watershed ability to support target steelhead population assumes that a viable population goal and habitat needs can be quantified, and general relationships between potential habitat and flow can be developed. This work addresses the first steps in this process, which are to determine the minimum spawning and rearing habitat requirements needed to support a viable anadromous steelhead population in Suisun Creek using a life cycle model approach.

Information needed to parameterize the life cycle model (Figure 59) used for this analysis include the following parameters which are described in more detail later:

1. Population targets
2. Adult age, size, and sex structure
3. Adult migration and spawning timing
4. Redd size, territory requirements, and fecundity
5. Incubation timing, duration, and emergence timing and survival
6. Freshwater growth, size structure, and mortality
7. Juvenile emigration timing, duration, and production
8. Juvenile rearing territory requirements

Findings
For a minimum viable population of 833 adult steelhead spawners with no harvest goal, the model estimates that between 0.04 acres to 0.73 acres of spawning habitat area is needed with a maximum of 0.73 acres needed in April. We estimate that rearing habitat needs, for a minimum viable steelhead population, range between 75 to 118 acres throughout the year, with a peak of 118 acres required in April. These estimates do not consider habitat quality which could directly influence the required amount of habitat needed given the assumption that required habitat increases as habitat quality decreases. Appendix E includes the entire technical report on the lifecycle model. Additionally, an online interface to the model is available at https://fishsciences.shinyapps.io/Suisun_LCM/.

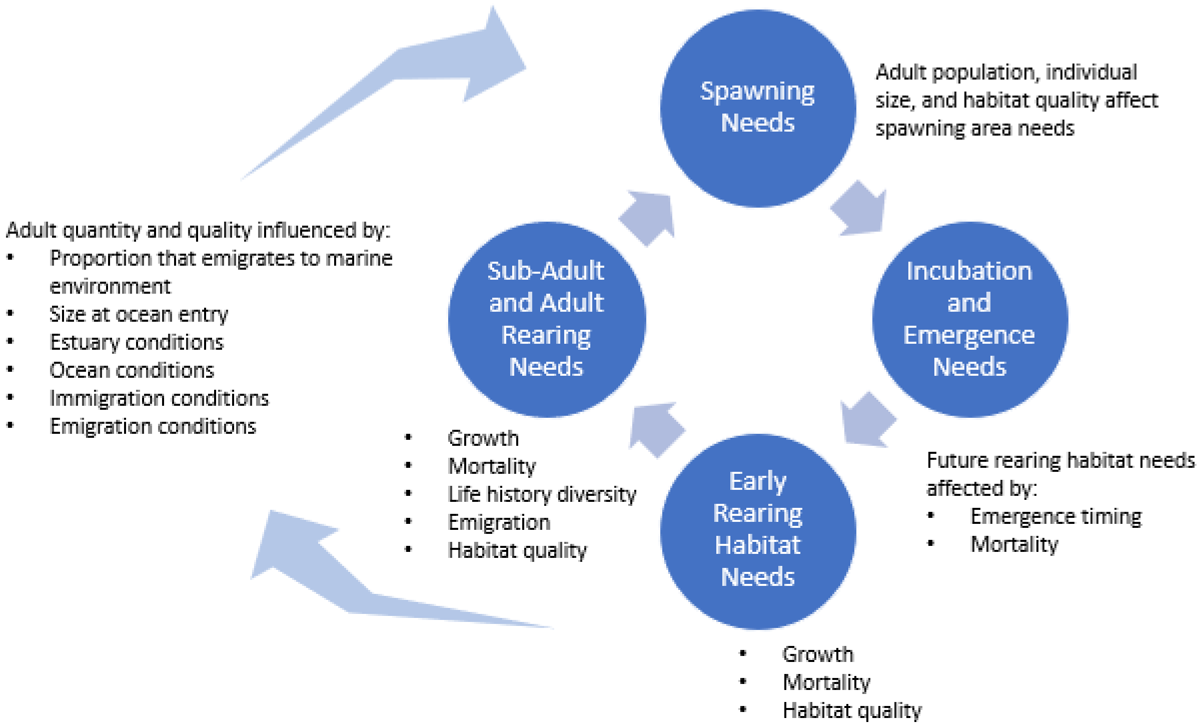


Figure 59. Conceptual diagram of the life cycle model approach used to estimate spawning and rearing habitat requirements for a target population using demographic information and relationships for key life stages.

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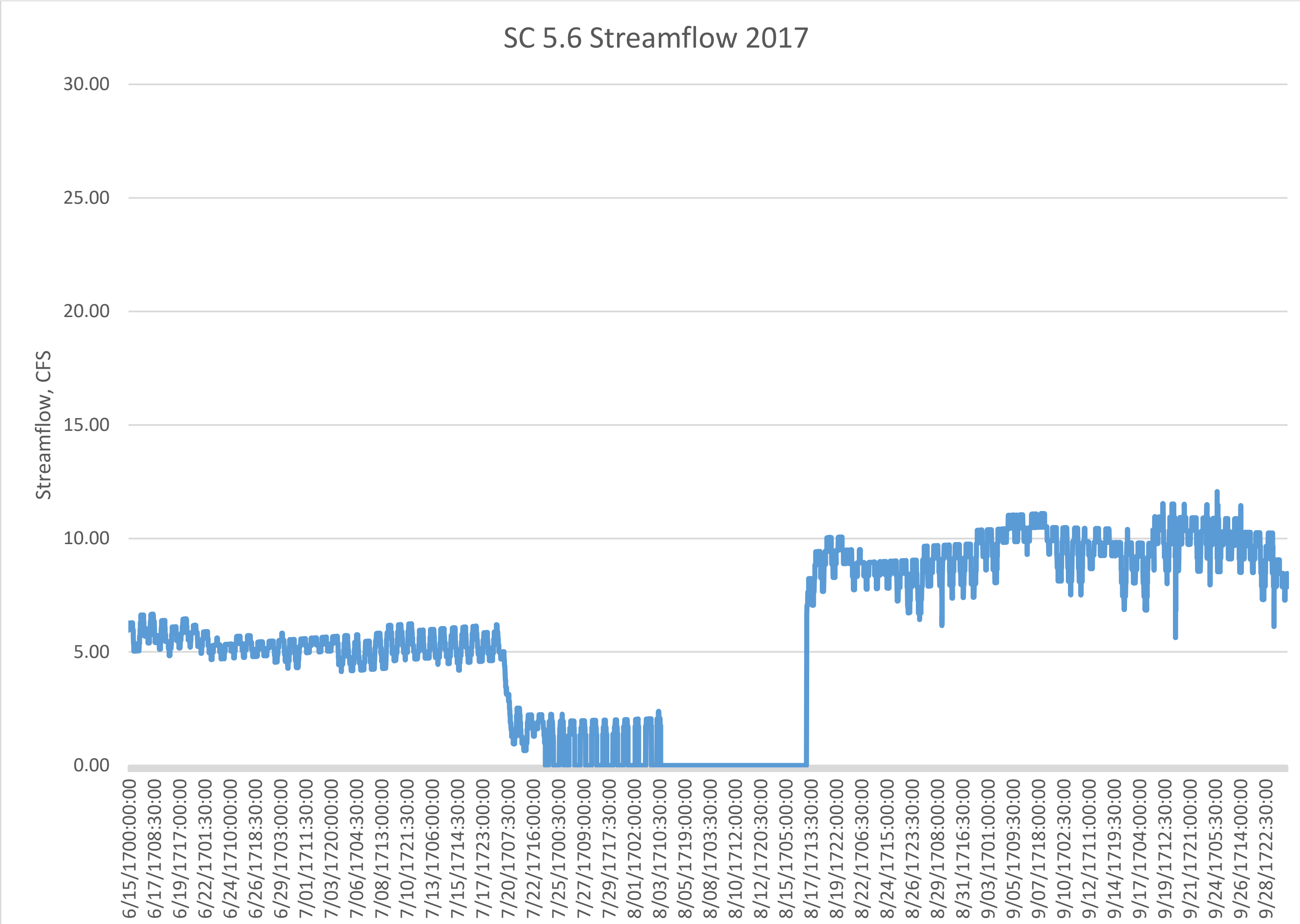
Appendix A

Hydrographs 2017-2020 Suisun Creek



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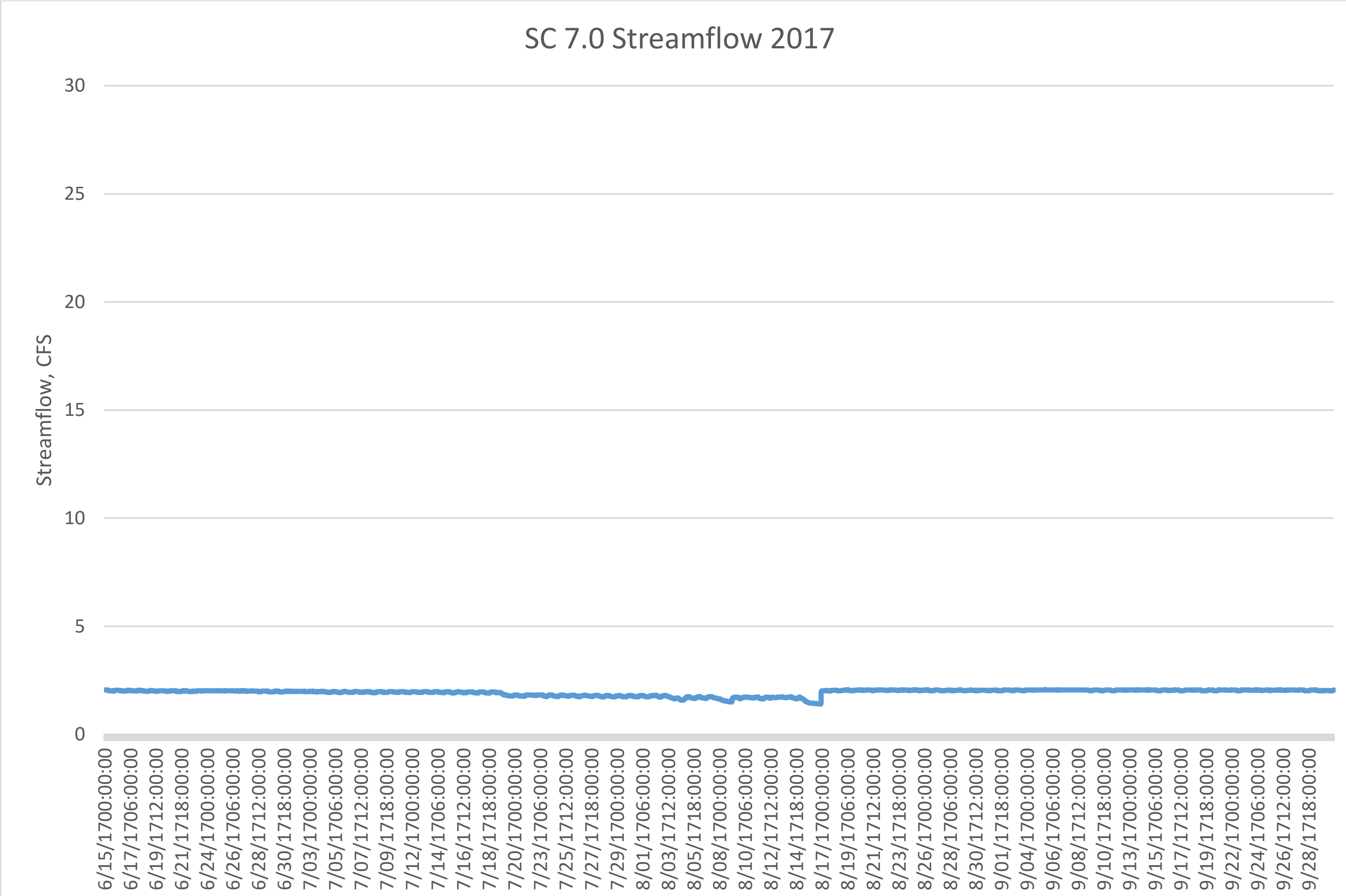
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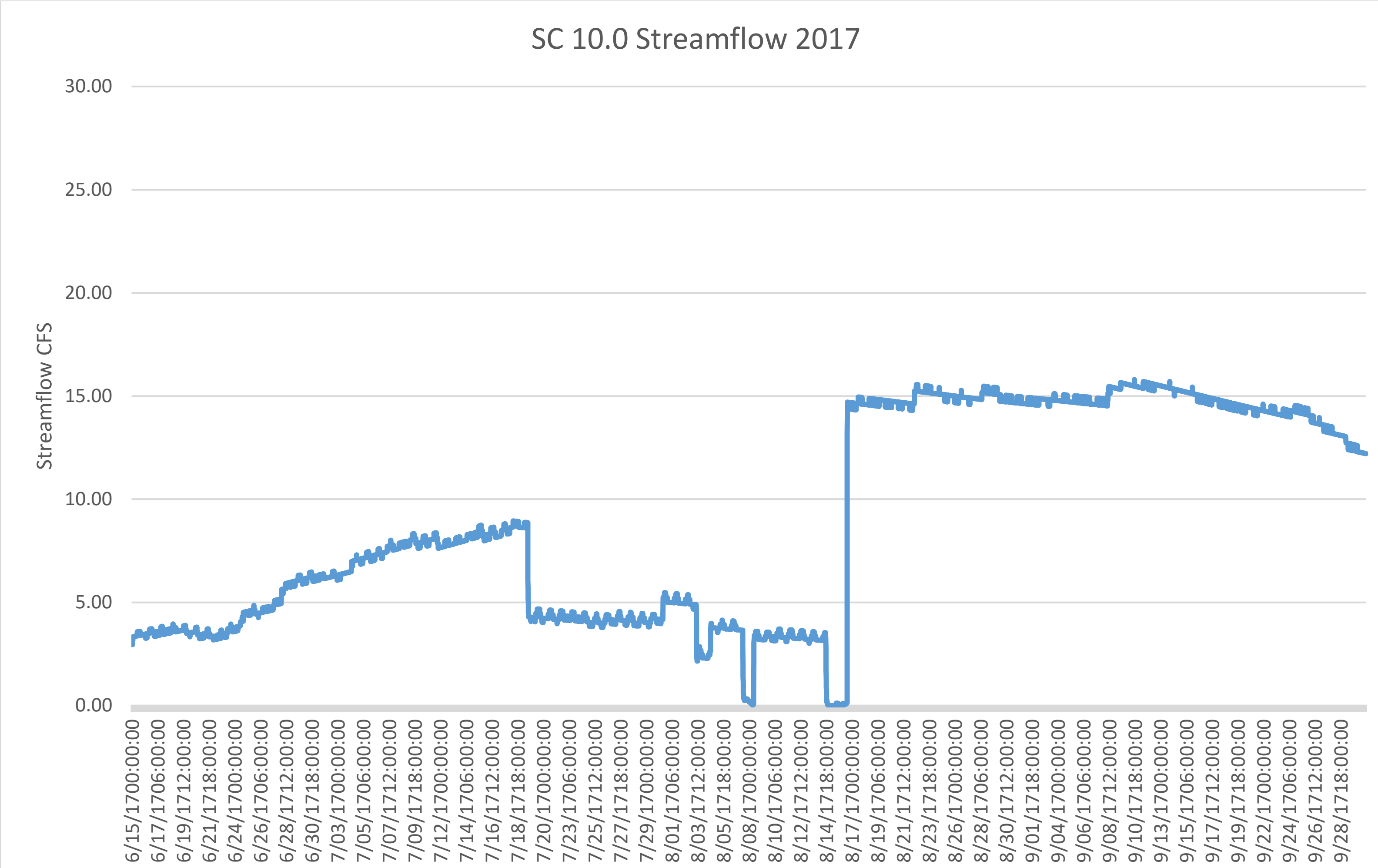

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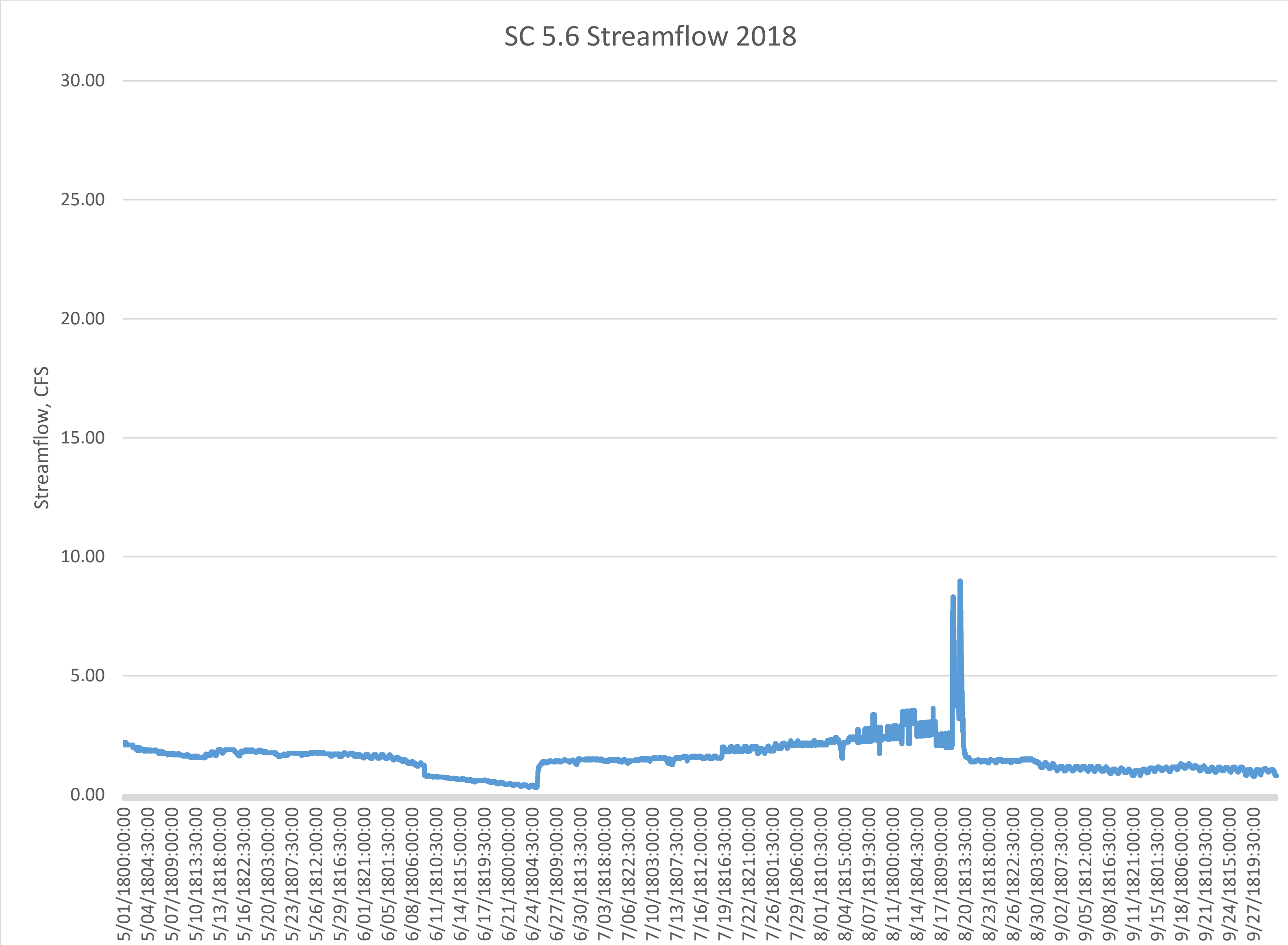

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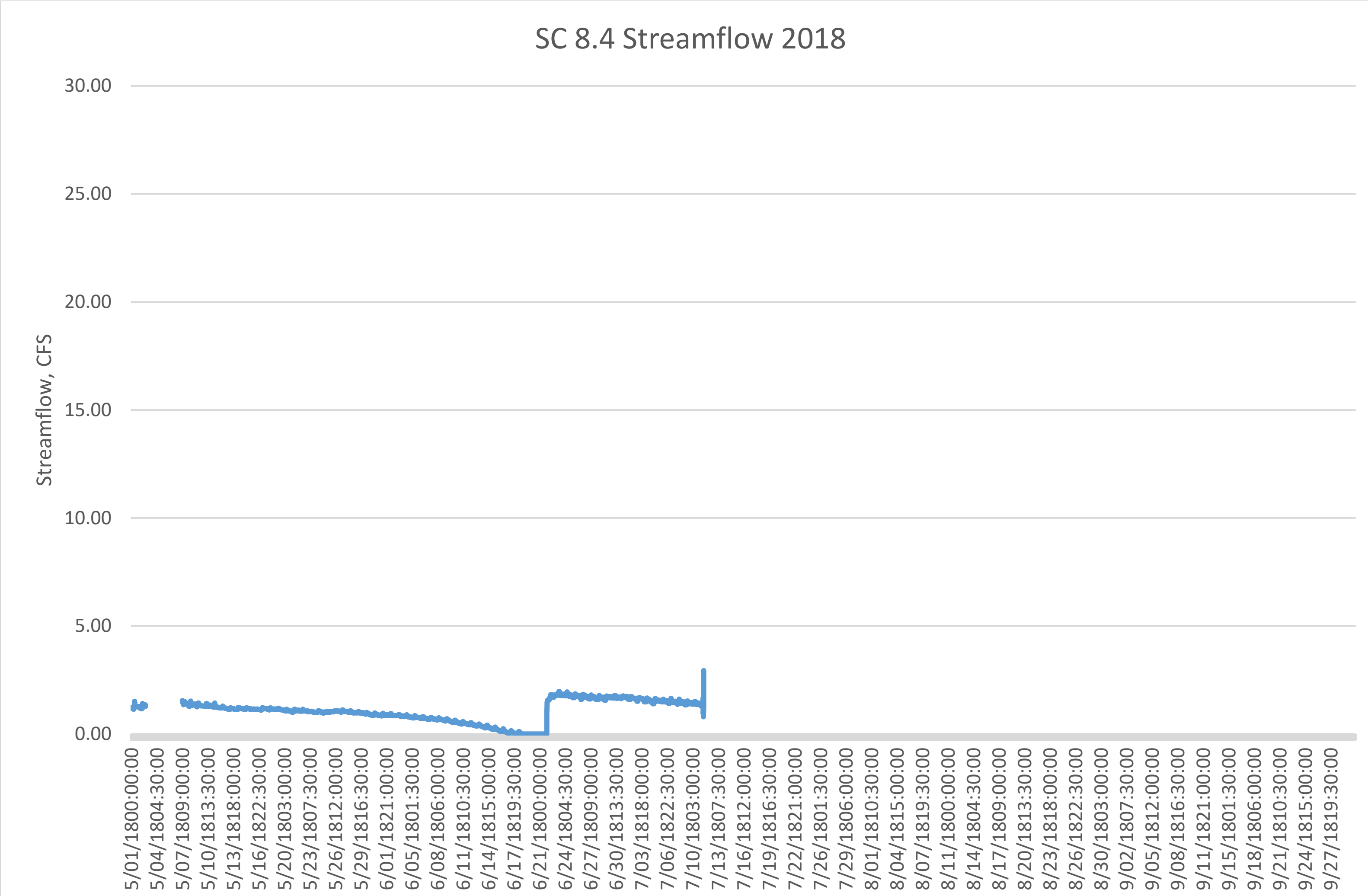
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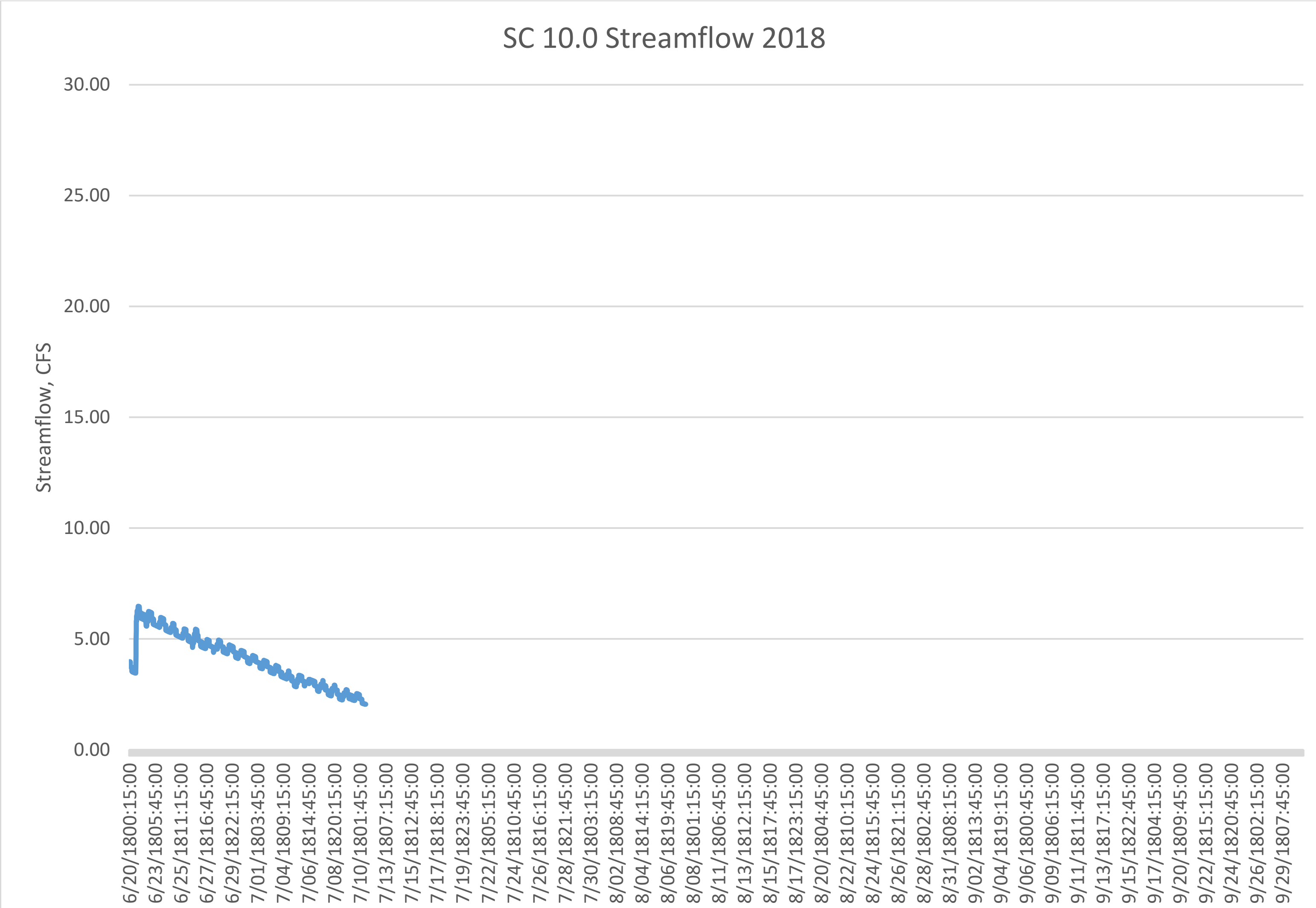

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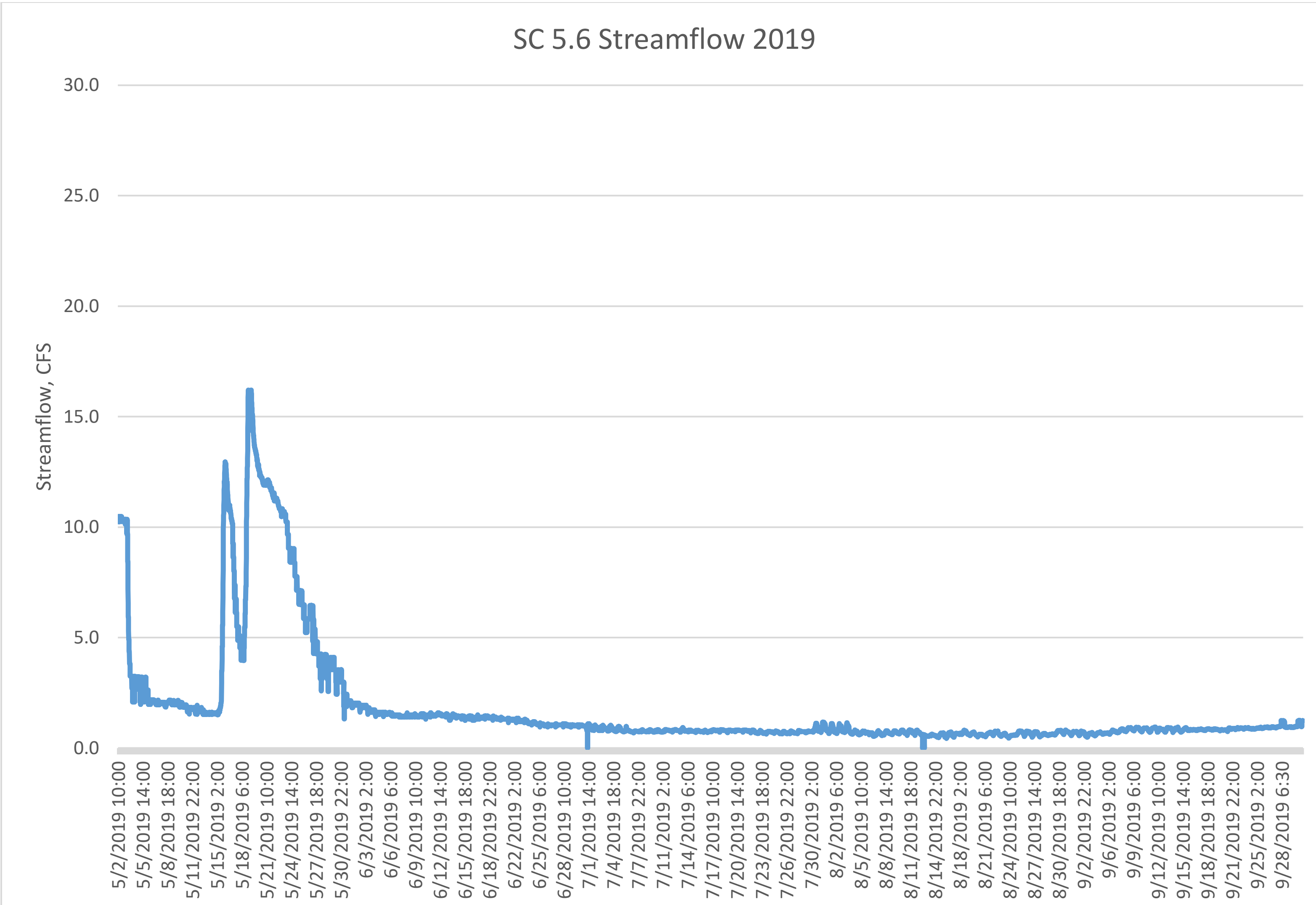

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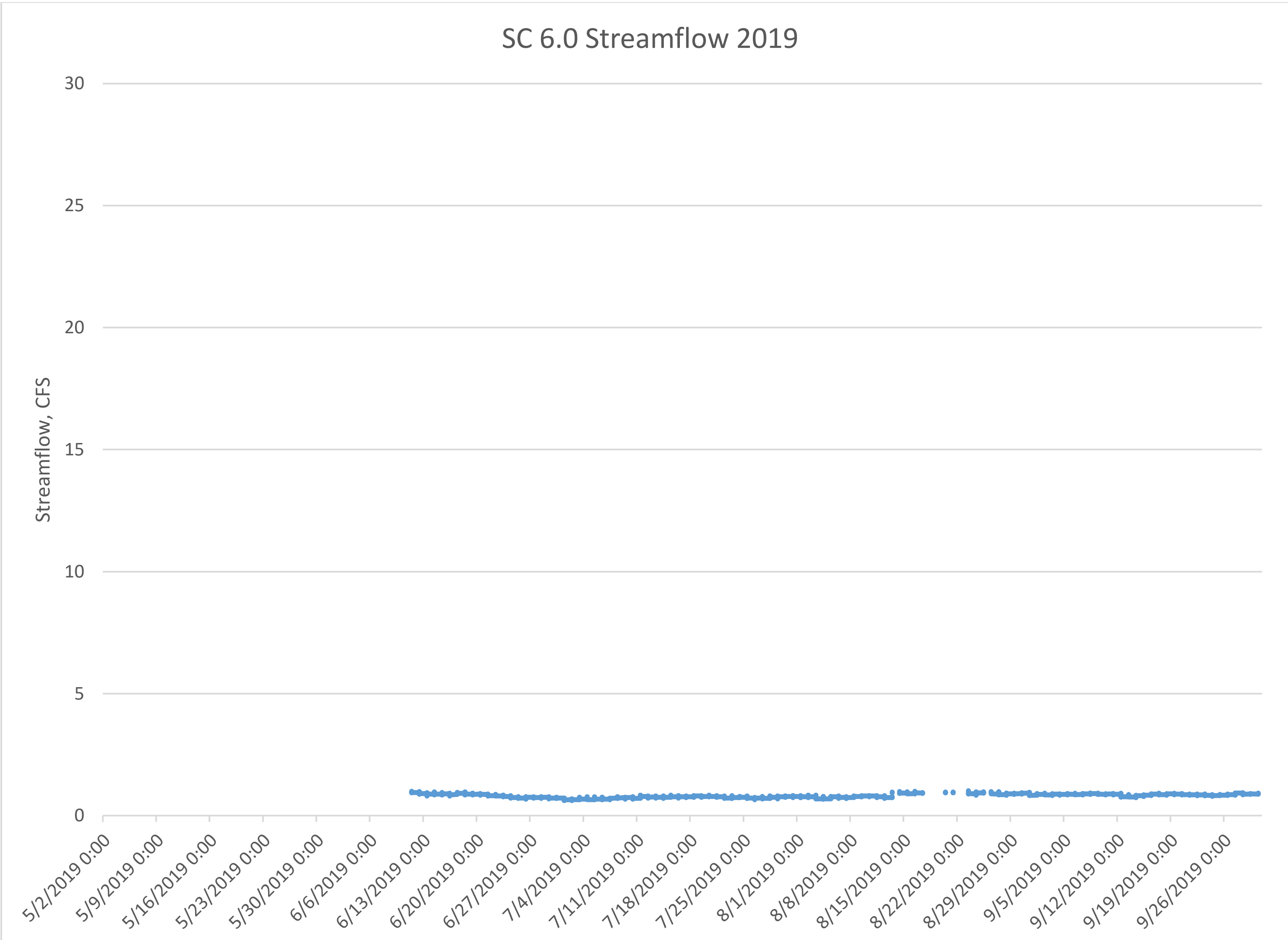
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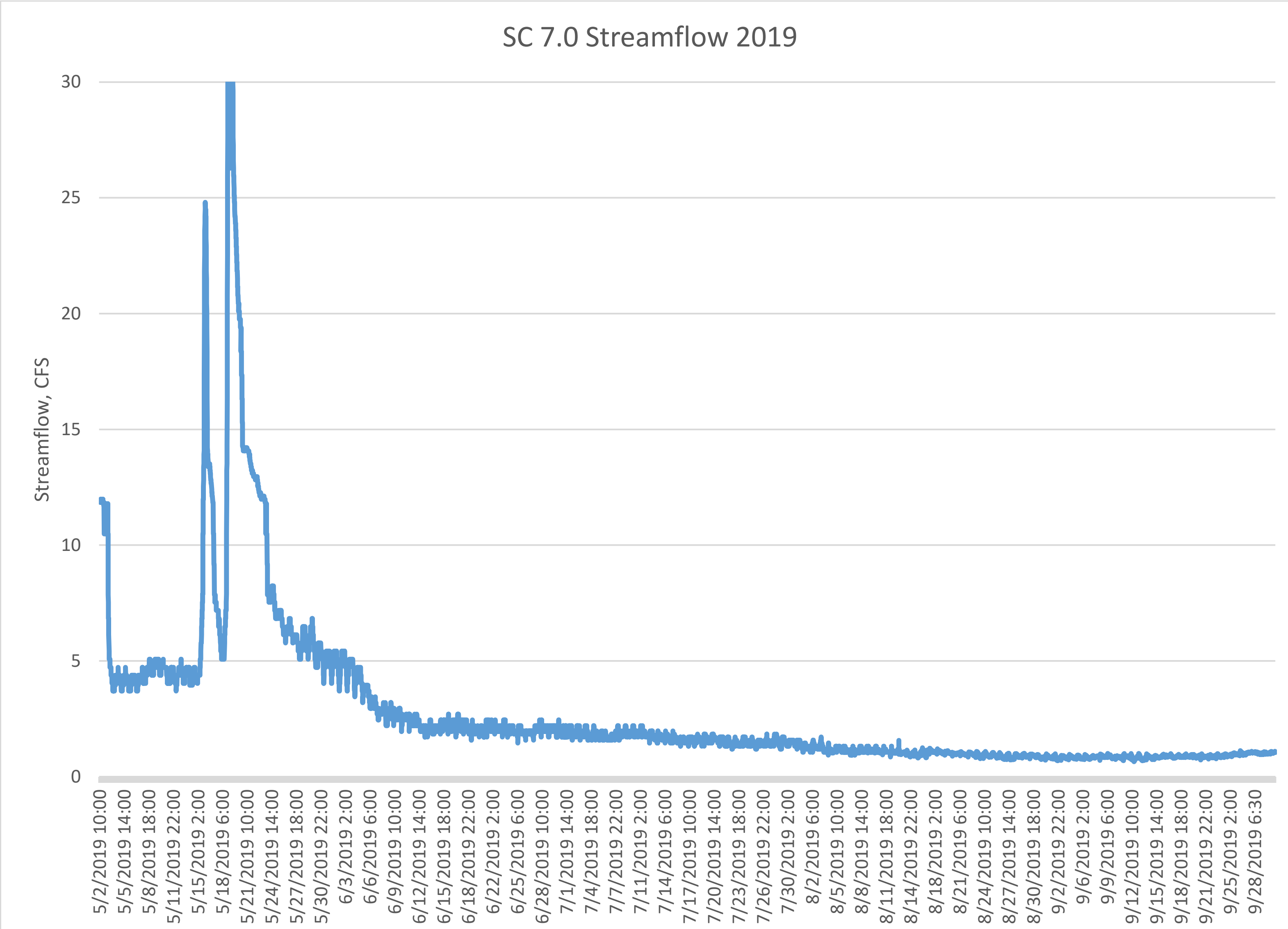
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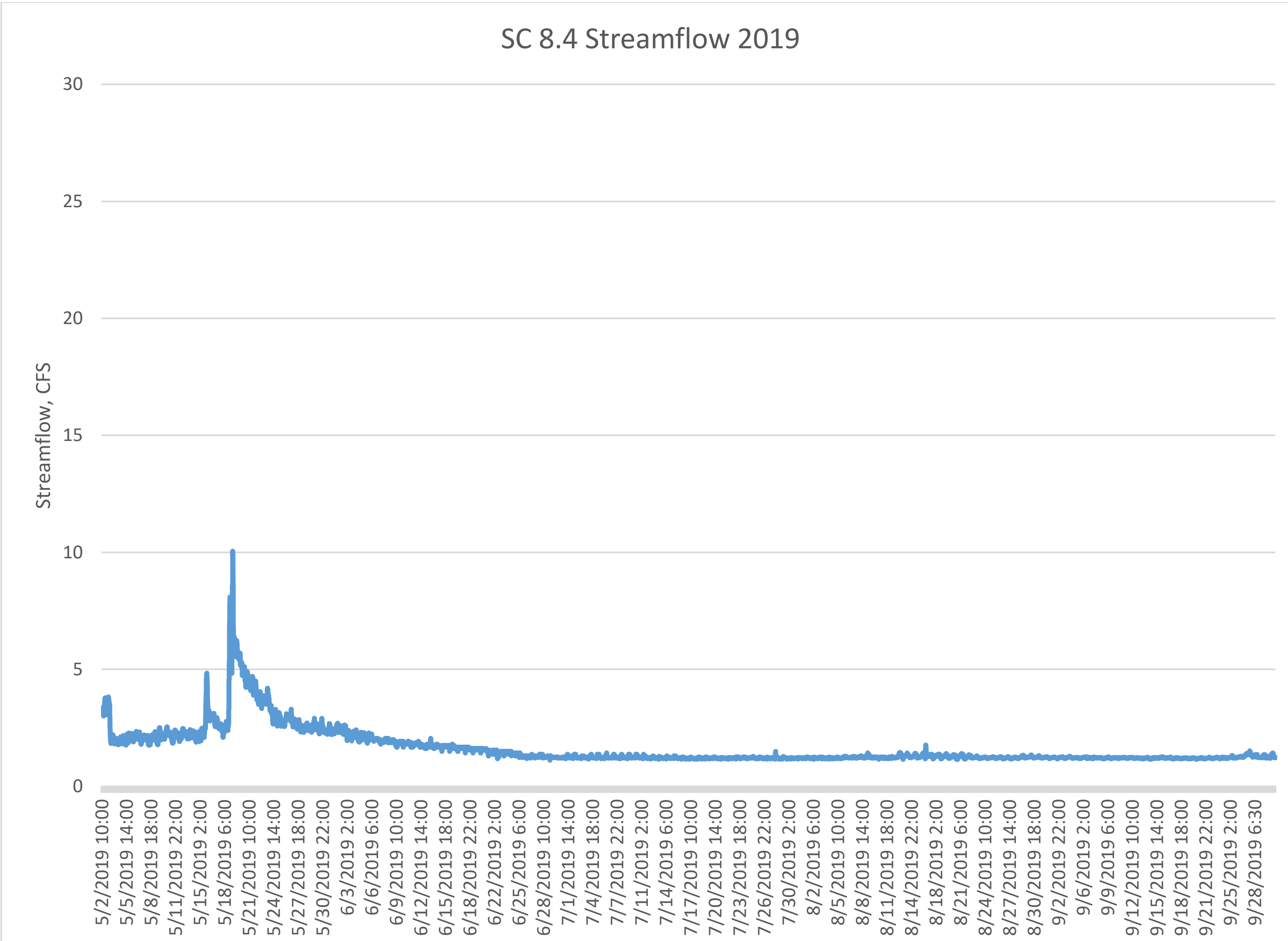
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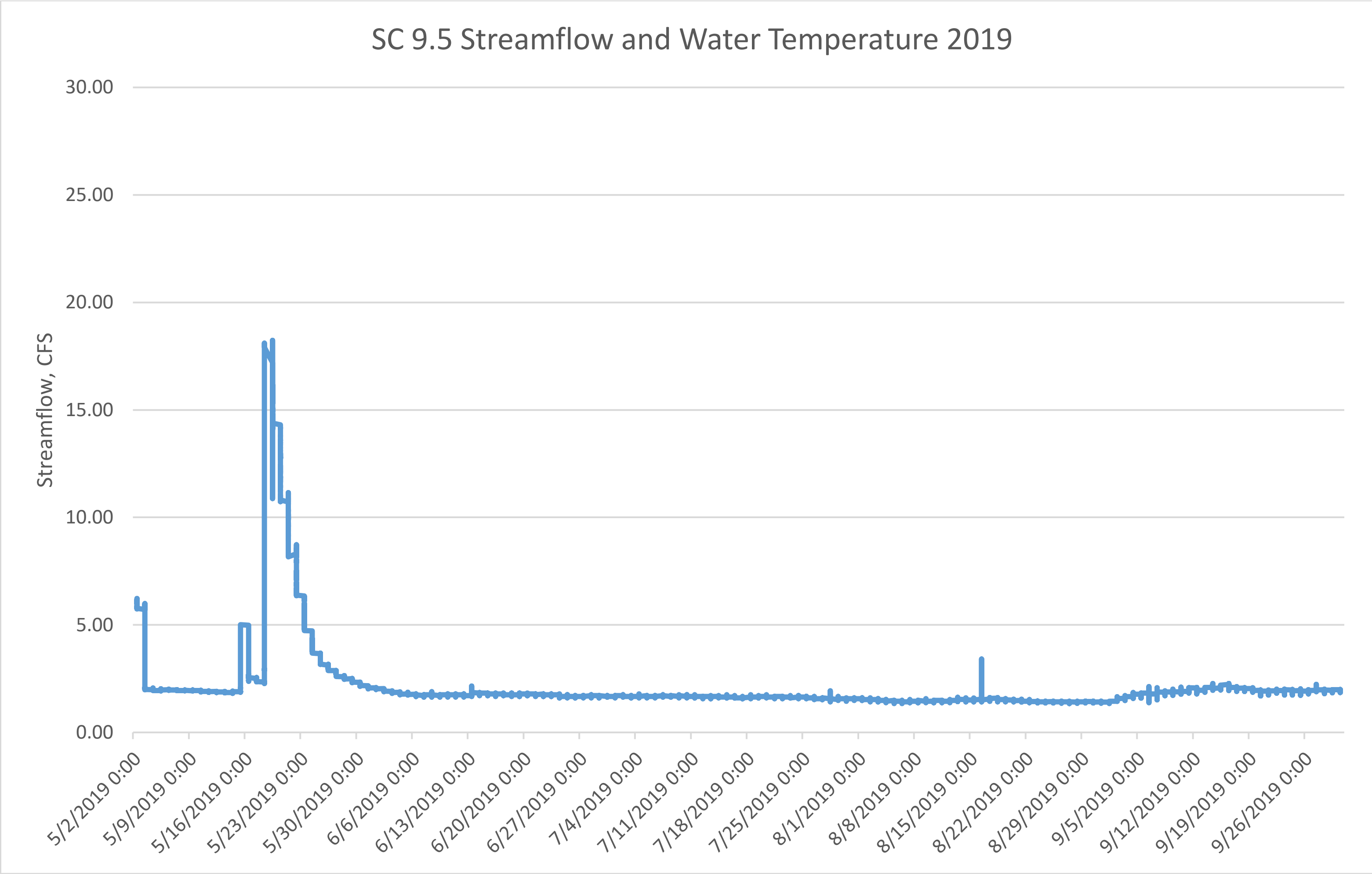

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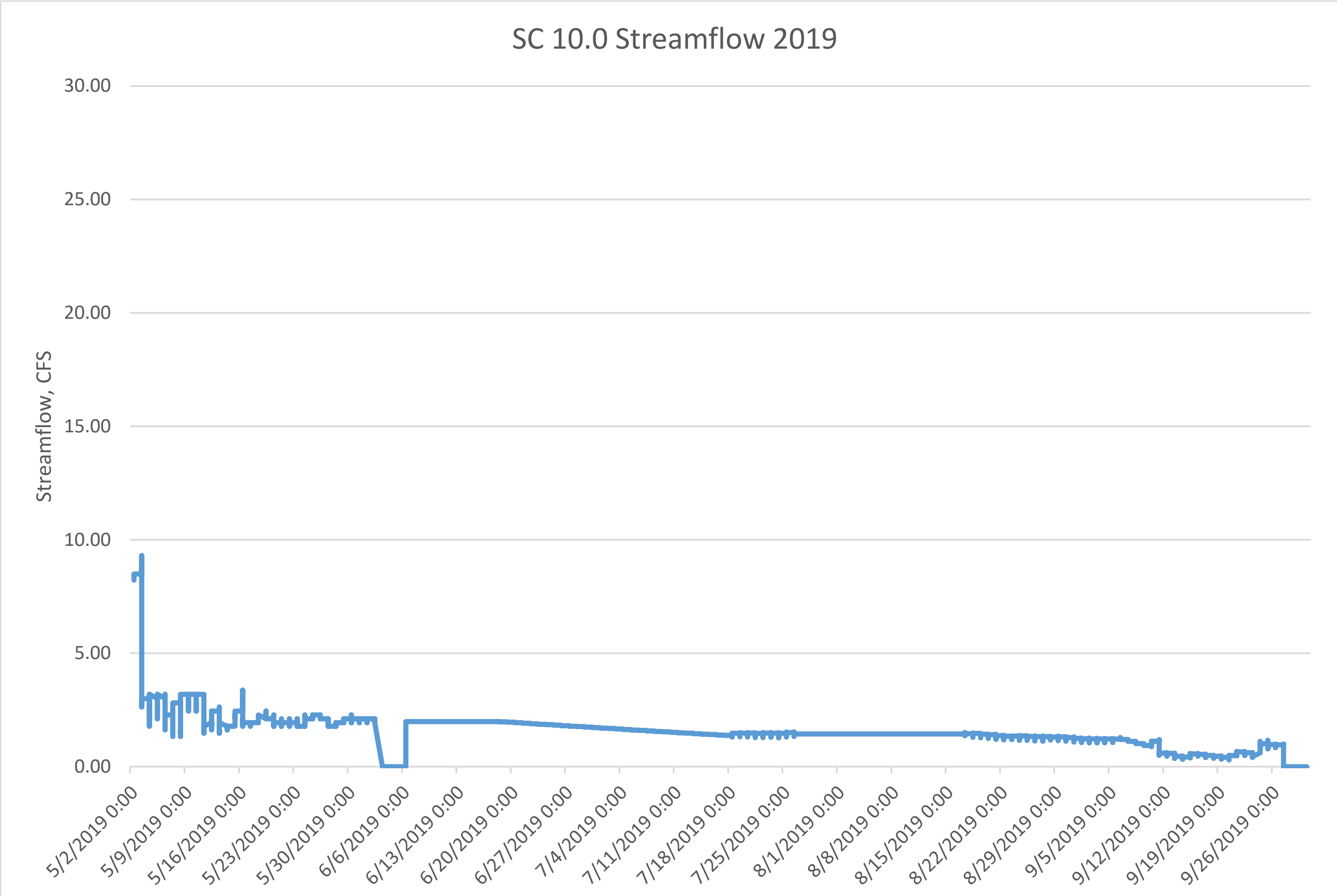

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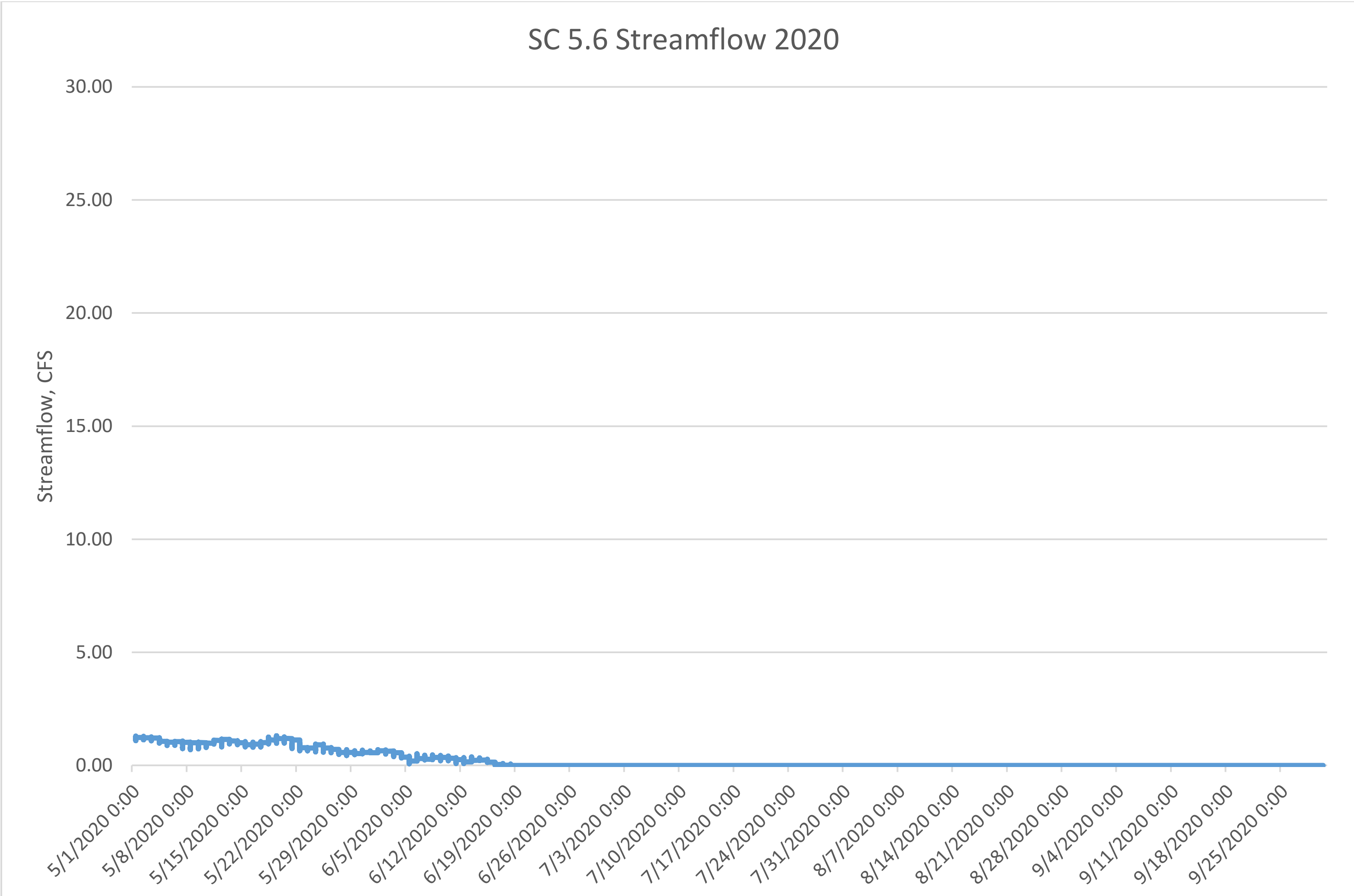

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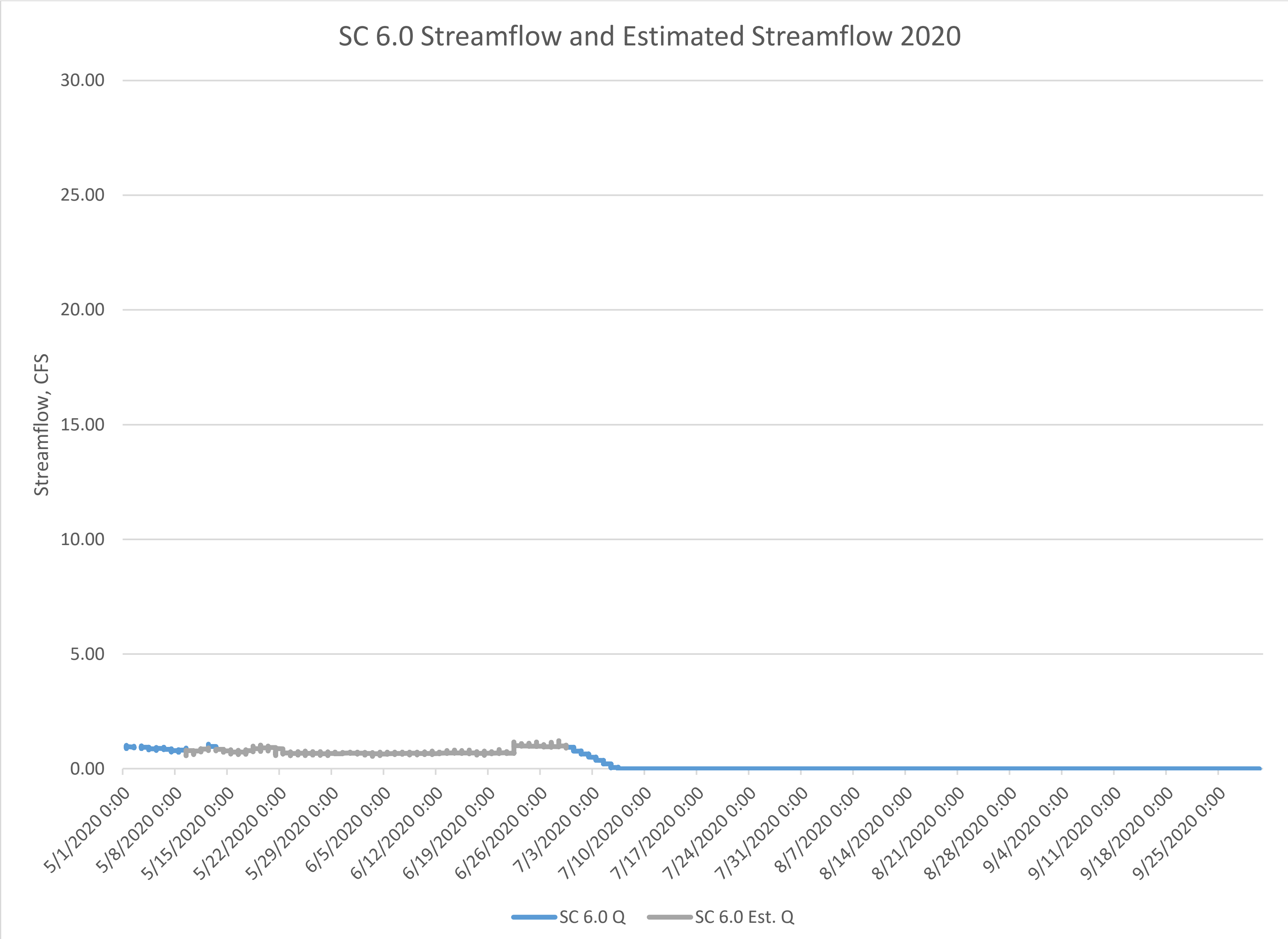
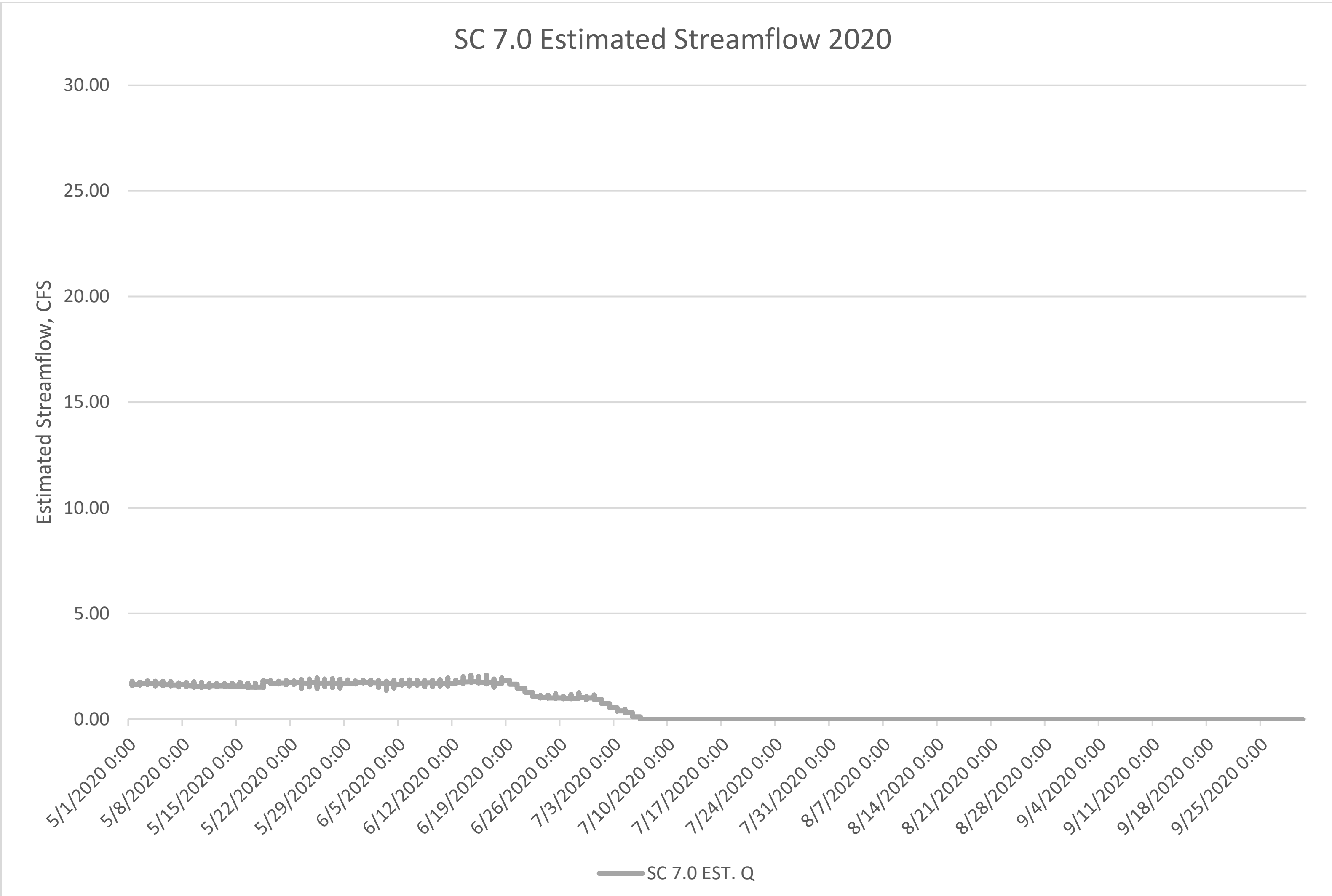
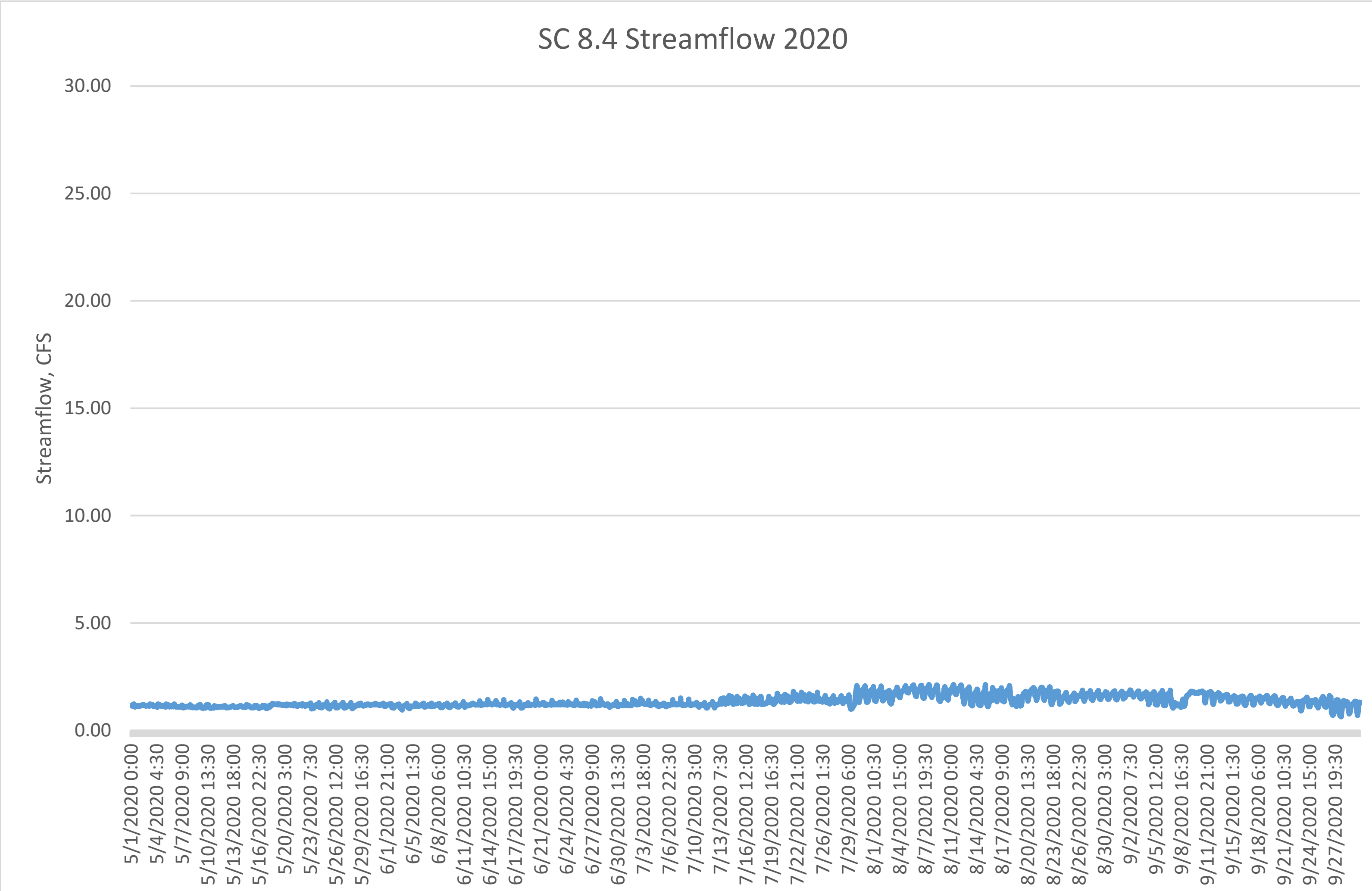
10.00
5.00
0.00
5/1/2020 0:00
5/8/2020 0:00
5/15/2020 0:00
5/22/2020 0:00
5/29/2020 0:00
6/5/2020 0:00
6/12/2020 0:00
6/19/2020 0:00
6/26/2020 0:00
7/3/2020 0:00
7/10/2020 0:00
7/17/2020 0:00
7/24/2020 0:00
7/31/2020 0:00
8/7/2020 0:00
8/14/2020 0:00
8/21/2020 0:00
8/28/2020 0:00
9/4/2020 0:00
9/11/2020 0:00
9/18/2020 0:00
9/25/2020 0:00



SC 6.0 Streamflow and Estimated Streamflow 2020
Streamflow, CFS
30.00
25.00
20.00
15.00
10.00
5.00
0.00
5/1/2020 0:00
5/8/2020 0:00
5/15/2020 0:00
5/22/2020 0:00
5/29/2020 0:00
6/5/2020 0:00
6/12/2020 0:00
6/19/2020 0:00
6/26/2020 0:00
7/3/2020 0:00
7/10/2020 0:00
7/17/2020 0:00
7/24/2020 0:00
7/31/2020 0:00
8/7/2020 0:00
8/14/2020 0:00
8/21/2020 0:00
8/28/2020 0:00
9/4/2020 0:00
9/11/2020 0:00
9/18/2020 0:00
9/25/2020 0:00
SC 6.0 Q
SC 6.0 Est. Q



SC 7.0 Estimated Streamflow 2020
Estimated Streamflow, CFS
30.00
25.00
20.00
15.00
10.00
5.00
0.00
5/1/2020 0:00
5/8/2020 0:00
5/15/2020 0:00
5/22/2020 0:00
5/29/2020 0:00
6/5/2020 0:00
6/12/2020 0:00
6/19/2020 0:00
6/26/2020 0:00
7/3/2020 0:00
7/10/2020 0:00
7/17/2020 0:00
7/24/2020 0:00
7/31/2020 0:00
8/7/2020 0:00
8/14/2020 0:00
8/21/2020 0:00
8/28/2020 0:00
9/4/2020 0:00
9/11/2020 0:00
9/18/2020 0:00
9/25/2020 0:00
SC 7.0 EST. Q


SC 8.4 Streamflow 2020
Streamflow, CFS
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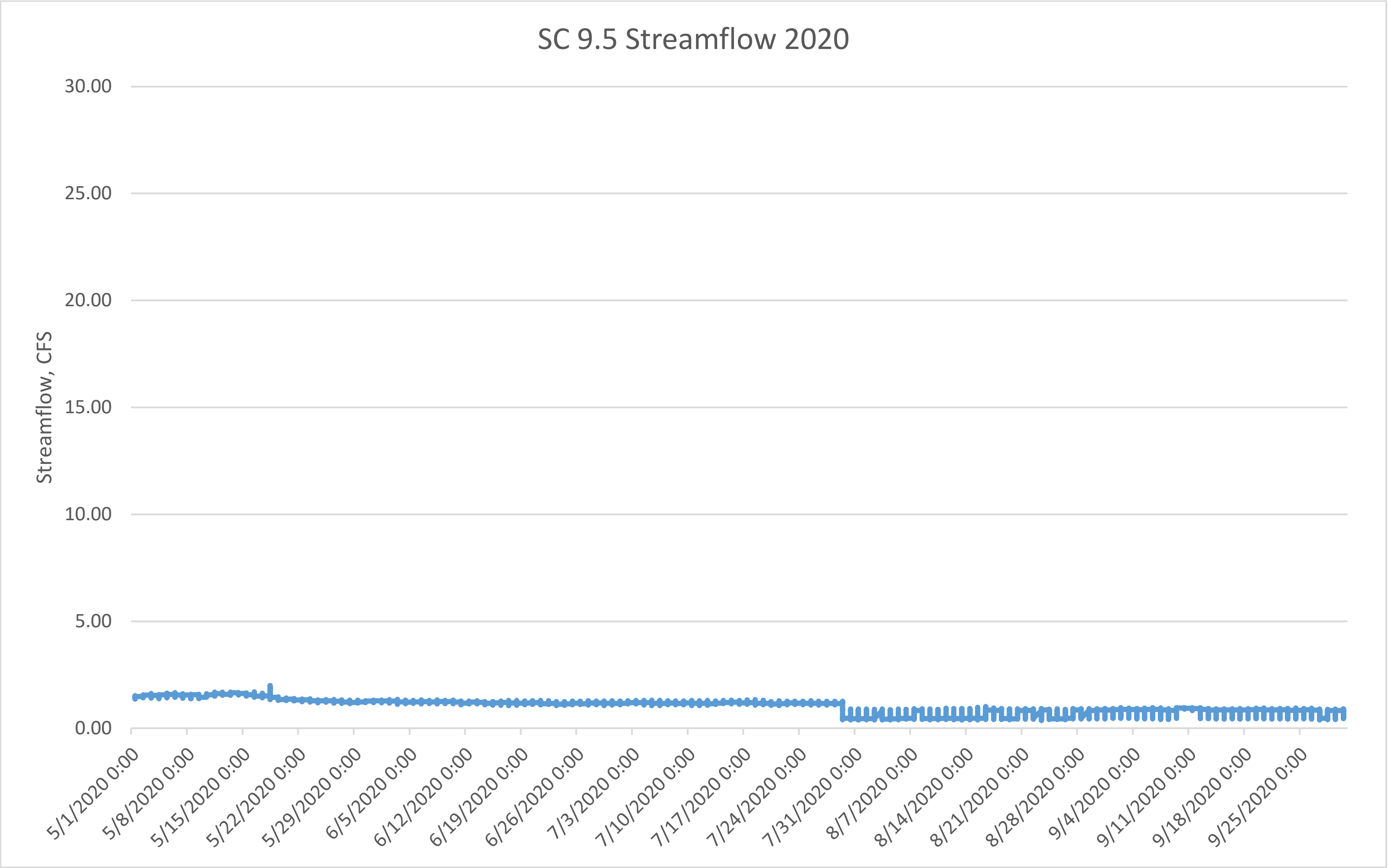
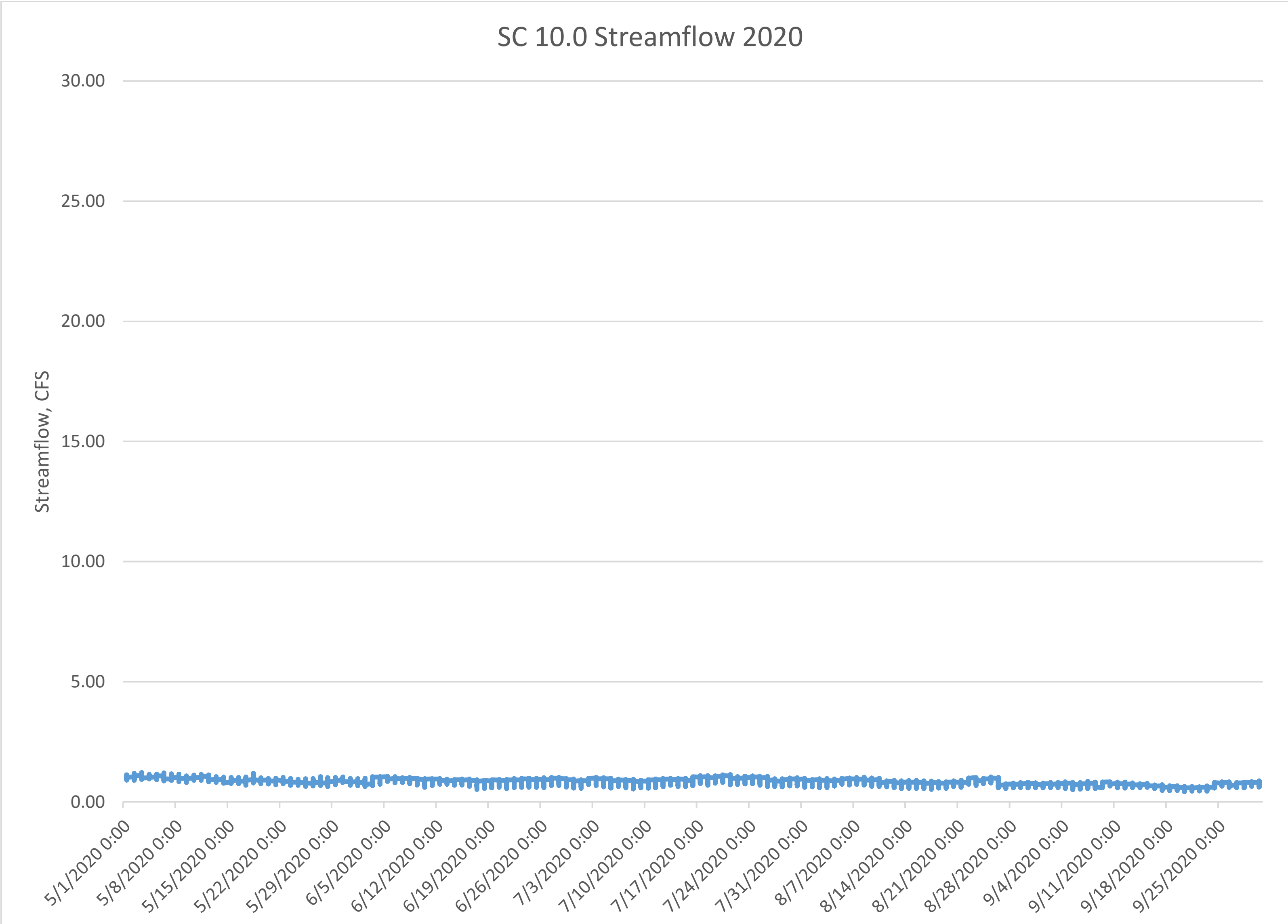
25.00
20.00
15.00
10.00
5.00
0.00
5/1/2020 0:00
5/4/2020 4:30
5/7/2020 9:00
5/10/2020 13:30
5/13/2020 18:00
5/16/2020 22:30
5/20/2020 3:00
5/23/2020 7:30
5/26/2020 12:00
5/29/2020 16:30
6/1/2020 21:00
6/5/2020 1:30
6/8/2020 6:00
6/11/2020 10:30
6/14/2020 15:00
6/17/2020 19:30
6/21/2020 0:00
6/24/2020 4:30
6/27/2020 9:00
6/30/2020 13:30
7/3/2020 18:00
7/6/2020 22:30
7/10/2020 3:00
7/13/2020 7:30
7/16/2020 12:00
7/19/2020 16:30
7/22/2020 21:00
7/26/2020 1:30
7/29/2020 6:00
8/1/2020 10:30
8/4/2020 15:00
8/7/2020 19:30
8/11/2020 0:00
8/14/2020 4:30
8/17/2020 9:00
8/20/2020 13:30
8/23/2020 18:00
8/26/2020 22:30
8/30/2020 3:00
9/2/2020 7:30
9/5/2020 12:00
9/8/2020 16:30
9/11/2020 21:00
9/15/2020 1:30
9/18/2020 6:00
9/21/2020 10:30
9/24/2020 15:00
9/27/2020 19:30



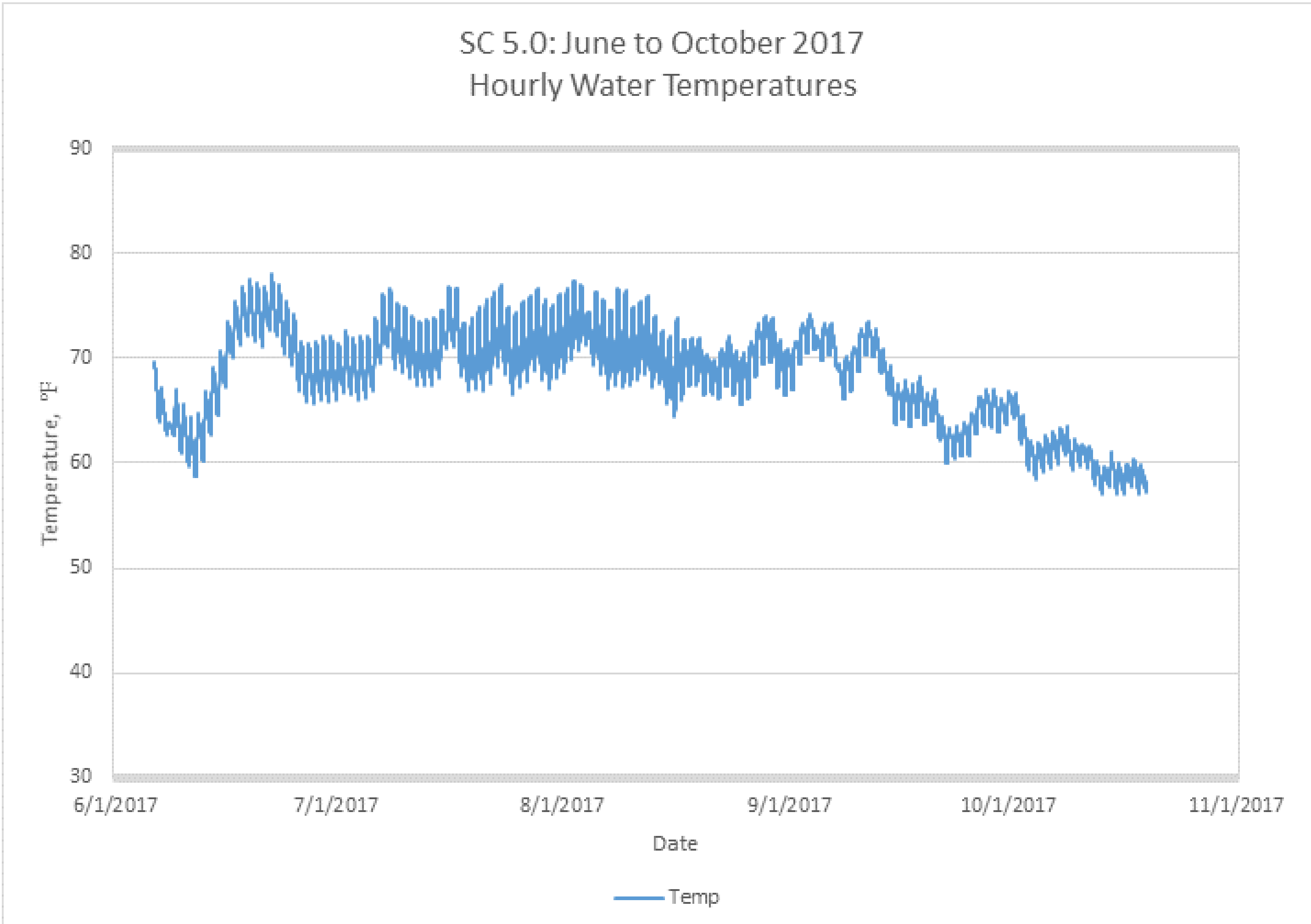
SC 9.5 Streamflow 2020
Streamflow, CFS
30.00
25.00
20.00
15.00
10.00
5.00
0.00
5/1/2020 0:00
5/8/2020 0:00
5/15/2020 0:00
5/22/2020 0:00
5/29/2020 0:00
6/5/2020 0:00
6/12/2020 0:00
6/19/2020 0:00
6/26/2020 0:00
7/3/2020 0:00
7/10/2020 0:00
7/17/2020 0:00
7/24/2020 0:00
7/31/2020 0:00
8/7/2020 0:00
8/14/2020 0:00
8/21/2020 0:00
8/28/2020 0:00
9/4/2020 0:00
9/11/2020 0:00
9/18/2020 0:00
9/25/2020 0:00

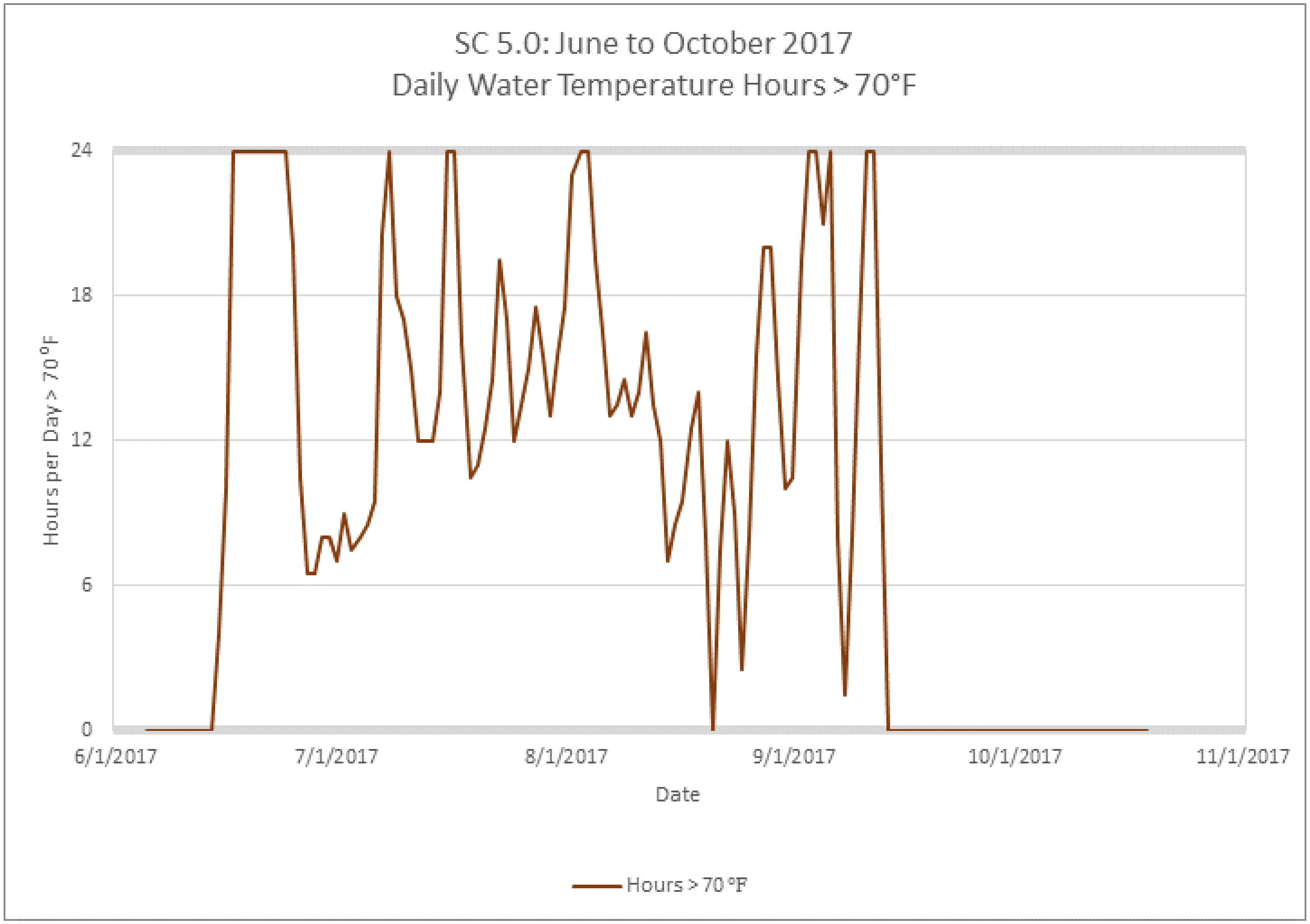


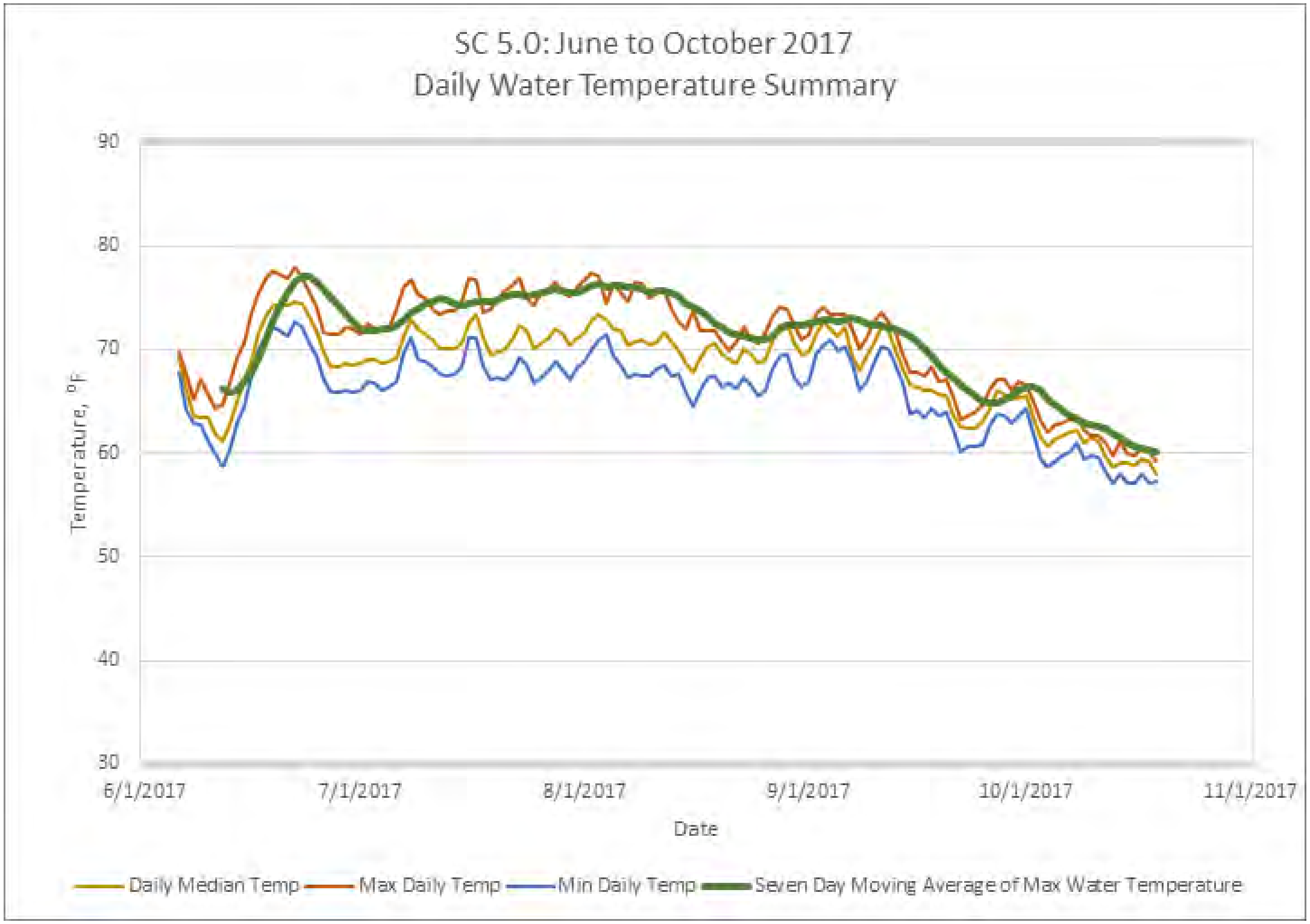
SC 10.0 Streamflow 2020
Streamflow, CFS
30.00
25.00
20.00
15.00
10.00
5.00
0.00
5/1/2020 0:00
5/8/2020 0:00
5/15/2020 0:00
5/22/2020 0:00
5/29/2020 0:00
6/5/2020 0:00
6/12/2020 0:00
6/19/2020 0:00
6/26/2020 0:00
7/3/2020 0:00
7/10/2020 0:00
7/17/2020 0:00
7/24/2020 0:00
7/31/2020 0:00
8/7/2020 0:00
8/14/2020 0:00
8/21/2020 0:00
8/28/2020 0:00
9/4/2020 0:00
9/11/2020 0:00
9/18/2020 0:00
9/25/2020 0:00

Appendix B

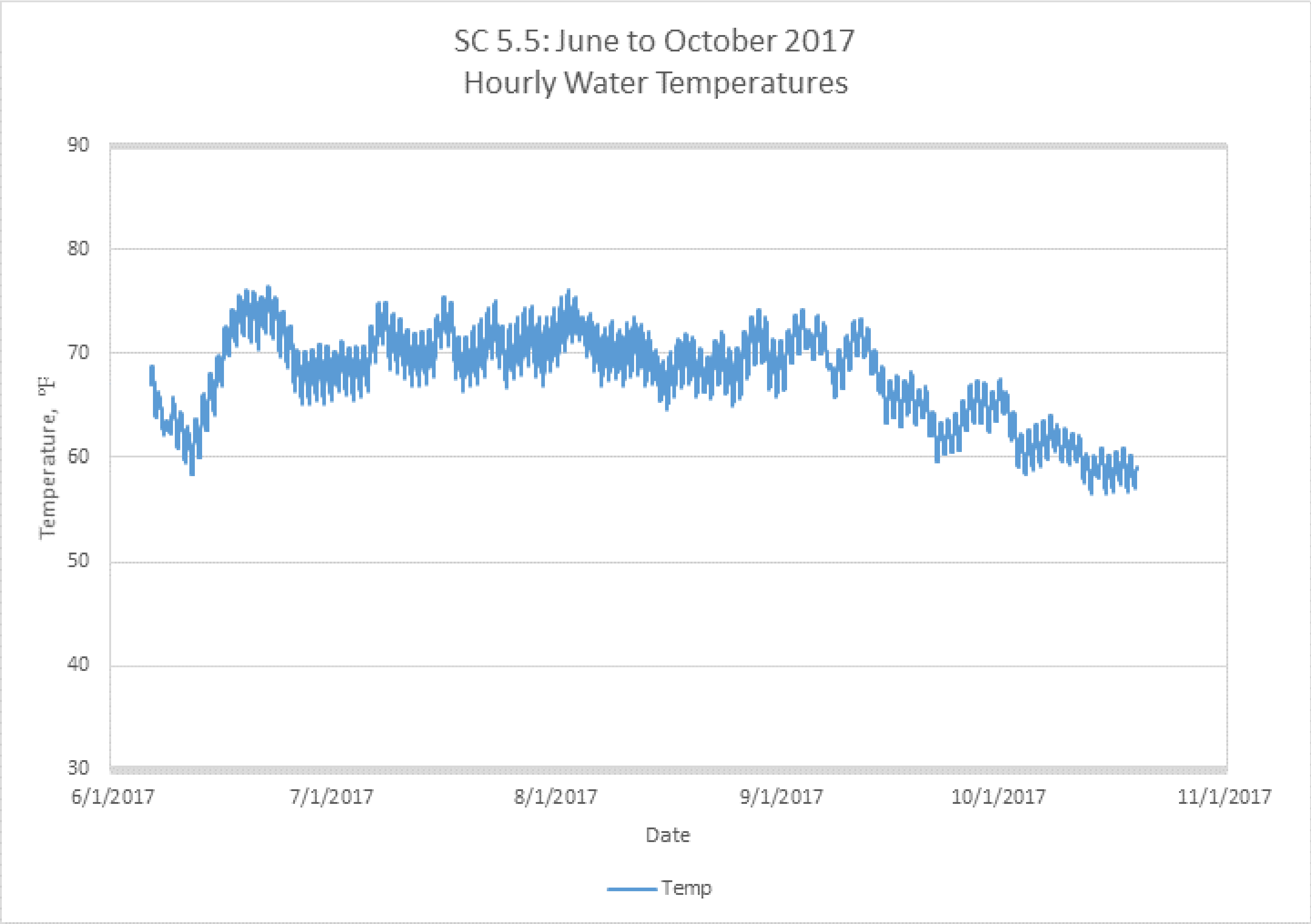
Water Temperature Graphs 2017-2020 Suisun Creek

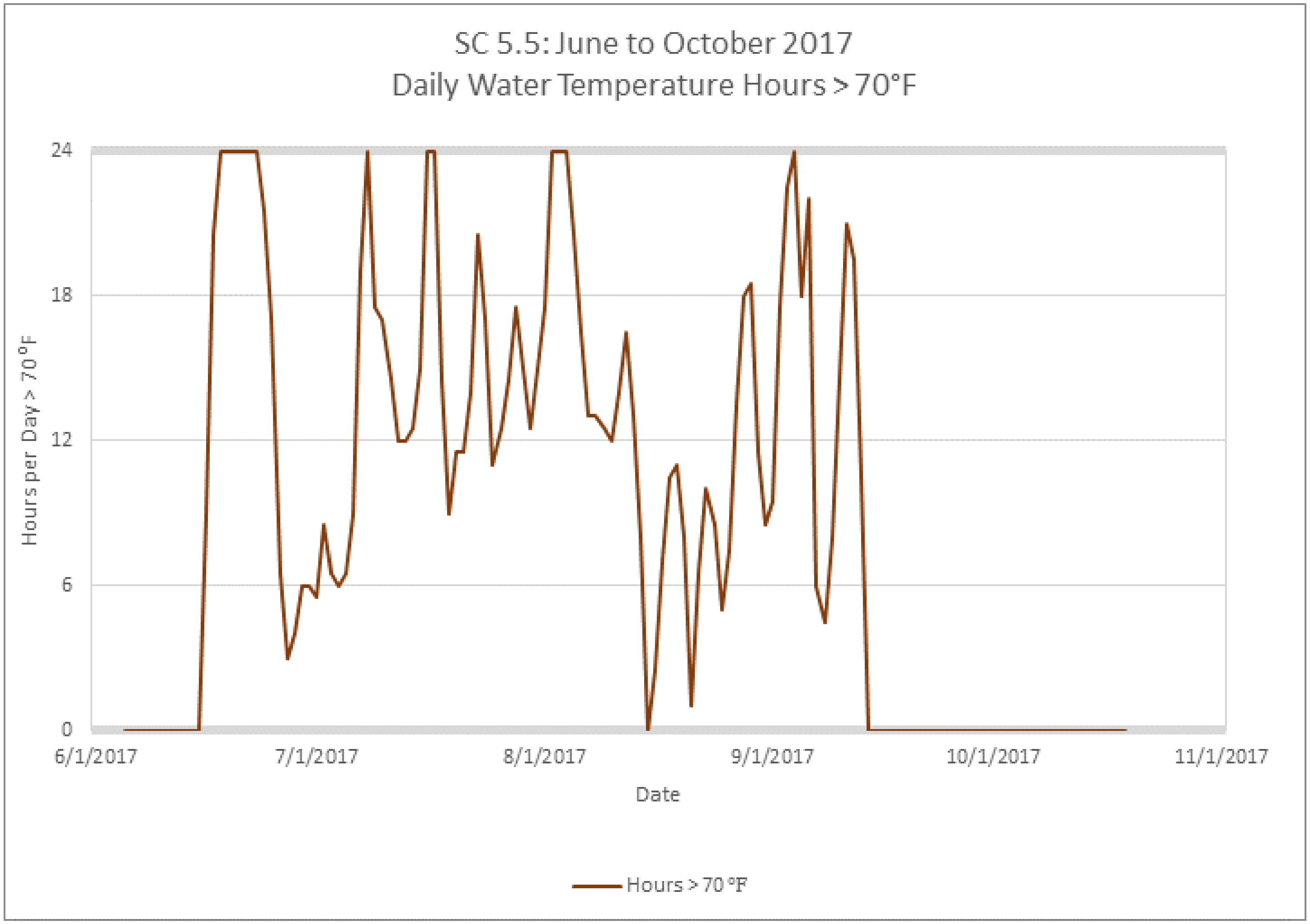

SC 5.0: June to October 2017
Hourly Water Temperatures
90
80
70
60
50
40
30
Temperature, °F
6/1/2017
7/1/2017
8/1/2017
9/1/2017
10/1/2017
11/1/2017
Date
Temp


SC 5.0: June to October 2017
Daily Water Temperature Hours > 70°F
24
18
12
6
0
Hours per Day > 70°F
6/1/2017
7/1/2017
8/1/2017
9/1/2017
10/1/2017
11/1/2017
Date
Hours > 70 °F

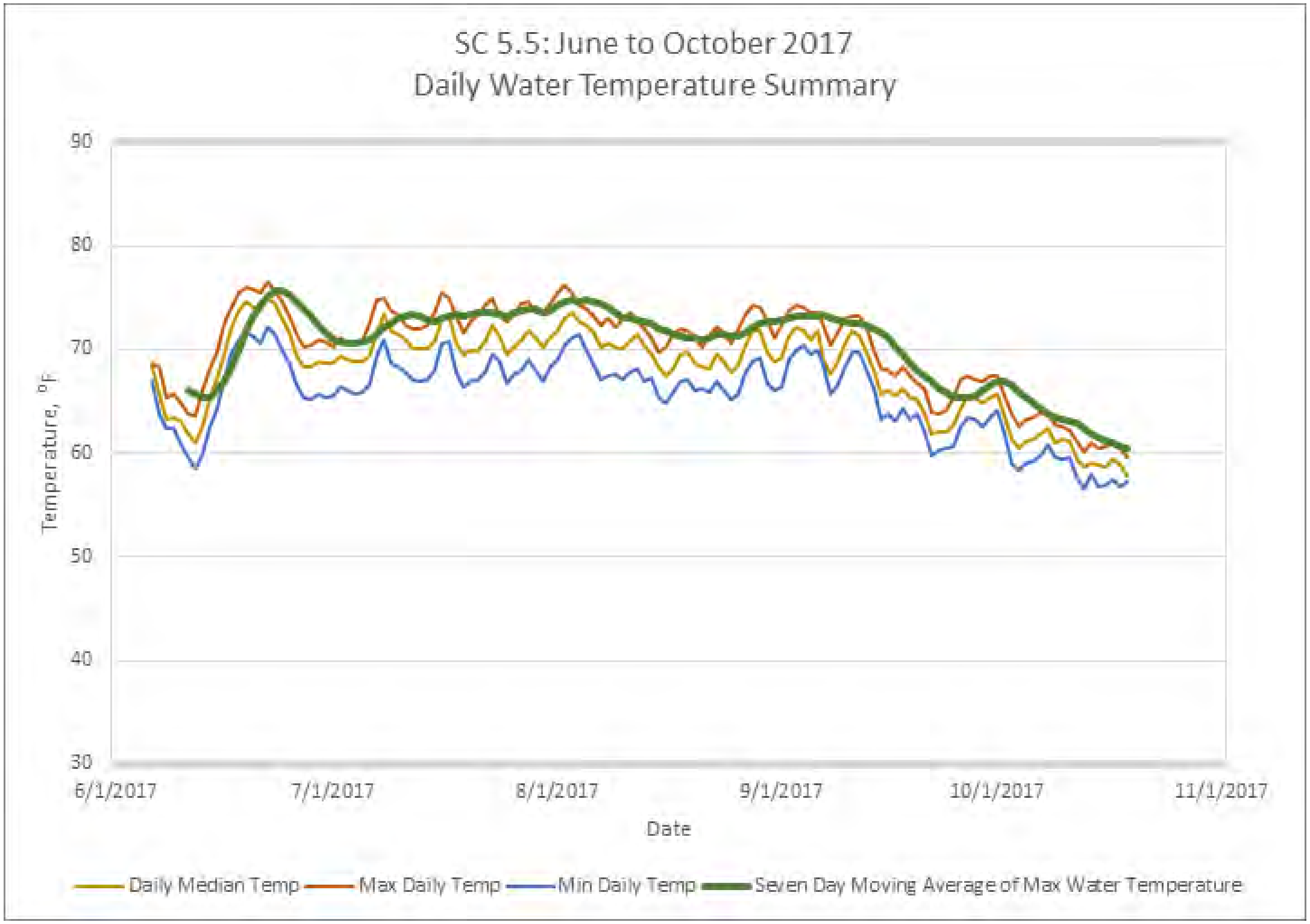


SC 5.0: June to October 2017
Daily Water Temperature Summary
90
80
70
60
50
40
30
Temperature, °F
6/1/2017
7/1/2017
8/1/2017
9/1/2017
10/1/2017
11/1/2017
Date
Daily Median Temp
Max Daily Temp
Min Daily Temp
Seven Day Moving Average of Max Water Temperature

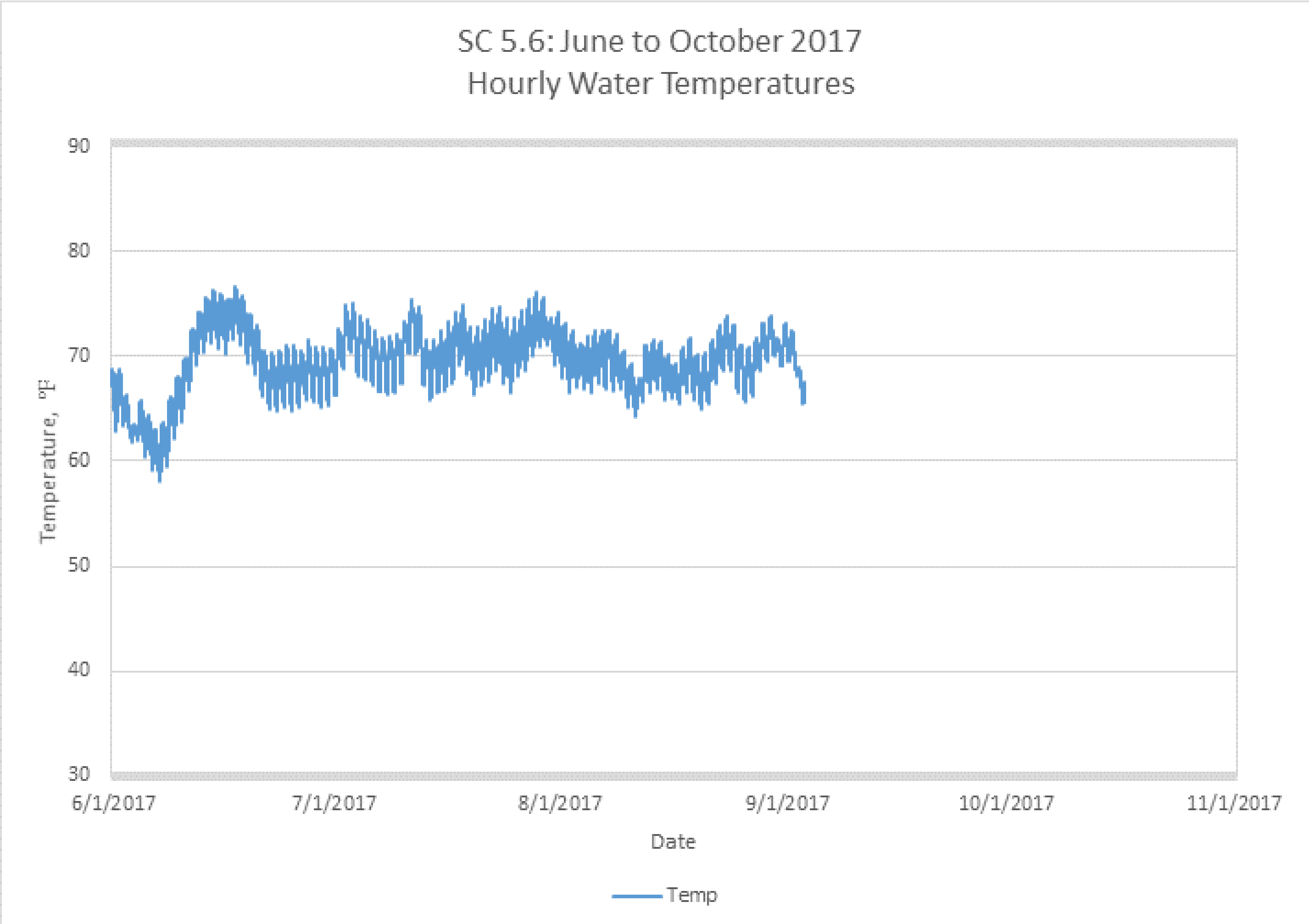

SC 5.5: June to October 2017
Hourly Water Temperatures
90
80
70
60
50
40
30
Temperature, °F
6/1/2017
7/1/2017
8/1/2017
9/1/2017
10/1/2017
11/1/2017
Date
Temp



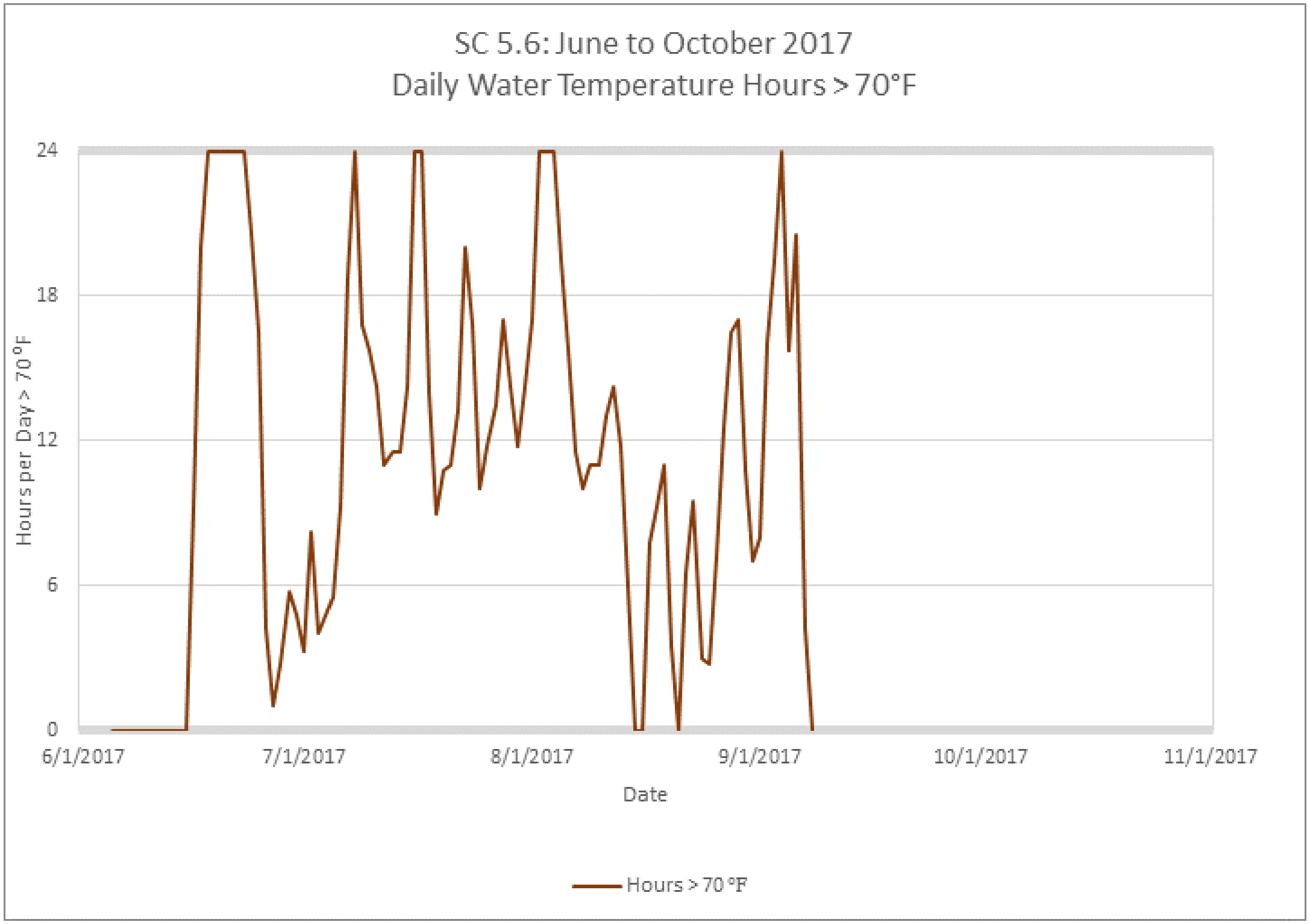
SC 5.5: June to October 2017
Daily Water Temperature Hours > 70°F
24
18
12
6
0
Hours per Day > 70°F
6/1/2017
7/1/2017
8/1/2017
9/1/2017
10/1/2017
11/1/2017
Date
Hours > 70 °F



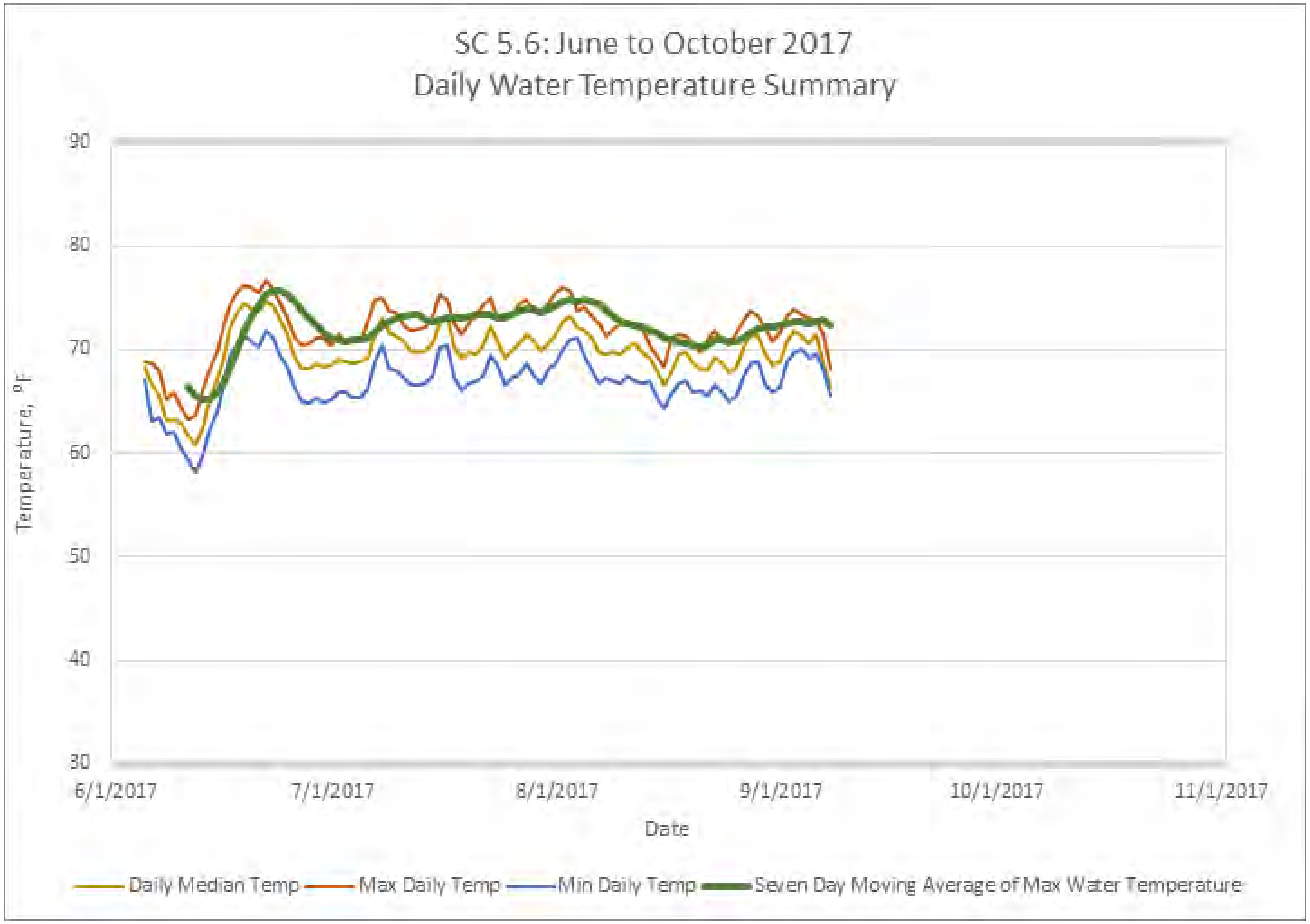
SC 5.5: June to October 2017
Daily Water Temperature Summary
90
80
70
60
50
40
30
Temperature, °F
6/1/2017
7/1/2017
8/1/2017
9/1/2017
10/1/2017
11/1/2017
Date
Daily Median Temp
Max Daily Temp
Min Daily Temp
Seven Day Moving Average of Max Water Temperature

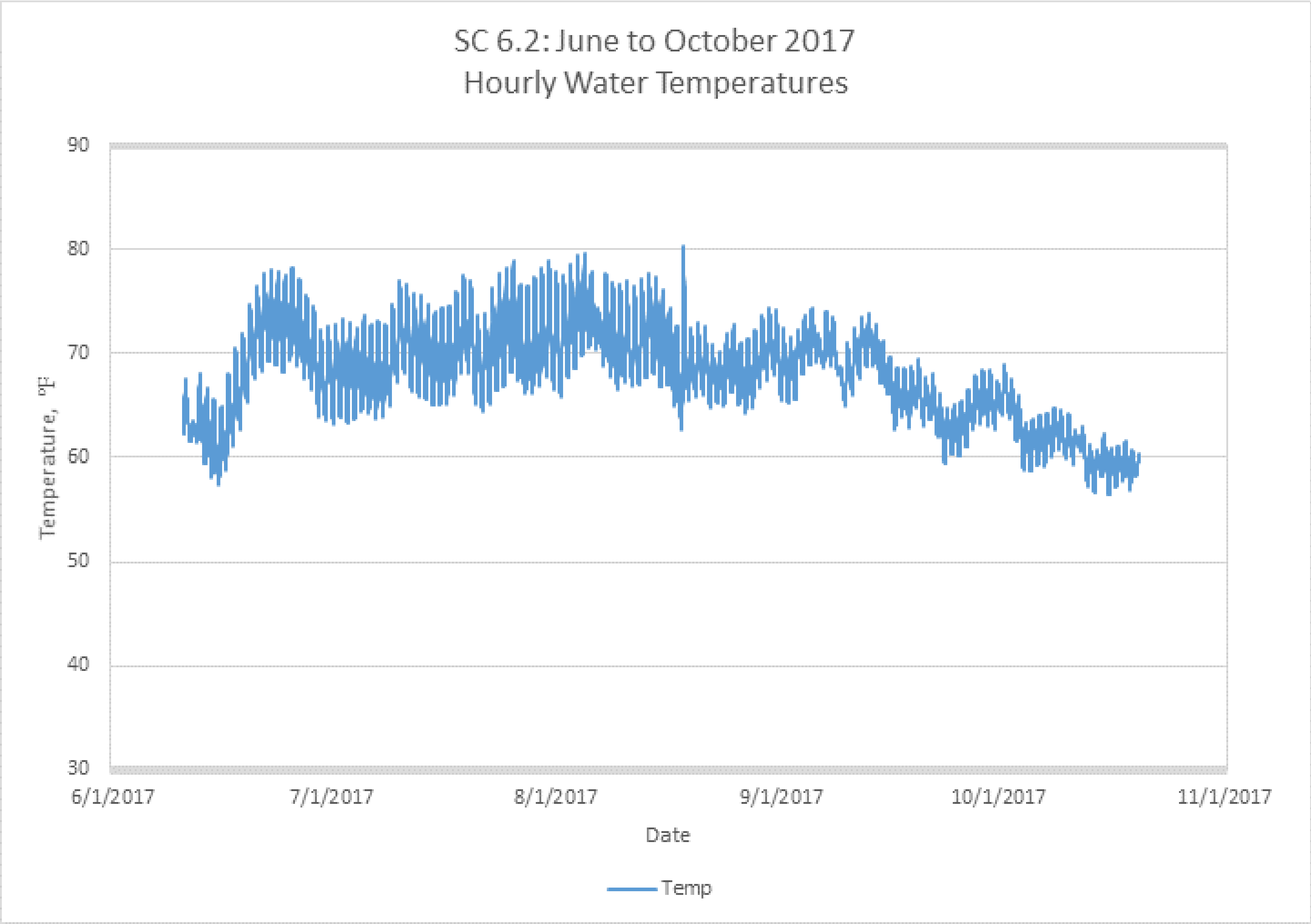


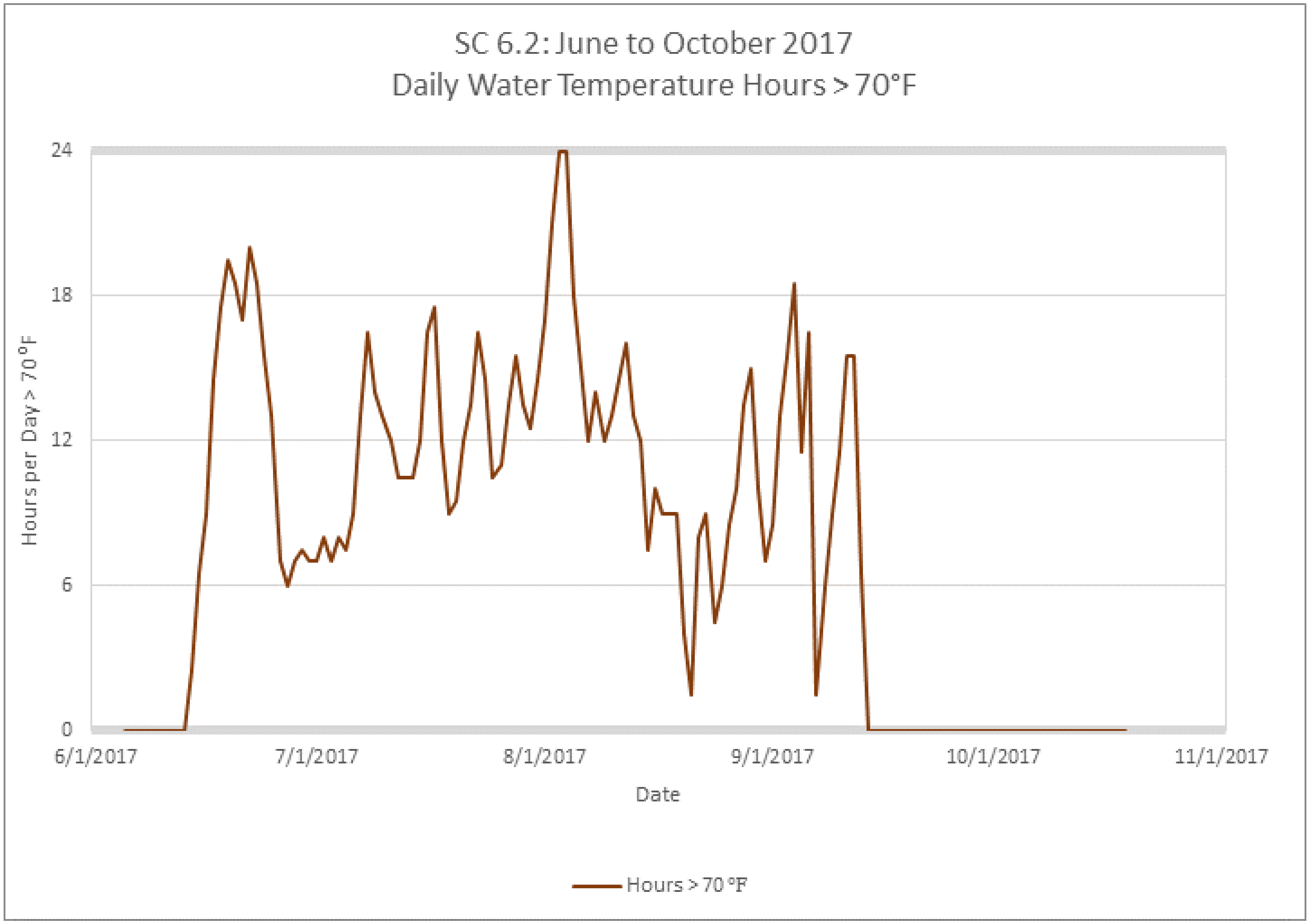
SC 5.6: June to October 2017
Hourly Water Temperatures
Temperature, °F
90
80
70
60
50
40
30
6/1/2017
7/1/2017
8/1/2017
9/1/2017
10/1/2017
11/1/2017
Date
Temp

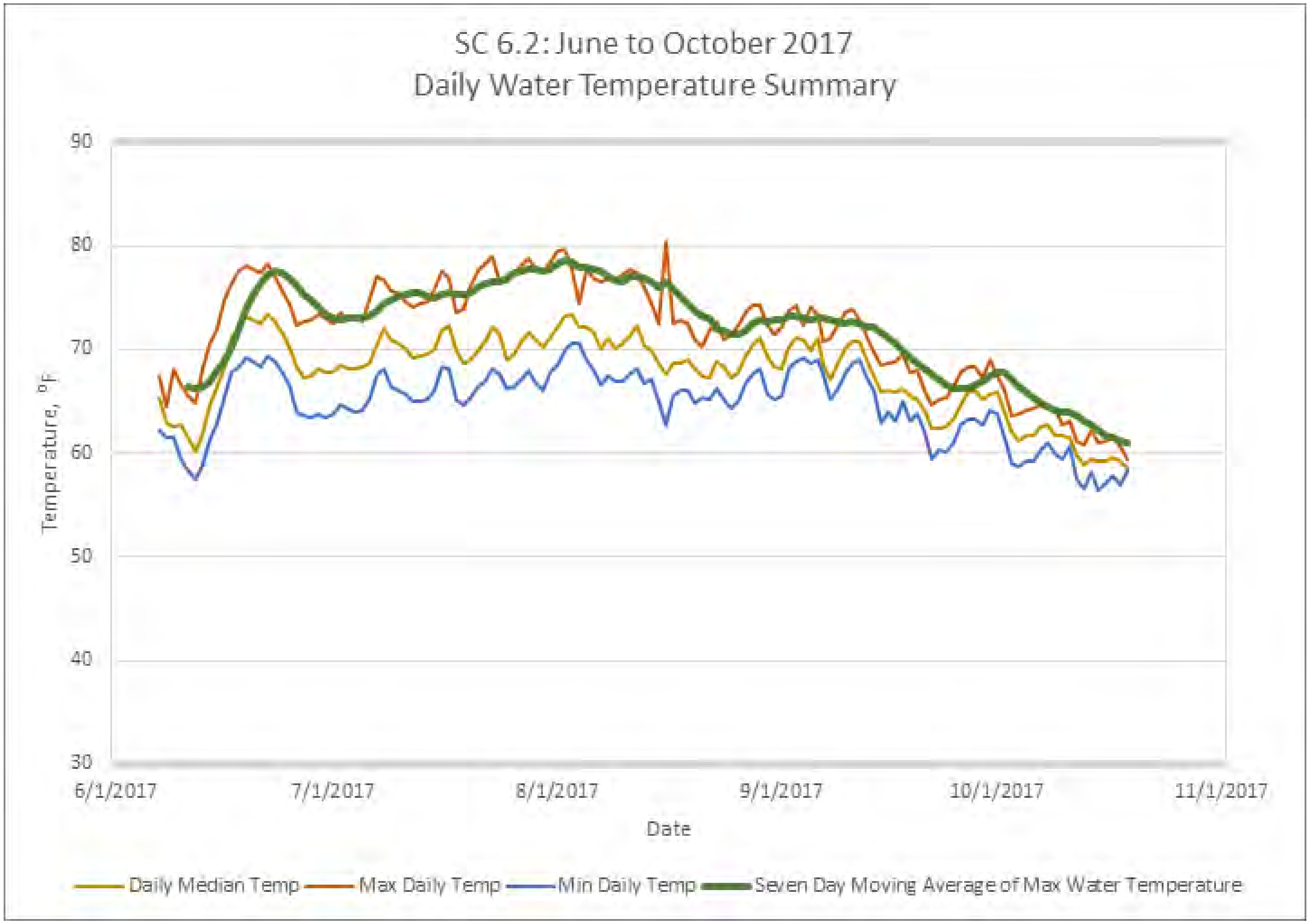


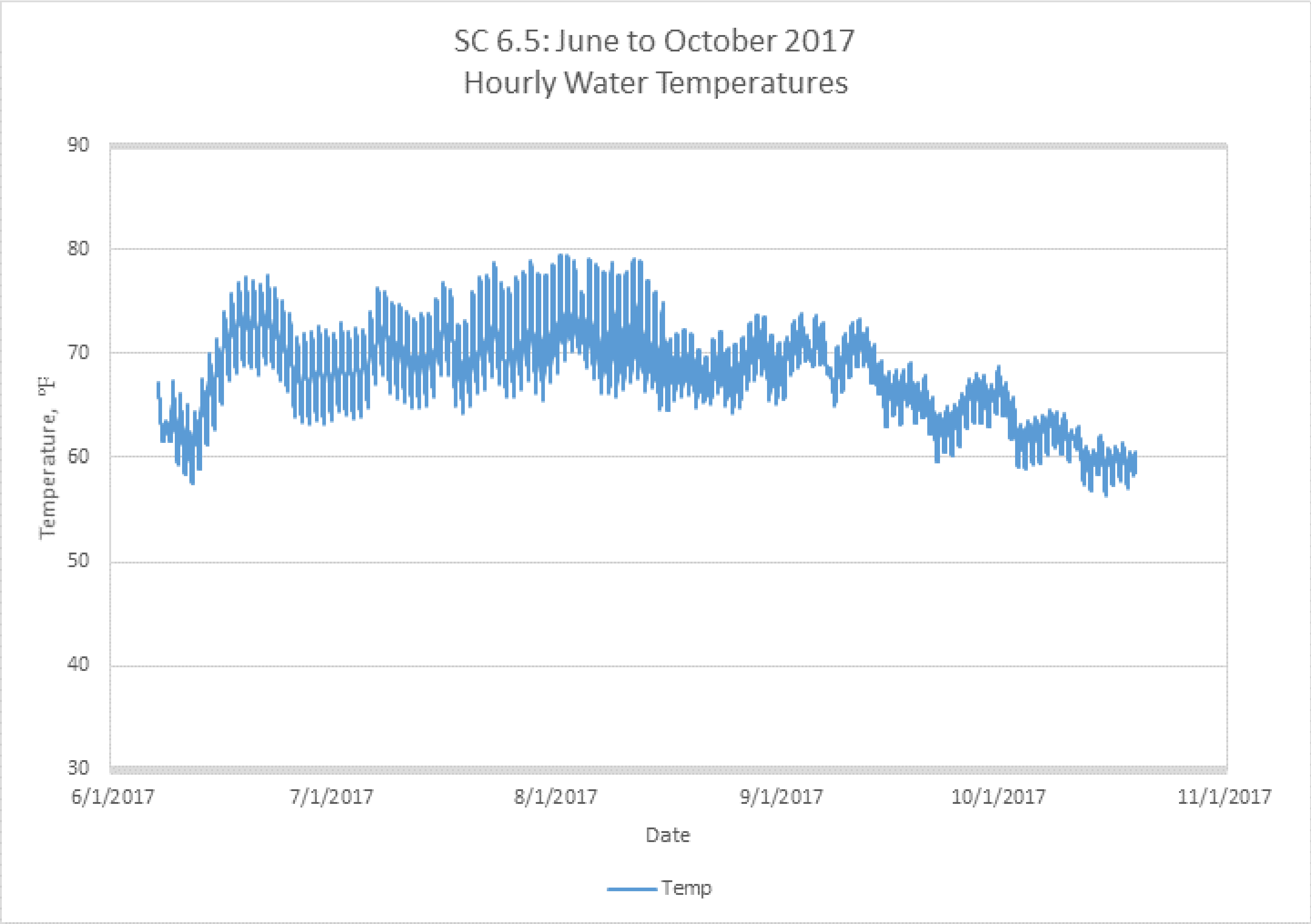
SC 5.6: June to October 2017
Daily Water Temperature Hours > 70°F
24
18
12
6
0
Hours per Day > 70°F
6/1/2017
7/1/2017
8/1/2017
9/1/2017
10/1/2017
11/1/2017
Date
Hours > 70 °F

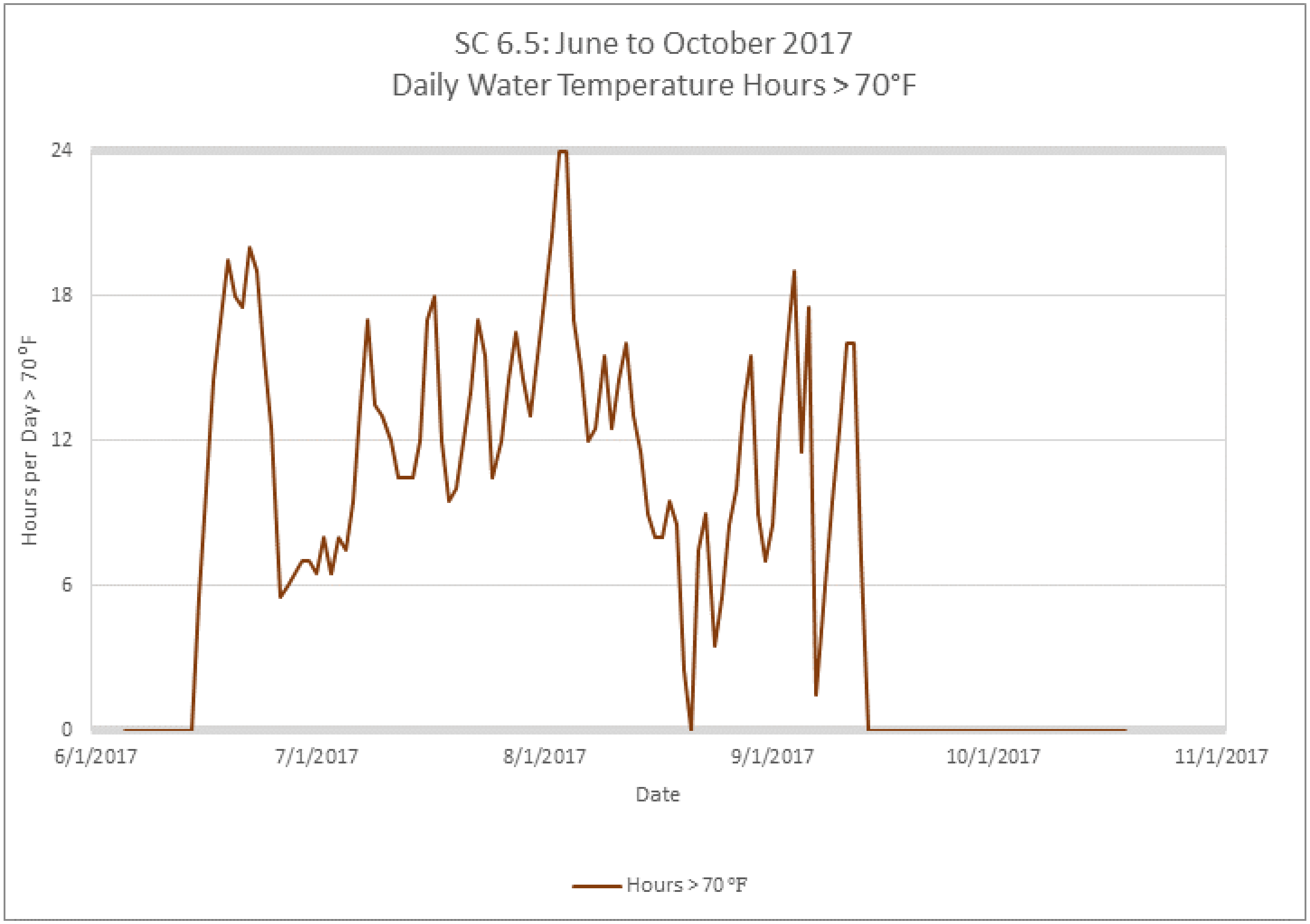

SC 5.6: June to October 2017
Daily Water Temperature Summary
90
80
70
60
50
40
30
Temperature, °F
6/1/2017
7/1/2017
8/1/2017
9/1/2017
10/1/2017
11/1/2017
Date
Daily Median Temp
Max Daily Temp
Min Daily Temp
Seven Day Moving Average of Max Water Temperature


SC 6.2: June to October 2017
Hourly Water Temperatures
90
80
70
60
50
40
30
Temperature, °F
6/1/2017
7/1/2017
8/1/2017
9/1/2017
10/1/2017
11/1/2017
Date
Temp

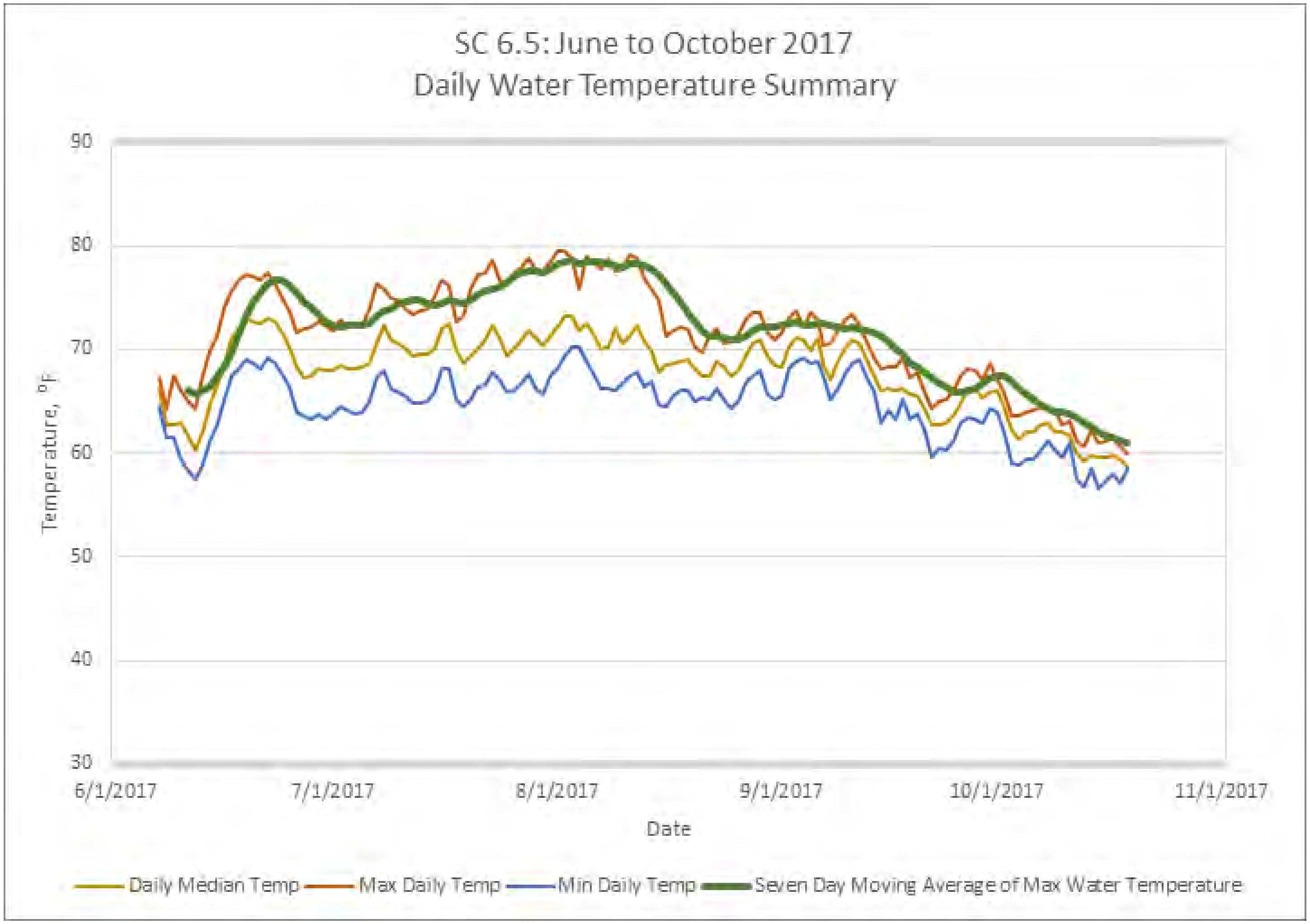

SC 6.2: June to October 2017
Daily Water Temperature Hours > 70°F
24
18
12
6
0
Hours per Day > 70°F
6/1/2017
7/1/2017
8/1/2017
9/1/2017
10/1/2017
11/1/2017
Date
Hours > 70 °F


SC 6.2: June to October 2017
Daily Water Temperature Summary
90
80
70
60
50
40
30
Temperature, °F
6/1/2017
7/1/2017
8/1/2017
9/1/2017
10/1/2017
11/1/2017
Date
Daily Median Temp
Max Daily Temp
Min Daily Temp
Seven Day Moving Average of Max Water Temperature

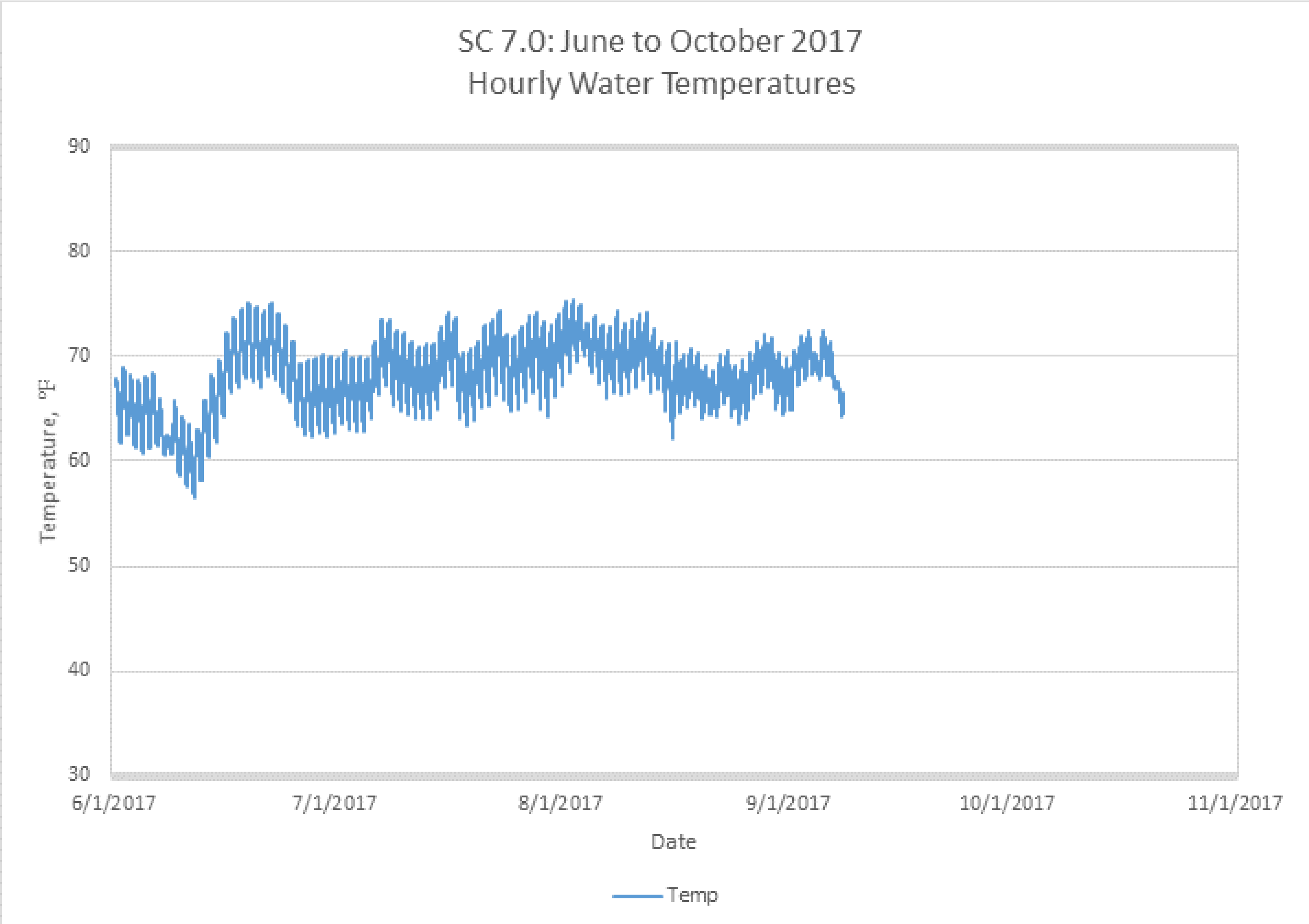

SC 6.5: June to October 2017
Hourly Water Temperatures
90
80
70
60
50
40
30
Temperature, °F
6/1/2017
7/1/2017
8/1/2017
9/1/2017
10/1/2017
11/1/2017
Date
Temp

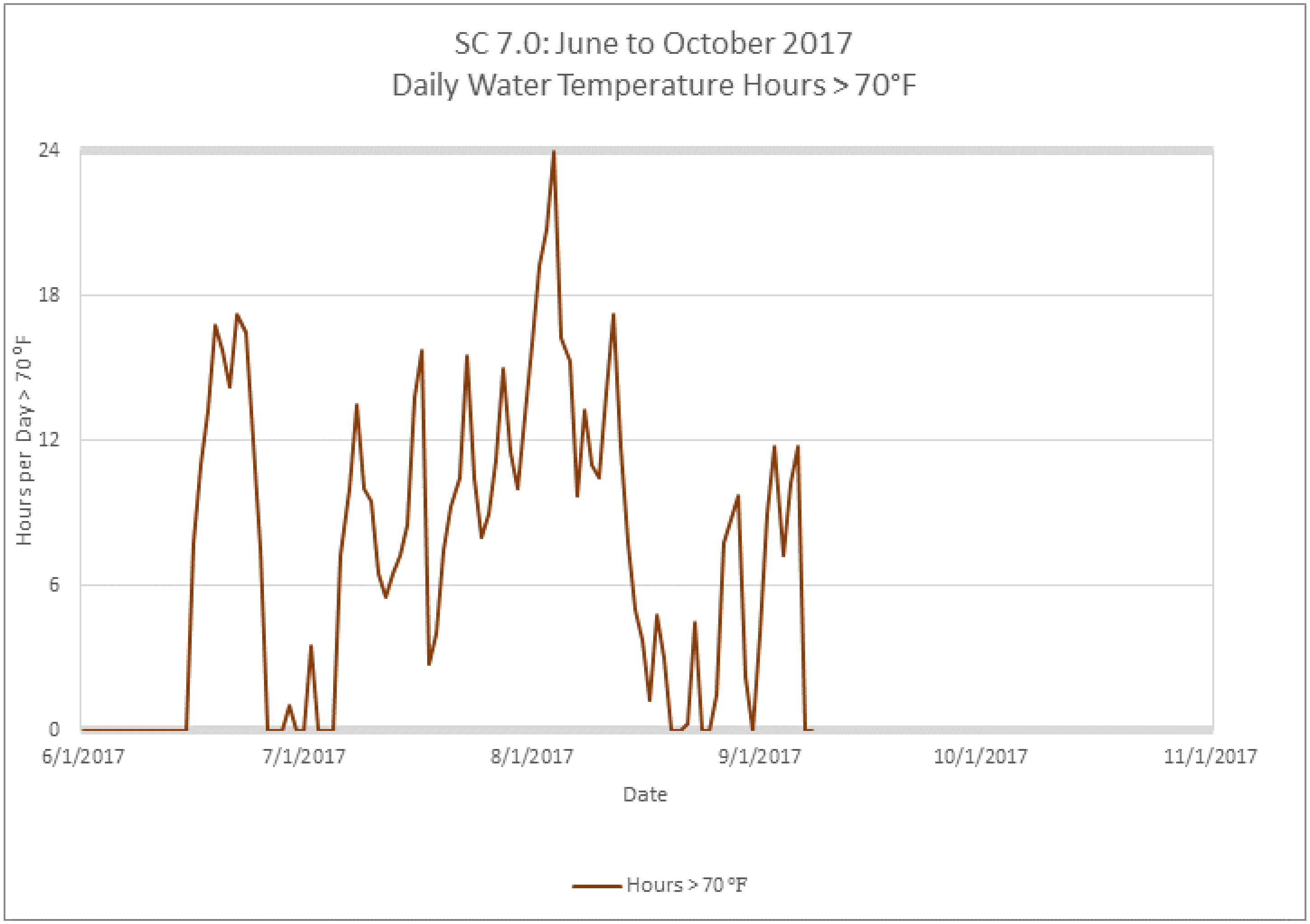


SC 6.5: June to October 2017
Daily Water Temperature Hours > 70°F
Hours per Day > 70°F
24
18
12
6
0
6/1/2017
7/1/2017
8/1/2017
9/1/2017
10/1/2017
11/1/2017
Date
Hours > 70 °F

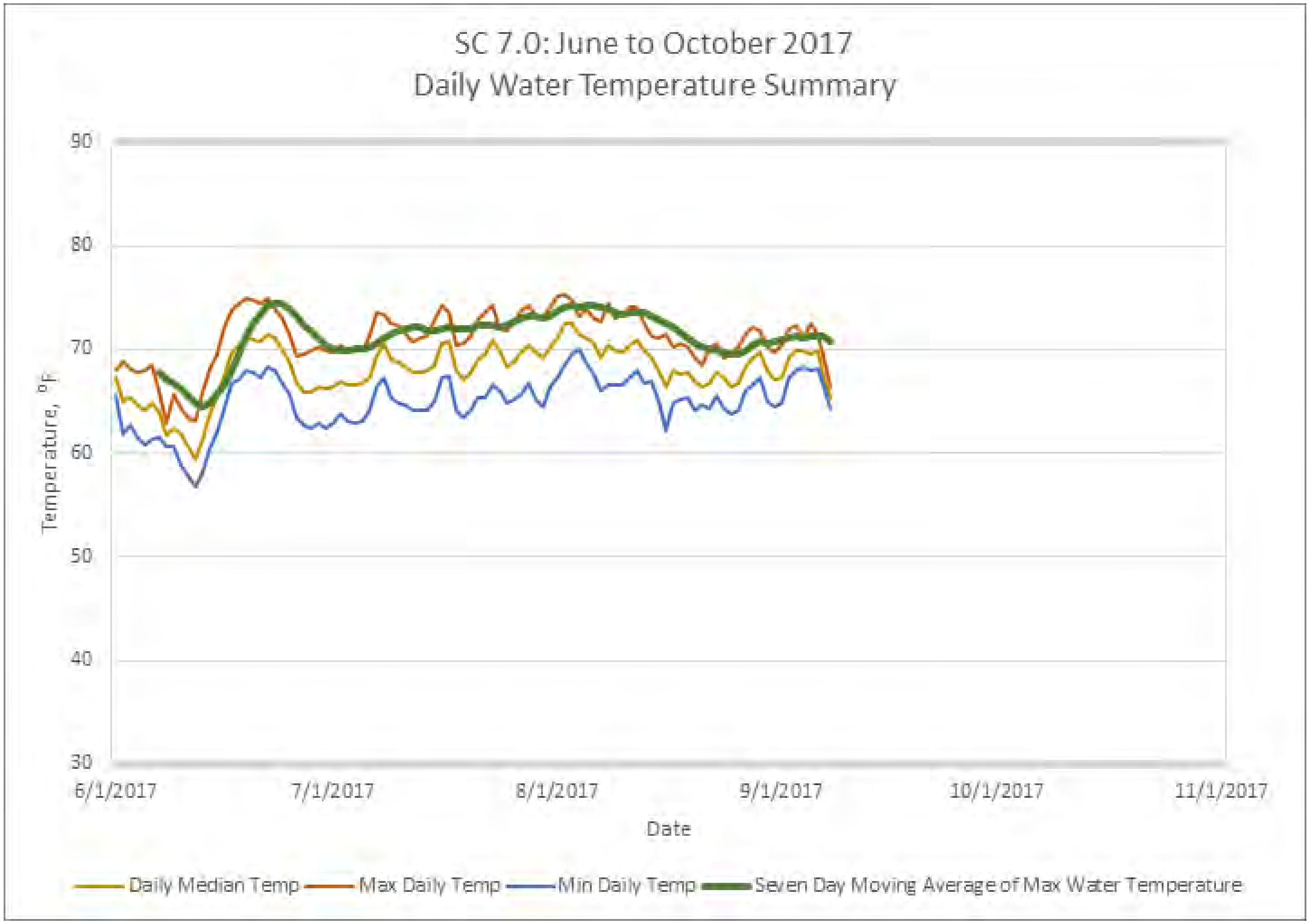


SC 6.5: June to October 2017
Daily Water Temperature Summary
90
80
70
60
50
40
30
Temperature, °F
6/1/2017
7/1/2017
8/1/2017
9/1/2017
10/1/2017
11/1/2017
Date
Daily Median Temp
Max Daily Temp
Min Daily Temp
Seven Day Moving Average of Max Water Temperature

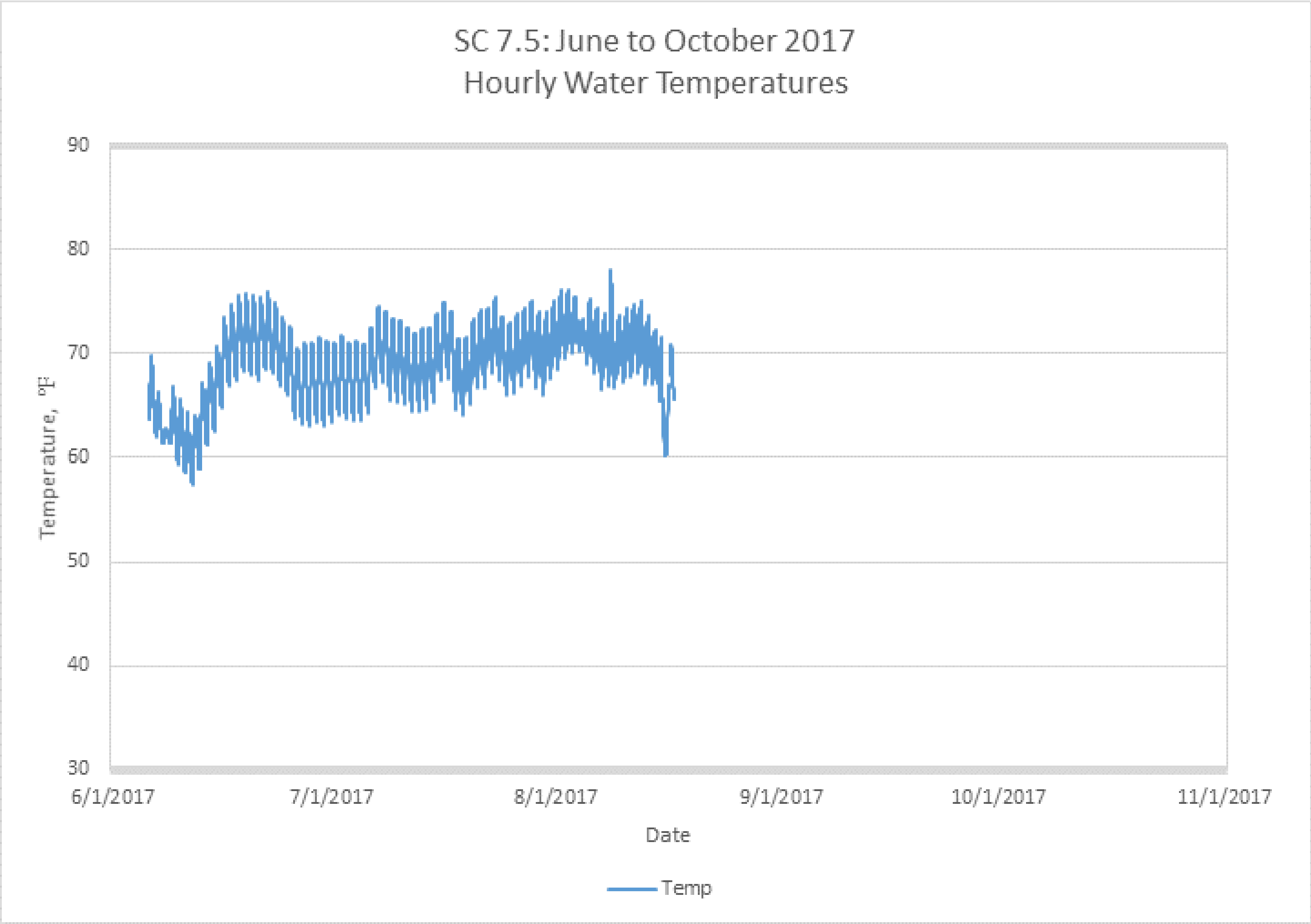

SC 7.0: June to October 2017
Hourly Water Temperatures
90
80
70
60
50
40
30
Temperature, °F
6/1/2017
7/1/2017
8/1/2017
9/1/2017
10/1/2017
11/1/2017
Date
Temp

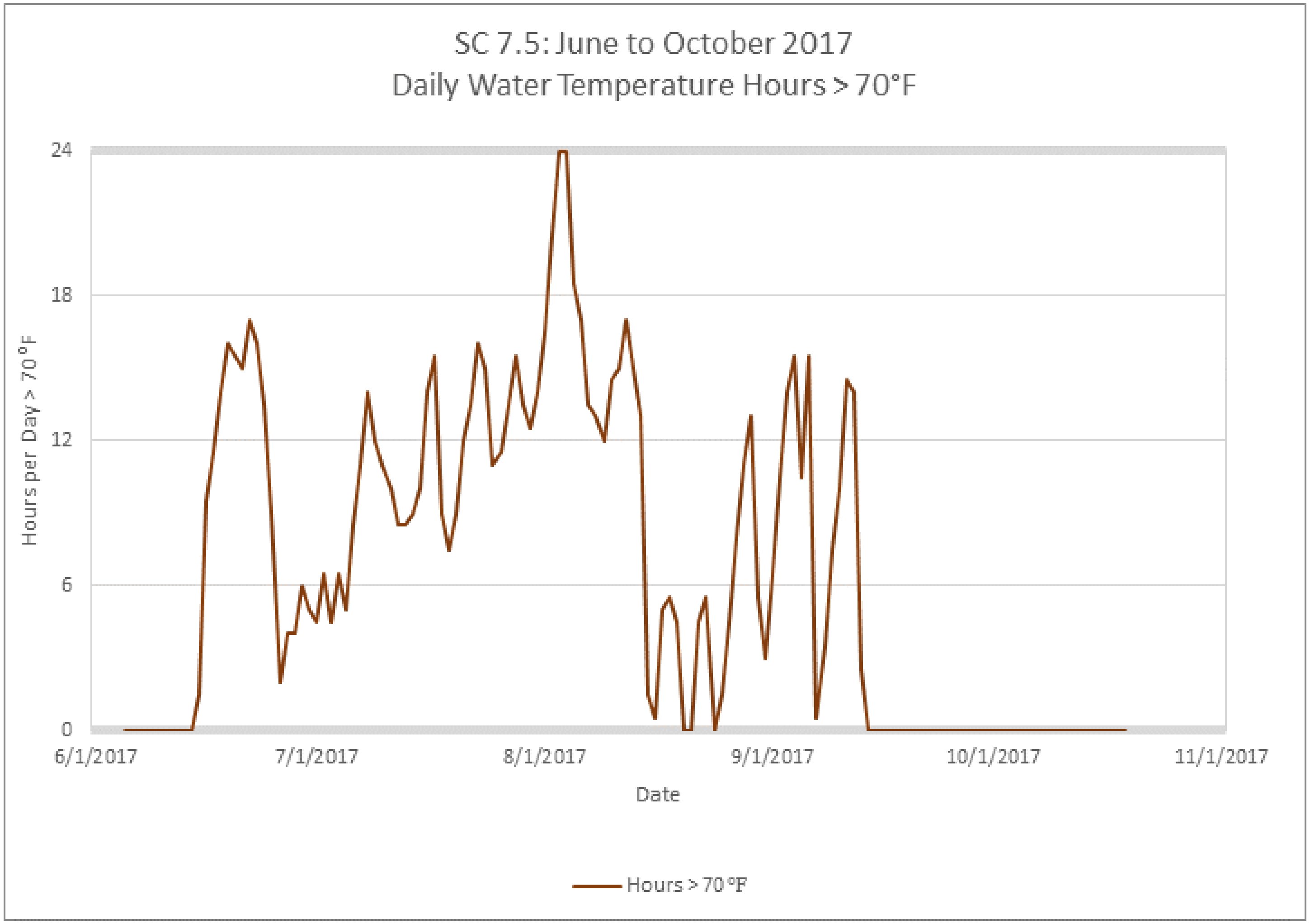


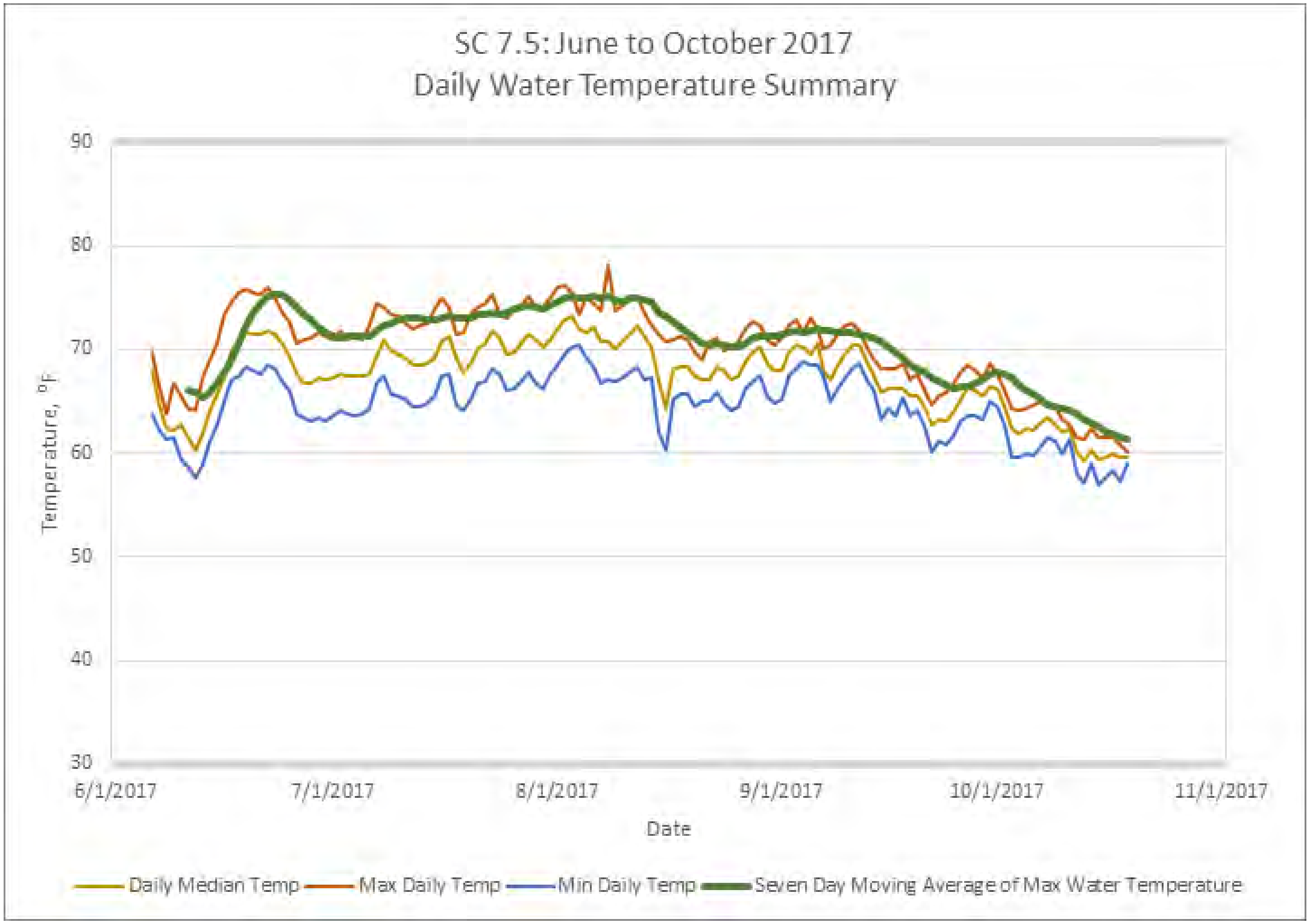
SC 7.0: June to October 2017
Daily Water Temperature Hours > 70°F
24
18
12
6
0
Hours per Day > 70°F
6/1/2017
7/1/2017
8/1/2017
9/1/2017
10/1/2017
11/1/2017
Date
Hours > 70 °F

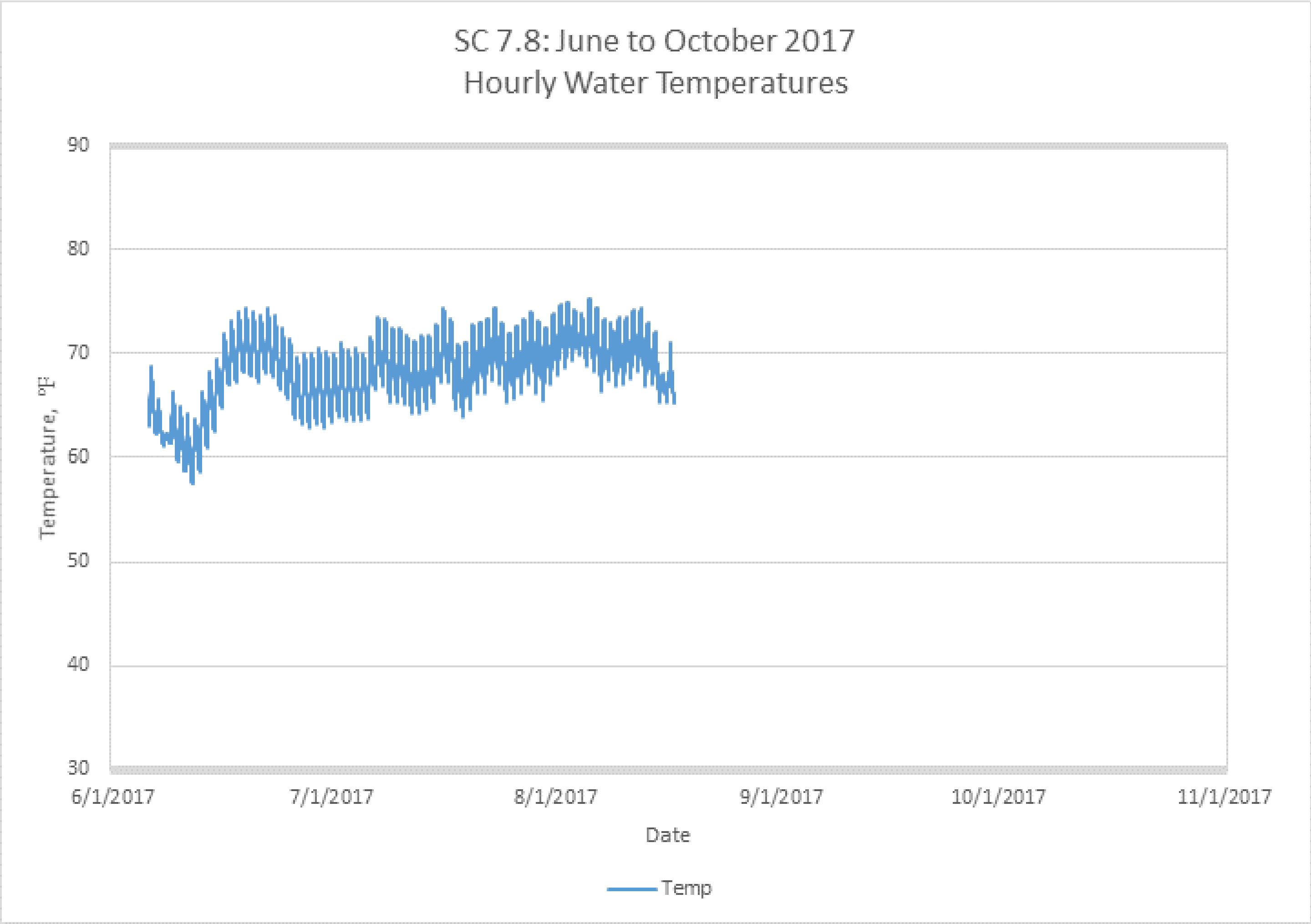


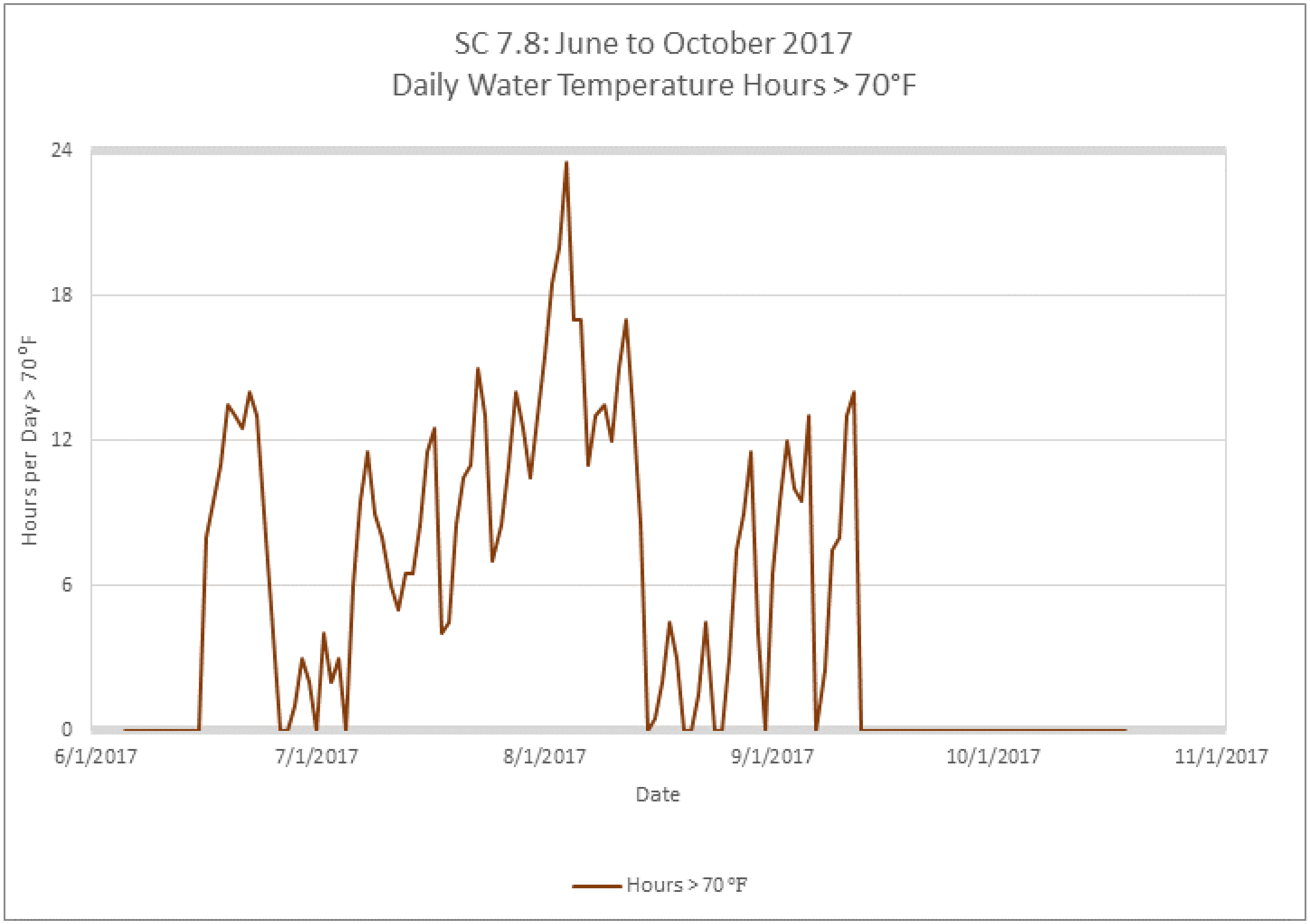
SC 7.0: June to October 2017
Daily Water Temperature Summary
90
80
70
60
50
40
30
Temperature, °F
6/1/2017
7/1/2017
8/1/2017
9/1/2017
10/1/2017
11/1/2017
Date
Daily Median Temp
Max Daily Temp
Min Daily Temp
Seven Day Moving Average of Max Water Temperature


SC 7.5: June to October 2017
Hourly Water Temperatures
Temperature, °F
90
80
70
60
50
40
30
6/1/2017
7/1/2017
8/1/2017
9/1/2017
10/1/2017
11/1/2017
Date
Temp


SC 7.5: June to October 2017
Daily Water Temperature Hours > 70°F
24
18
12
6
0
Hours per Day > 70°F
6/1/2017
7/1/2017
8/1/2017
9/1/2017
10/1/2017
11/1/2017
Date
Hours > 70 °F

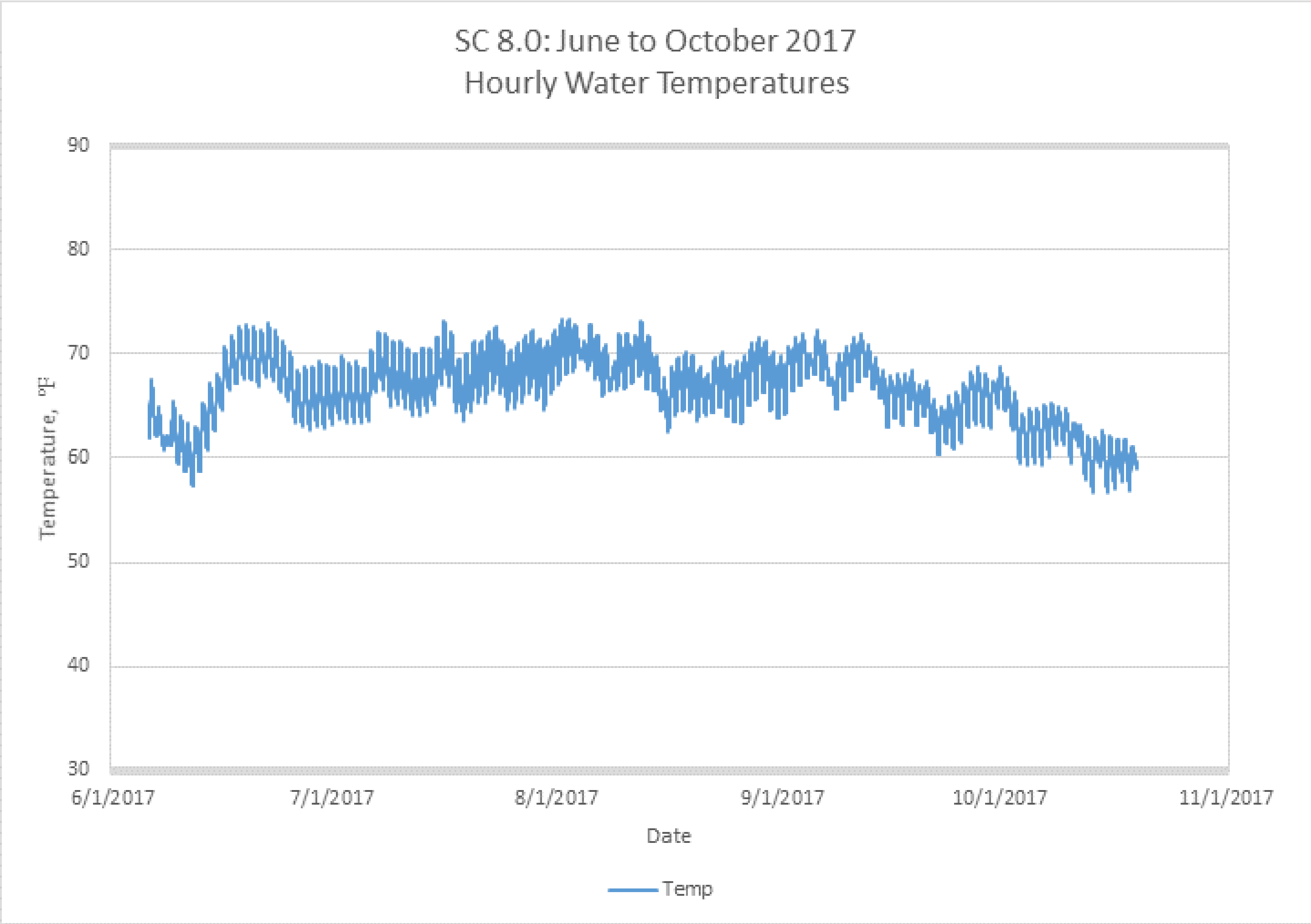

SC 7.5: June to October 2017
Daily Water Temperature Summary
90
80
70
60
50
40
30
Temperature, °F
6/1/2017
7/1/2017
8/1/2017
9/1/2017
10/1/2017
11/1/2017
Date
Daily Median Temp
Max Daily Temp
Min Daily Temp
Seven Day Moving Average of Max Water Temperature

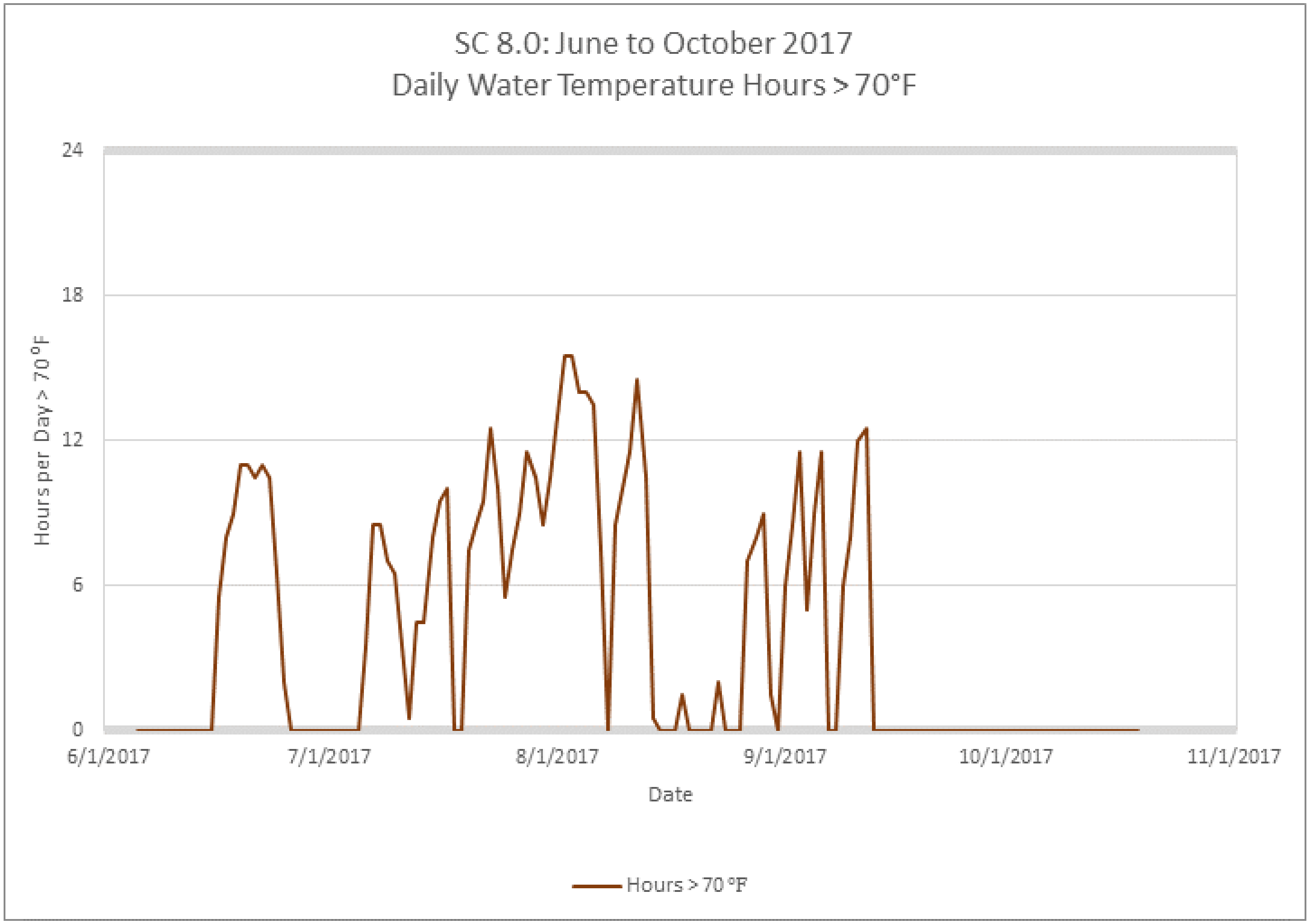

SC 7.8: June to October 2017
Hourly Water Temperatures
Temperature, °F
90
80
70
60
50
40
30
6/1/2017
7/1/2017
8/1/2017
9/1/2017
10/1/2017
11/1/2017
Date
Temp

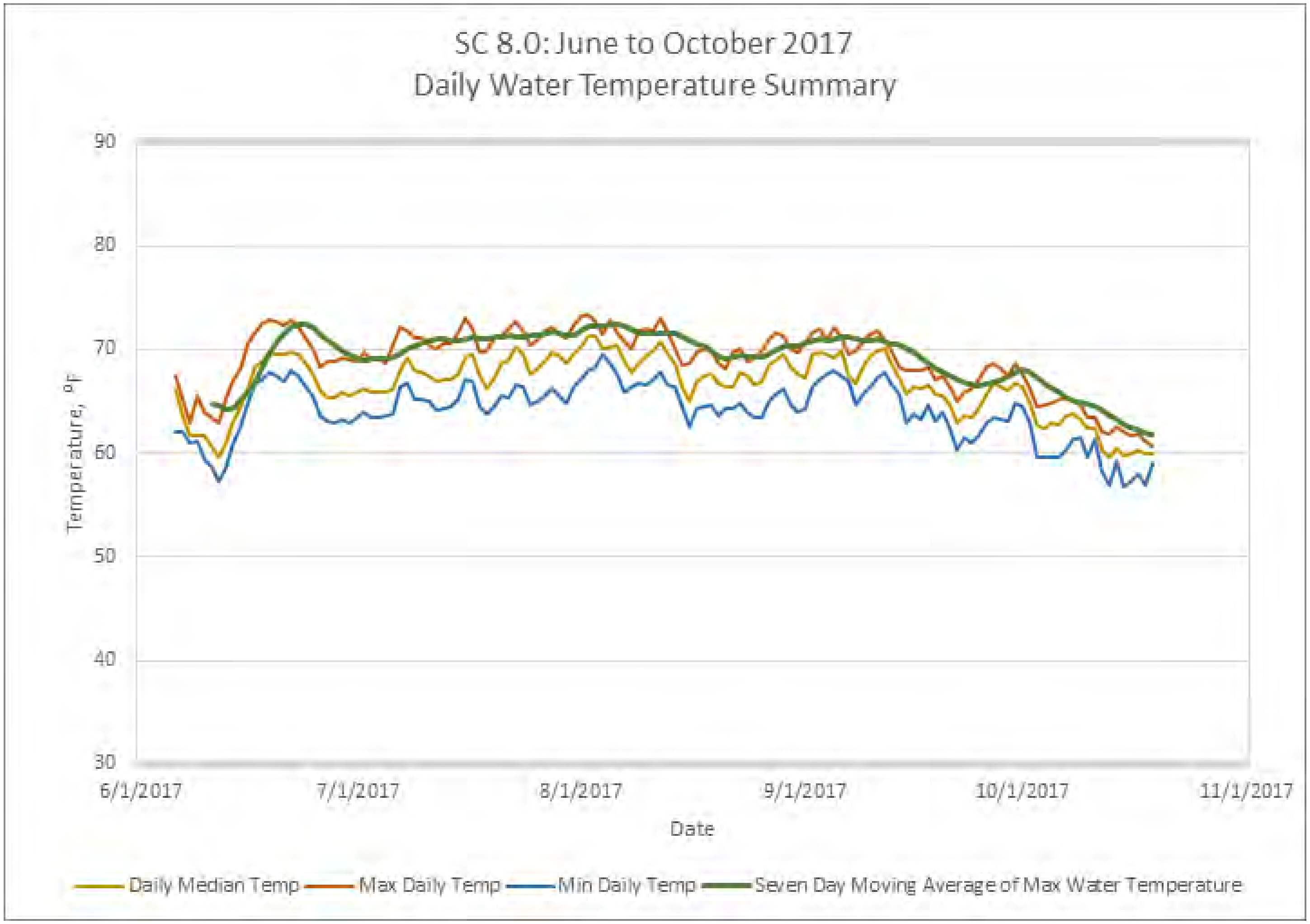


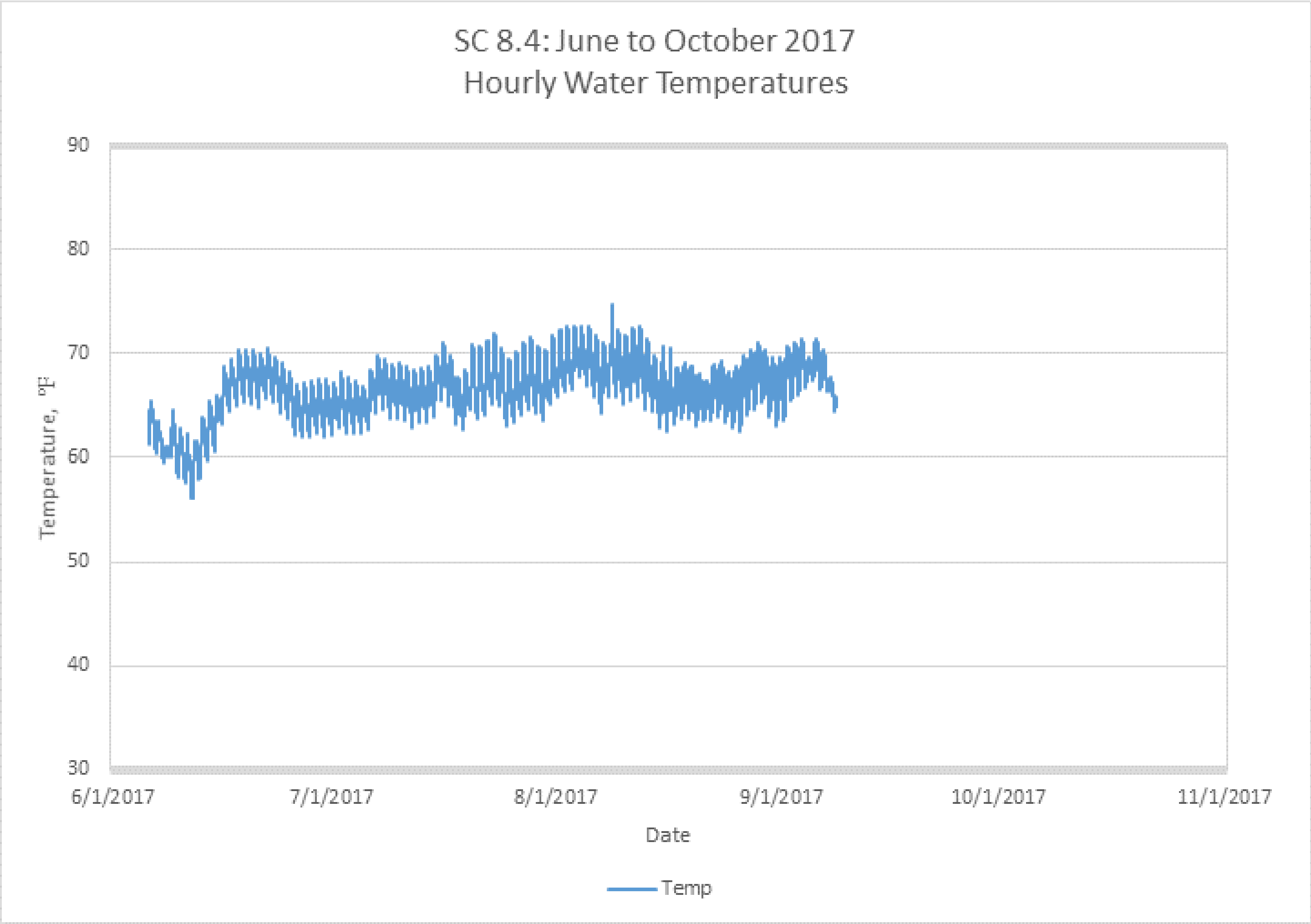
SC 7.8: June to October 2017
Daily Water Temperature Hours > 70°F
24
18
12
6
0
Hours per Day > 70°F
6/1/2017
7/1/2017
8/1/2017
9/1/2017
10/1/2017
11/1/2017
Date
Hours > 70 °F

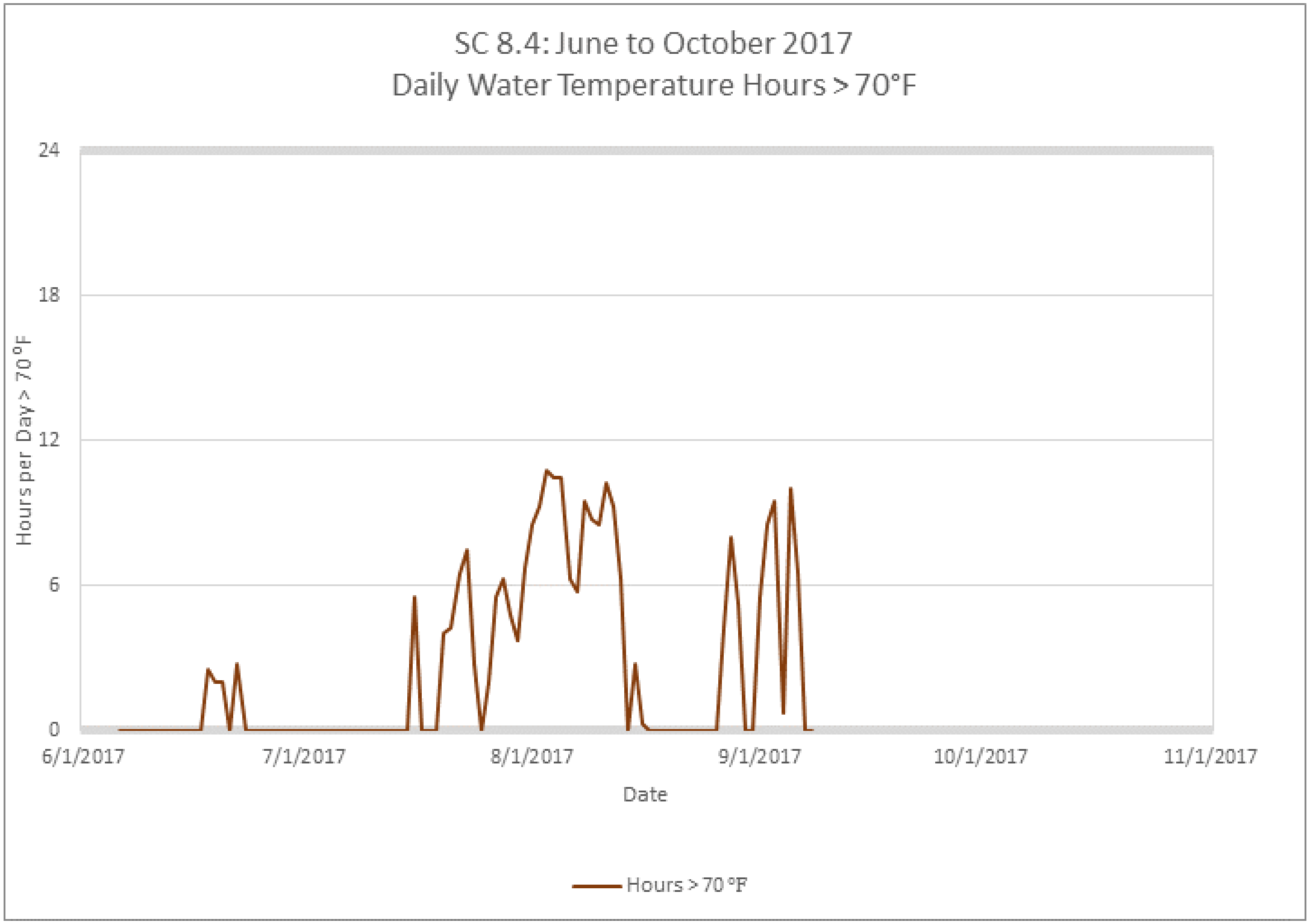
SC 7.8: June to October 2017
Daily Water Temperature Summary
90
80
70
60
50
40
30
Temperature, °F
6/1/2017
7/1/2017
8/1/2017
9/1/2017
10/1/2017
11/1/2017
Date
Daily Median Temp
Max Daily Temp
Min Daily Temp
Seven Day Moving Average of Max Water Temperature


SC 8.0: June to October 2017
Hourly Water Temperatures
90
80
70
60
50
40
30
Temperature, °F
6/1/2017
7/1/2017
8/1/2017
9/1/2017
10/1/2017
11/1/2017
Date
Temp

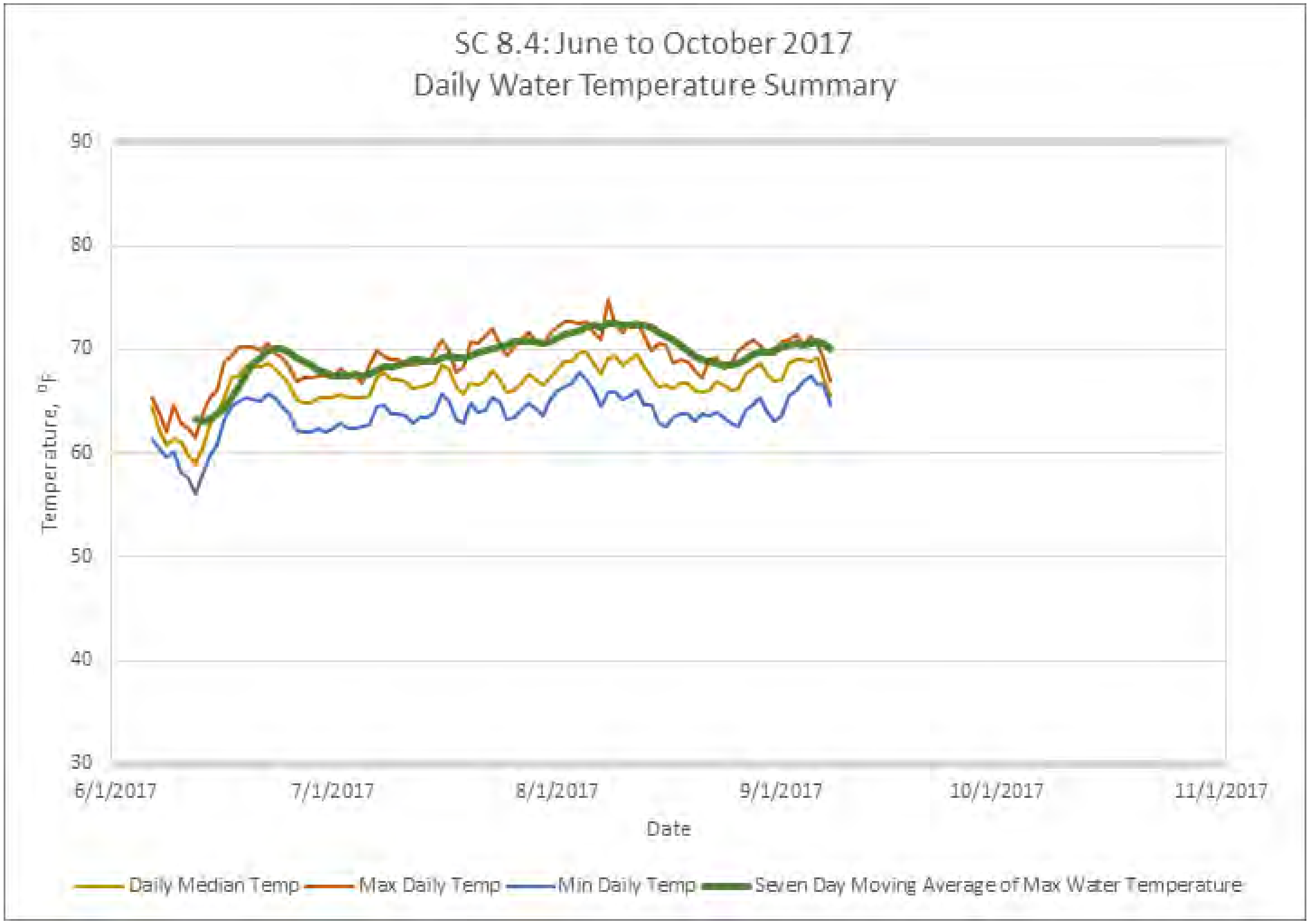

SC 8.0: June to October 2017
Daily Water Temperature Hours > 70°F
24
18
12
6
0
Hours per Day > 70°F
6/1/2017
7/1/2017
8/1/2017
9/1/2017
10/1/2017
11/1/2017
Date
Hours > 70 °F


SC 8.0: June to October 2017
Daily Water Temperature Summary
90
80
70
60
50
40
30
Temperature, ºF
6/1/2017
7/1/2017
8/1/2017
9/1/2017
10/1/2017
11/1/2017
Date
Daily Median Temp
Max Daily Temp
Min Daily Temp
Seven Day Moving Average of Max Water Temperature

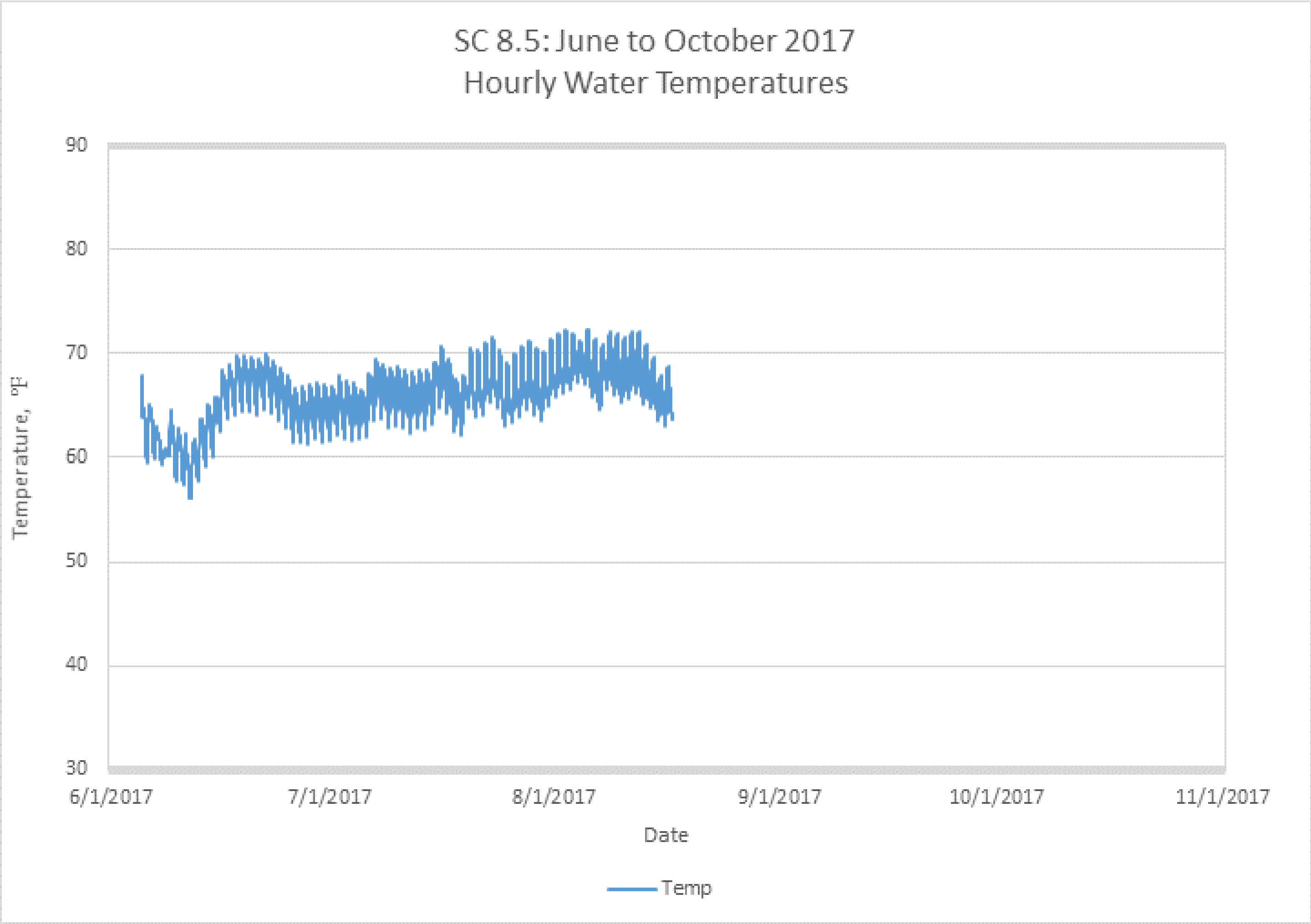

SC 8.4: June to October 2017
Hourly Water Temperatures
90
80
70
60
50
40
30
Temperature, °F
6/1/2017
7/1/2017
8/1/2017
9/1/2017
10/1/2017
11/1/2017
Date
Temp



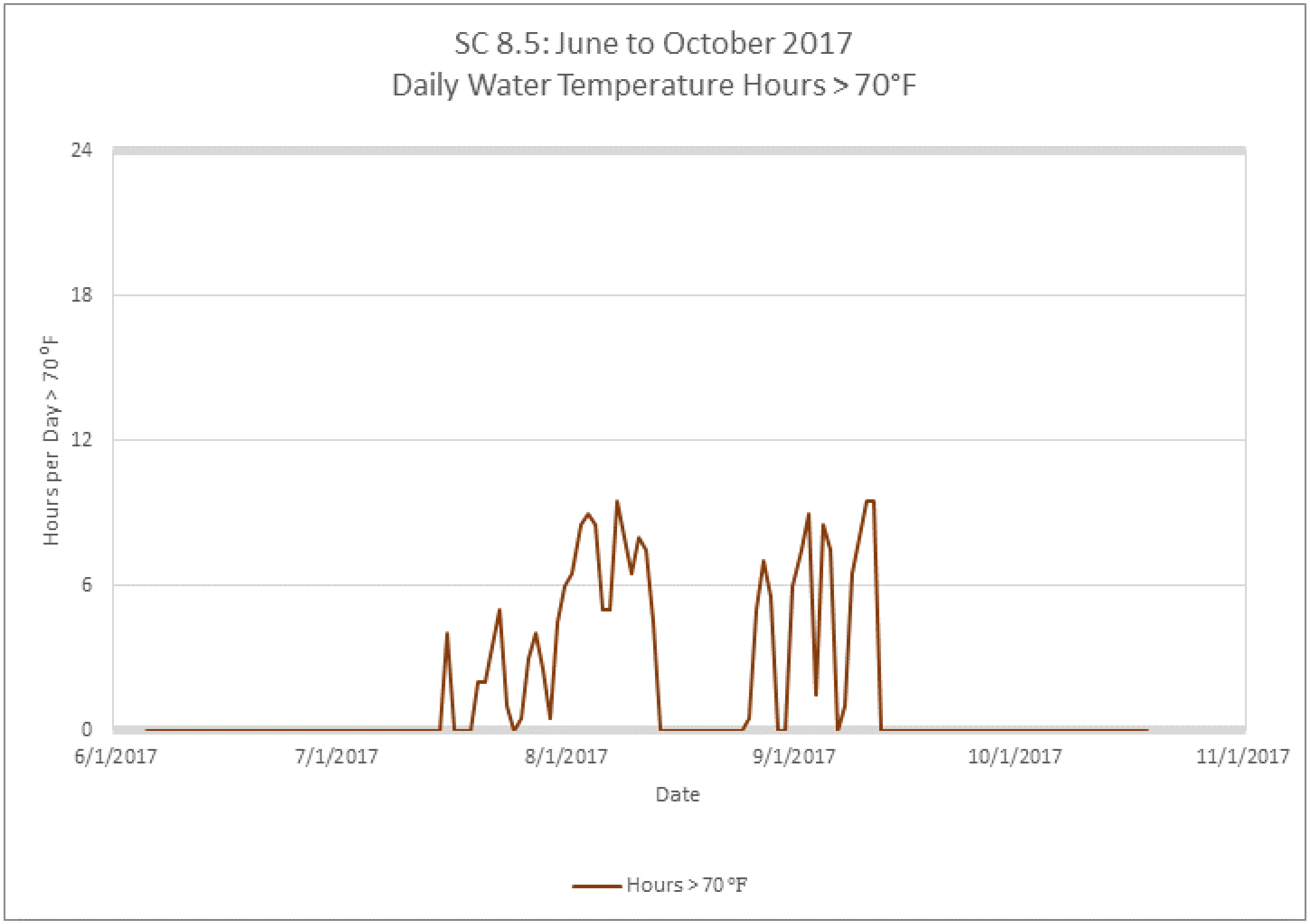
SC 8.4: June to October 2017
Daily Water Temperature Hours > 70°F
Hours per Day > 70°F
24
18
12
6
0
6/1/2017
7/1/2017
8/1/2017
9/1/2017
10/1/2017
11/1/2017
Date
Hours > 70 °F



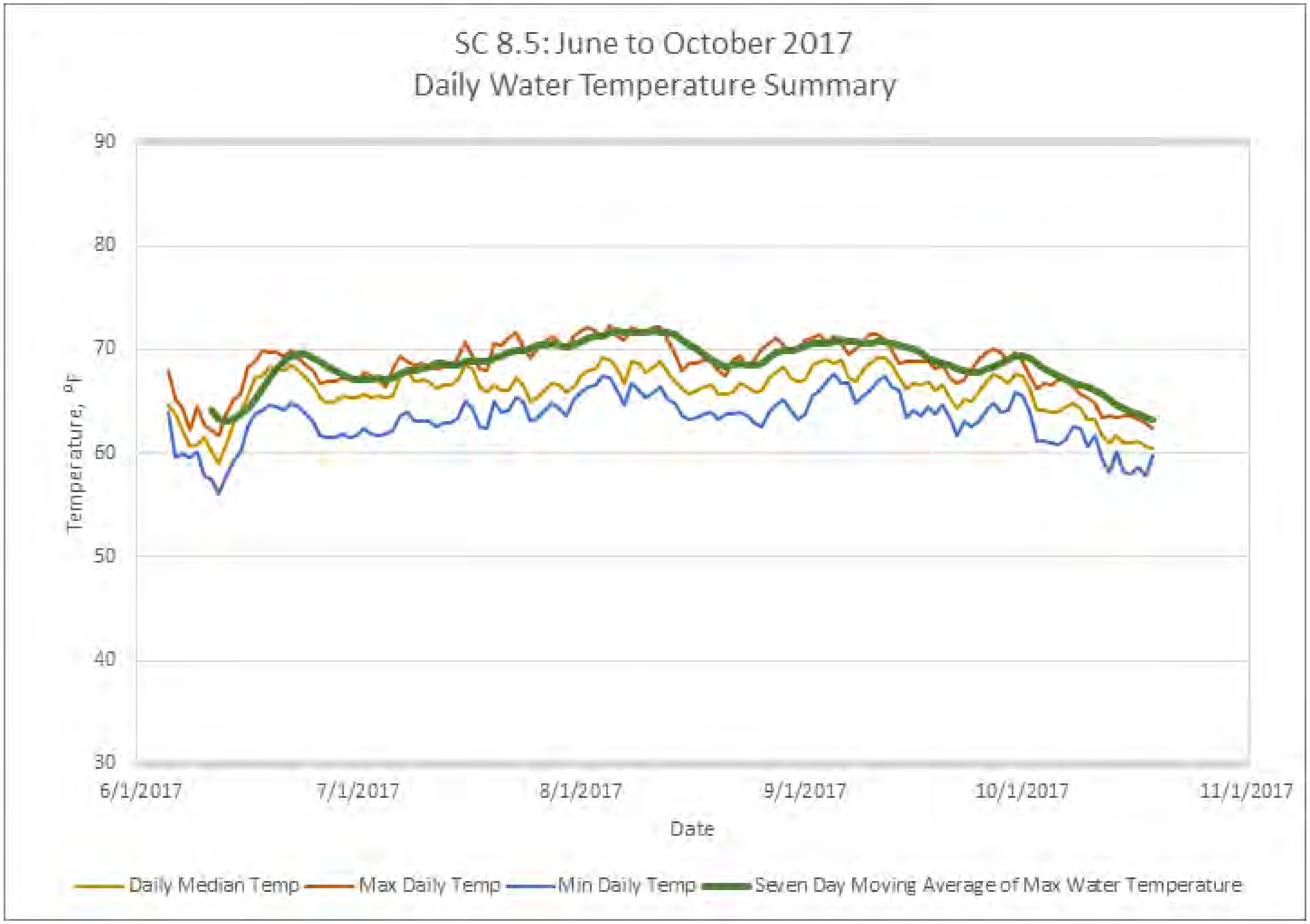
SC 8.4: June to October 2017
Daily Water Temperature Summary
90
80
70
60
50
40
30
Temperature, °F
6/1/2017
7/1/2017
8/1/2017
9/1/2017
10/1/2017
11/1/2017
Date
Daily Median Temp
Max Daily Temp
Min Daily Temp
Seven Day Moving Average of Max Water Temperature



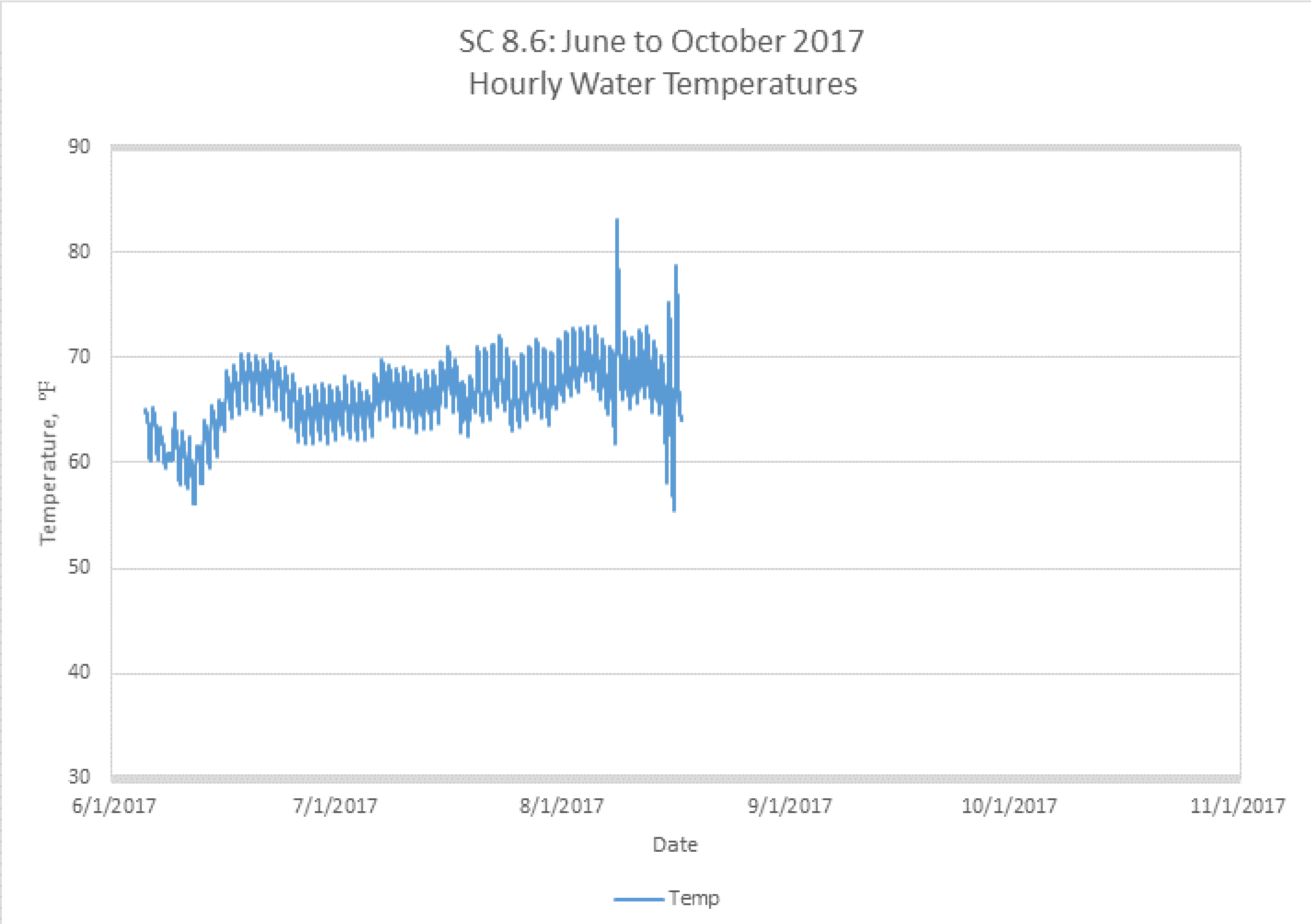
SC 8.5: June to October 2017
Hourly Water Temperatures
90
80
70
60
50
40
30
Temperature, °F
6/1/2017
7/1/2017
8/1/2017
9/1/2017
10/1/2017
11/1/2017
Date
Temp



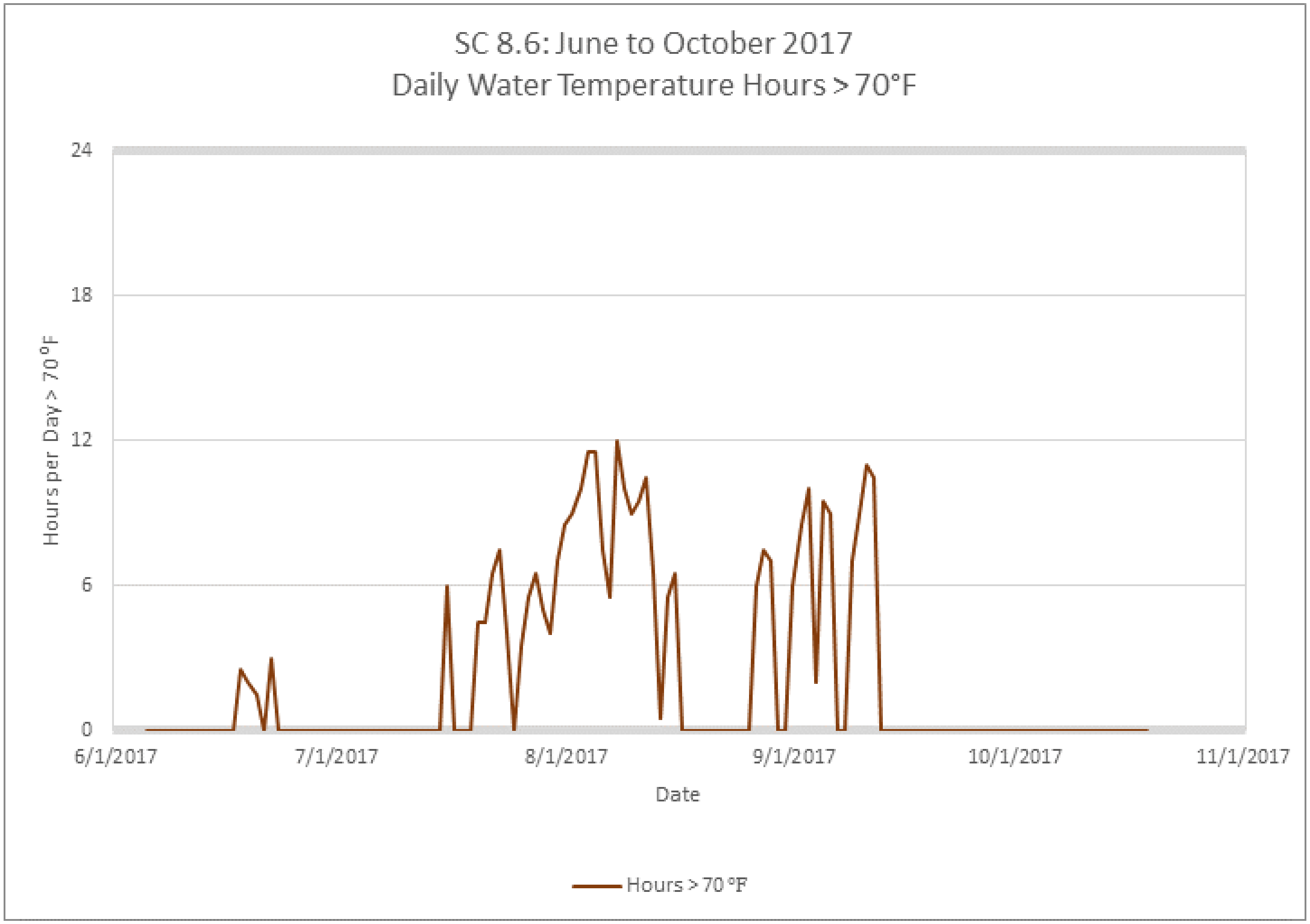
SC 8.5: June to October 2017
Daily Water Temperature Hours > 70°F
24
18
12
6
0
Hours per Day > 70°F
6/1/2017
7/1/2017
8/1/2017
9/1/2017
10/1/2017
11/1/2017
Date
Hours > 70 °F

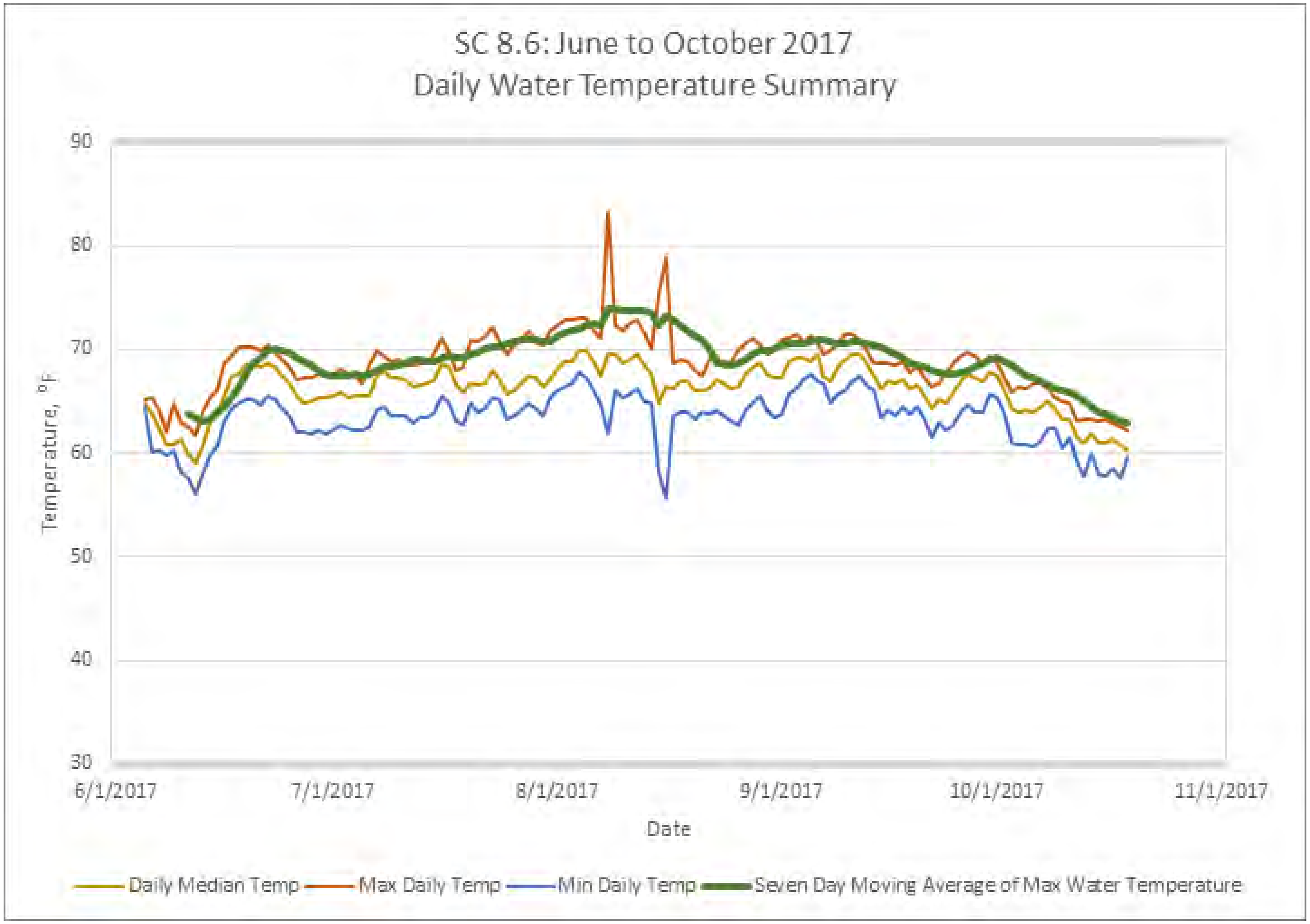


SC 8.5: June to October 2017
Daily Water Temperature Summary
90
80
70
60
50
40
30
Temperature, °F
6/1/2017
7/1/2017
8/1/2017
9/1/2017
10/1/2017
11/1/2017
Date
Daily Median Temp
Max Daily Temp
Min Daily Temp
Seven Day Moving Average of Max Water Temperature

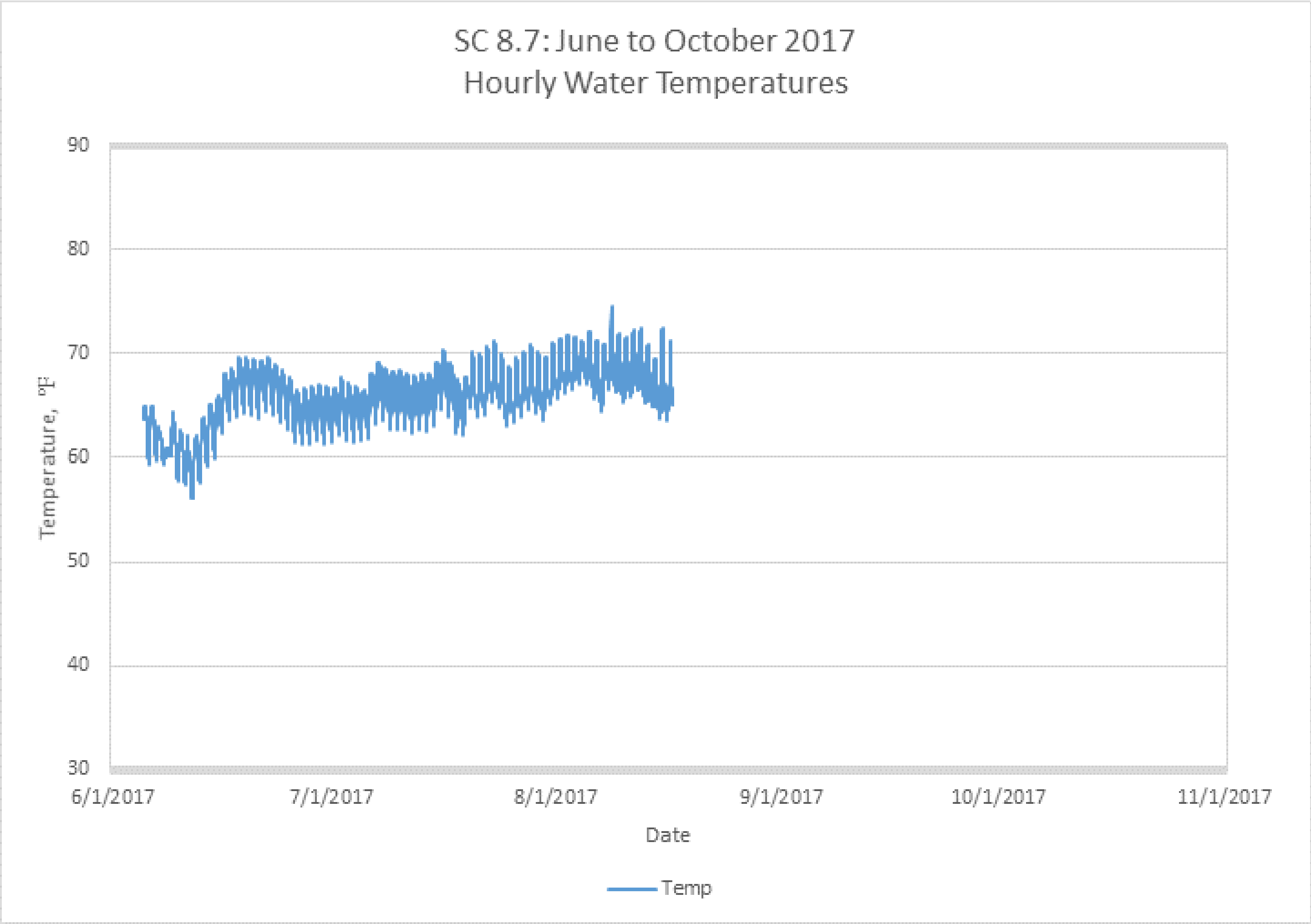


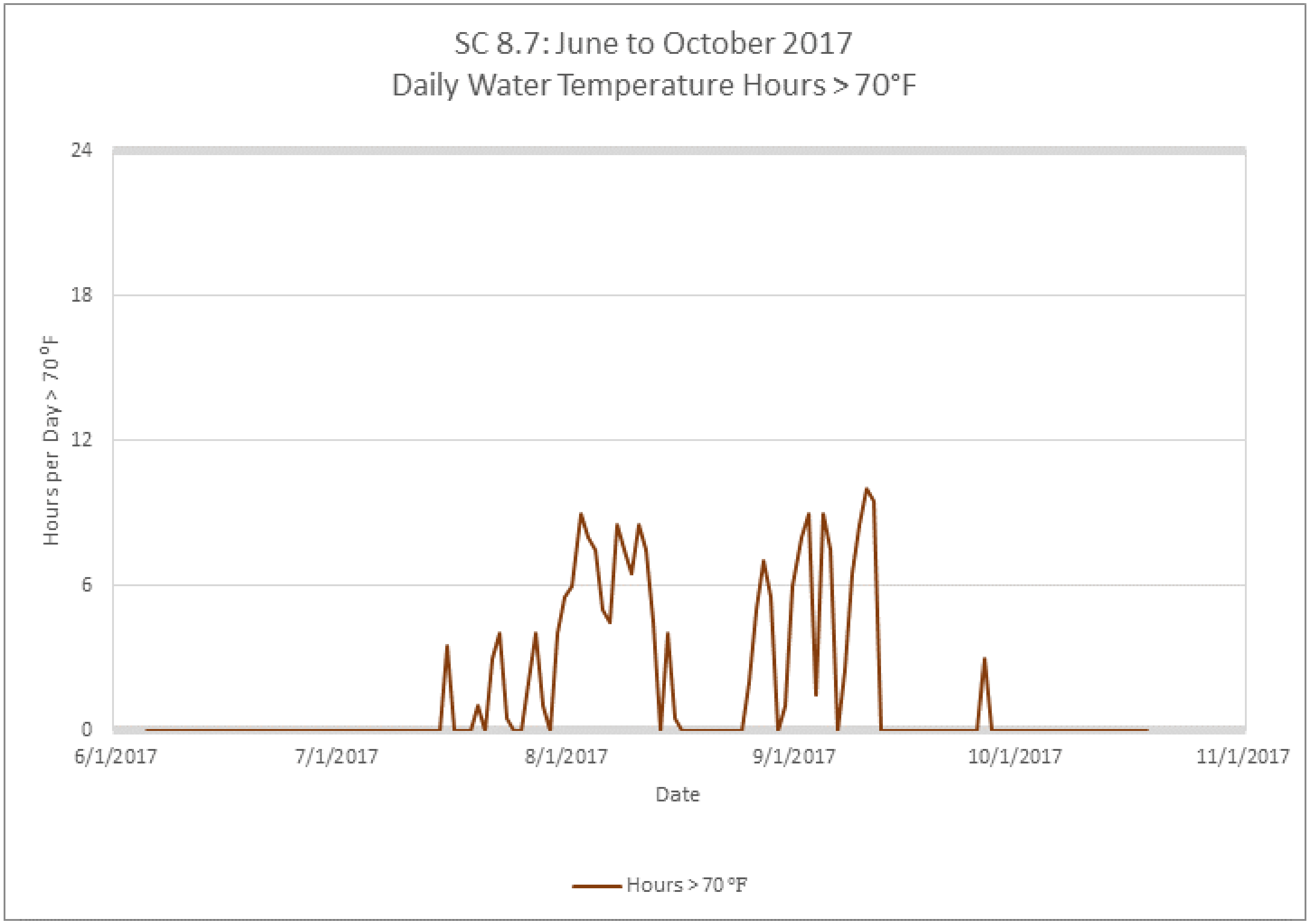
SC 8.6: June to October 2017
Hourly Water Temperatures
90
80
70
60
50
40
30
Temperature, °F
6/1/2017
7/1/2017
8/1/2017
9/1/2017
10/1/2017
11/1/2017
Date
Temp


SC 8.6: June to October 2017
Daily Water Temperature Hours > 70°F
24
18
12
6
0
Hours per Day > 70°F
6/1/2017
7/1/2017
8/1/2017
9/1/2017
10/1/2017
11/1/2017
Date
Hours > 70°F

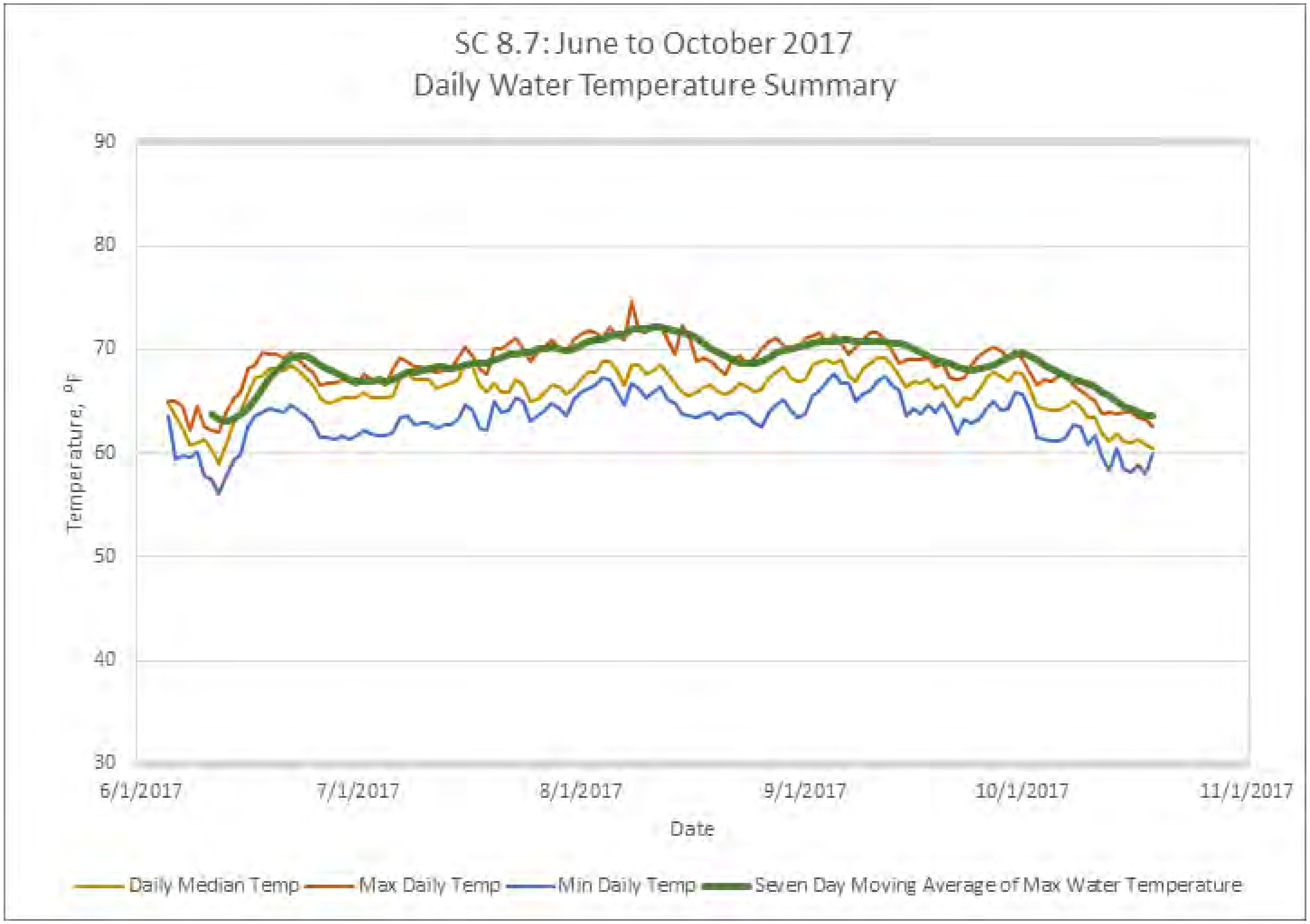


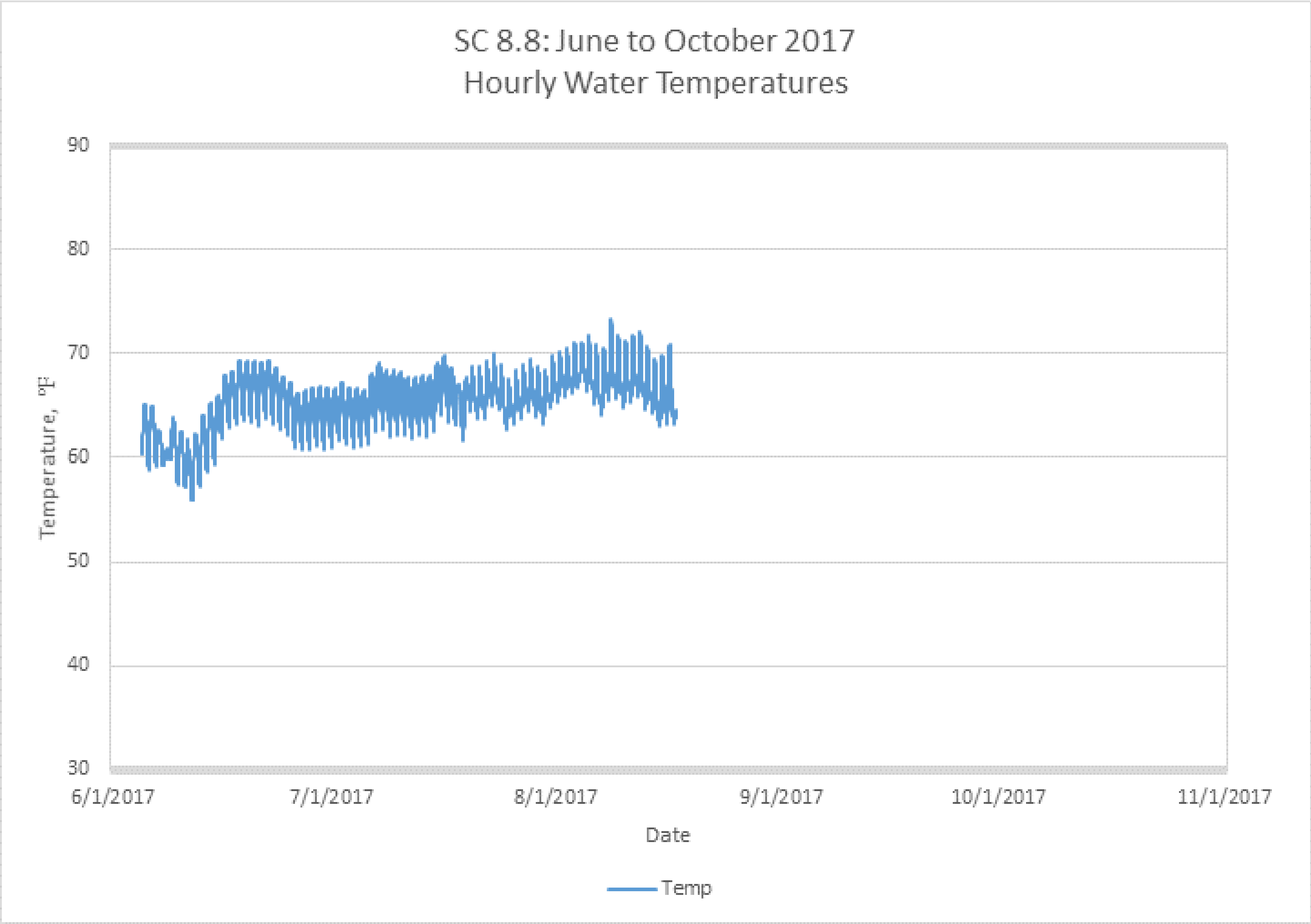
SC 8.6: June to October 2017
Daily Water Temperature Summary
90
80
70
60
50
40
30
Temperature, °F
6/1/2017
7/1/2017
8/1/2017
9/1/2017
10/1/2017
11/1/2017
Date
Daily Median Temp
Max Daily Temp
Min Daily Temp
Seven Day Moving Average of Max Water Temperature


SC 8.7: June to October 2017
Hourly Water Temperatures
90
80
70
60
50
40
30
Temperature, °F
6/1/2017
7/1/2017
8/1/2017
9/1/2017
10/1/2017
11/1/2017
Date
Temp



SC 8.7: June to October 2017
Daily Water Temperature Hours > 70°F
24
18
12
6
0
Hours per Day > 70°F
6/1/2017
7/1/2017
8/1/2017
9/1/2017
10/1/2017
11/1/2017
Date
Hours > 70 °F


SC 8.7: June to October 2017
Daily Water Temperature Summary
90
80
70
60
50
40
30
Temperature, °F
6/1/2017
7/1/2017
8/1/2017
9/1/2017
10/1/2017
11/1/2017
Date
Daily Median Temp
Max Daily Temp
Min Daily Temp
Seven Day Moving Average of Max Water Temperature


SC 8.8: June to October 2017
Hourly Water Temperatures
90
80
70
60
50
40
30
Temperature, °F
6/1/2017
7/1/2017
8/1/2017
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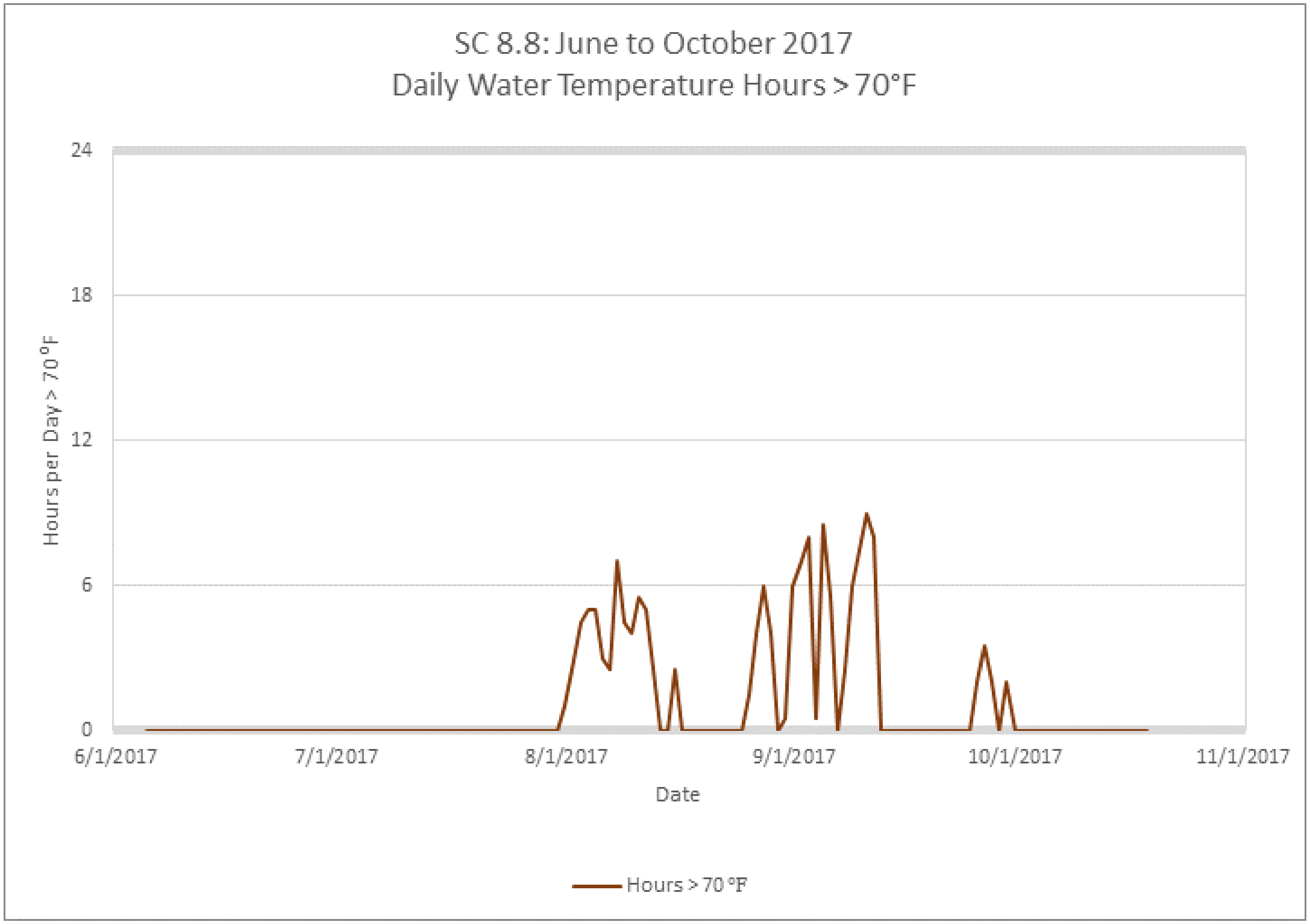
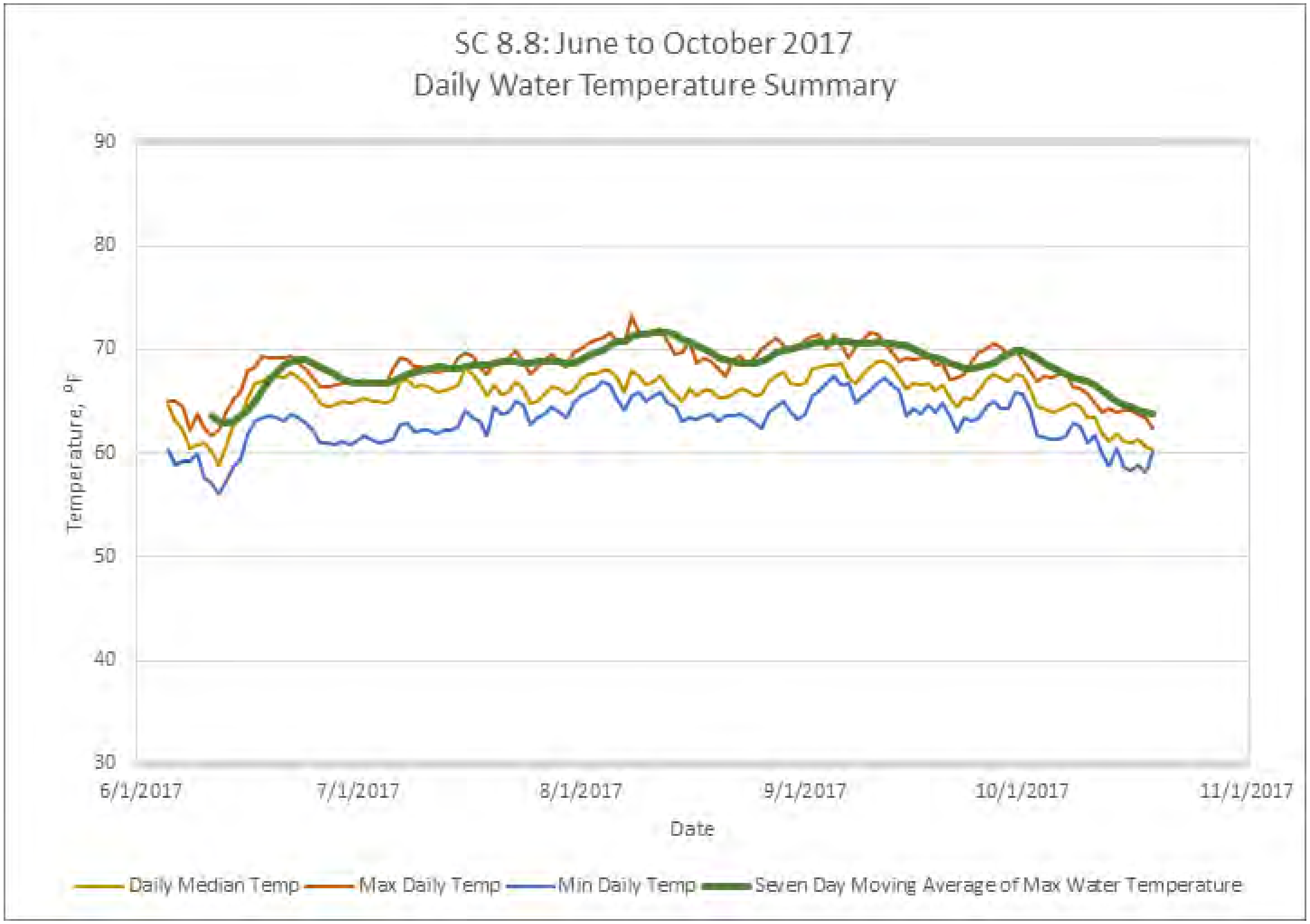
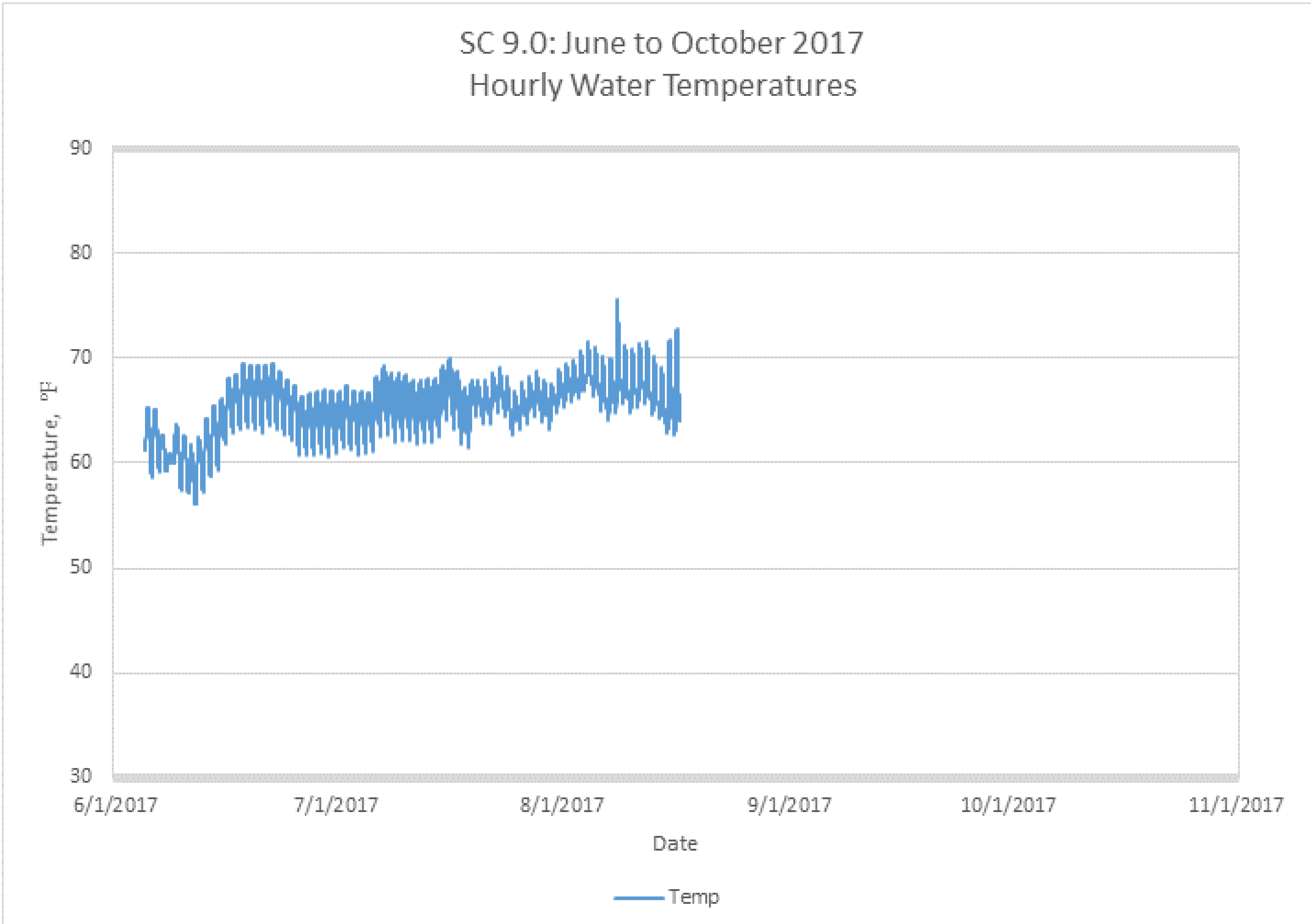
10/1/2017
11/1/2017
Date
Temp

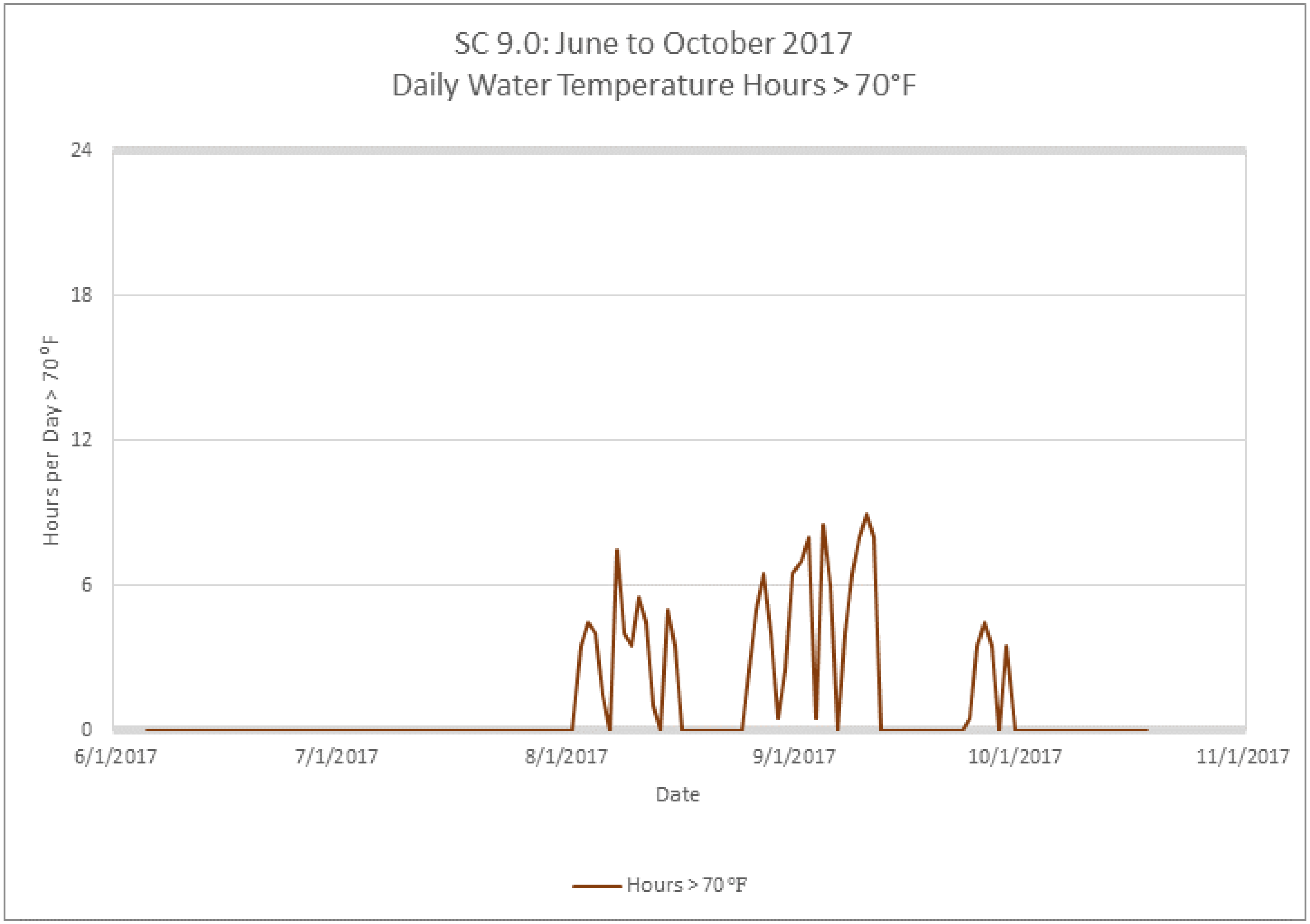


SC 8.8: June to October 2017
Daily Water Temperature Hours > 70°F
24
18
12
6
0
Hours per Day > 70°F
6/1/2017
7/1/2017
8/1/2017
9/1/2017
10/1/2017
11/1/2017
Date
Hours > 70 °F


SC 8.8: June to October 2017
Daily Water Temperature Summary
90
80
70
60
50
40
30
Temperature, °F
6/1/2017
7/1/2017
8/1/2017
9/1/2017
10/1/2017
11/1/2017
Date
Daily Median Temp
Max Daily Temp
Min Daily Temp
Seven Day Moving Average of Max Water Temperature



SC 9.0: June to October 2017
Hourly Water Temperatures
Temperature, °F
90
80
70
60
50
40
30
6/1/2017
7/1/2017
8/1/2017
9/1/2017
10/1/2017
11/1/2017
Date
Temp


SC 9.0: June to October 2017
Daily Water Temperature Hours > 70°F
24
18
12
6
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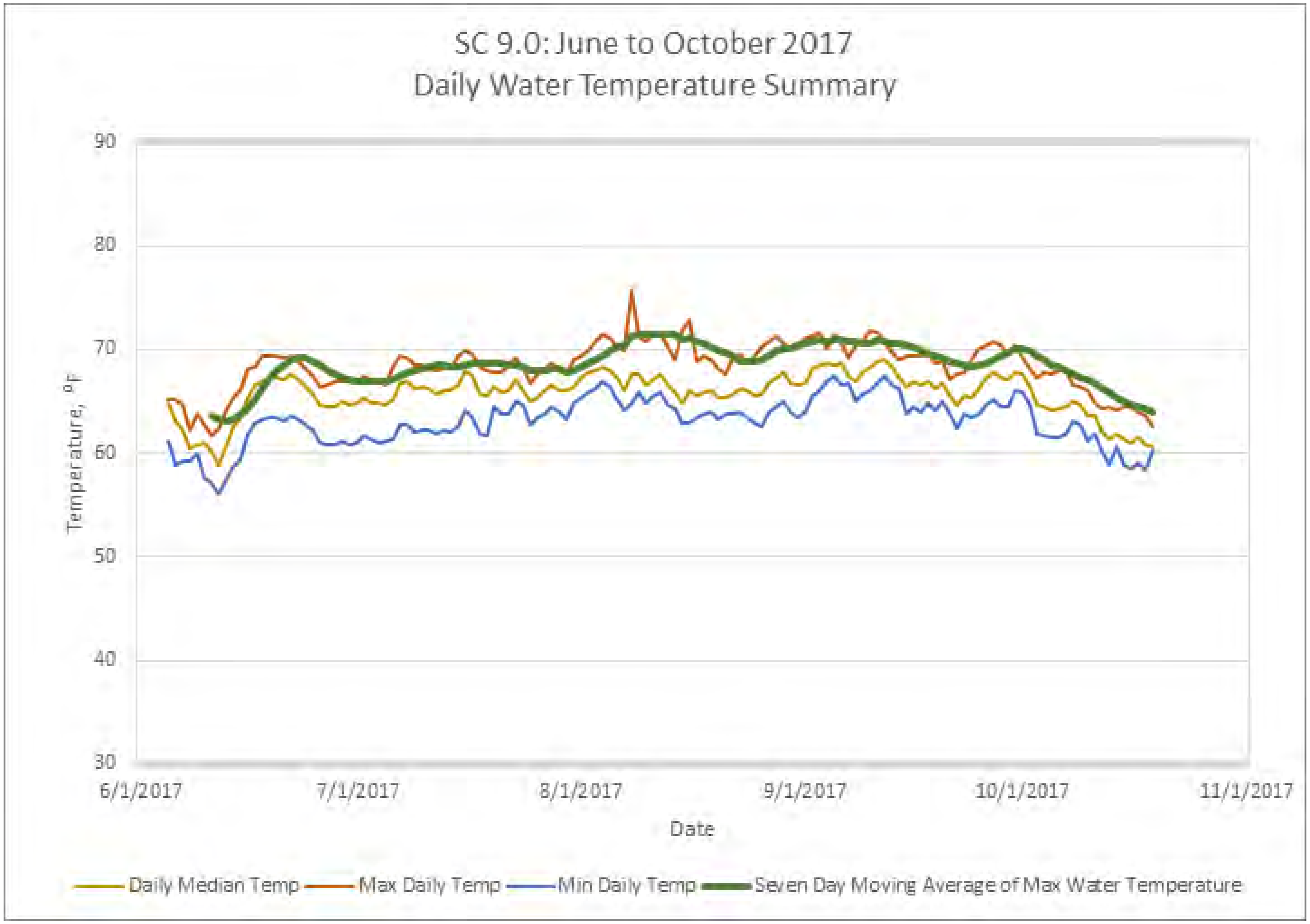
Hours per Day > 70°F
6/1/2017
7/1/2017
8/1/2017
9/1/2017
10/1/2017
11/1/2017
Date
Hours > 70 °F


SC 9.0: June to October 2017
Daily Water Temperature Summary
90
80
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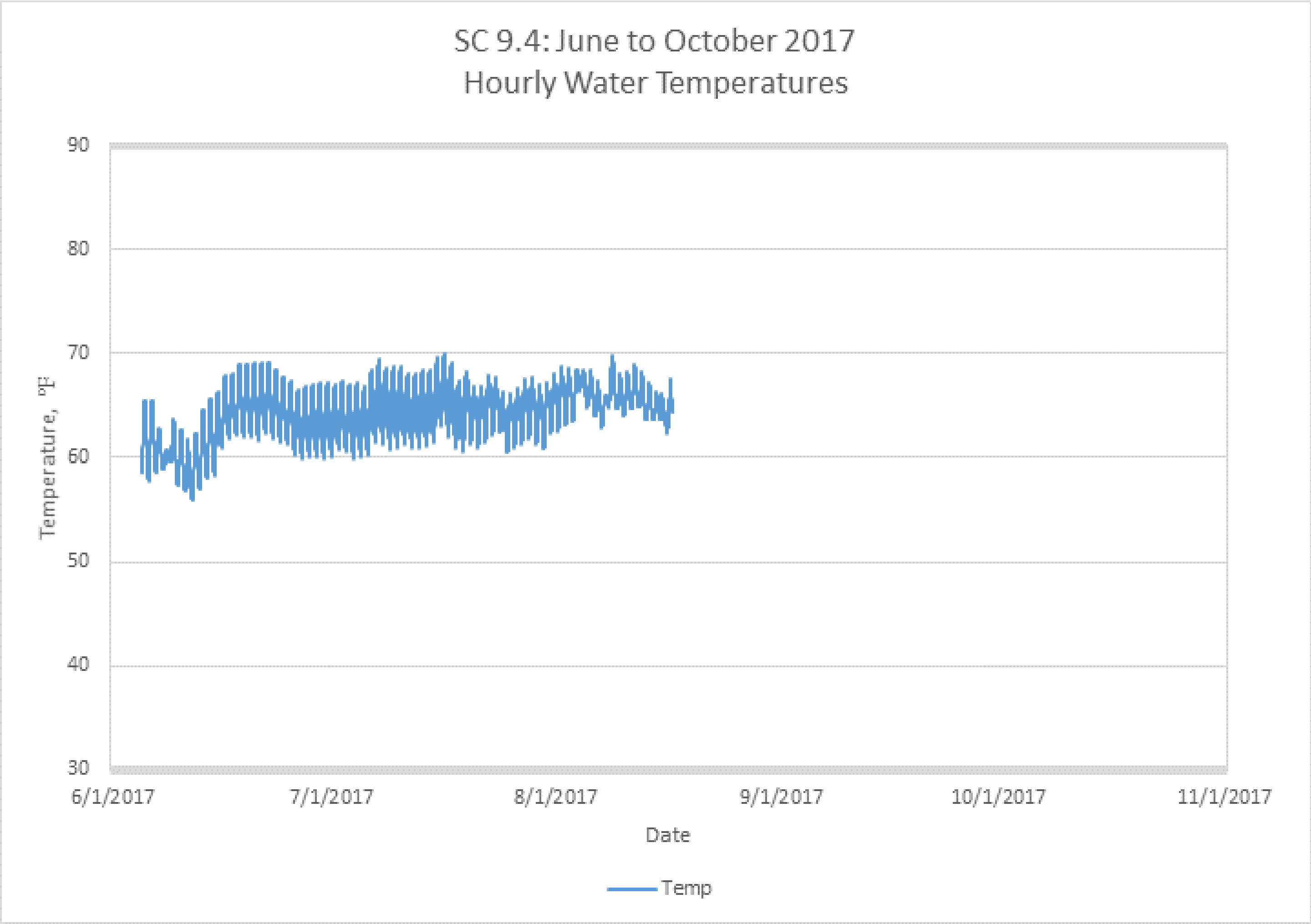
60
50
40
30
Temperature, °F
6/1/2017
7/1/2017
8/1/2017
9/1/2017
10/1/2017
11/1/2017
Date
Daily Median Temp
Max Daily Temp
Min Daily Temp
Seven Day Moving Average of Max Water Temperature


SC 9.4: June to October 2017
Hourly Water Temperatures
90
80
70
60
50
40
30
Temperature, °F
6/1/2017
7/1/2017
8/1/2017
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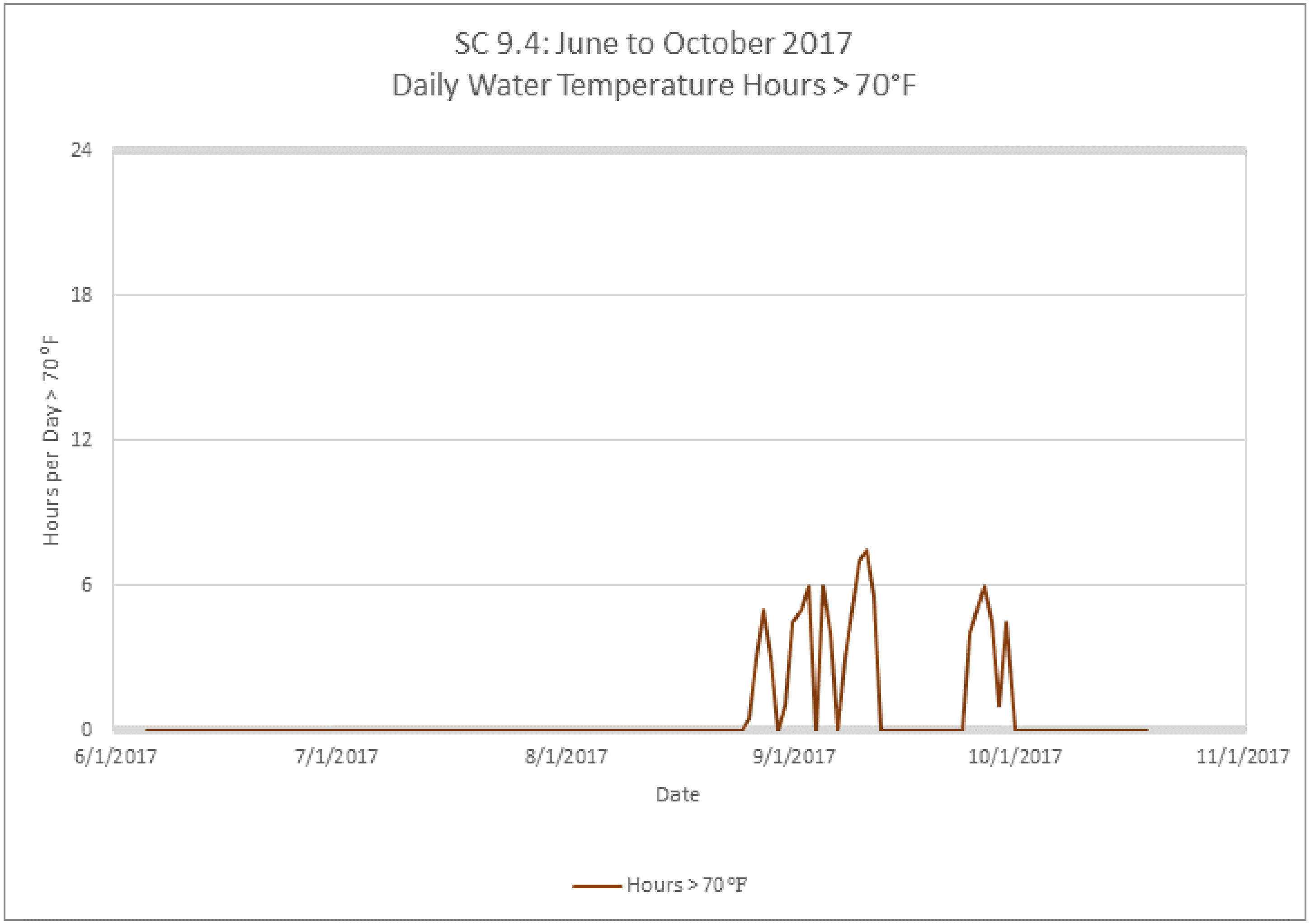
10/1/2017
11/1/2017
Date
Temp



SC 9.4: June to October 2017
Daily Water Temperature Hours > 70°F
24
18
12
6
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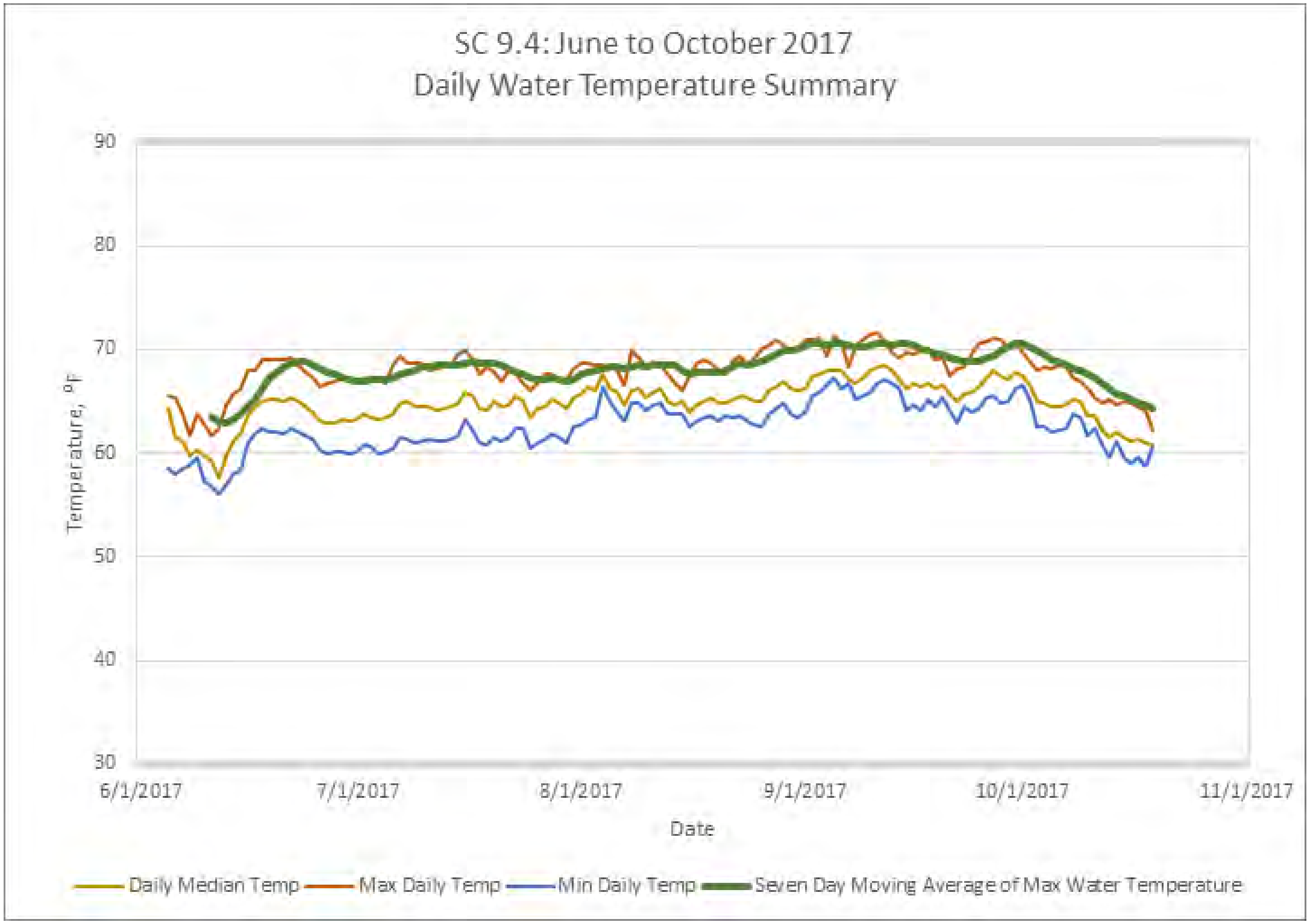
Hours per Day > 70°F
6/1/2017
7/1/2017
8/1/2017
9/1/2017
10/1/2017
11/1/2017
Date
Hours > 70 °F


SC 9.4: June to October 2017
Daily Water Temperature Summary
90
80
70
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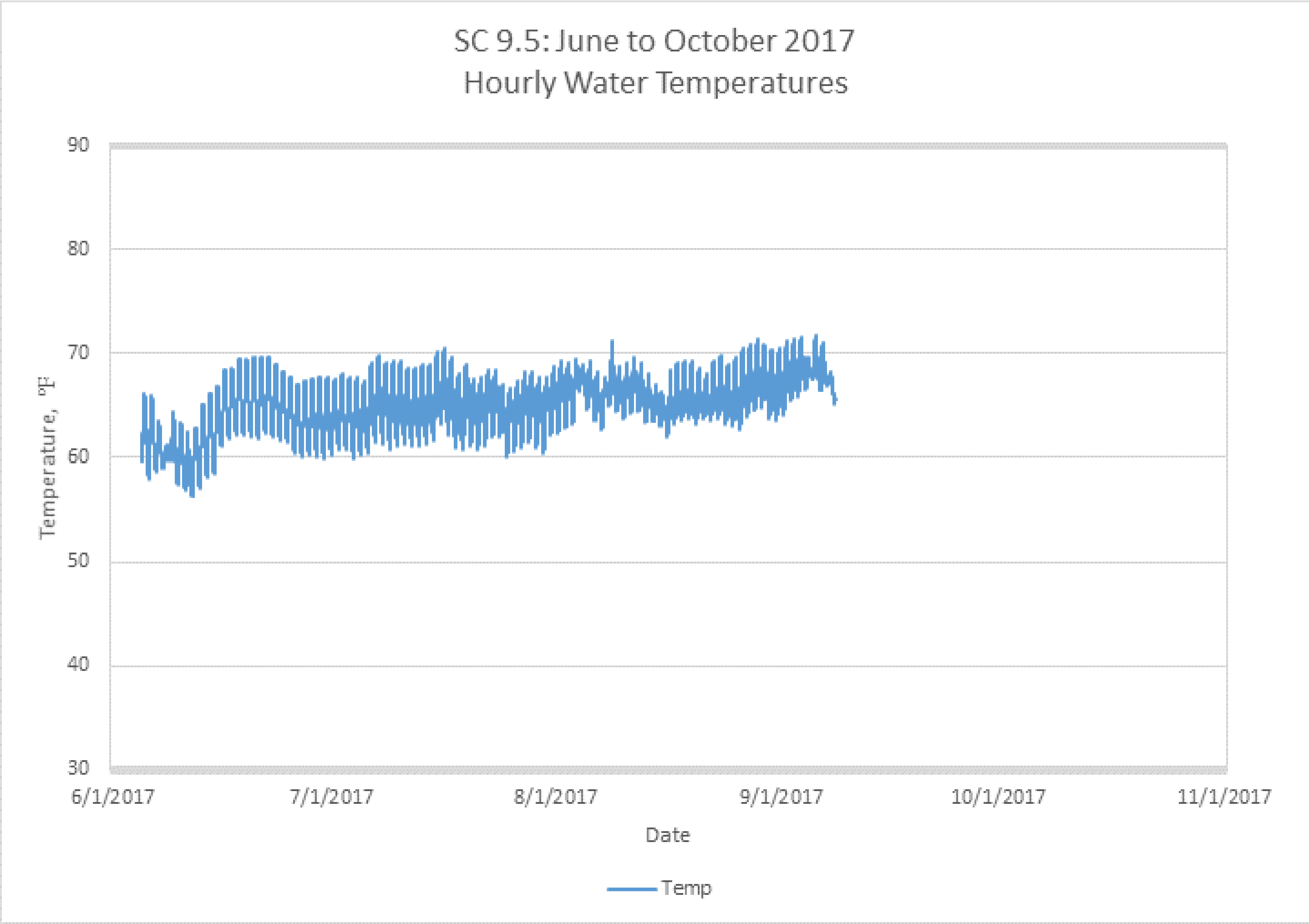
30
Temperature, ºF
6/1/2017
7/1/2017
8/1/2017
9/1/2017
10/1/2017
11/1/2017
Date
Daily Median Temp
Max Daily Temp
Min Daily Temp
Seven Day Moving Average of Max Water Temperature


SC 9.5: June to October 2017
Hourly Water Temperatures
90
80
70
60
50
40
30
Temperature, °F
6/1/2017
7/1/2017
8/1/2017
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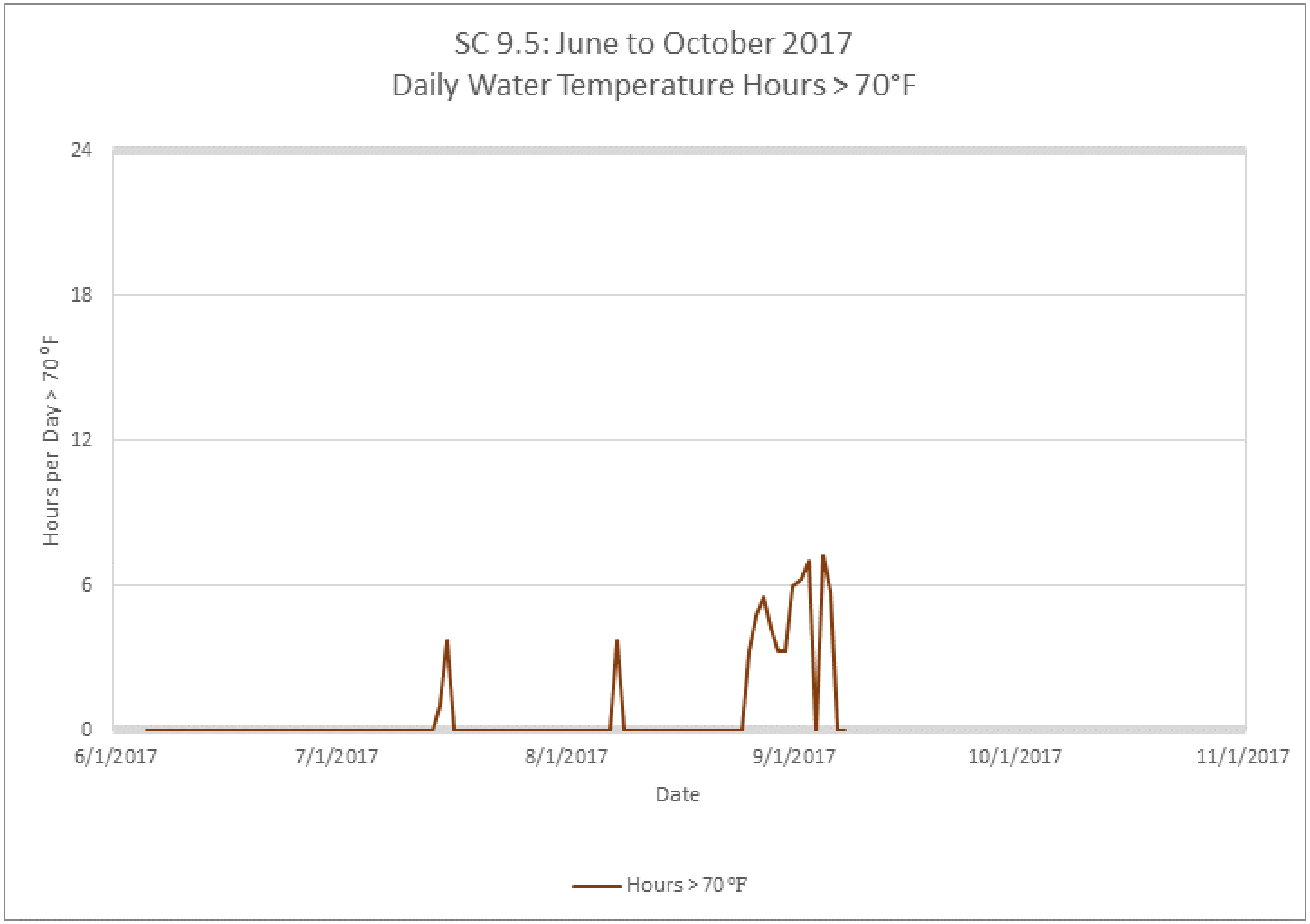
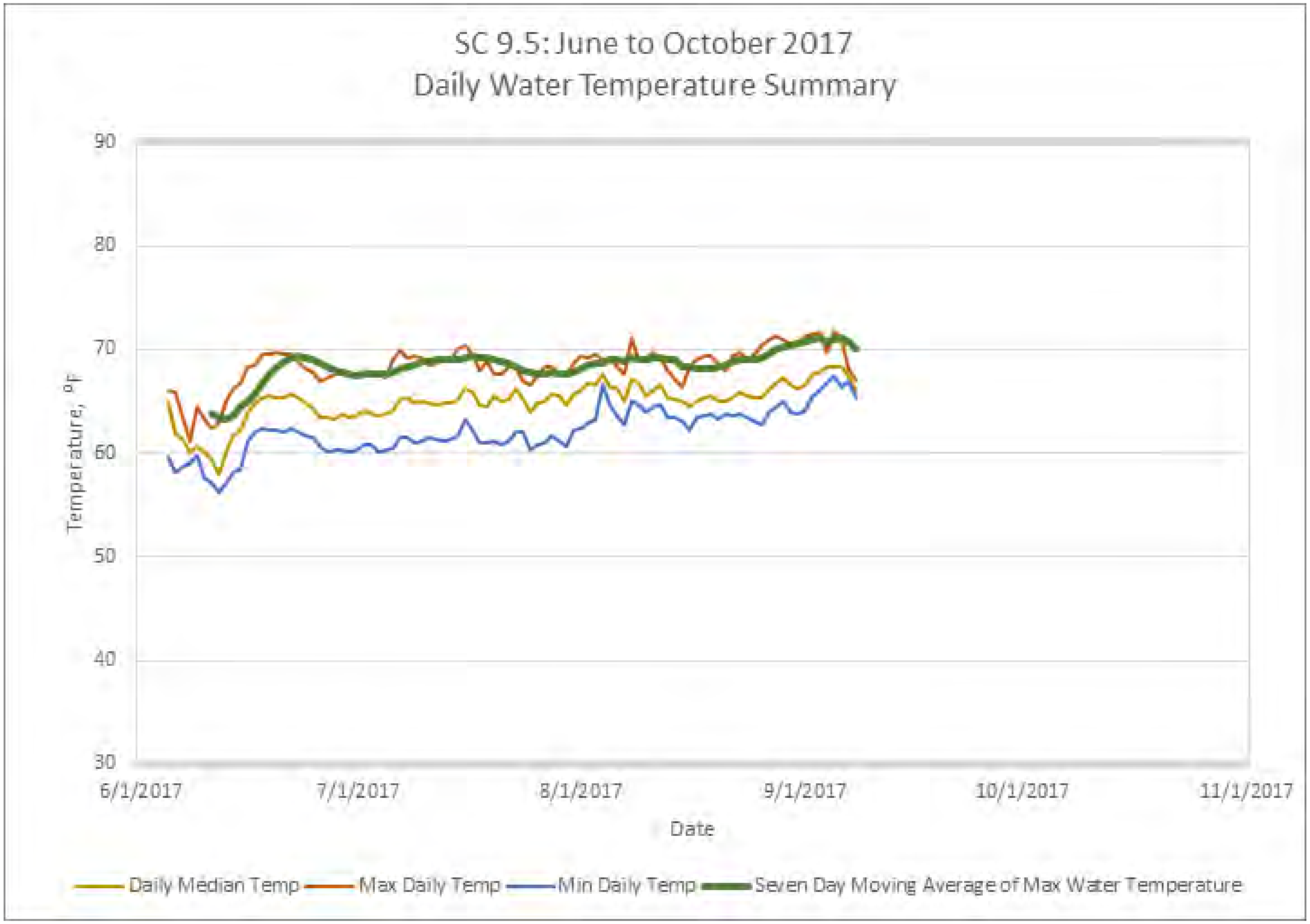
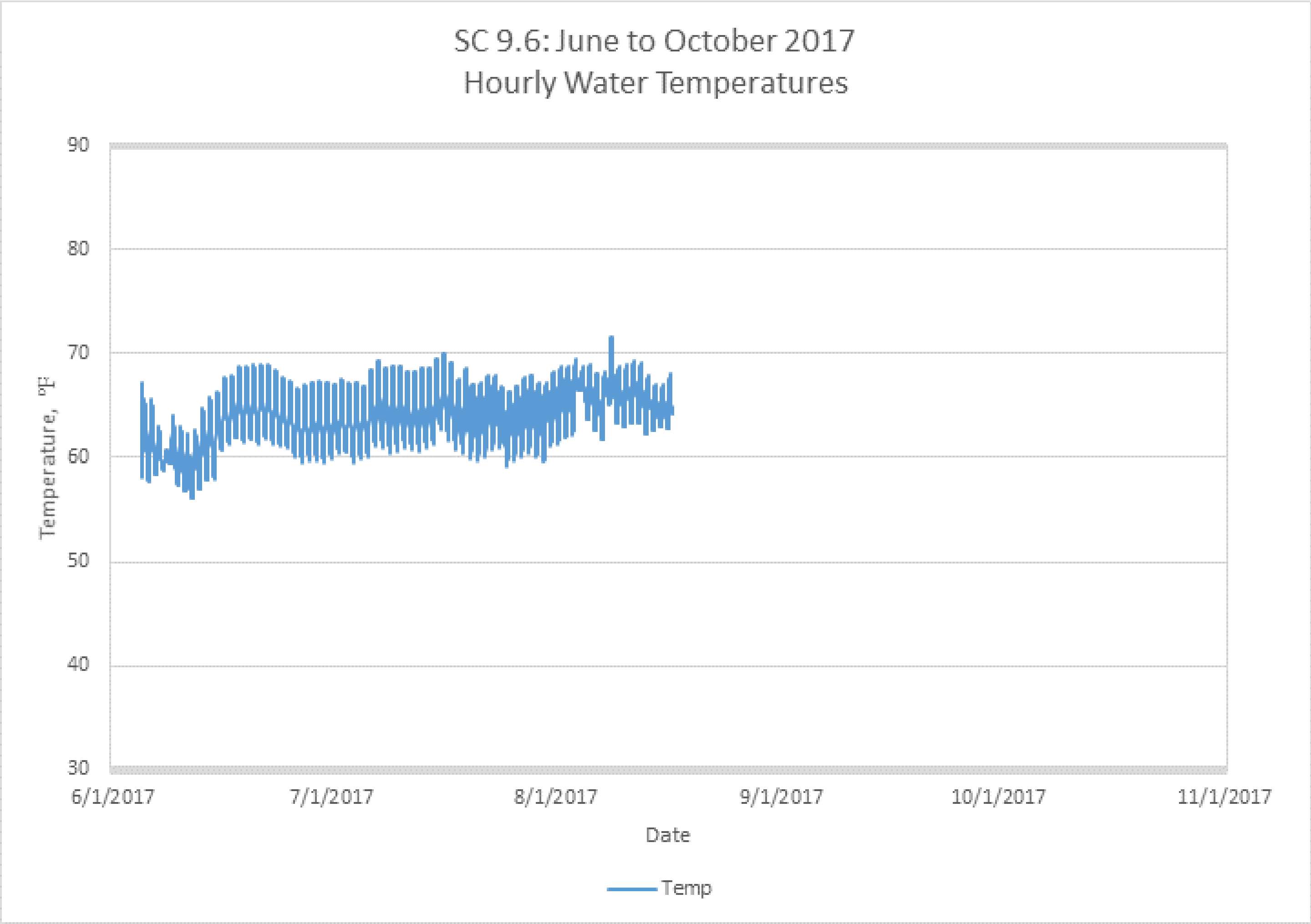
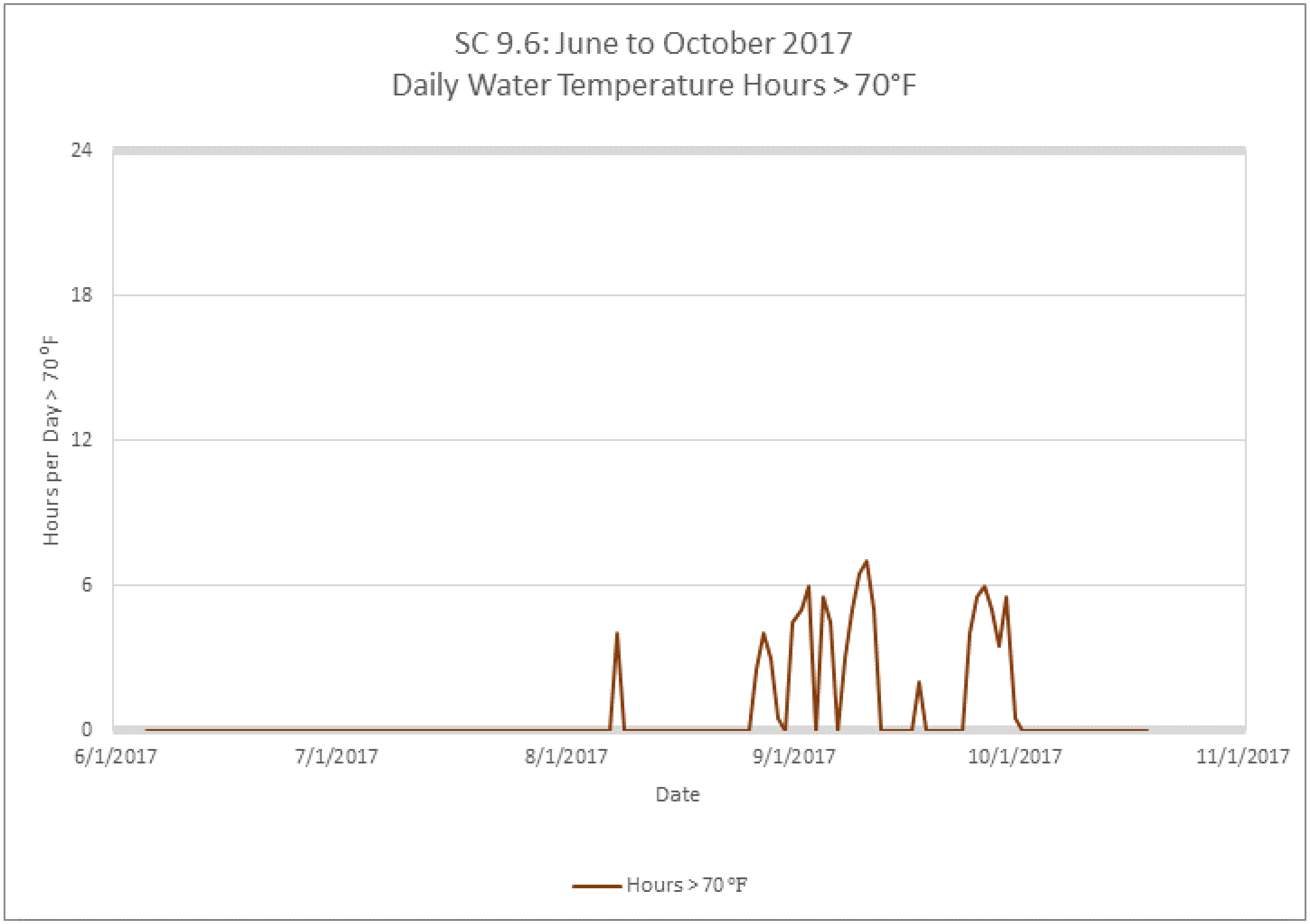
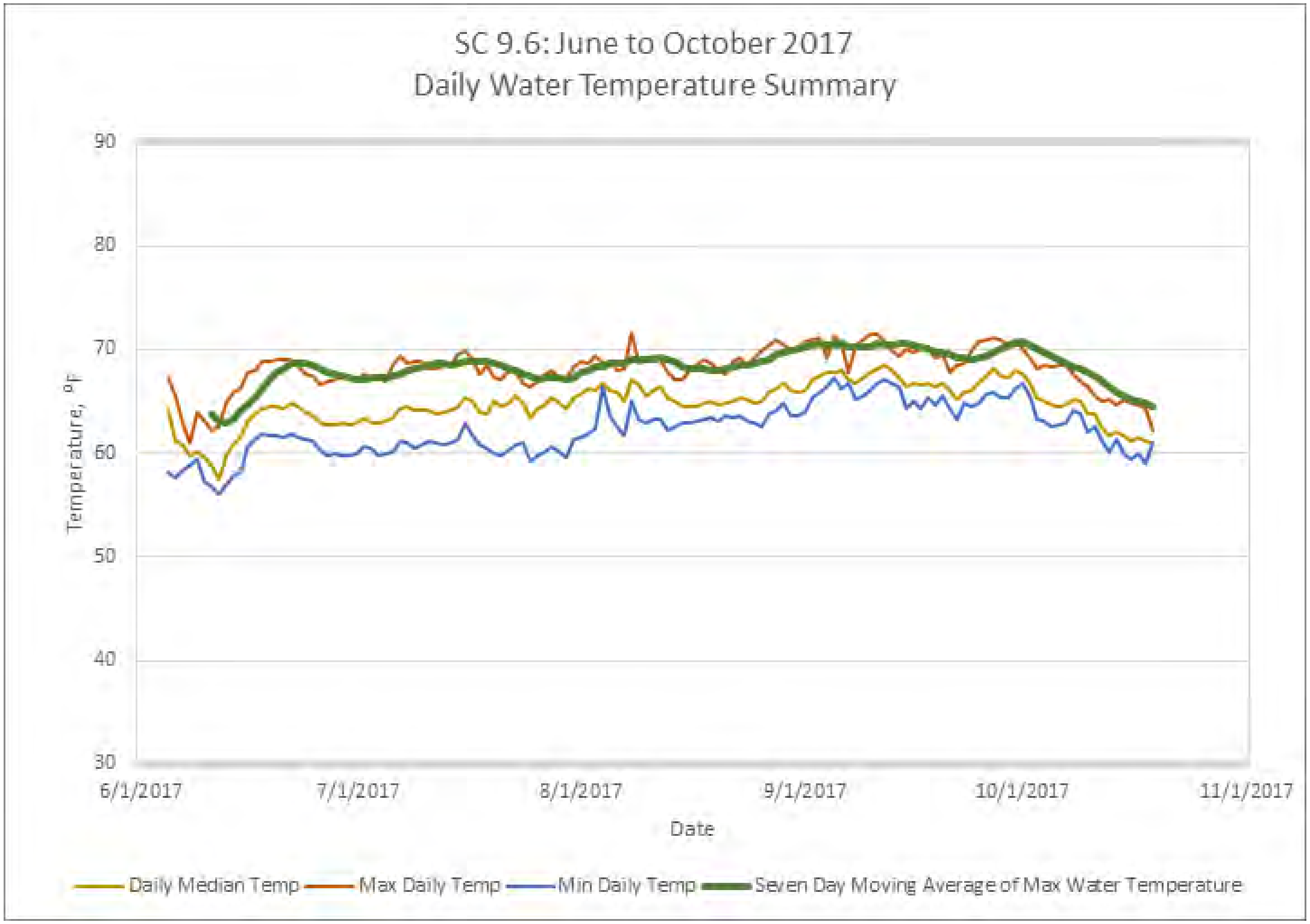
10/1/2017
11/1/2017
Date
Temp

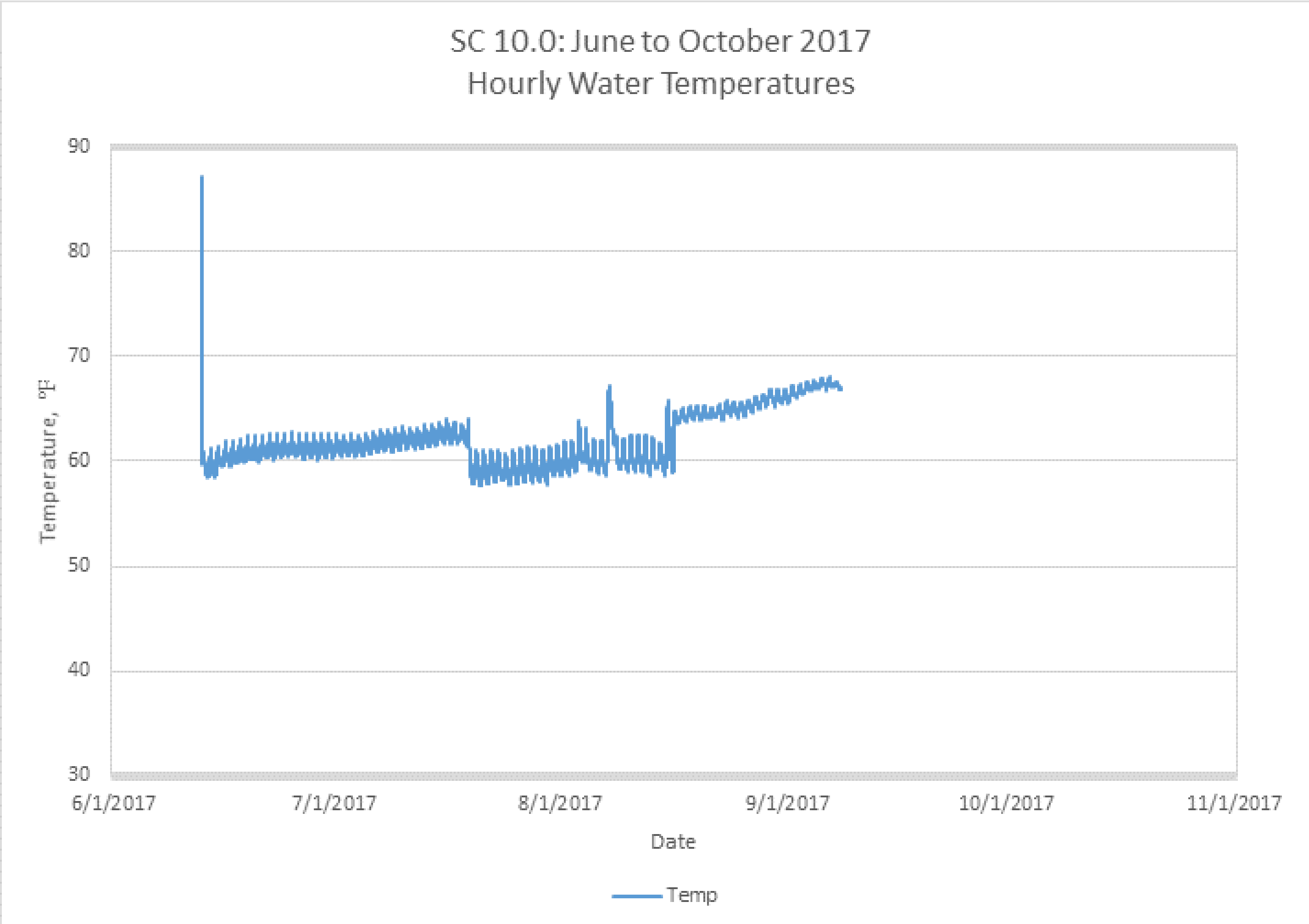

SC 9.5: June to October 2017
Daily Water Temperature Hours > 70°F
24
18
12
6
0
Hours per Day > 70°F
6/1/2017
7/1/2017
8/1/2017
9/1/2017
10/1/2017
11/1/2017
Date
Hours > 70 °F


SC 9.5: June to October 2017
Daily Water Temperature Summary
90
80
70
60
50
40
30
Temperature, °F
6/1/2017
7/1/2017
8/1/2017
9/1/2017
10/1/2017
11/1/2017
Date
Daily Median Temp
Max Daily Temp
Min Daily Temp
Seven Day Moving Average of Max Water Temperature


SC 9.6: June to October 2017
Hourly Water Temperatures
90
80
70
60
50
40
30
Temperature, °F
6/1/2017
7/1/2017
8/1/2017
9/1/2017
10/1/2017
11/1/2017
Date
Temp


SC 9.6: June to October 2017
Daily Water Temperature Hours > 70°F
24
18
12
6
0
Hours per Day > 70°F
6/1/2017
7/1/2017
8/1/2017
9/1/2017
10/1/2017
11/1/2017
Date
Hours > 70 °F


SC 9.6: June to October 2017
Daily Water Temperature Summary
90
80
70
60
50
40
30
Temperature, ºF
6/1/2017
7/1/2017
8/1/2017
9/1/2017
10/1/2017
11/1/2017
Date
Daily Median Temp
Max Daily Temp
Min Daily Temp
Seven Day Moving Average of Max Water Temperature


SC 10.0: June to October 2017
Hourly Water Temperatures
90
80
70
60
50
40
30
Temperature, °F
6/1/2017
7/1/2017
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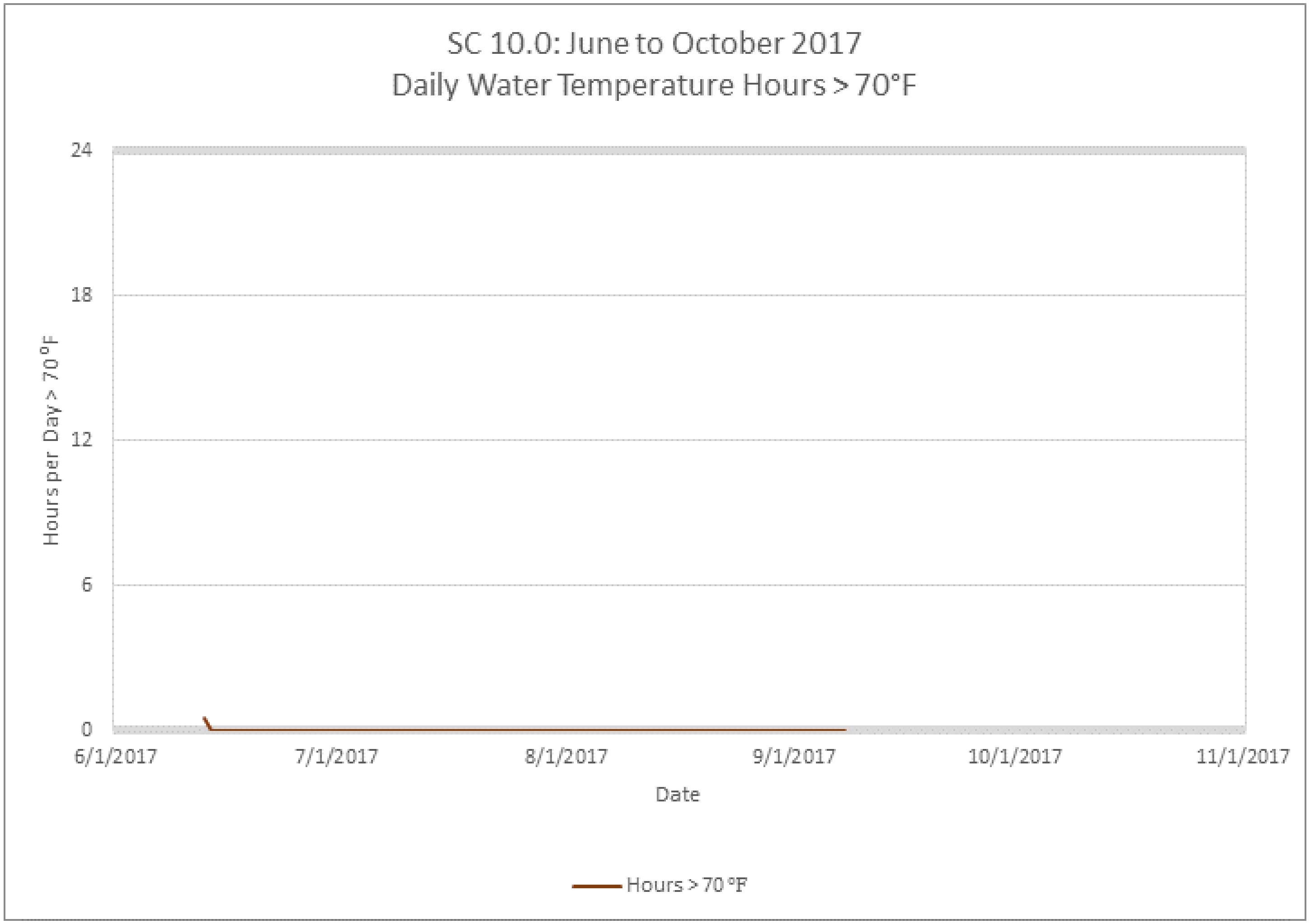
10/1/2017
11/1/2017
Date
Temp



SC 10.0: June to October 2017
Daily Water Temperature Hours > 70°F
24
18
12
6
0
Hours per Day > 70°F
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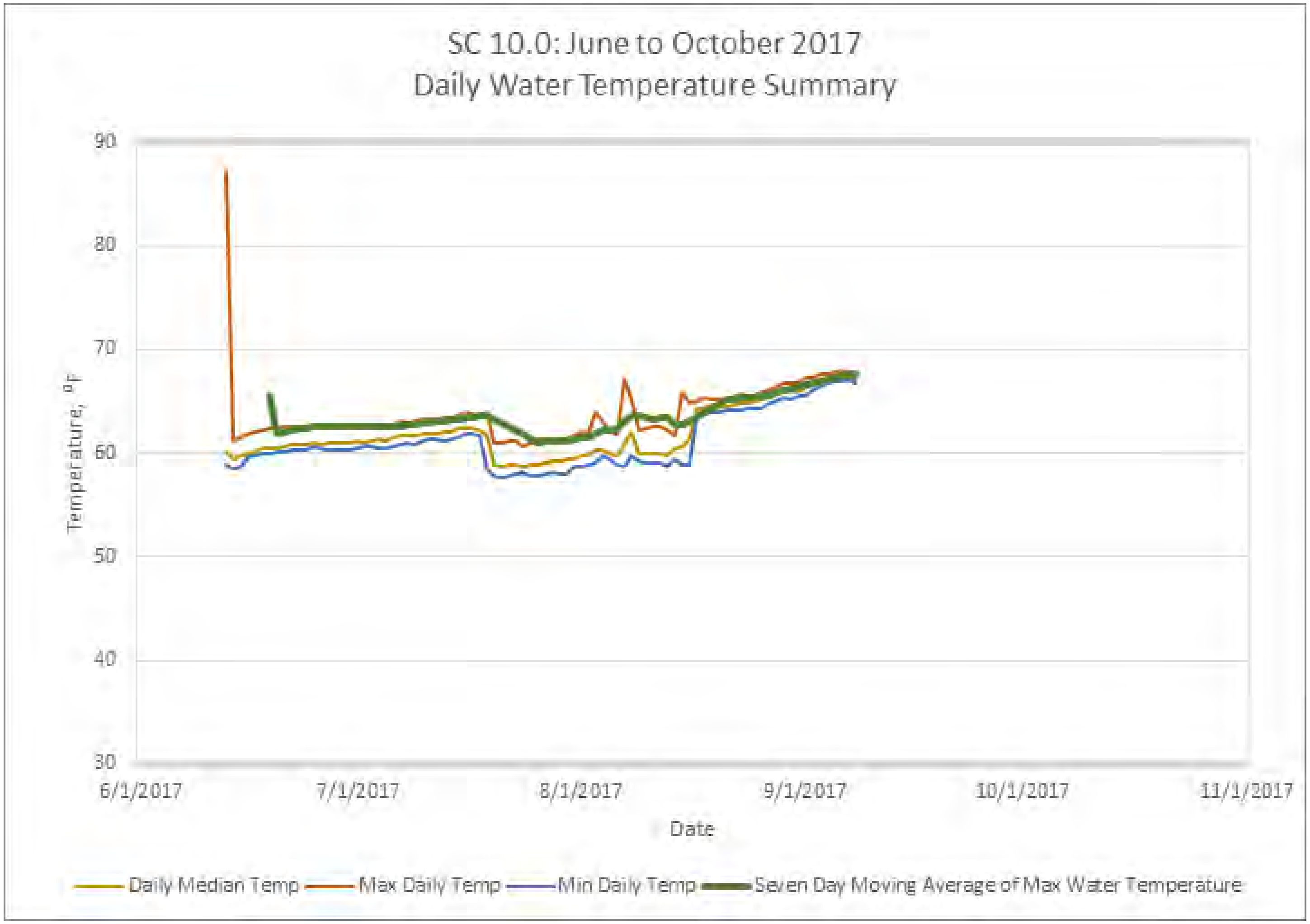
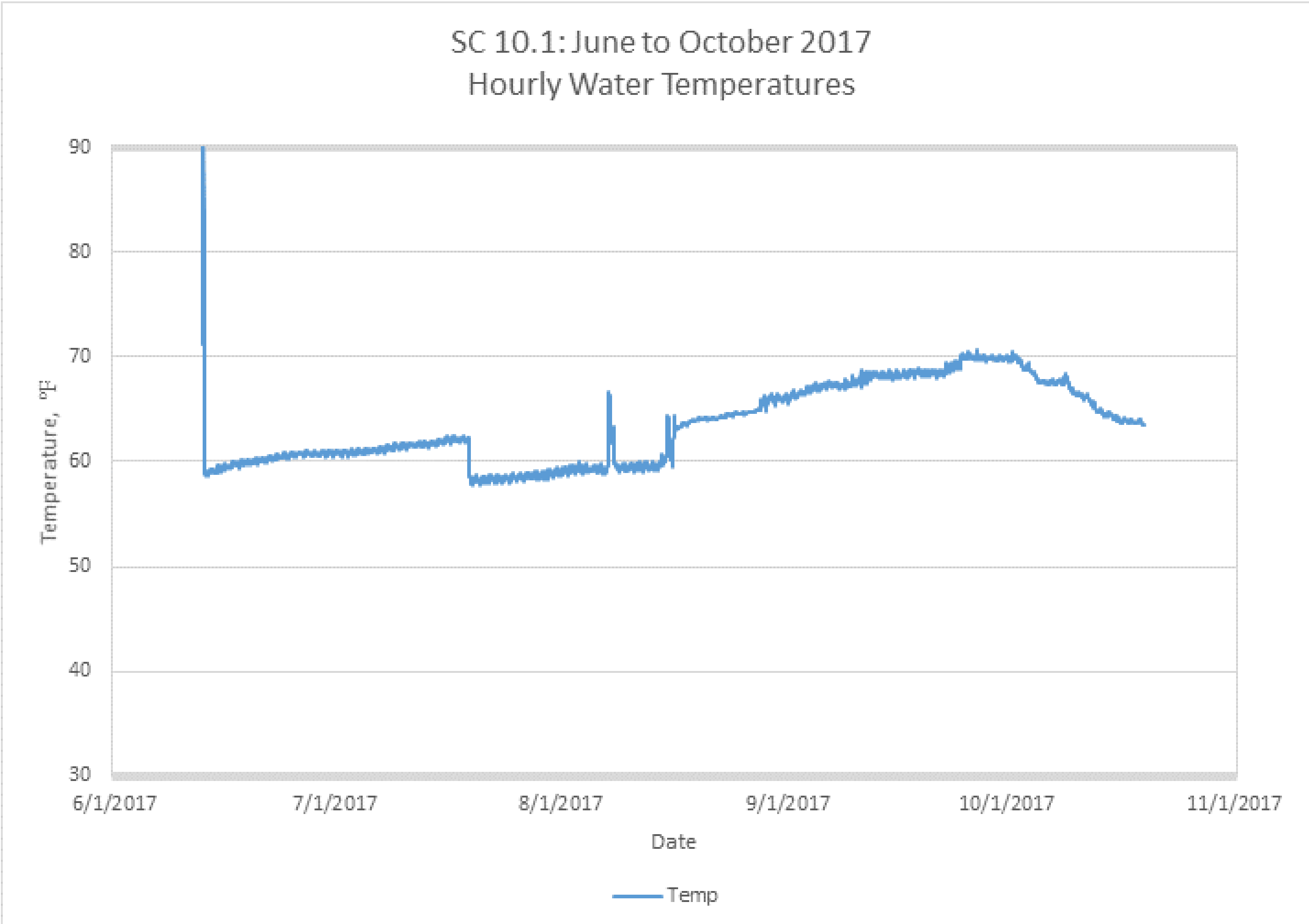
7/1/2017
8/1/2017
9/1/2017
10/1/2017
11/1/2017
Date
Hours > 70 °F


SC 10.0: June to October 2017
Daily Water Temperature Summary
90
80
70
60
50
40
30
Temperature, ºF
6/1/2017
7/1/2017
8/1/2017
9/1/2017
10/1/2017
11/1/2017
Date
Daily Median Temp
Max Daily Temp
Min Daily Temp
Seven Day Moving Average of Max Water Temperature


SC 10.1: June to October 2017
Hourly Water Temperatures
90
80
70
60
50
40
30
Temperature, °F
6/1/2017
7/1/2017
8/1/2017
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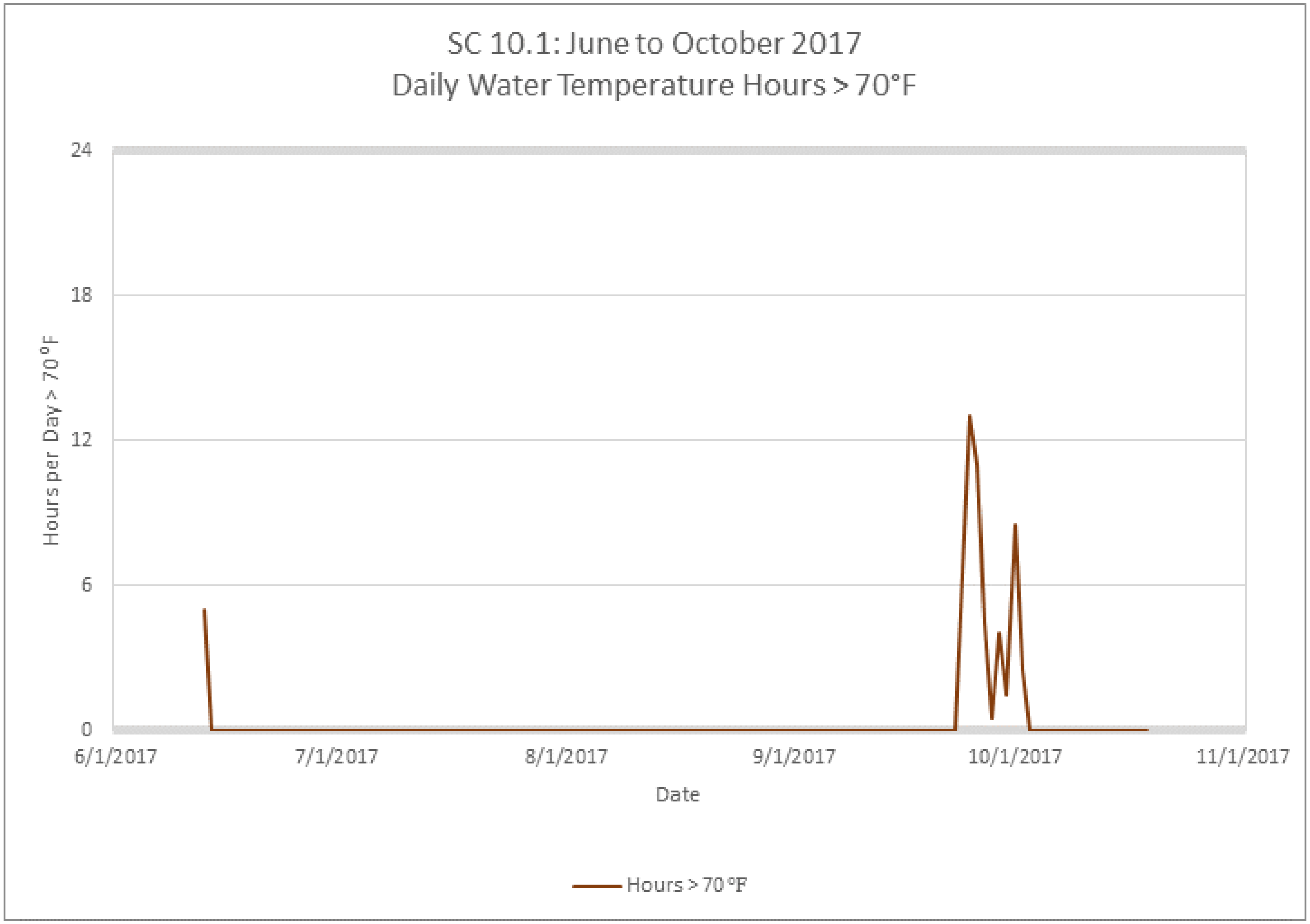
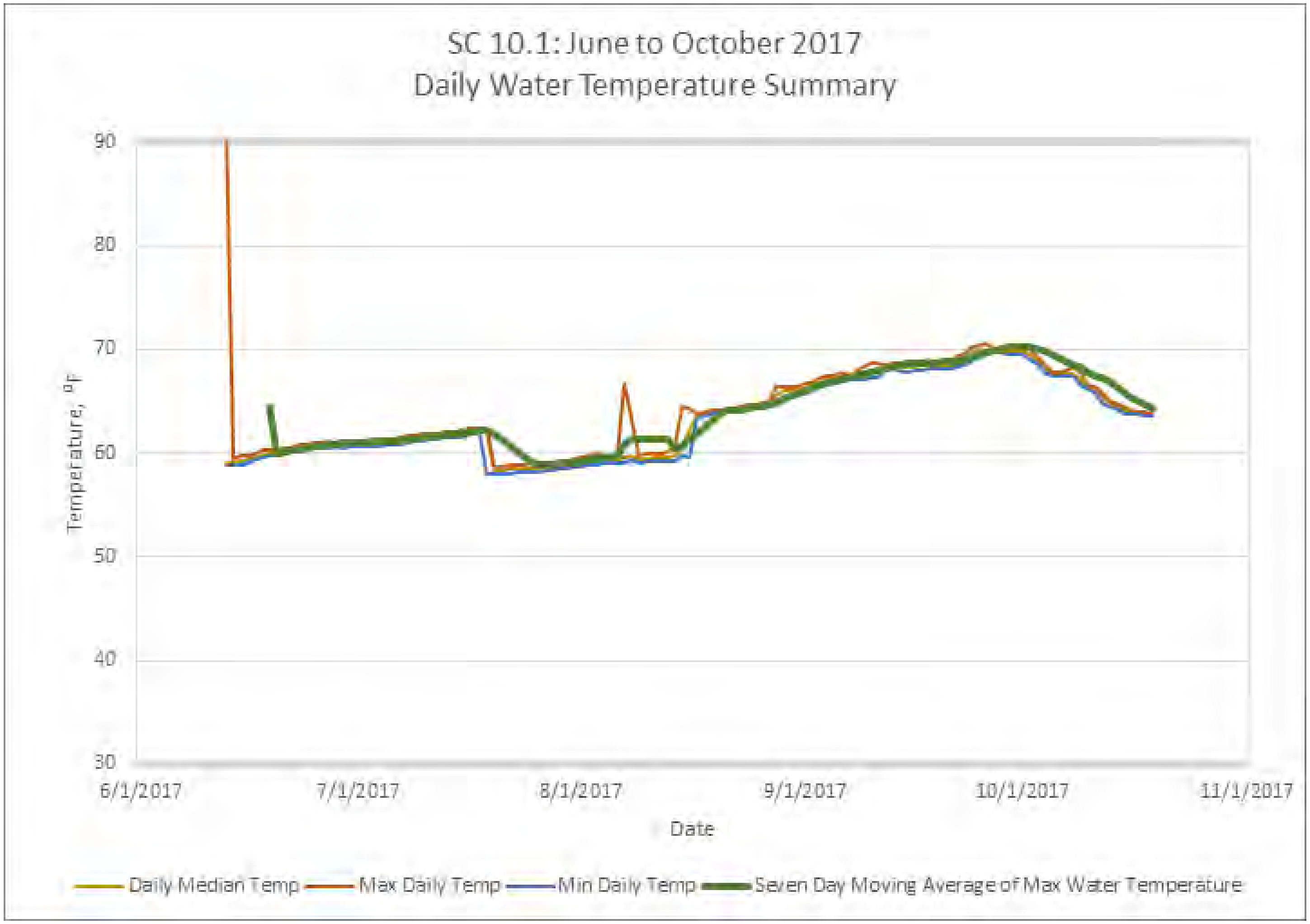
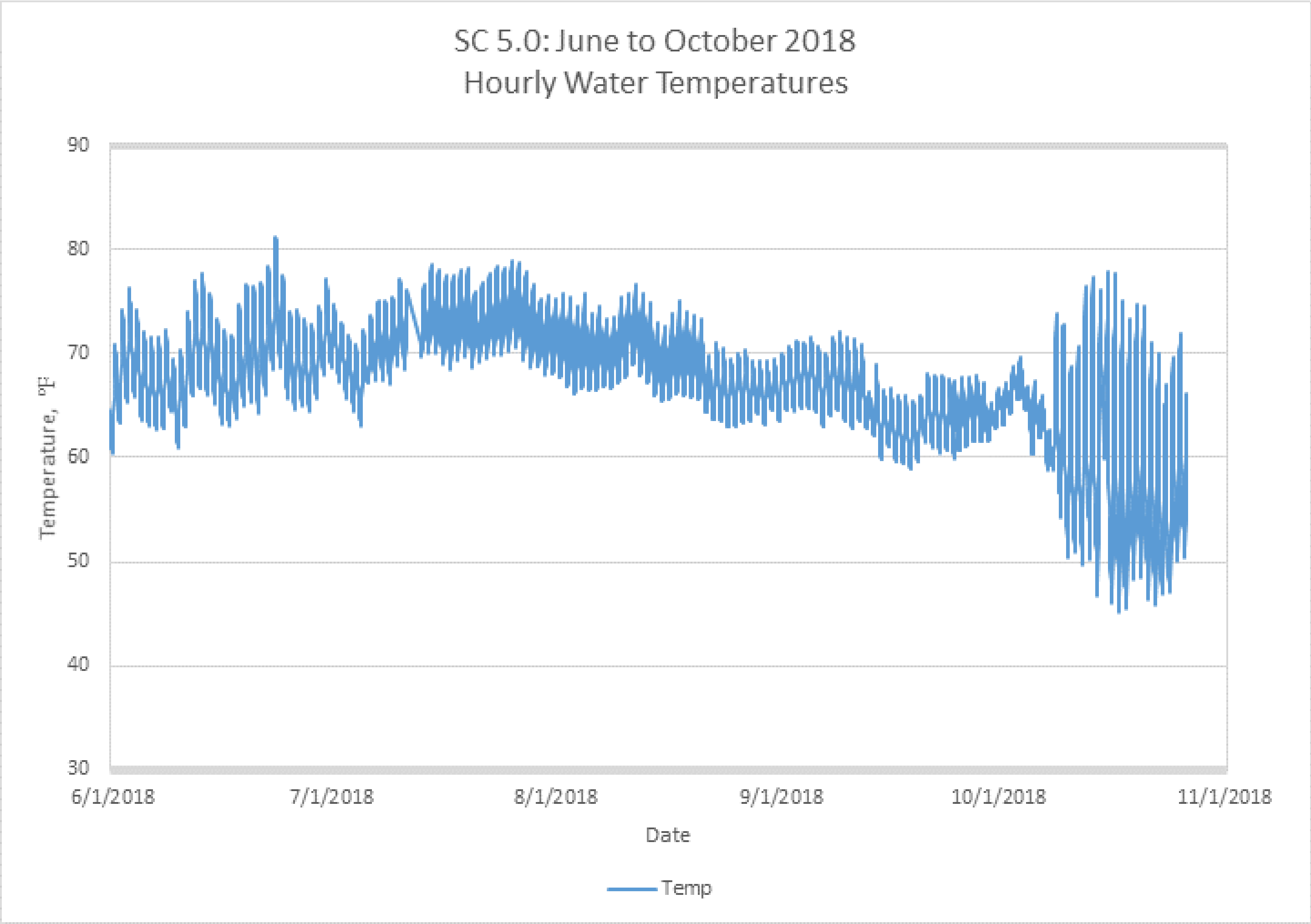
11/1/2017
Date
Temp

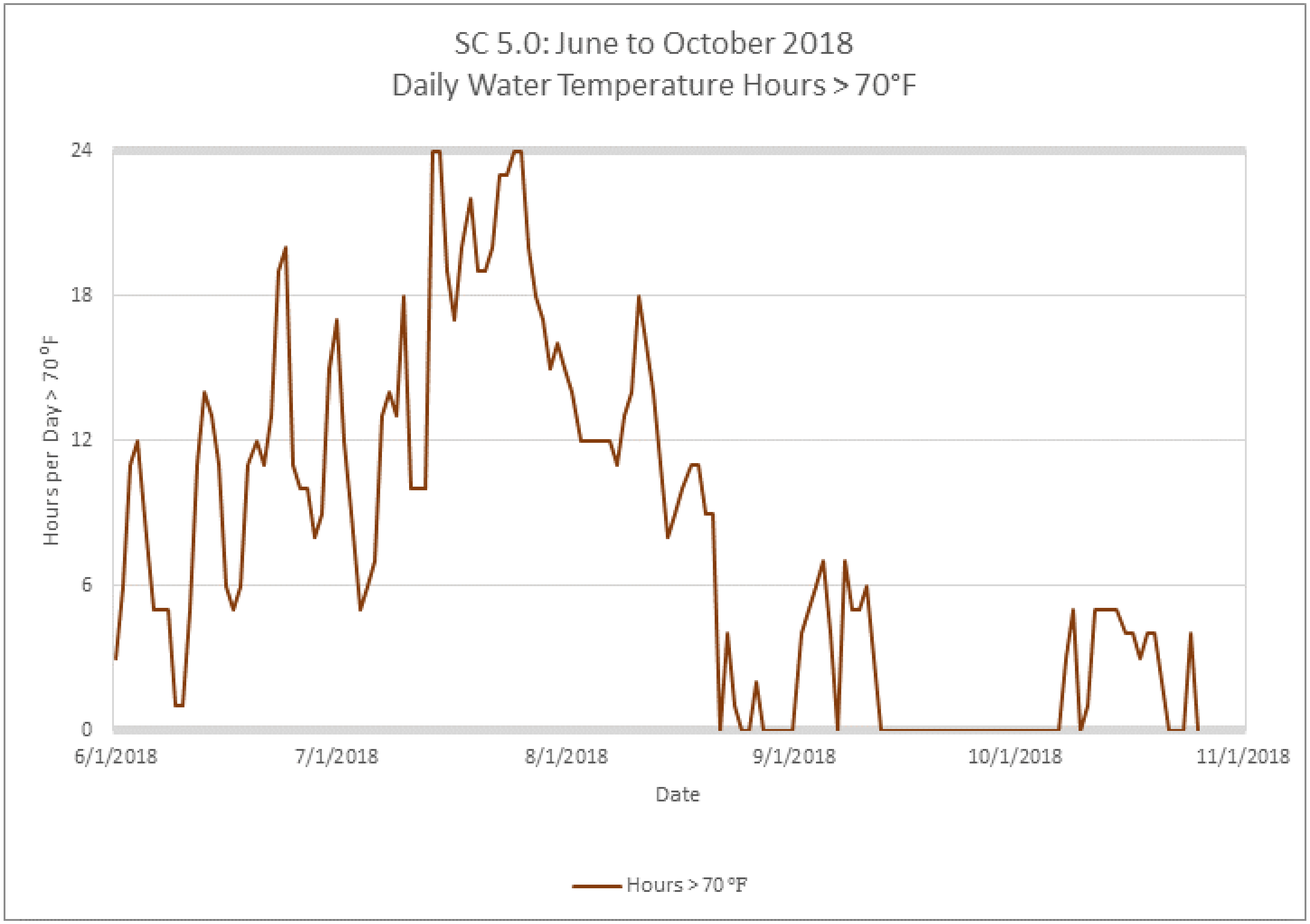


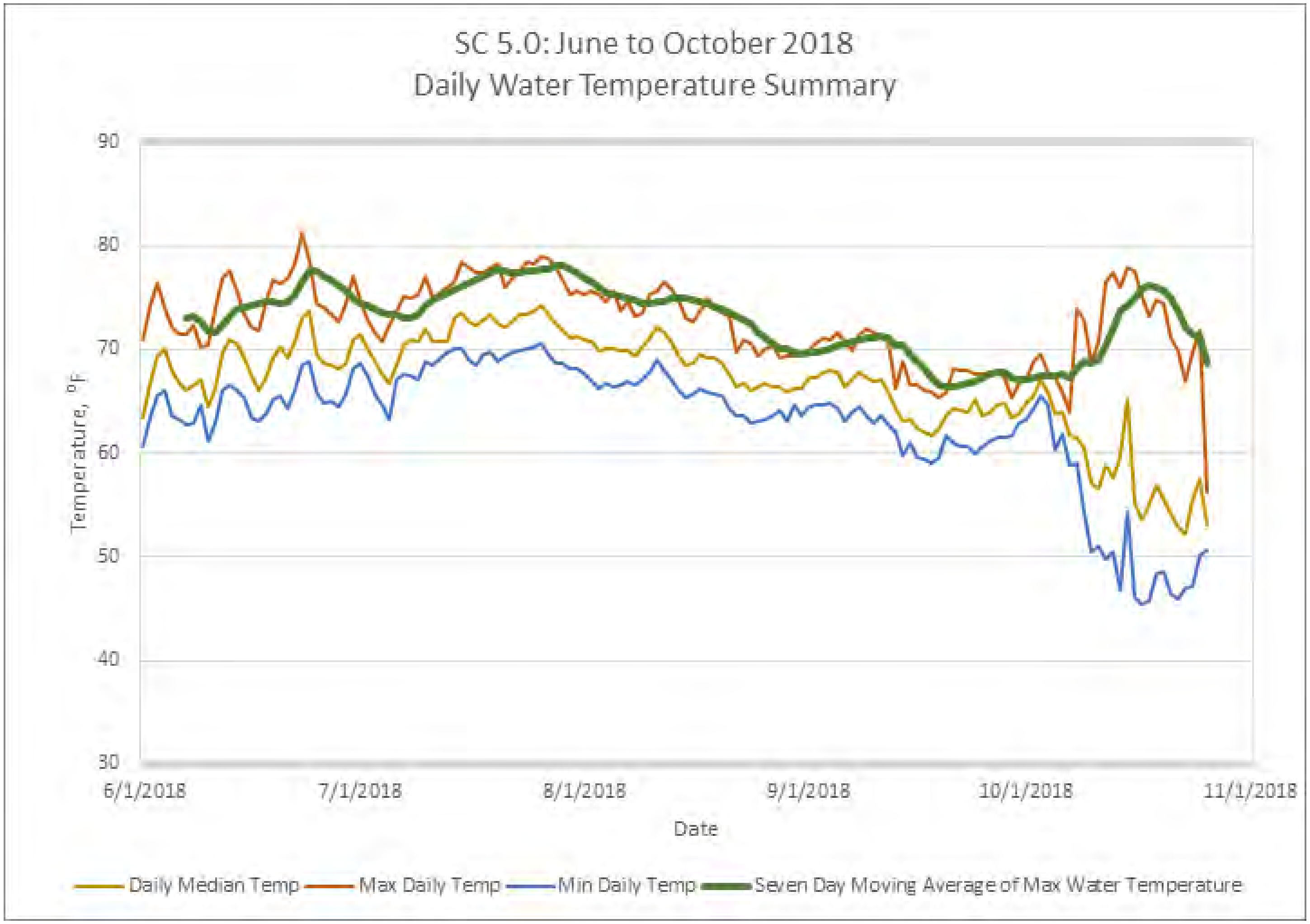
SC 10.1: June to October 2017
Daily Water Temperature Hours > 70°F
24
18
12
6
0
Hours per Day > 70°F
6/1/2017
7/1/2017
8/1/2017
9/1/2017
10/1/2017
11/1/2017
Date
Hours > 70 °F


SC 10.1: June to October 2017
Daily Water Temperature Summary
90
80
70
60
50
40
30
Temperature, ºF
6/1/2017
7/1/2017
8/1/2017
9/1/2017
10/1/2017
11/1/2017
Date
Daily Median Temp
Max Daily Temp
Min Daily Temp
Seven Day Moving Average of Max Water Temperature

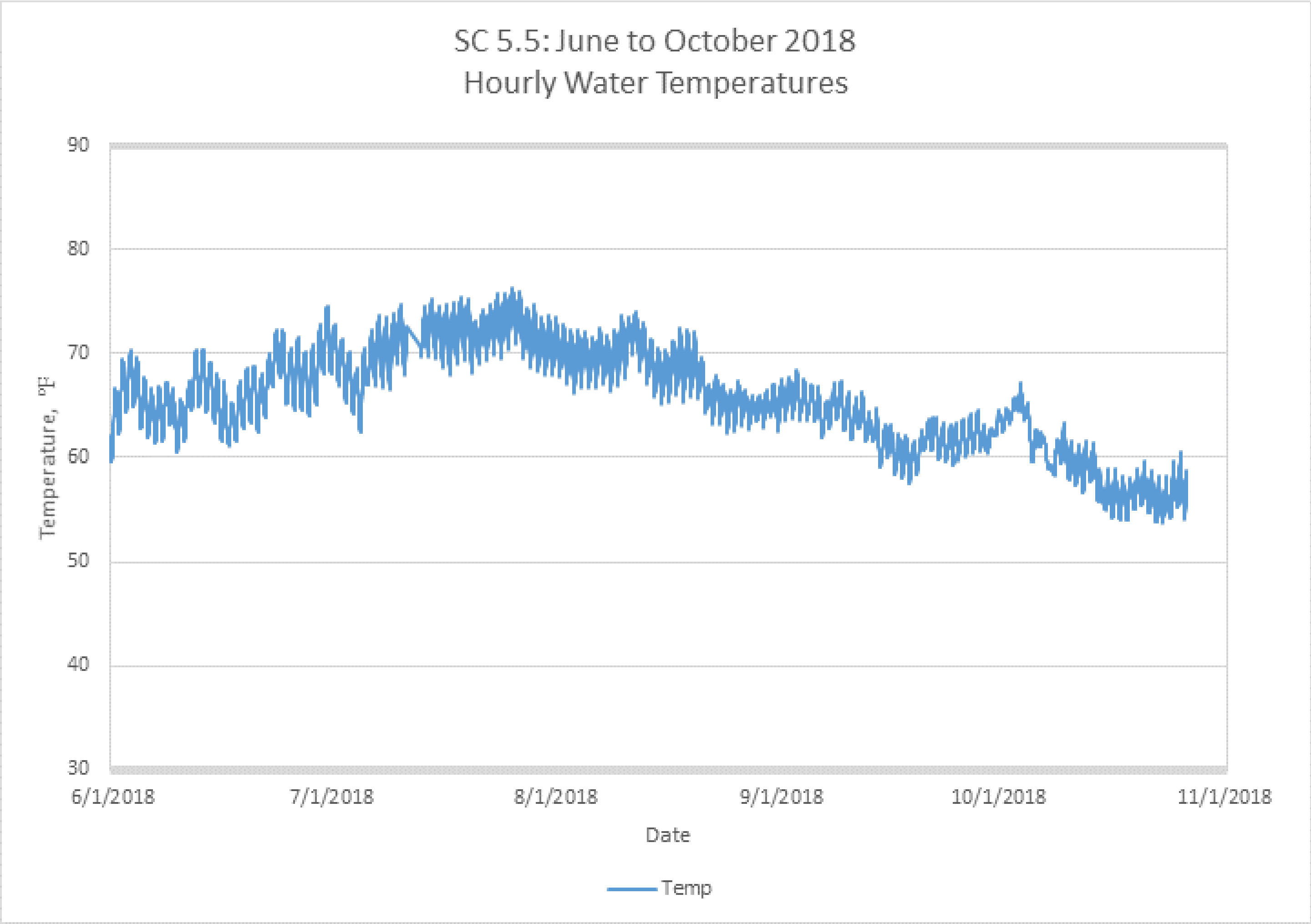


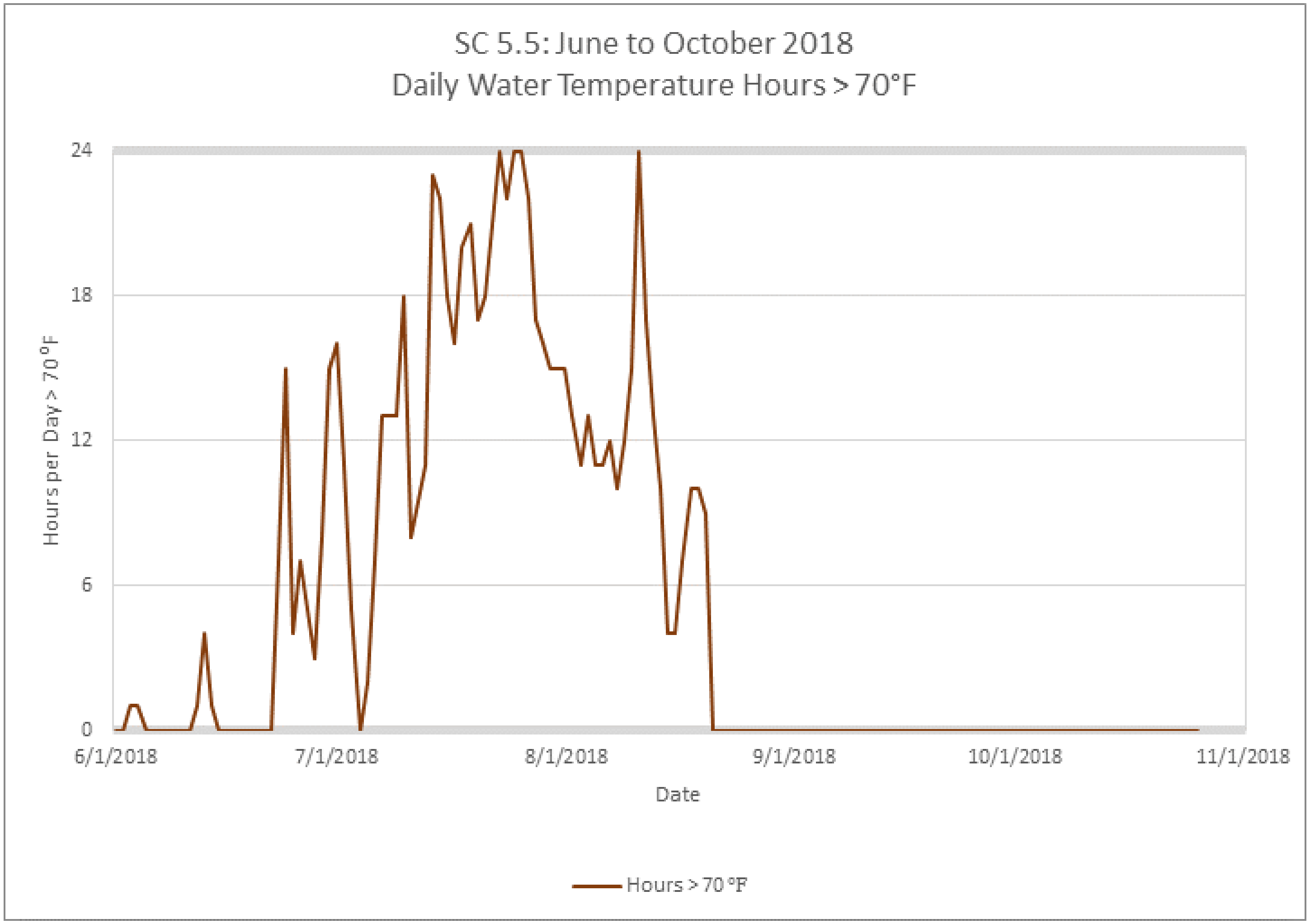
SC 5.0: June to October 2018
Hourly Water Temperatures
90
80
70
60
50
40
30
Temperature, °F
6/1/2018
7/1/2018
8/1/2018
9/1/2018
10/1/2018
11/1/2018
Date
Temp


SC 5.0: June to October 2018
Daily Water Temperature Hours > 70°F
24
18
12
6
0
Hours per Day > 70°F
6/1/2018
7/1/2018
8/1/2018
9/1/2018
10/1/2018
11/1/2018
Date
Hours > 70 °F



SC 5.0: June to October 2018
Daily Water Temperature Summary
90
80
70
60
50
40
30
Temperature, °F
6/1/2018
7/1/2018
8/1/2018
9/1/2018
10/1/2018
11/1/2018
Date
Daily Median Temp
Max Daily Temp
Min Daily Temp
Seven Day Moving Average of Max Water Temperature


SC 5.5: June to October 2018
Hourly Water Temperatures
90
80
70
60
50
40
30
Temperature, °F
6/1/2018
7/1/2018
8/1/2018
9/1/2018
10/1/2018
11/1/2018
Date
Temp


SC 5.5: June to October 2018
Daily Water Temperature Hours > 70°F
24
18
12
6
0
Hours per Day > 70°F
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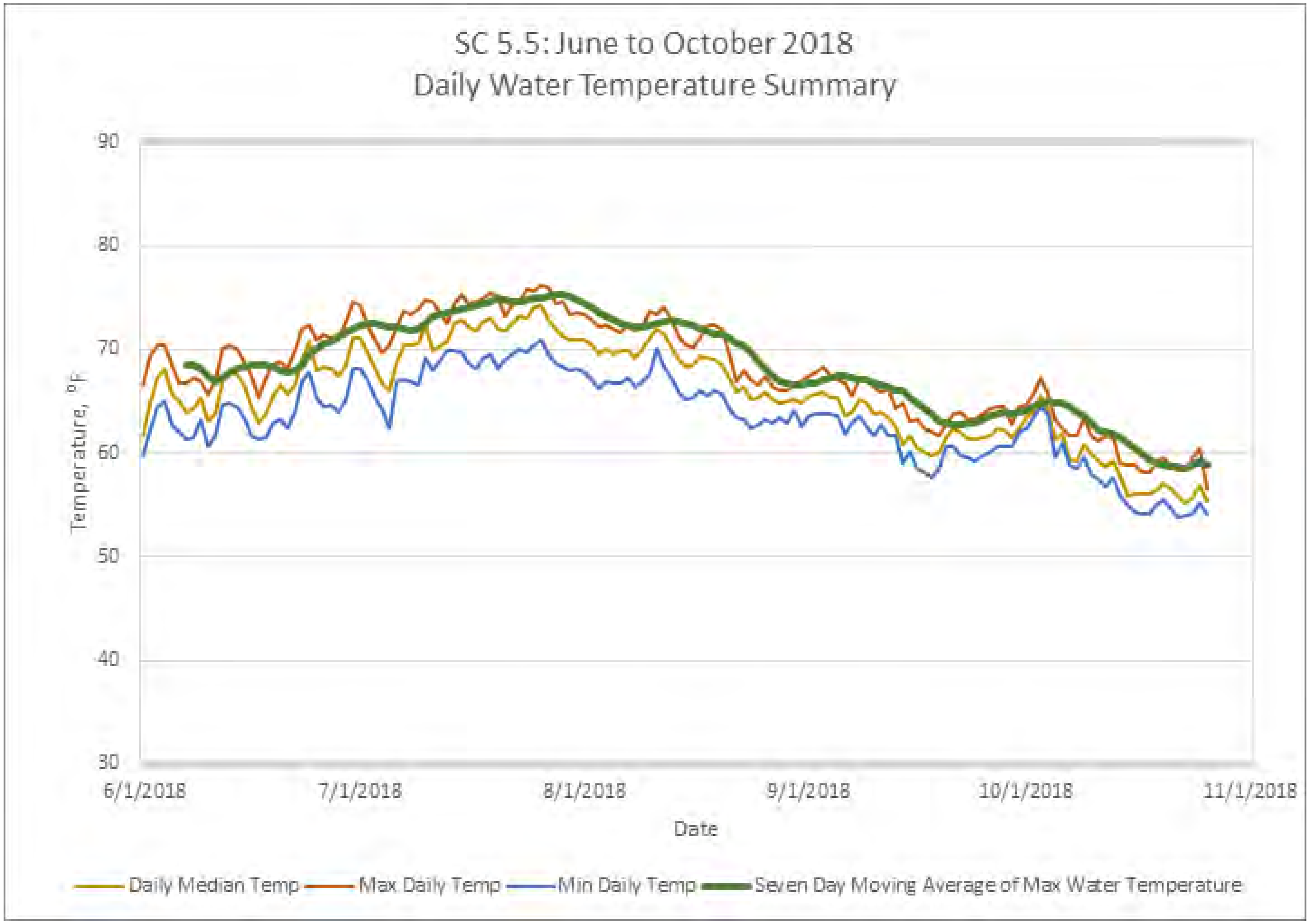
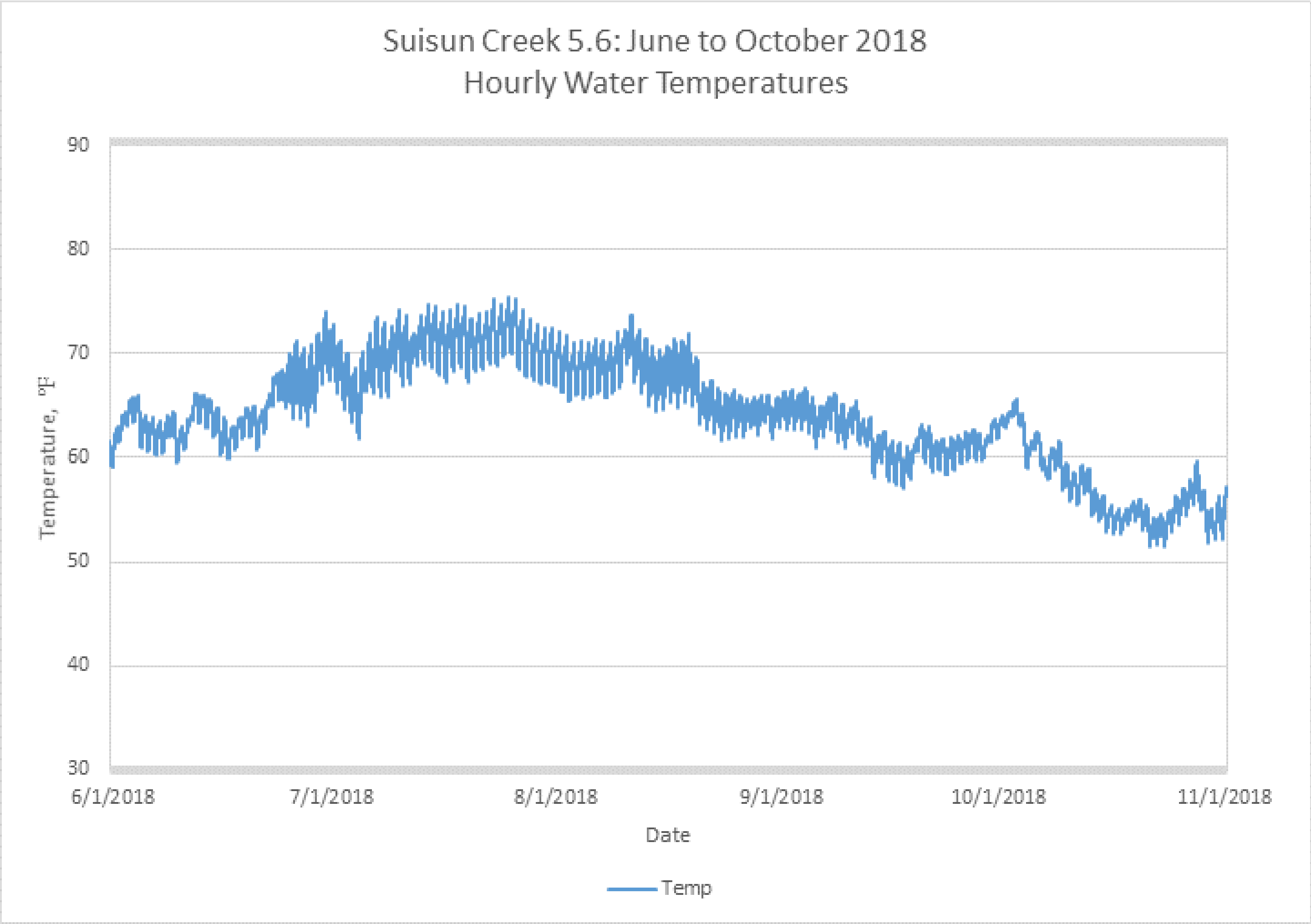
7/1/2018
8/1/2018
9/1/2018
10/1/2018
11/1/2018
Date
Hours > 70 °F



SC 5.5: June to October 2018
Daily Water Temperature Summary
90
80
70
60
50
40
30
Temperature, °F
6/1/2018
7/1/2018
8/1/2018
9/1/2018
10/1/2018
11/1/2018
Date
Daily Median Temp
Max Daily Temp
Min Daily Temp
Seven Day Moving Average of Max Water Temperature



Suisun Creek 5.6: June to October 2018
Hourly Water Temperatures
90
80
70
60
50
40
30
Temperature, °F
6/1/2018
7/1/2018
8/1/2018
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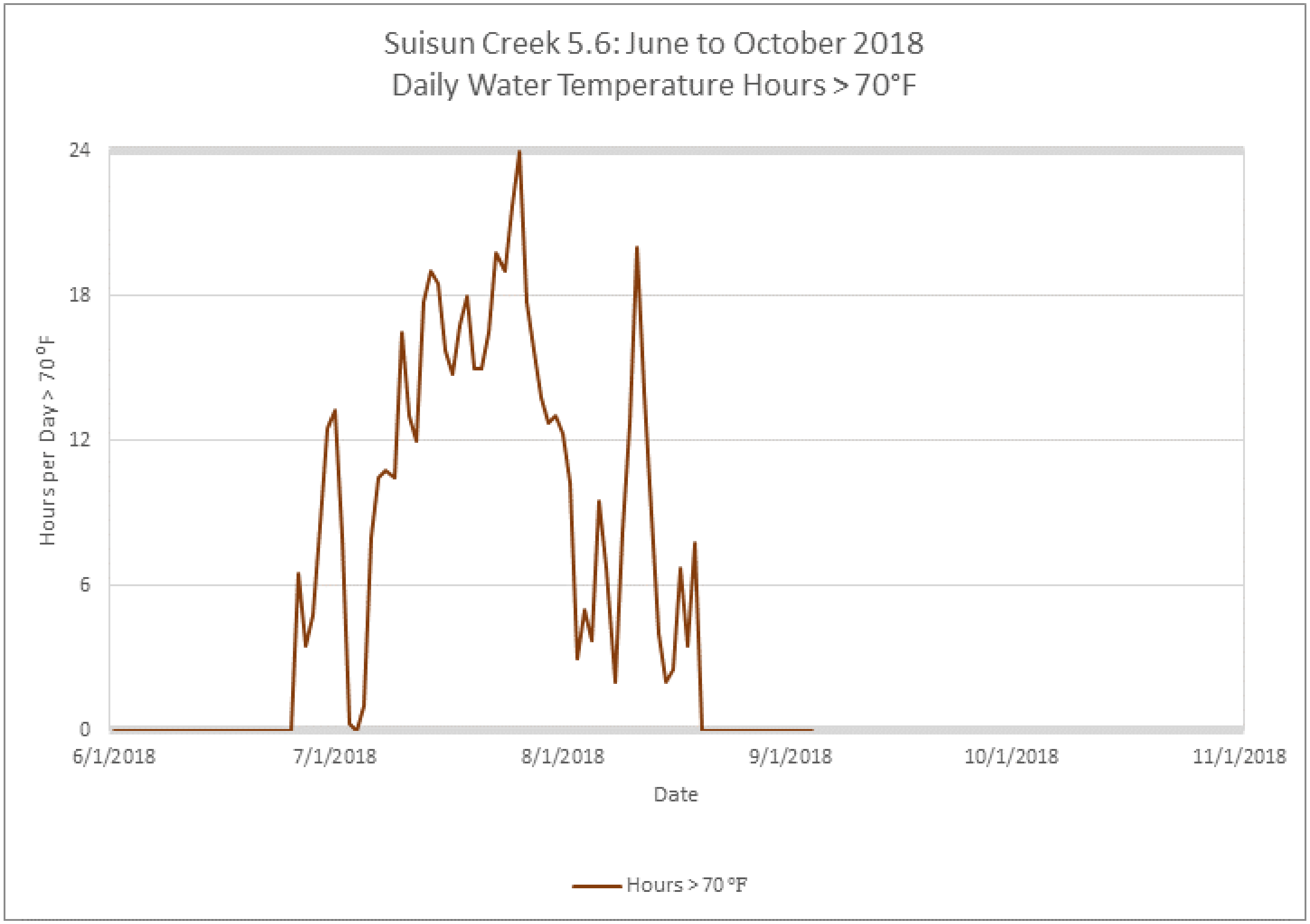
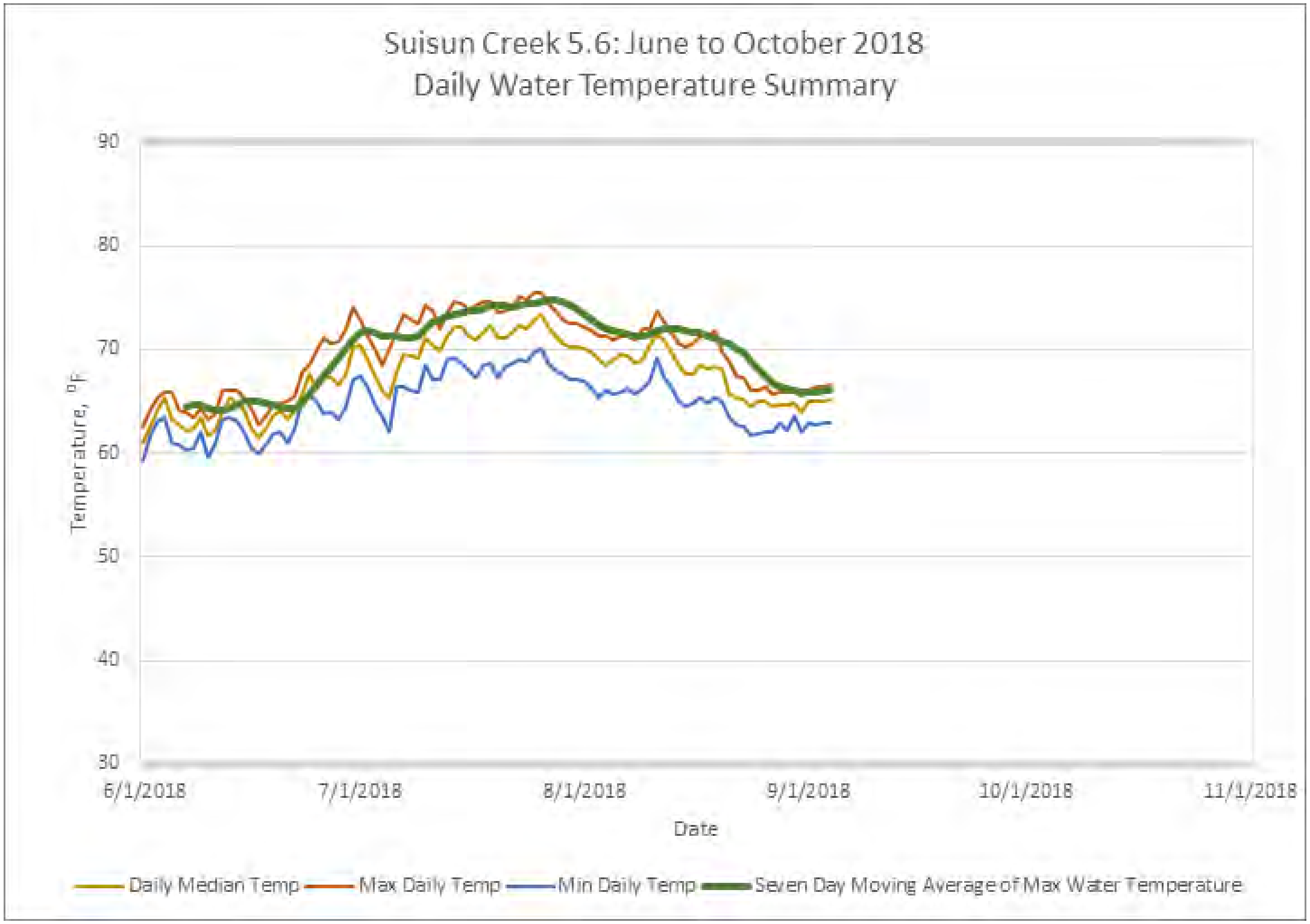
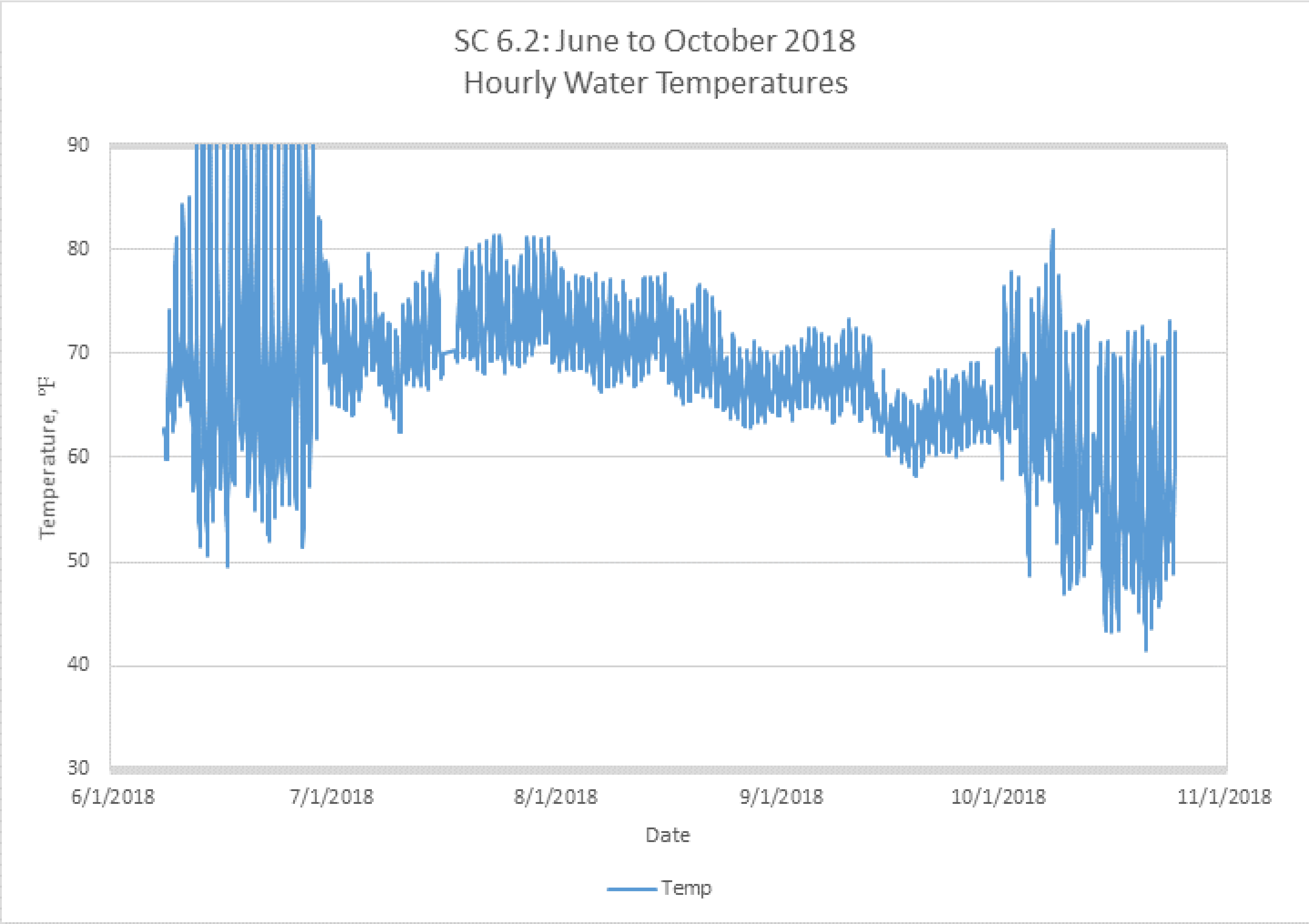
11/1/2018
Date
Temp

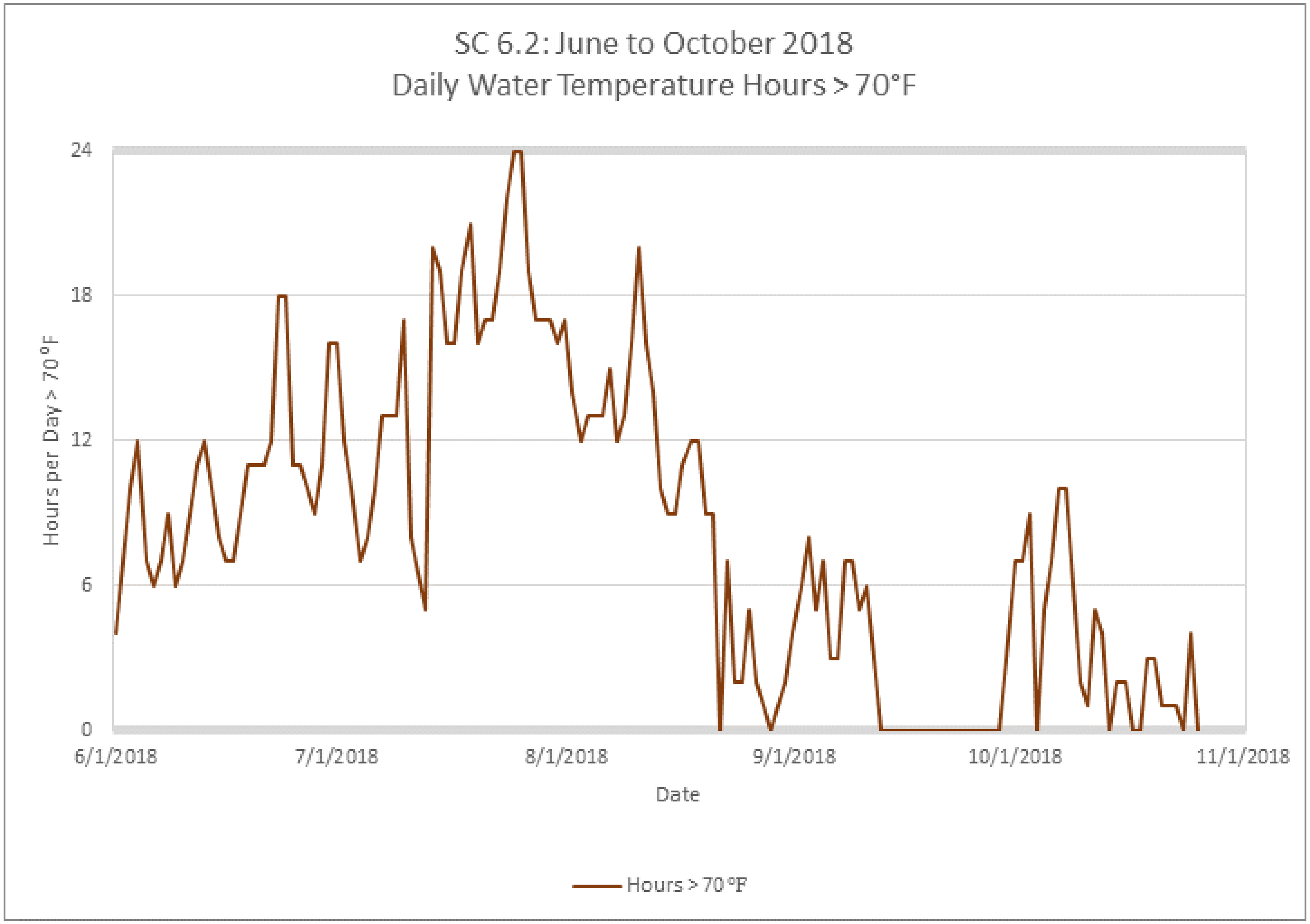


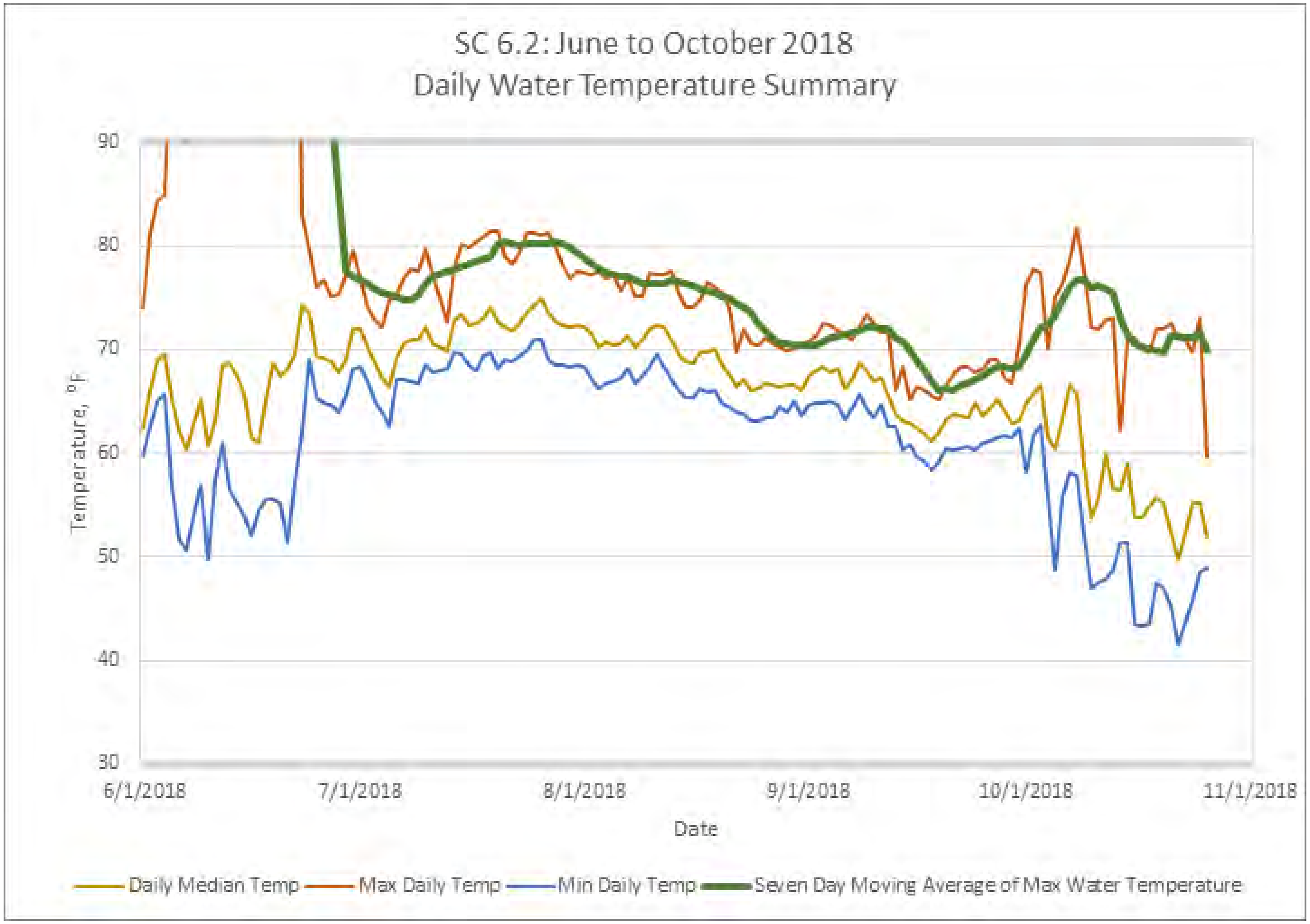
Suisun Creek 5.6: June to October 2018
Daily Water Temperature Hours > 70°F
24
18
12
6
0
Hours per Day > 70°F
6/1/2018
7/1/2018
8/1/2018
9/1/2018
10/1/2018
11/1/2018
Date
Hours > 70 °F

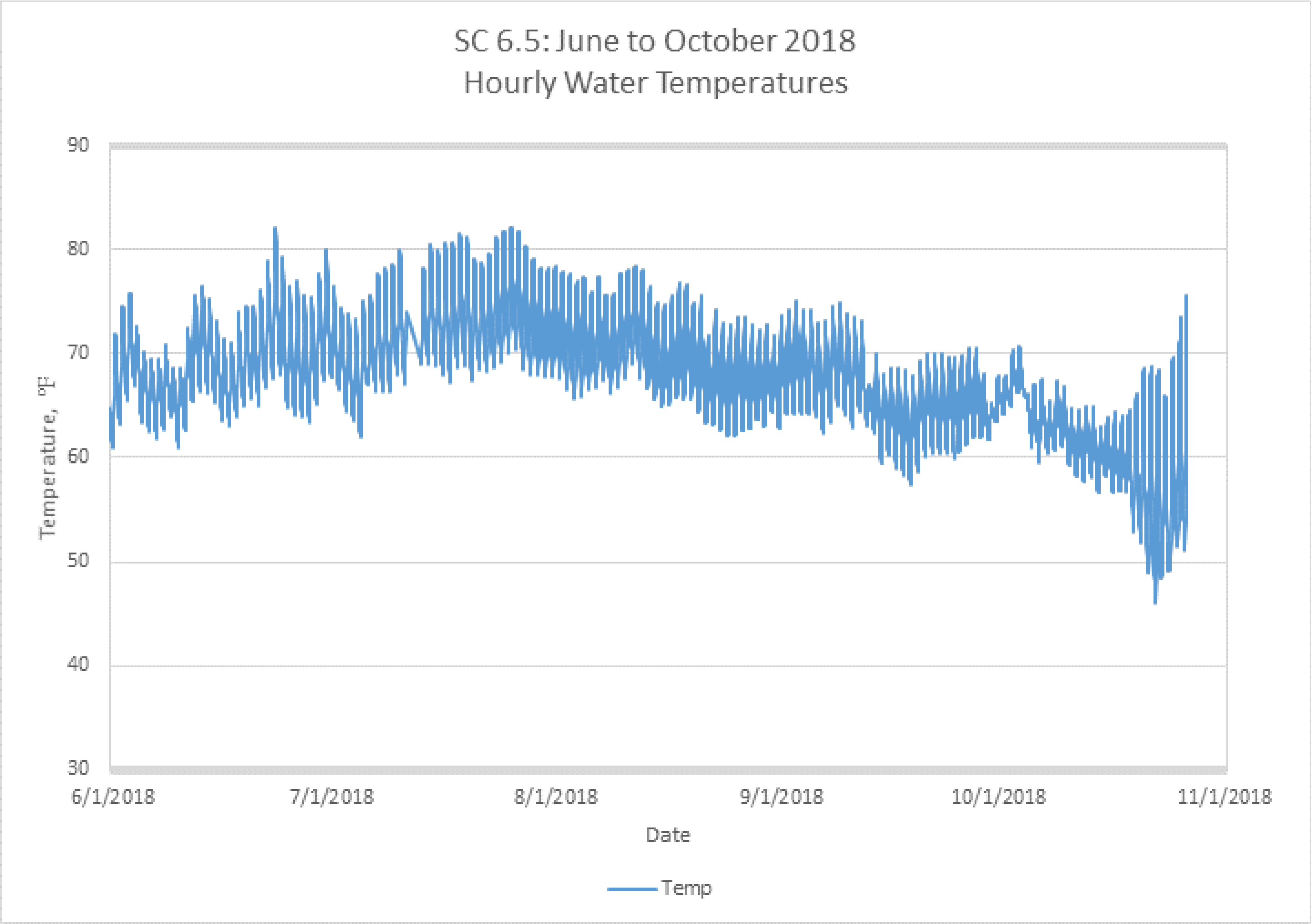


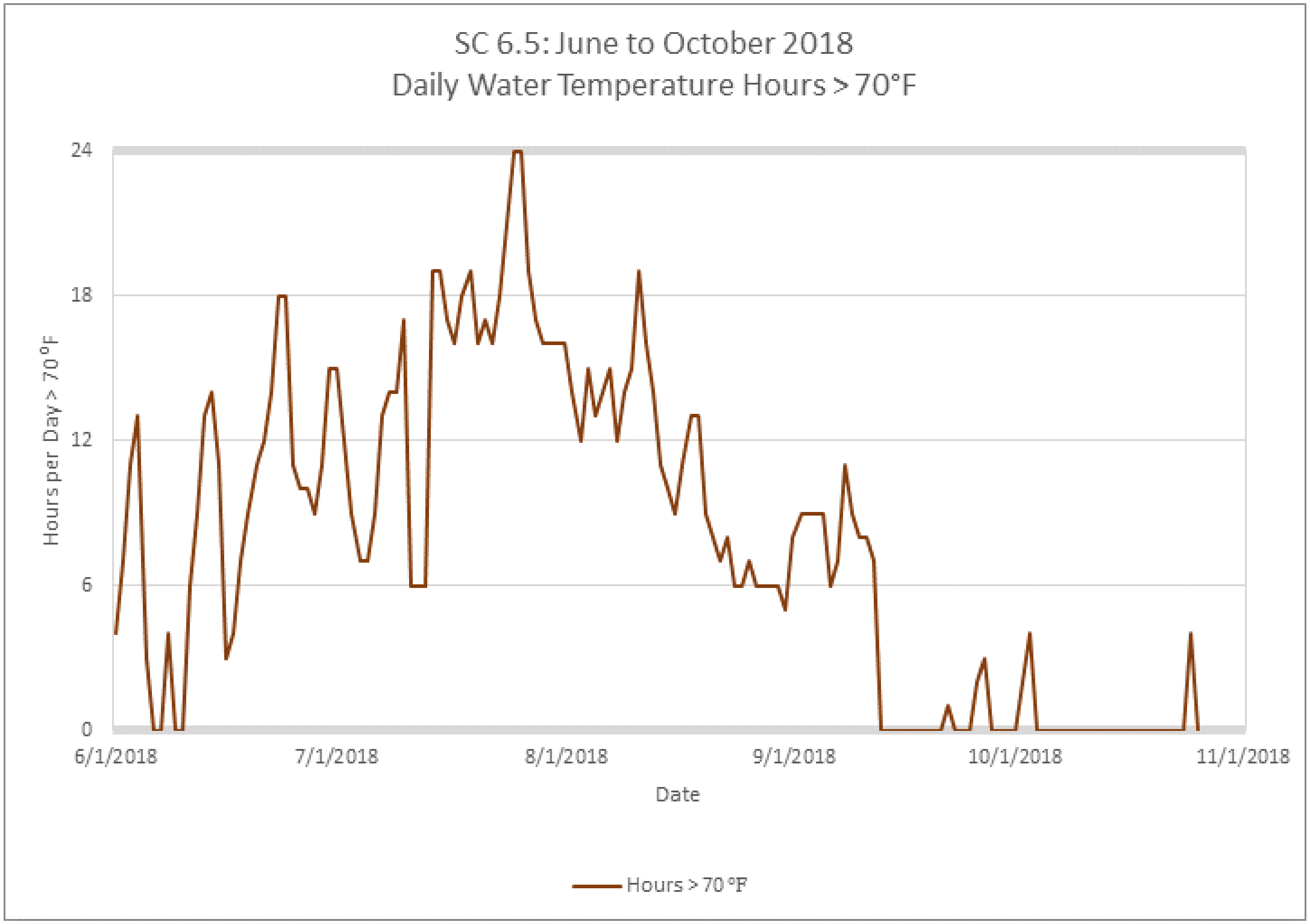
Suisun Creek 5.6: June to October 2018
Daily Water Temperature Summary
90
80
70
60
50
40
30
Temperature, °F
6/1/2018
7/1/2018
8/1/2018
9/1/2018
10/1/2018
11/1/2018
Date
Daily Median Temp
Max Daily Temp
Min Daily Temp
Seven Day Moving Average of Max Water Temperature


SC 6.2: June to October 2018
Hourly Water Temperatures
90
80
70
60
50
40
30
Temperature, °F
6/1/2018
7/1/2018
8/1/2018
9/1/2018
10/1/2018
11/1/2018
Date
Temp

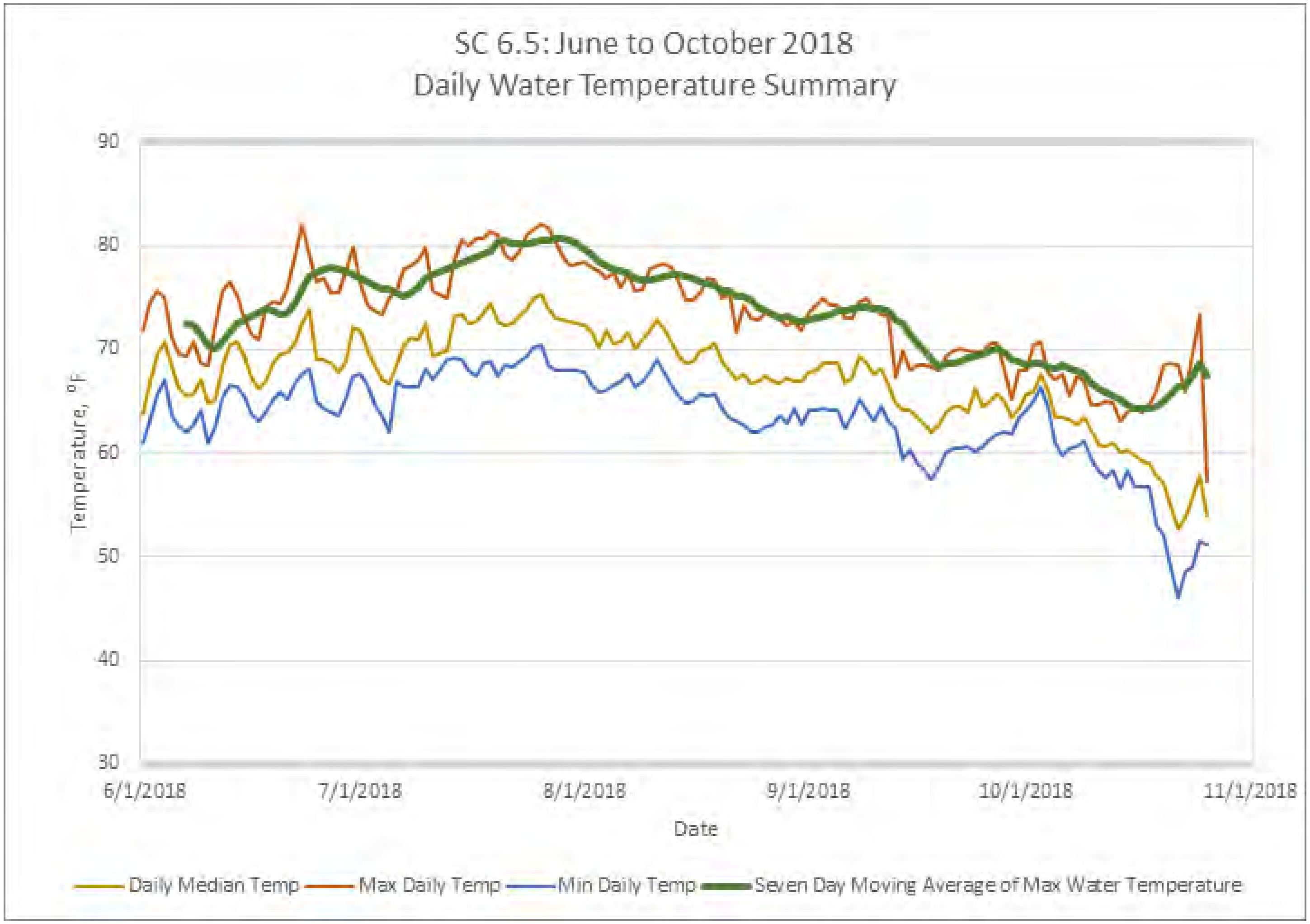

SC 6.2: June to October 2018
Daily Water Temperature Hours > 70°F
Hours per Day > 70°F
24
18
12
6
0
6/1/2018
7/1/2018
8/1/2018
9/1/2018
10/1/2018
11/1/2018
Date
Hours > 70 °F


SC 6.2: June to October 2018
Daily Water Temperature Summary
90
80
70
60
50
40
30
Temperature, °F
6/1/2018
7/1/2018
8/1/2018
9/1/2018
10/1/2018
11/1/2018
Date
Daily Median Temp
Max Daily Temp
Min Daily Temp
Seven Day Moving Average of Max Water Temperature

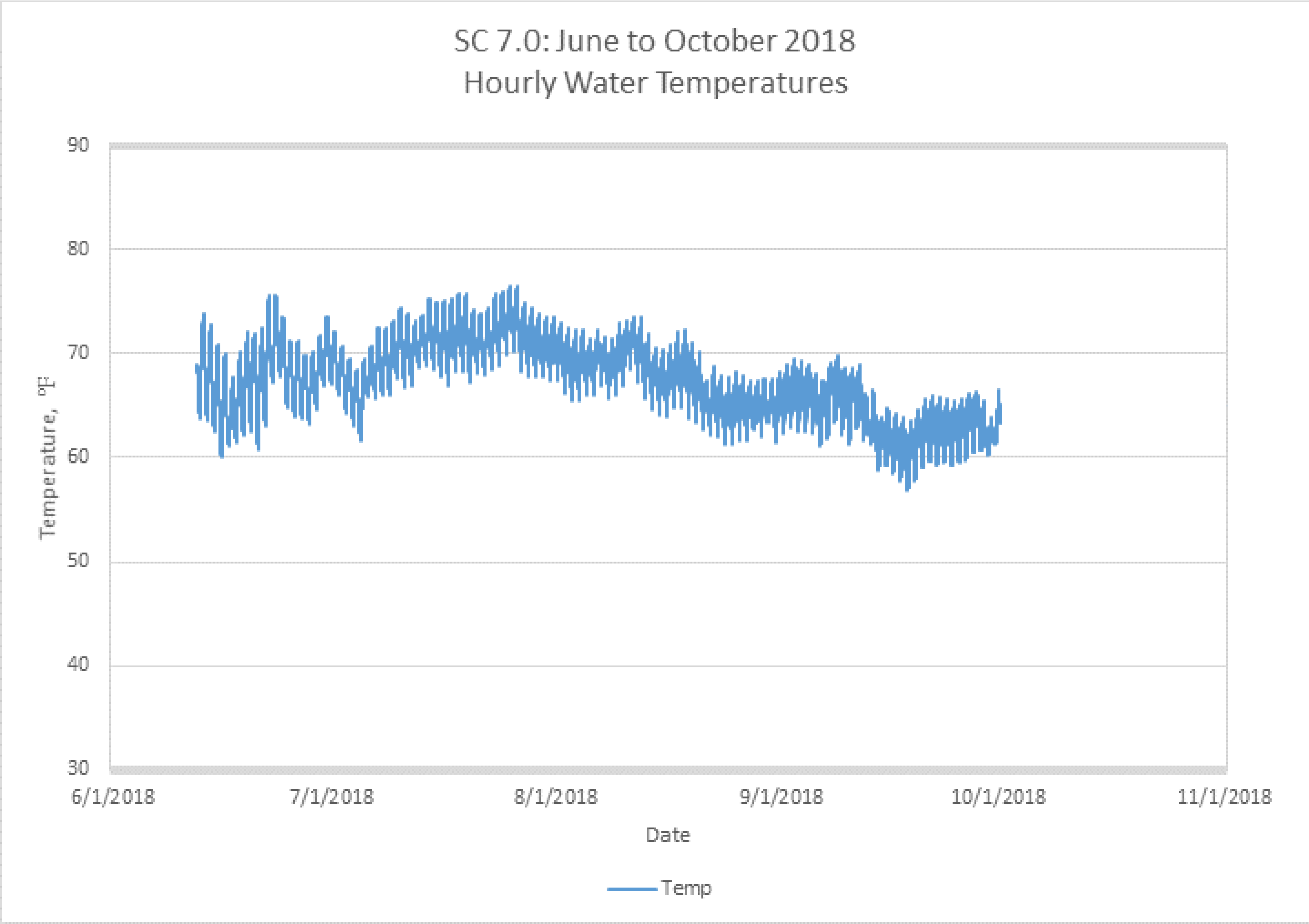

SC 6.5: June to October 2018
Hourly Water Temperatures
90
80
70
60
50
40
30
Temperature, °F
6/1/2018
7/1/2018
8/1/2018
9/1/2018
10/1/2018
11/1/2018
Date
Temp

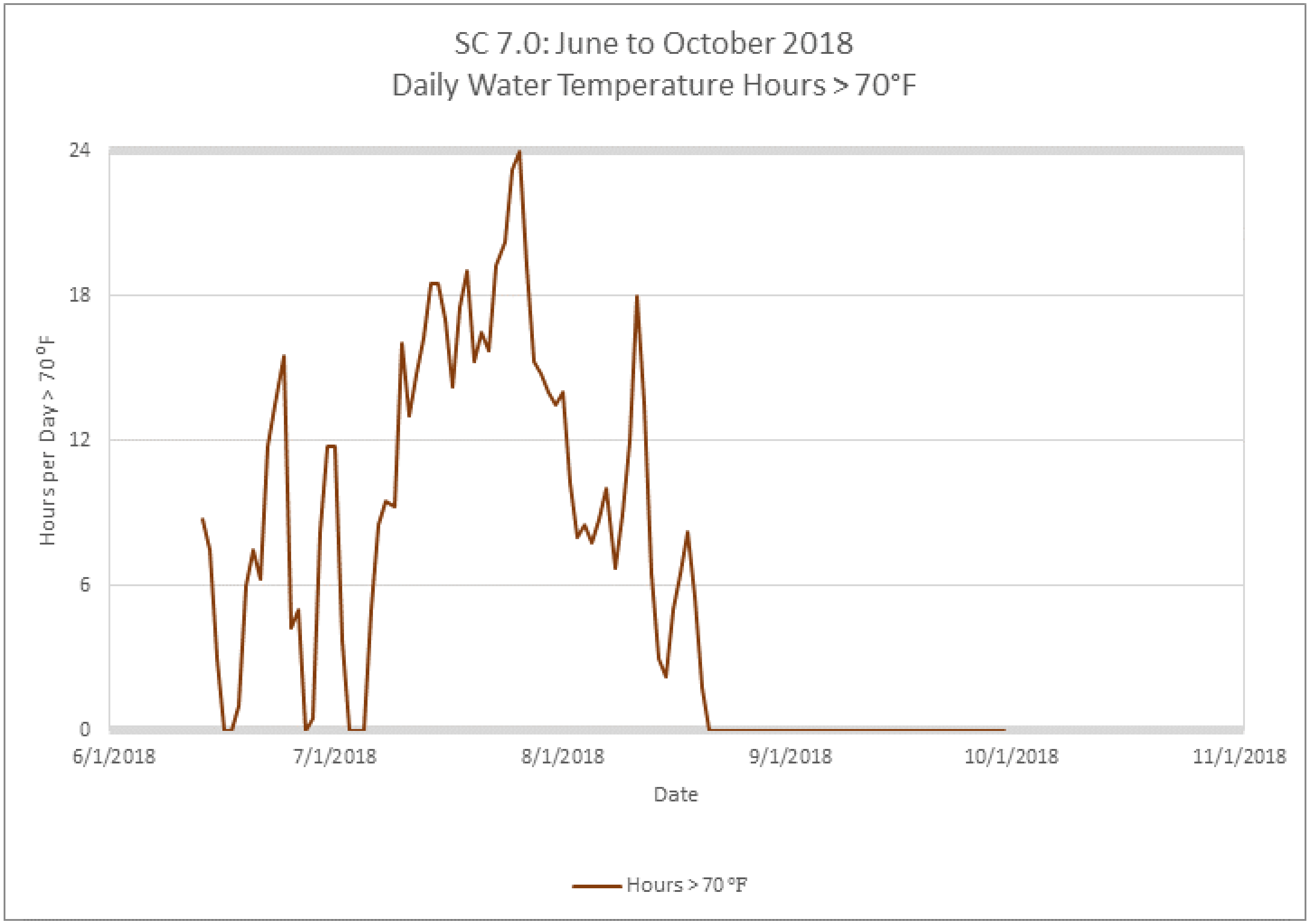


SC 6.5: June to October 2018
Daily Water Temperature Hours > 70°F
24
18
12
6
0
Hours per Day > 70°F
6/1/2018
7/1/2018
8/1/2018
9/1/2018
10/1/2018
11/1/2018
Date
Hours > 70 °F

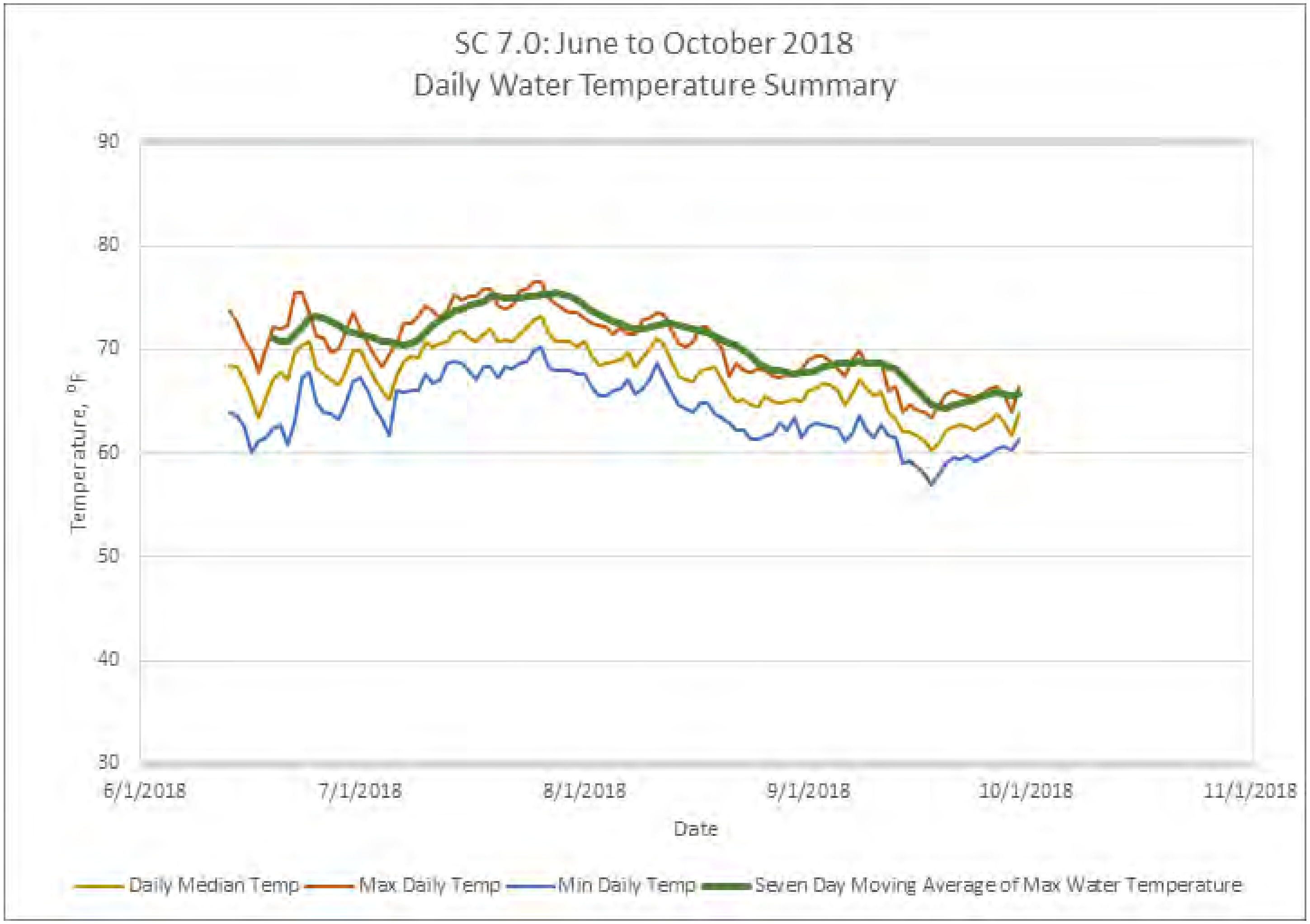


SC 6.5: June to October 2018
Daily Water Temperature Summary
90
80
70
60
50
40
30
Temperature, °F
6/1/2018
7/1/2018
8/1/2018
9/1/2018
10/1/2018
11/1/2018
Date
Daily Median Temp
Max Daily Temp
Min Daily Temp
Seven Day Moving Average of Max Water Temperature

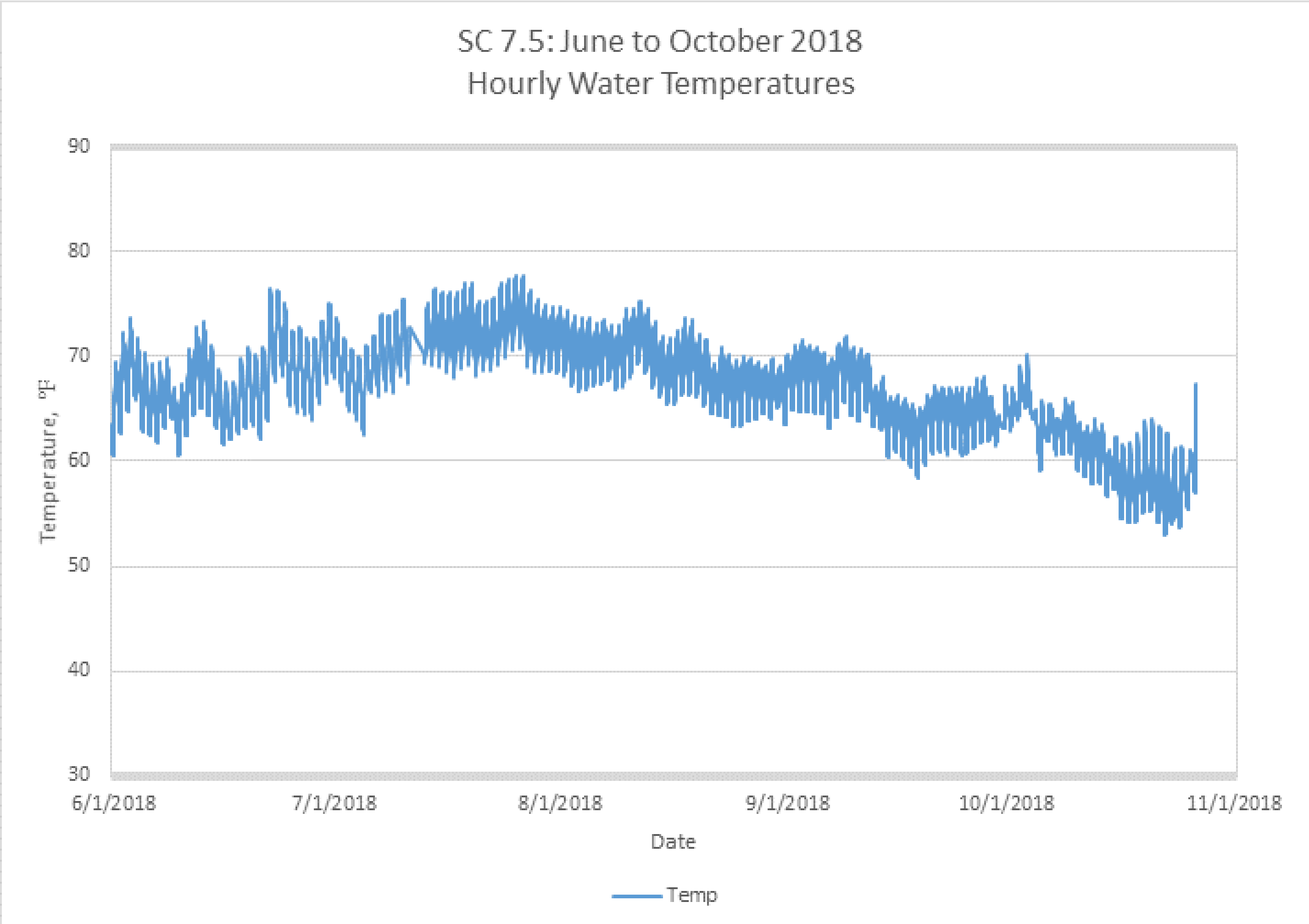

SC 7.0: June to October 2018
Hourly Water Temperatures
90
80
70
60
50
40
30
Temperature, °F
6/1/2018
7/1/2018
8/1/2018
9/1/2018
10/1/2018
11/1/2018
Date
Temp

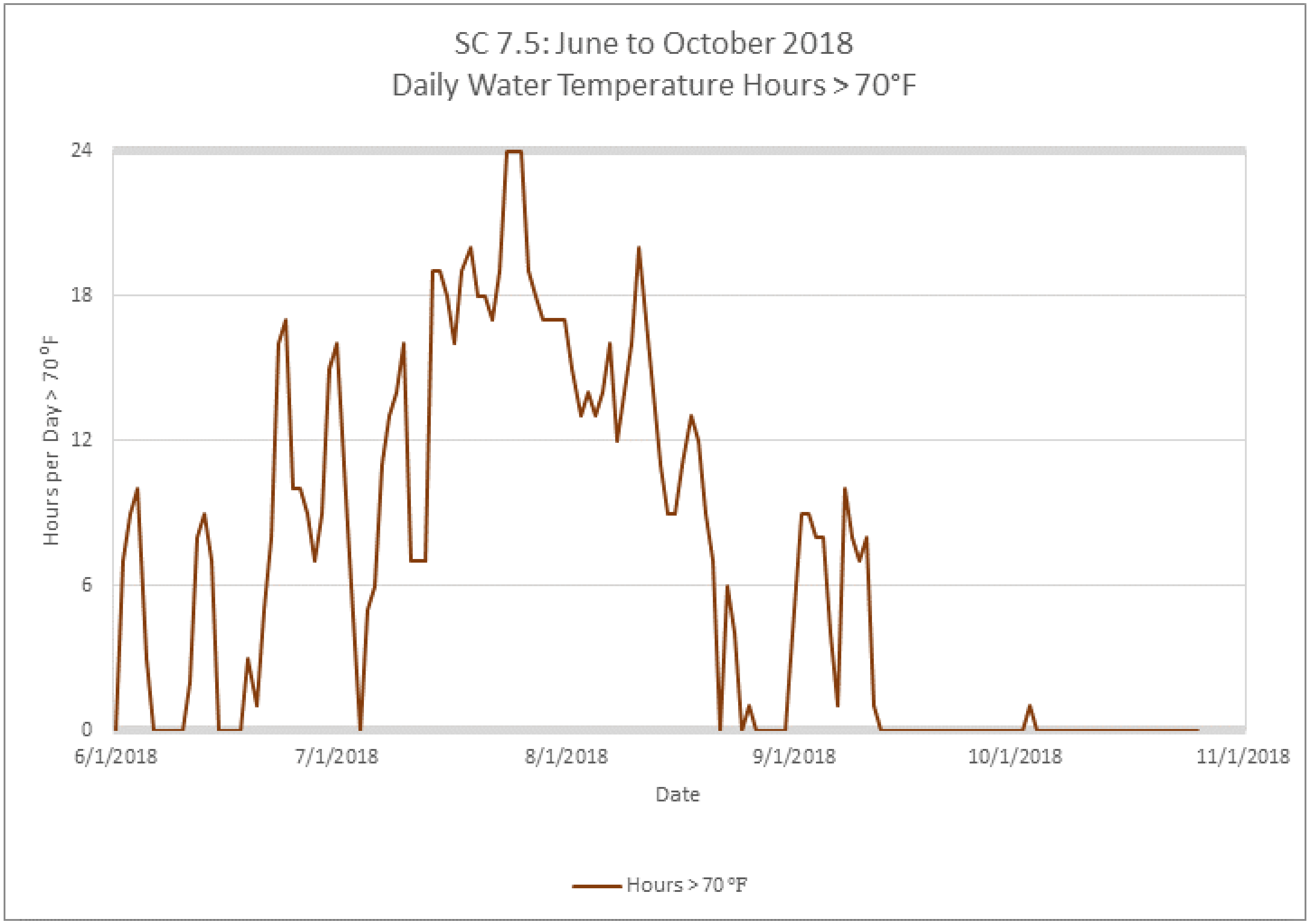


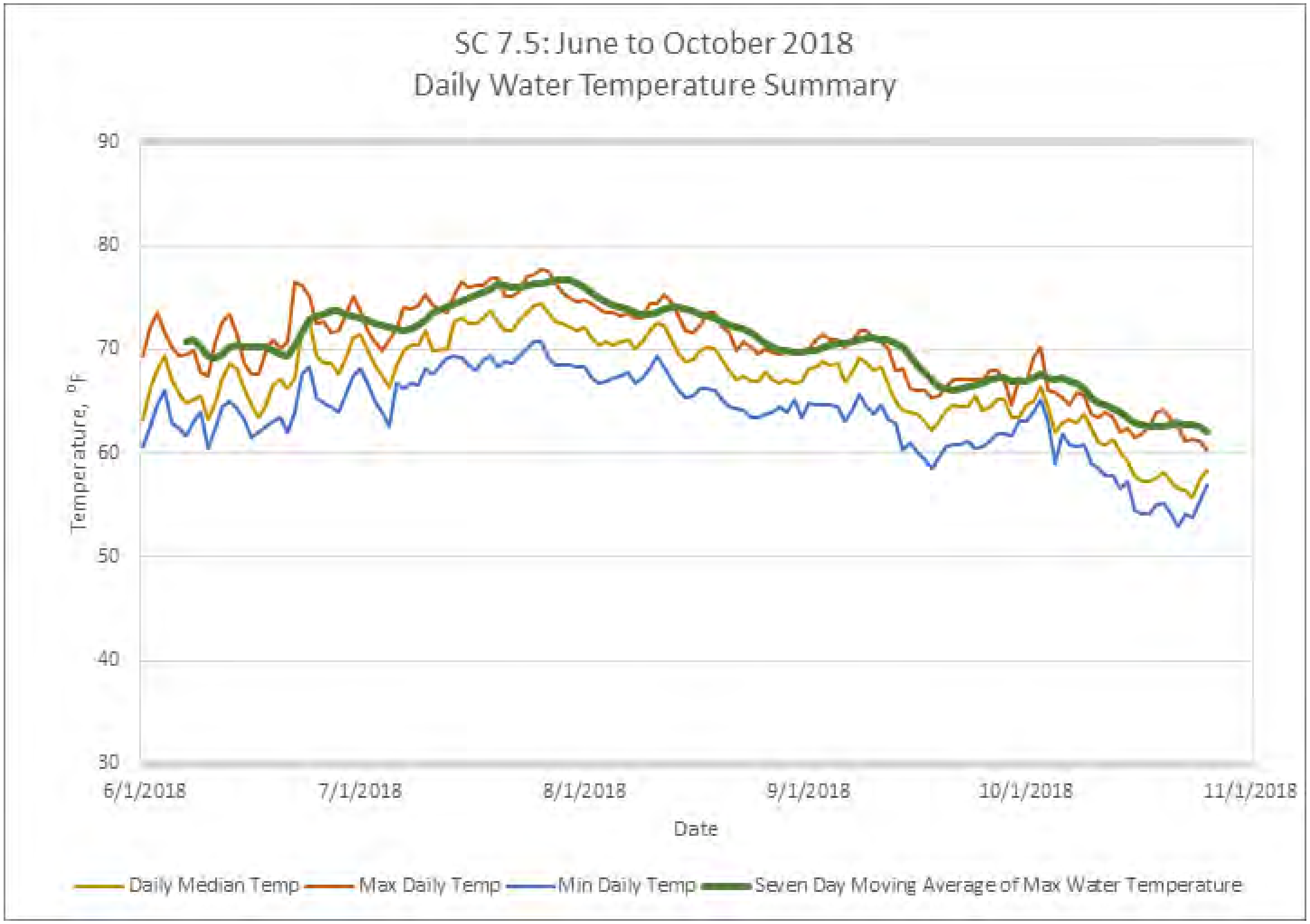
SC 7.0: June to October 2018
Daily Water Temperature Hours > 70°F
Hours per Day > 70°F
24
18
12
6
0
6/1/2018
7/1/2018
8/1/2018
9/1/2018
10/1/2018
11/1/2018
Date
Hours > 70 °F



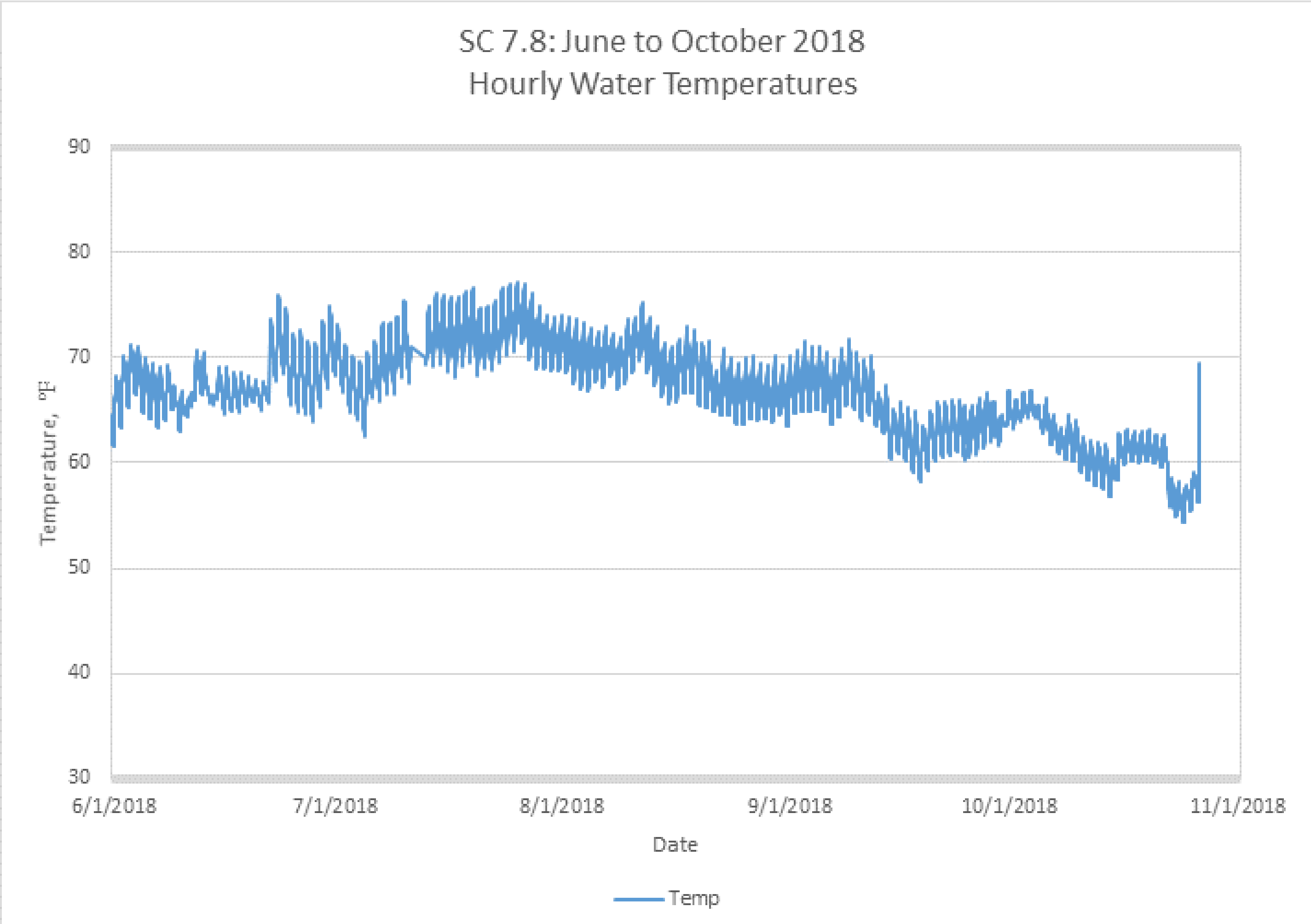
SC 7.0: June to October 2018
Daily Water Temperature Summary
90
80
70
60
50
40
30
Temperature, °F
6/1/2018
7/1/2018
8/1/2018
9/1/2018
10/1/2018
11/1/2018
Date
Daily Median Temp
Max Daily Temp
Min Daily Temp
Seven Day Moving Average of Max Water Temperature

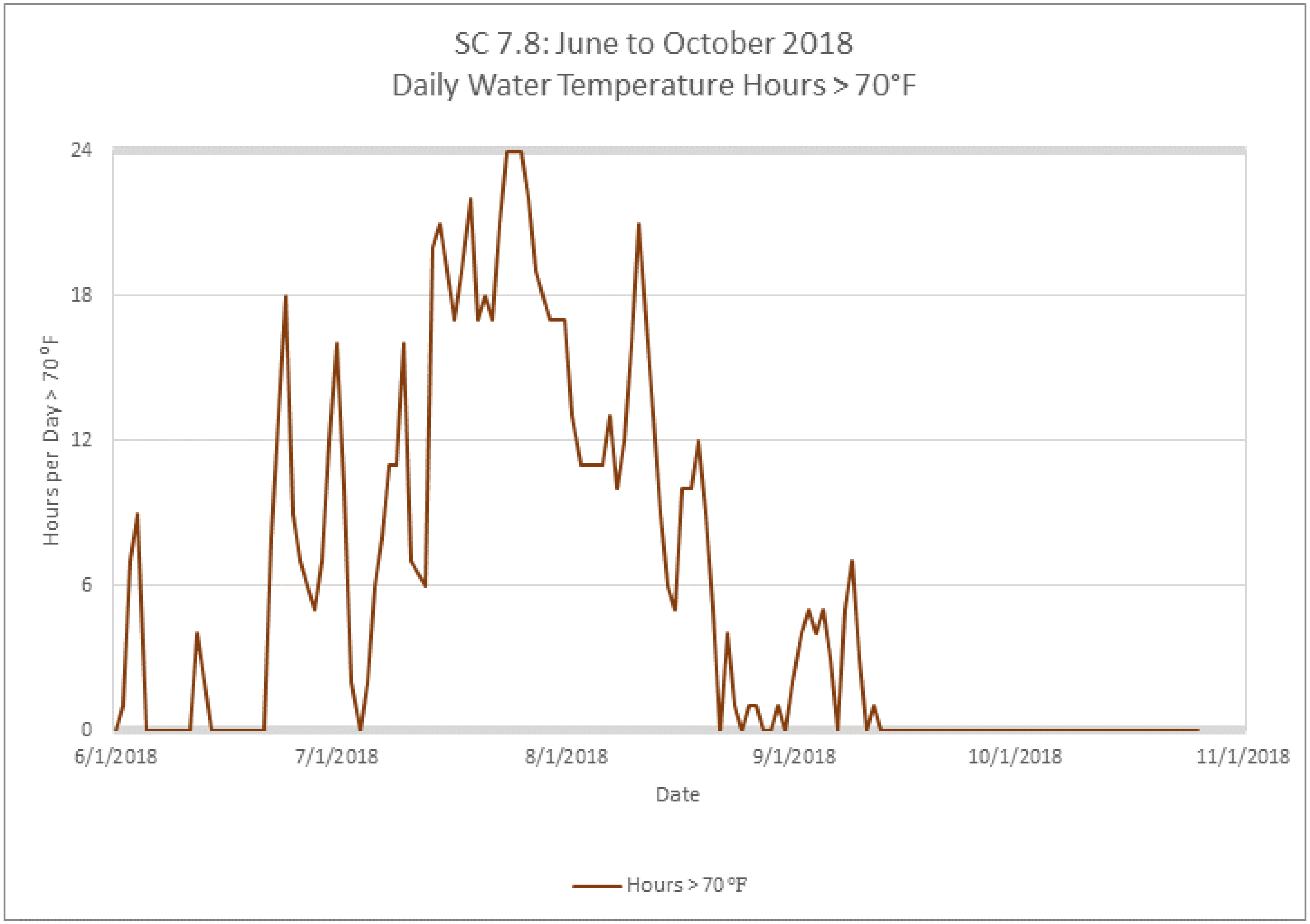

SC 7.5: June to October 2018
Hourly Water Temperatures
90
80
70
60
50
40
30
Temperature, °F
6/1/2018
7/1/2018
8/1/2018
9/1/2018
10/1/2018
11/1/2018
Date
Temp

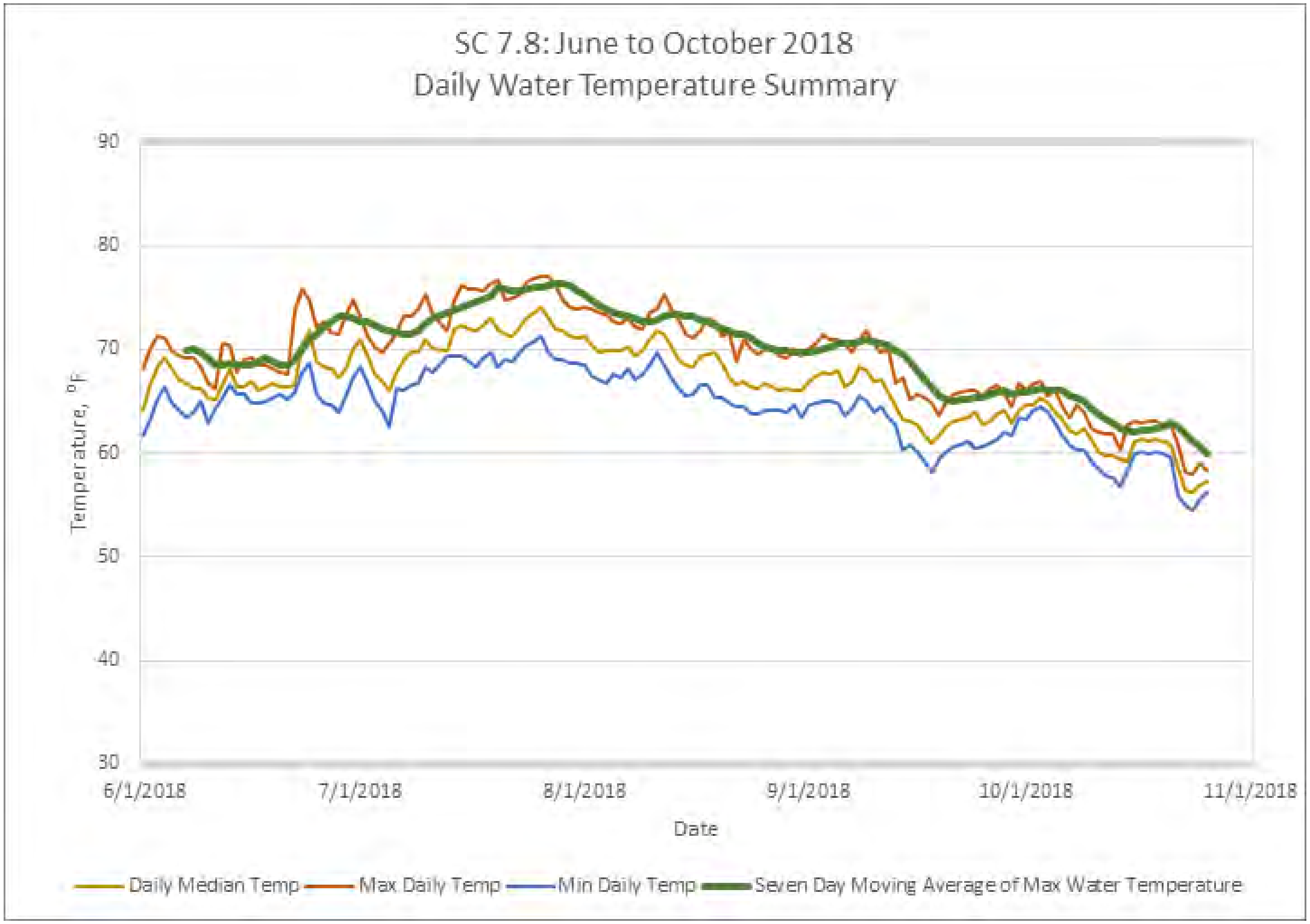

SC 7.5: June to October 2018
Daily Water Temperature Hours > 70°F
24
18
12
6
0
Hours per Day > 70°F
6/1/2018
7/1/2018
8/1/2018
9/1/2018
10/1/2018
11/1/2018
Date
Hours > 70 °F

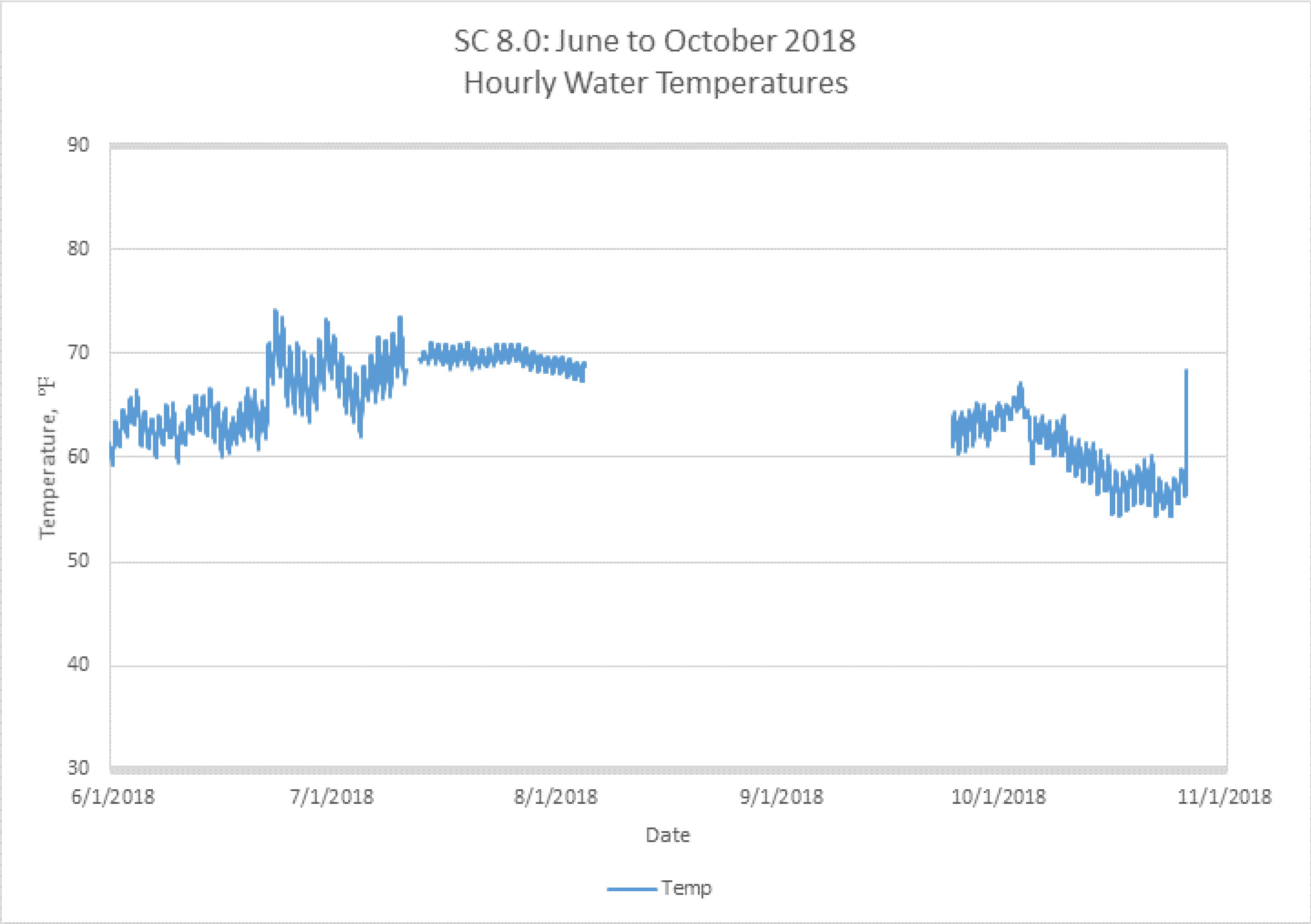


SC 7.5: June to October 2018
Daily Water Temperature Summary
90
80
70
60
50
40
30
Temperature, °F
6/1/2018
7/1/2018
8/1/2018
9/1/2018
10/1/2018
11/1/2018
Date
Daily Median Temp
Max Daily Temp
Min Daily Temp
Seven Day Moving Average of Max Water Temperature

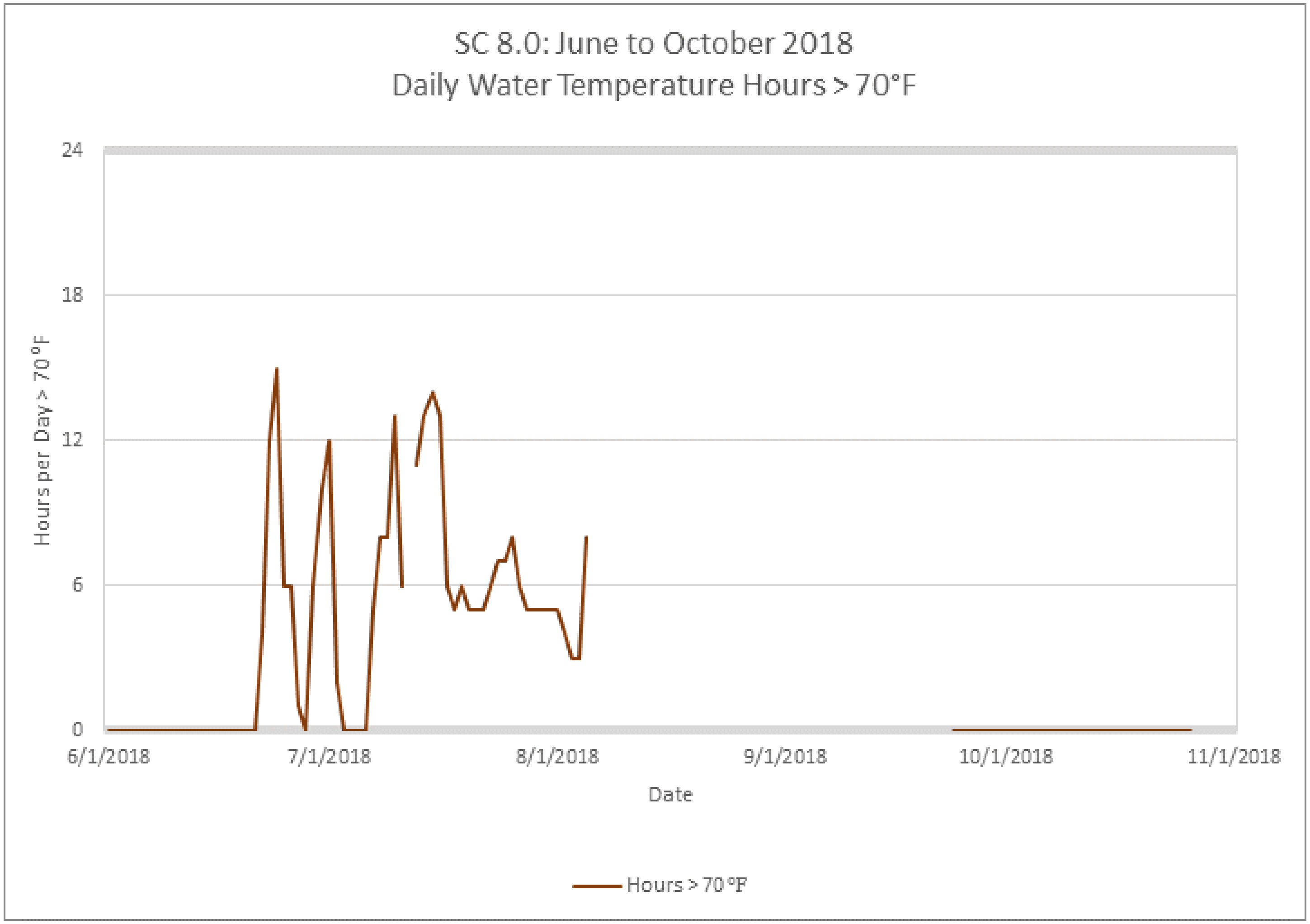

SC 7.8: June to October 2018
Hourly Water Temperatures
90
80
70
60
50
40
30
Temperature, °F
6/1/2018
7/1/2018
8/1/2018
9/1/2018
10/1/2018
11/1/2018
Date
Temp

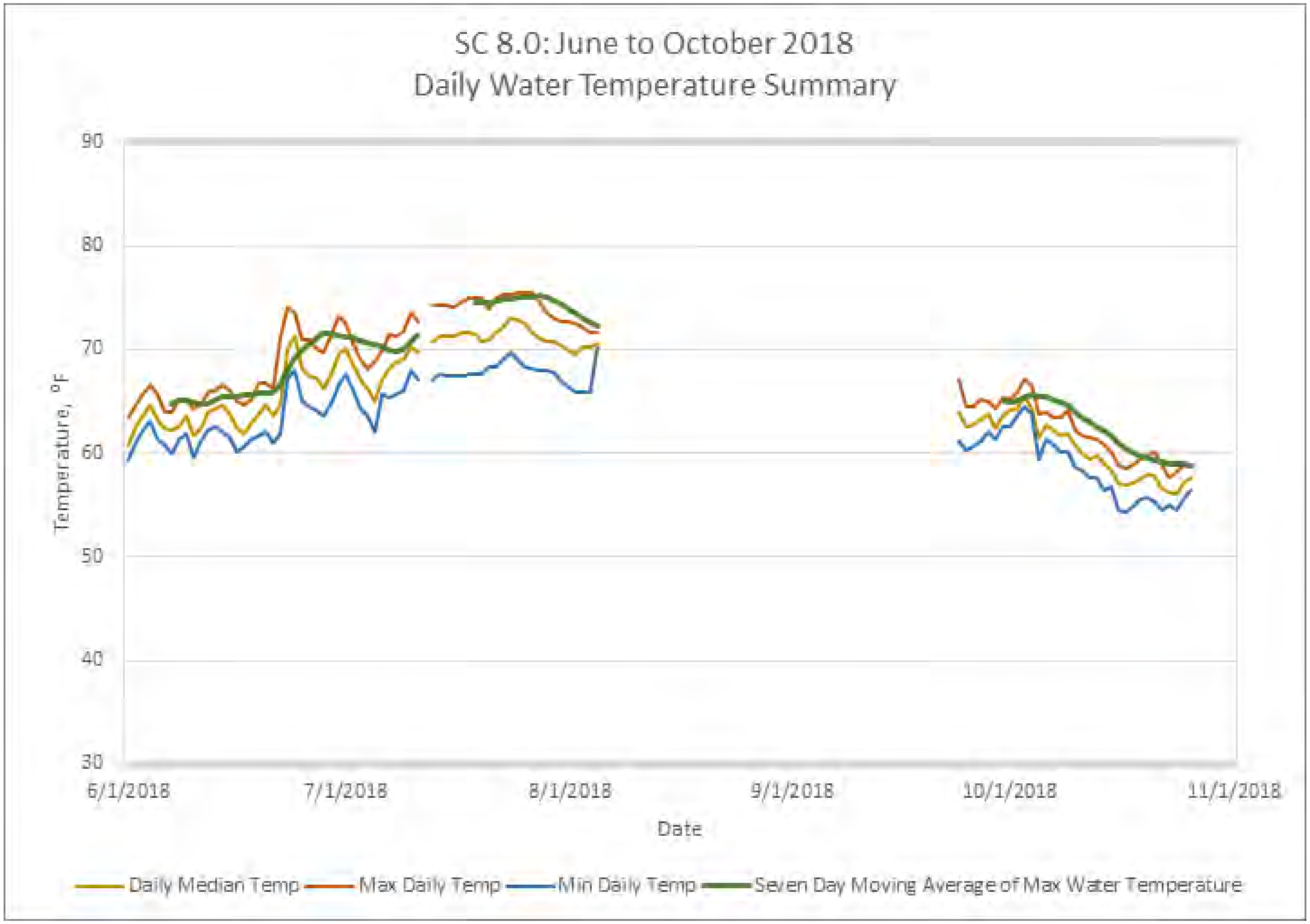

SC 7.8: June to October 2018
Daily Water Temperature Hours > 70°F
Hours per Day > 70°F
24
18
12
6
0
6/1/2018
7/1/2018
8/1/2018
9/1/2018
10/1/2018
11/1/2018
Date
Hours > 70 °F

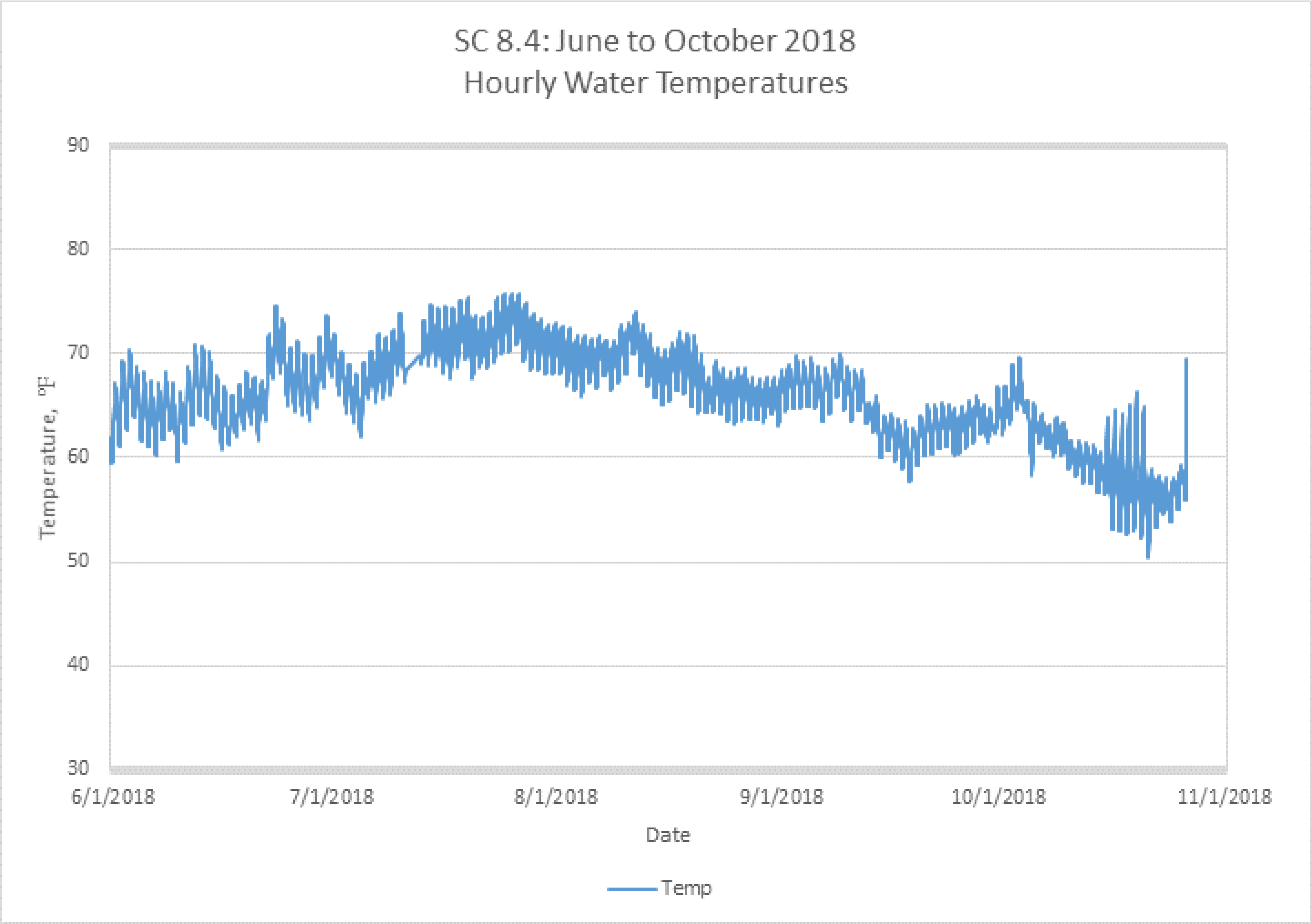

SC 7.8: June to October 2018
Daily Water Temperature Summary
Temperature, °F
90
80
70
60
50
40
30
6/1/2018
7/1/2018
8/1/2018
9/1/2018
10/1/2018
11/1/2018
Date
Daily Median Temp
Max Daily Temp
Min Daily Temp
Seven Day Moving Average of Max Water Temperature



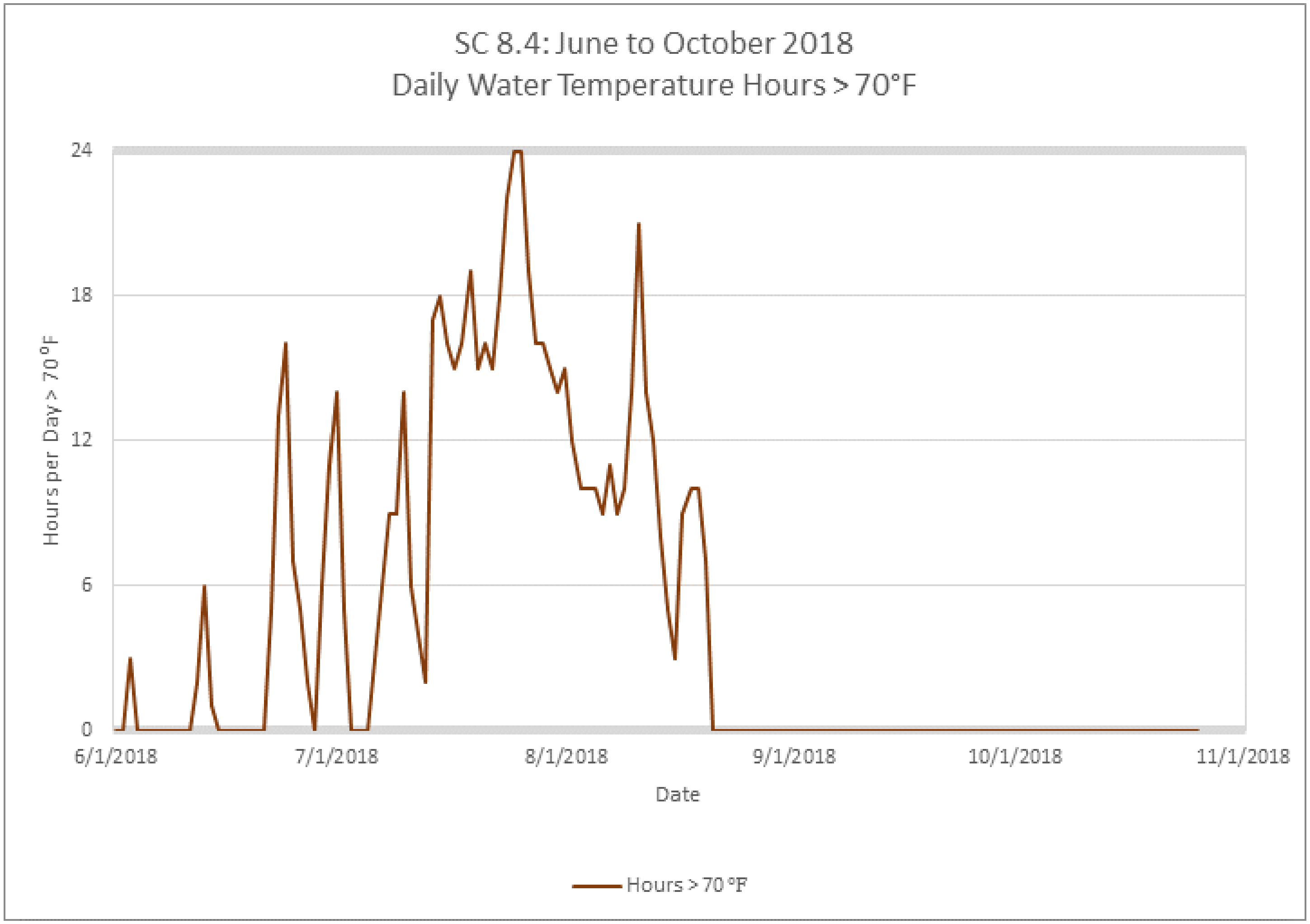
SC 8.0: June to October 2018
Hourly Water Temperatures
90
80
70
60
50
40
30
Temperature, °F
6/1/2018
7/1/2018
8/1/2018
9/1/2018
10/1/2018
11/1/2018
Date
Temp


SC 8.0: June to October 2018
Daily Water Temperature Hours > 70°F
24
18
12
6
0
Hours per Day > 70°F
6/1/2018
7/1/2018
8/1/2018
9/1/2018
10/1/2018
11/1/2018
Date
Hours > 70 °F

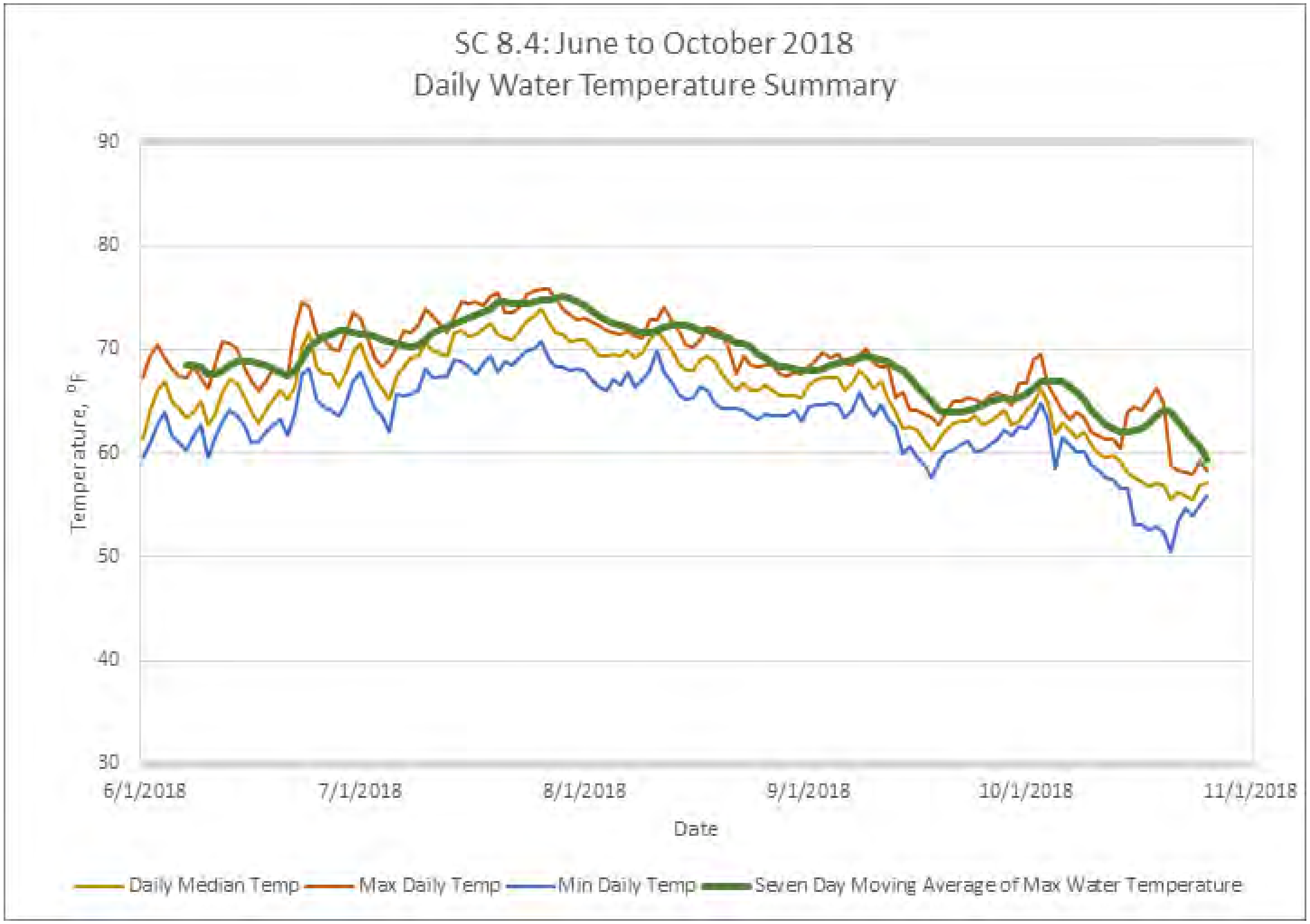

SC 8.0: June to October 2018
Daily Water Temperature Summary
90
80
70
60
50
40
30
Temperature, °F
6/1/2018
7/1/2018
8/1/2018
9/1/2018
10/1/2018
11/1/2018
Date
Daily Median Temp
Max Daily Temp
Min Daily Temp
Seven Day Moving Average of Max Water Temperature

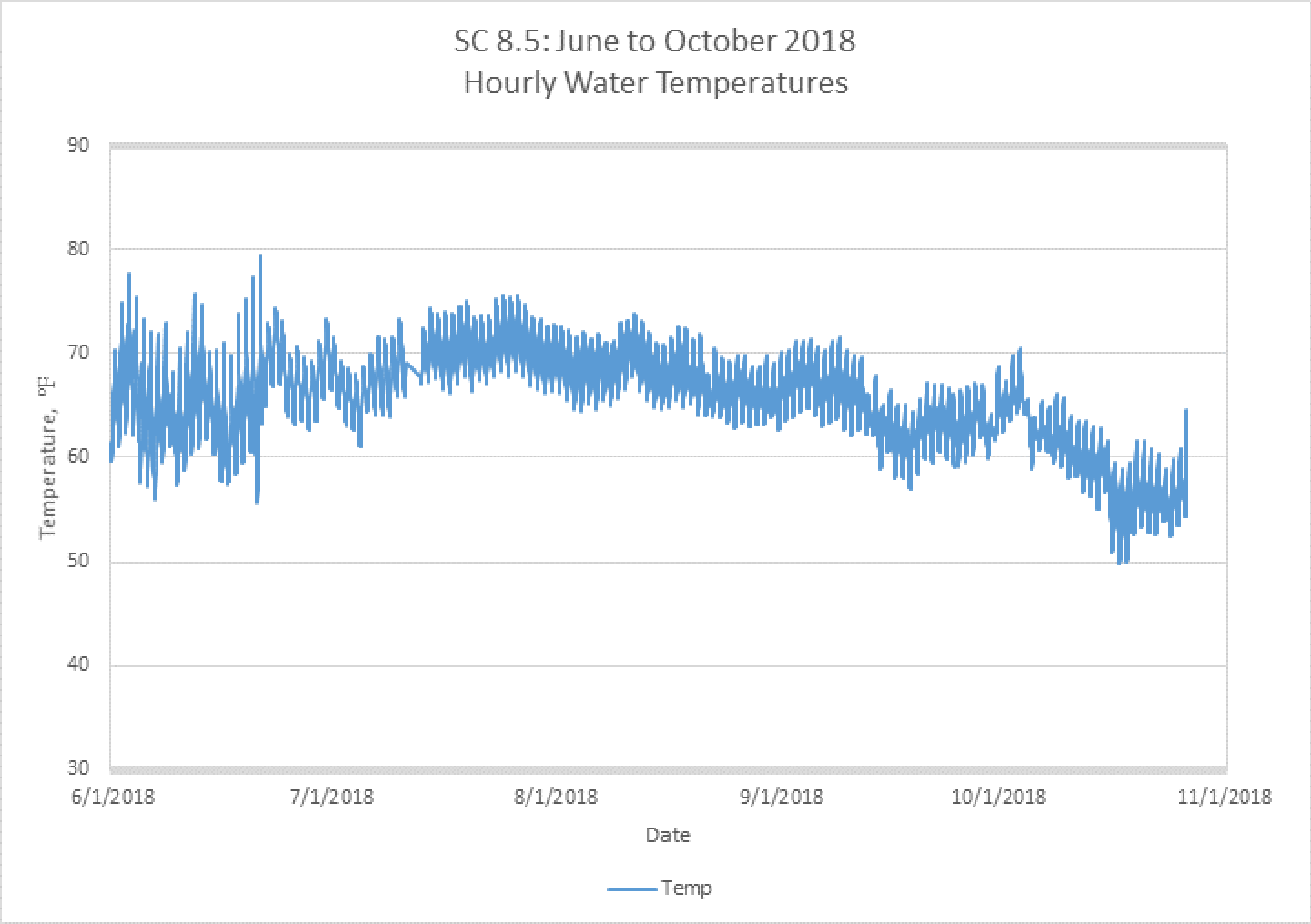


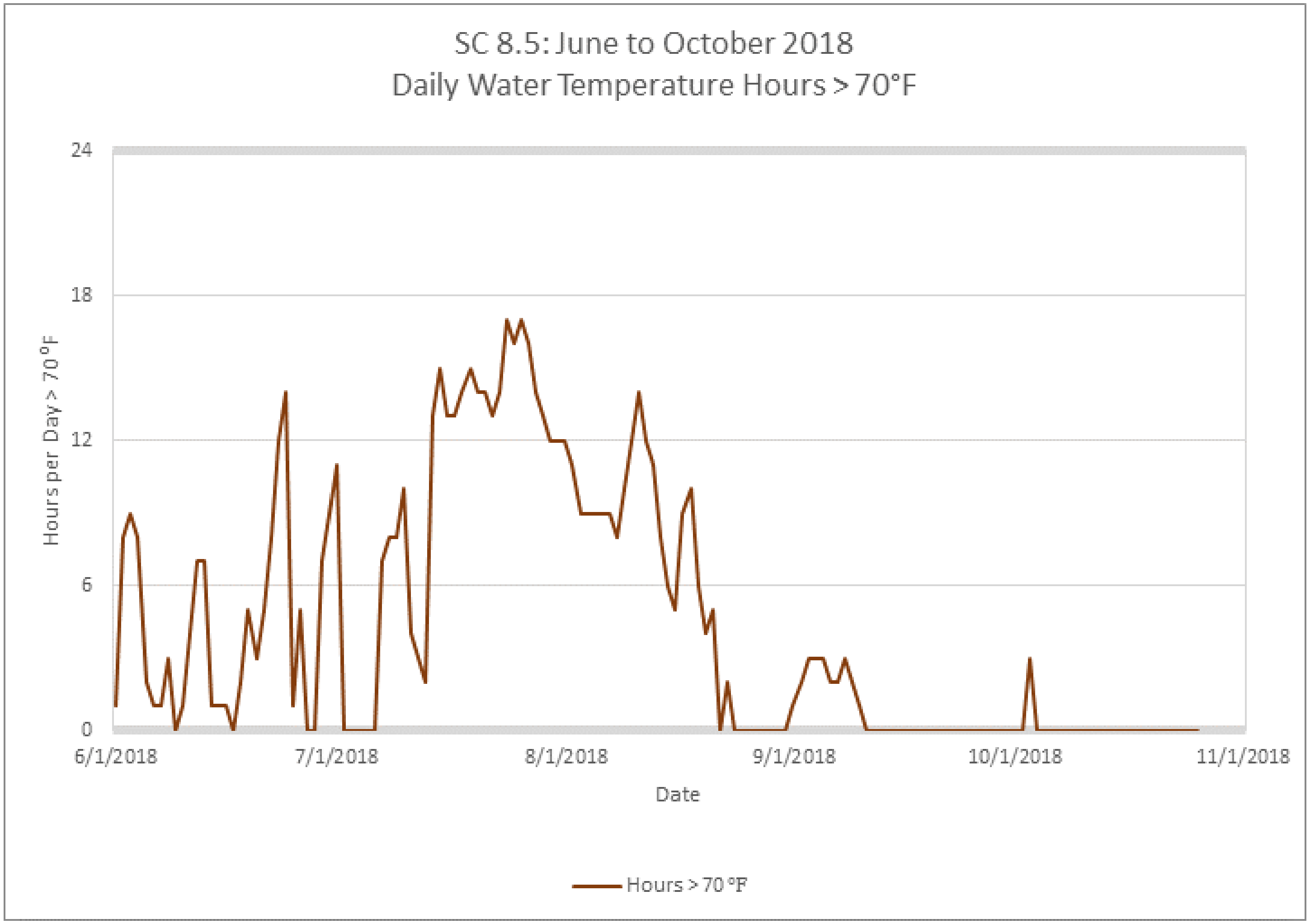
SC 8.4: June to October 2018
Hourly Water Temperatures
90
80
70
60
50
40
30
Temperature, °F
6/1/2018
7/1/2018
8/1/2018
9/1/2018
10/1/2018
11/1/2018
Date
Temp



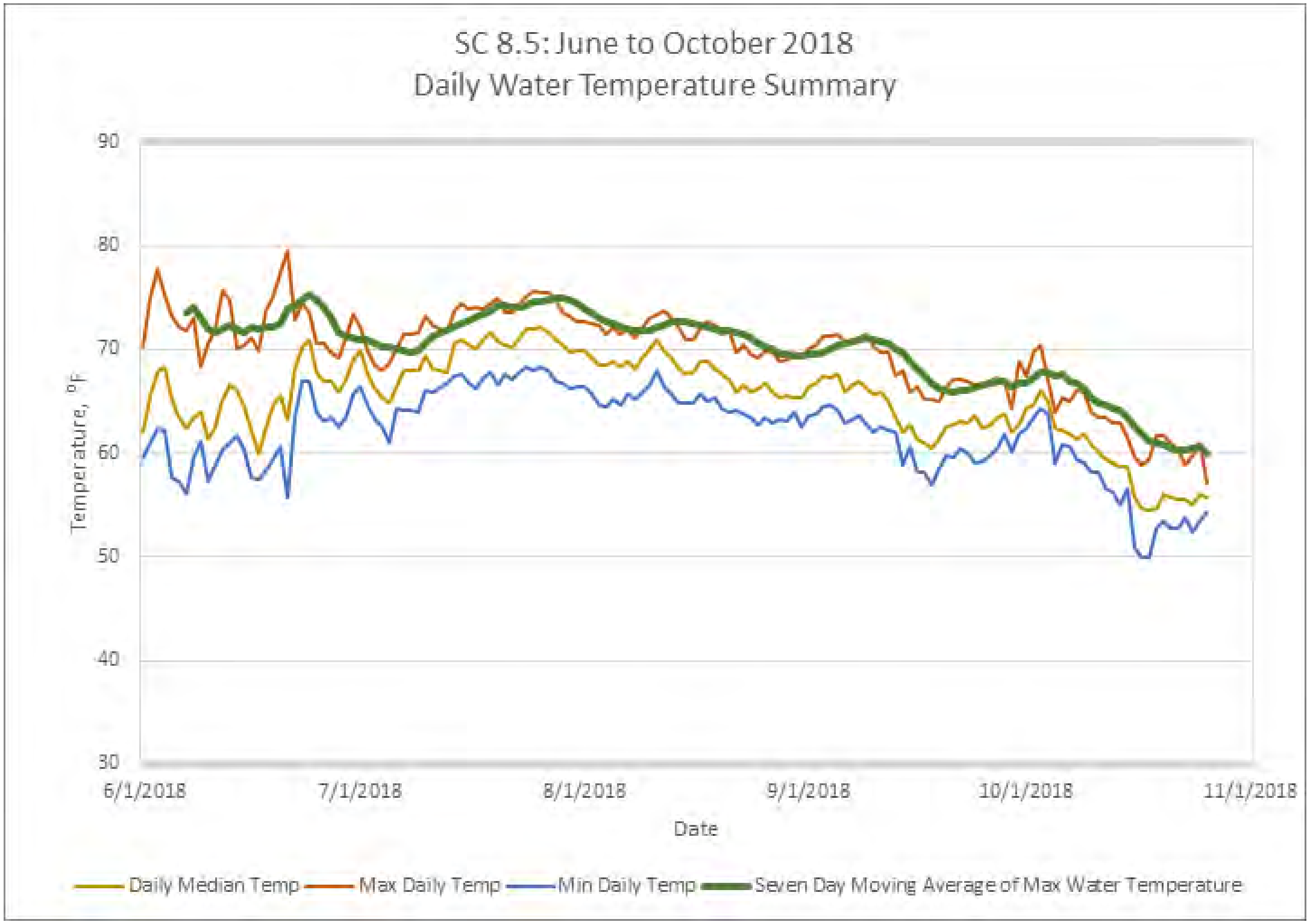
SC 8.4: June to October 2018
Daily Water Temperature Hours > 70°F
24
18
12
6
0
Hours per Day > 70°F
6/1/2018
7/1/2018
8/1/2018
9/1/2018
10/1/2018
11/1/2018
Date
Hours > 70 °F

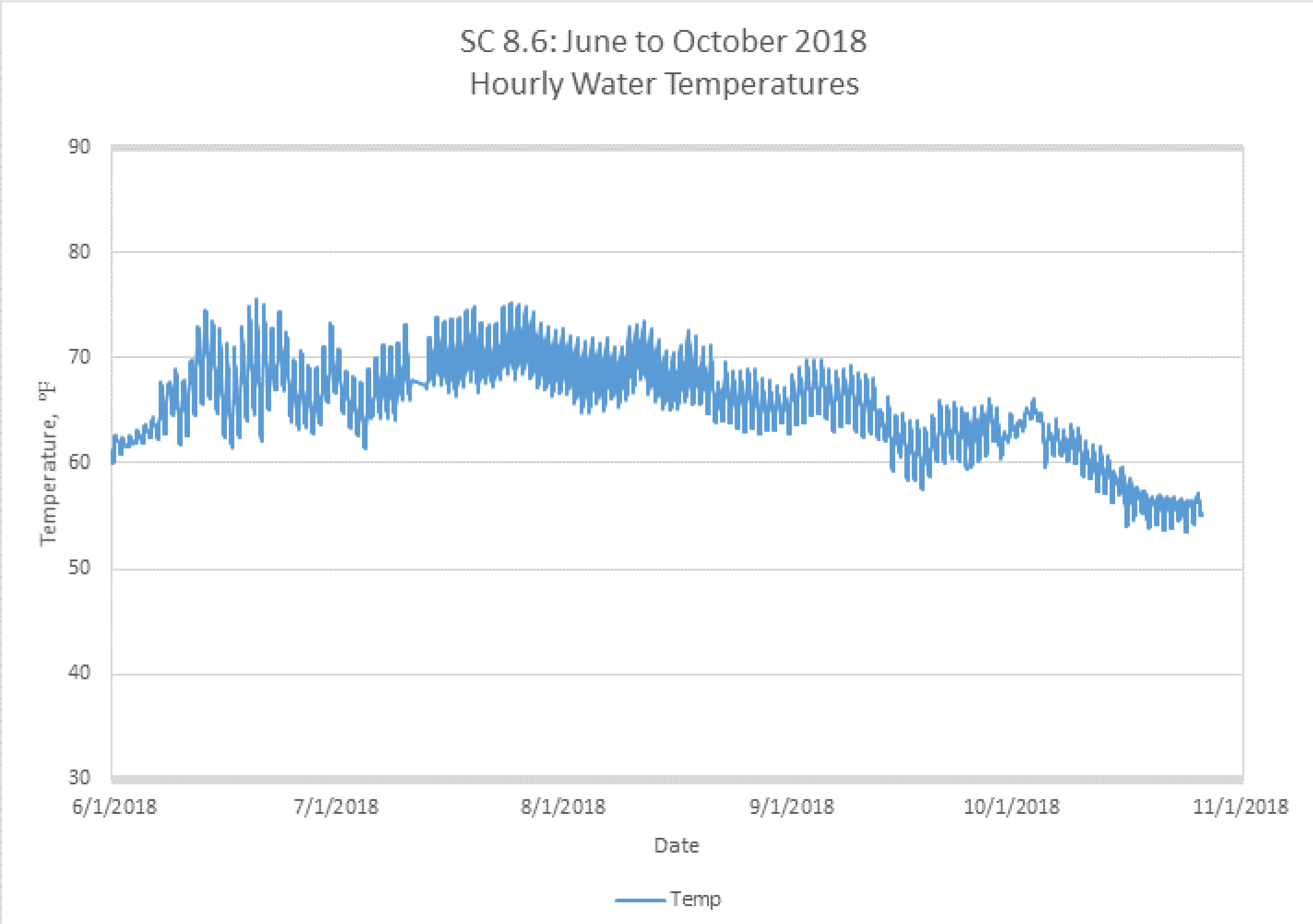

SC 8.4: June to October 2018
Daily Water Temperature Summary
90
80
70
60
50
40
30
Temperature, °F
6/1/2018
7/1/2018
8/1/2018
9/1/2018
10/1/2018
11/1/2018
Date
Daily Median Temp
Max Daily Temp
Min Daily Temp
Seven Day Moving Average of Max Water Temperature

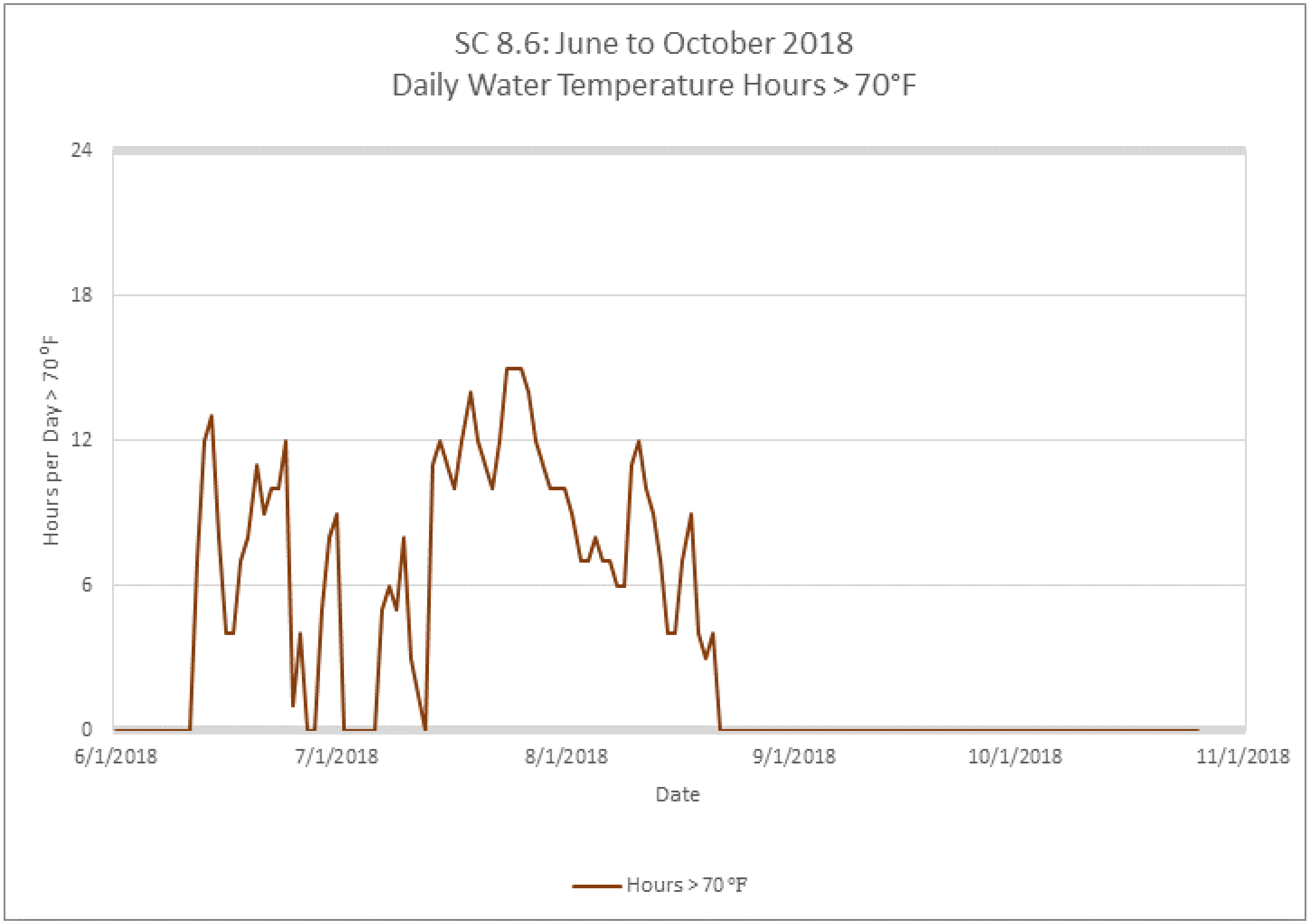

SC 8.5: June to October 2018
Hourly Water Temperatures
90
80
70
60
50
40
30
Temperature, °F
6/1/2018
7/1/2018
8/1/2018
9/1/2018
10/1/2018
11/1/2018
Date
Temp



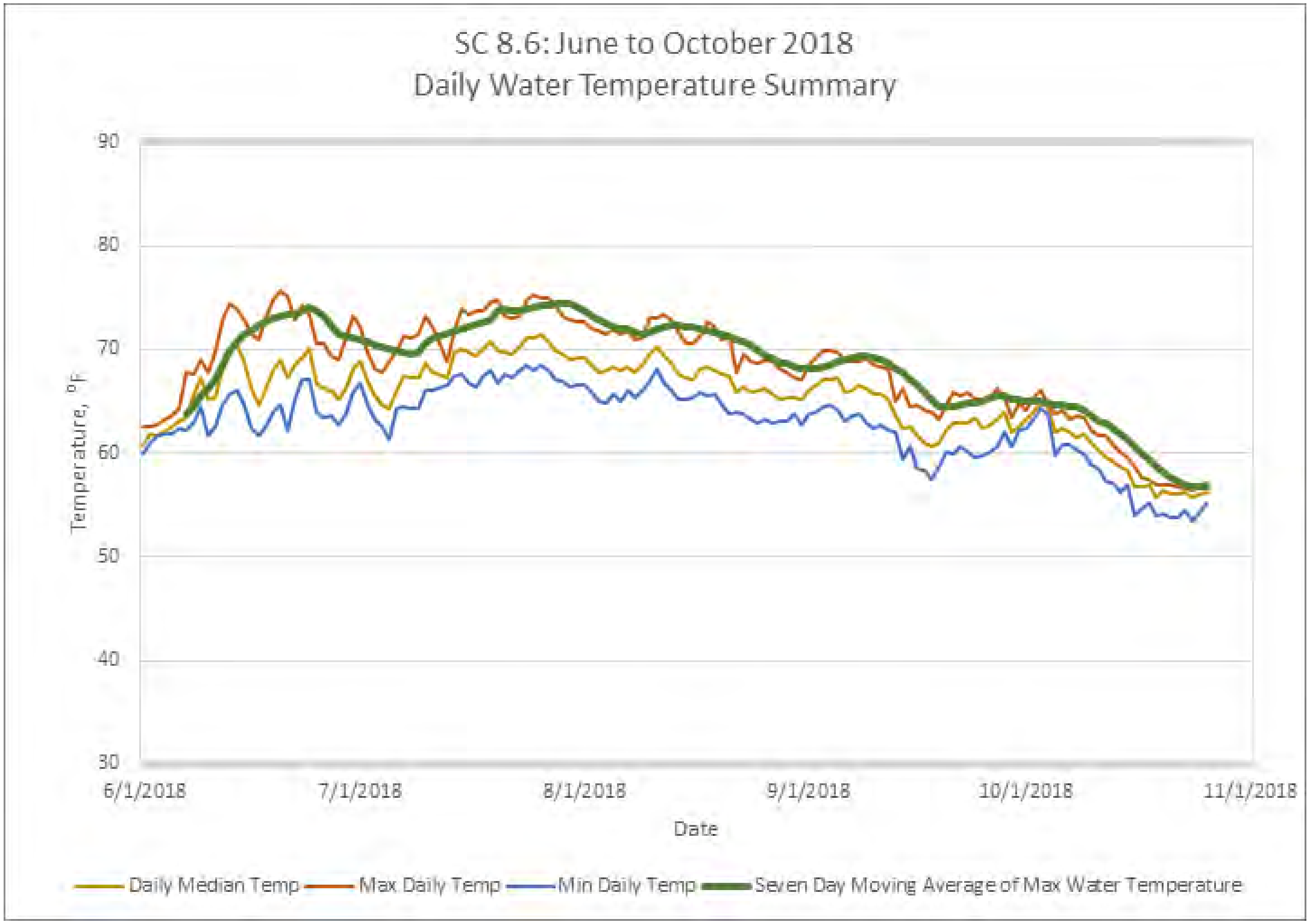
SC 8.5: June to October 2018
Daily Water Temperature Hours > 70°F
24
18
12
6
0
Hours per Day > 70°F
6/1/2018
7/1/2018
8/1/2018
9/1/2018
10/1/2018
11/1/2018
Date
Hours > 70 °F

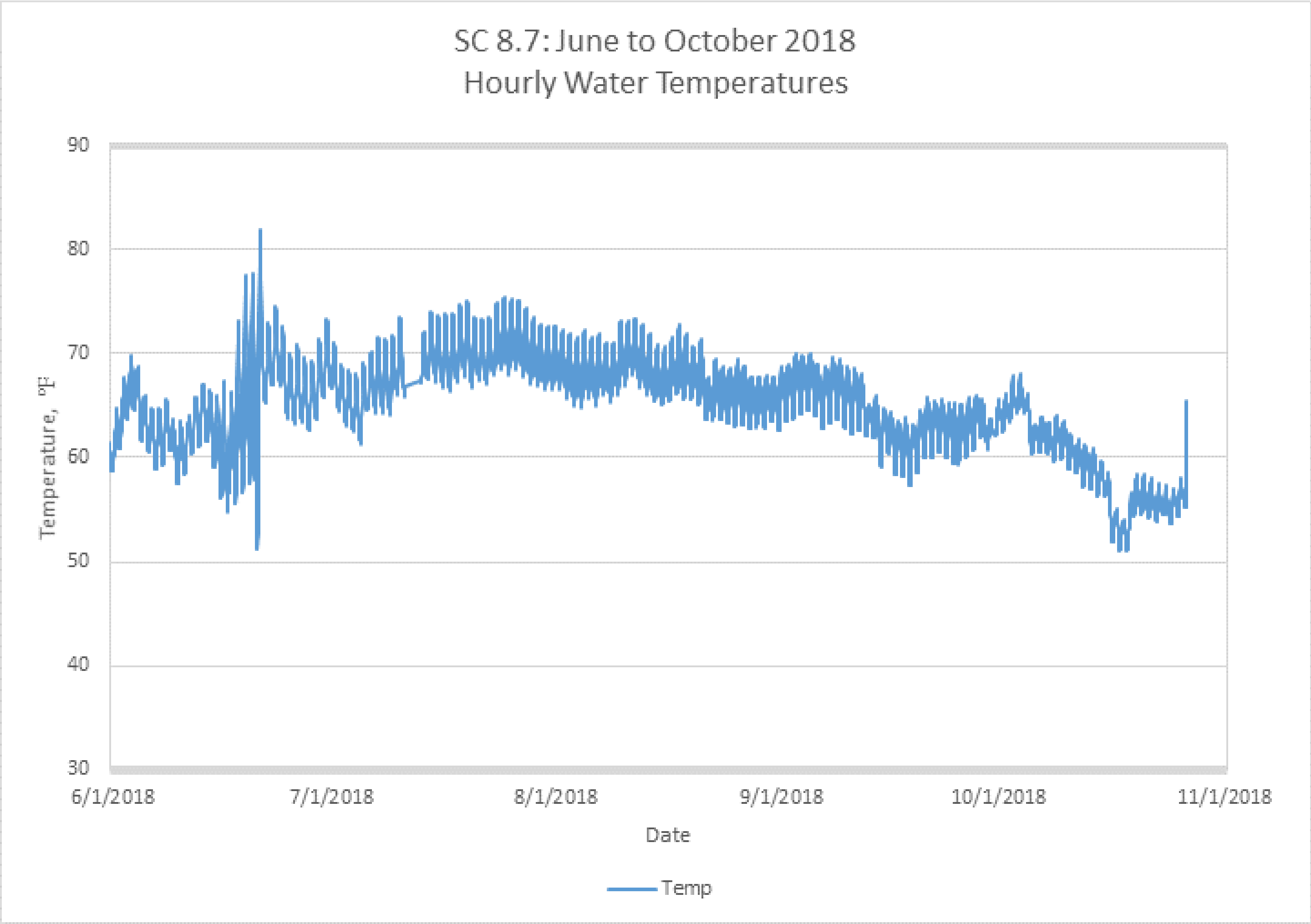

SC 8.5: June to October 2018
Daily Water Temperature Summary
90
80
70
60
50
40
30
Temperature, °F
6/1/2018
7/1/2018
8/1/2018
9/1/2018
10/1/2018
11/1/2018
Date
Daily Median Temp
Max Daily Temp
Min Daily Temp
Seven Day Moving Average of Max Water Temperature

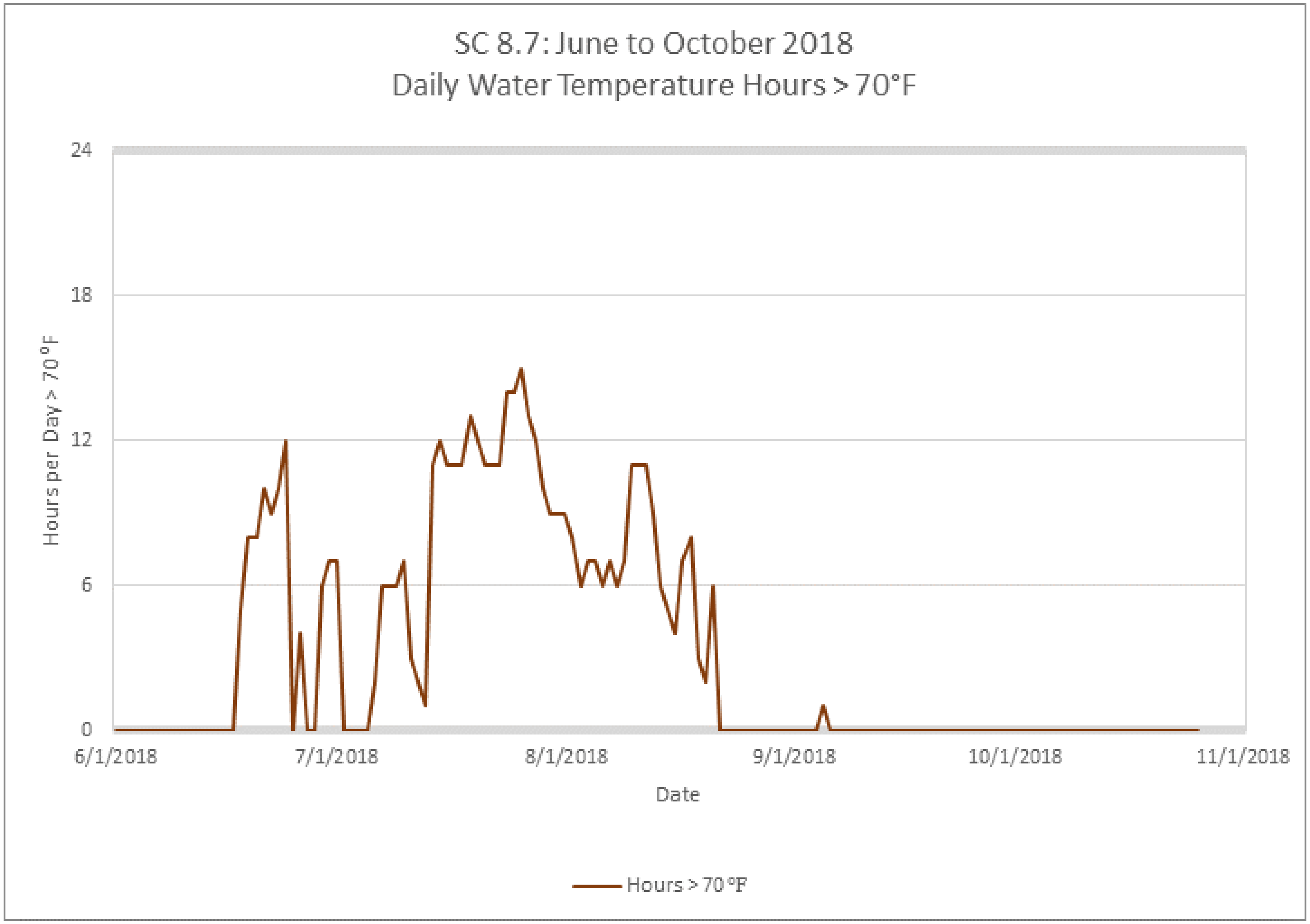

SC 8.6: June to October 2018
Hourly Water Temperatures
90
80
70
60
50
40
30
Temperature, °F
6/1/2018
7/1/2018
8/1/2018
9/1/2018
10/1/2018
11/1/2018
Date
Temp

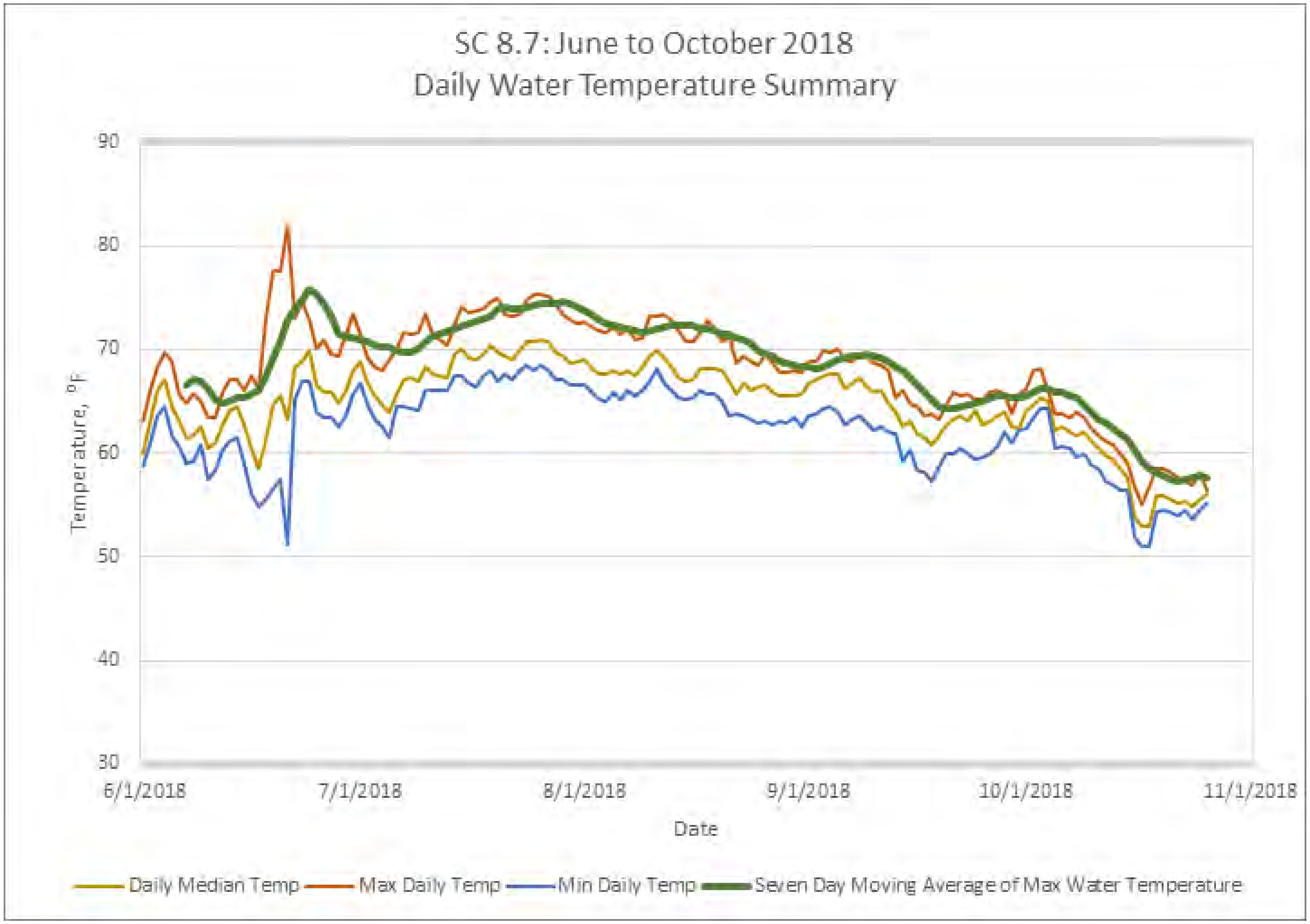


SC 8.6: June to October 2018
Daily Water Temperature Hours > 70°F
24
18
12
6
0
Hours per Day > 70°F
6/1/2018
7/1/2018
8/1/2018
9/1/2018
10/1/2018
11/1/2018
Date
Hours > 70 °F

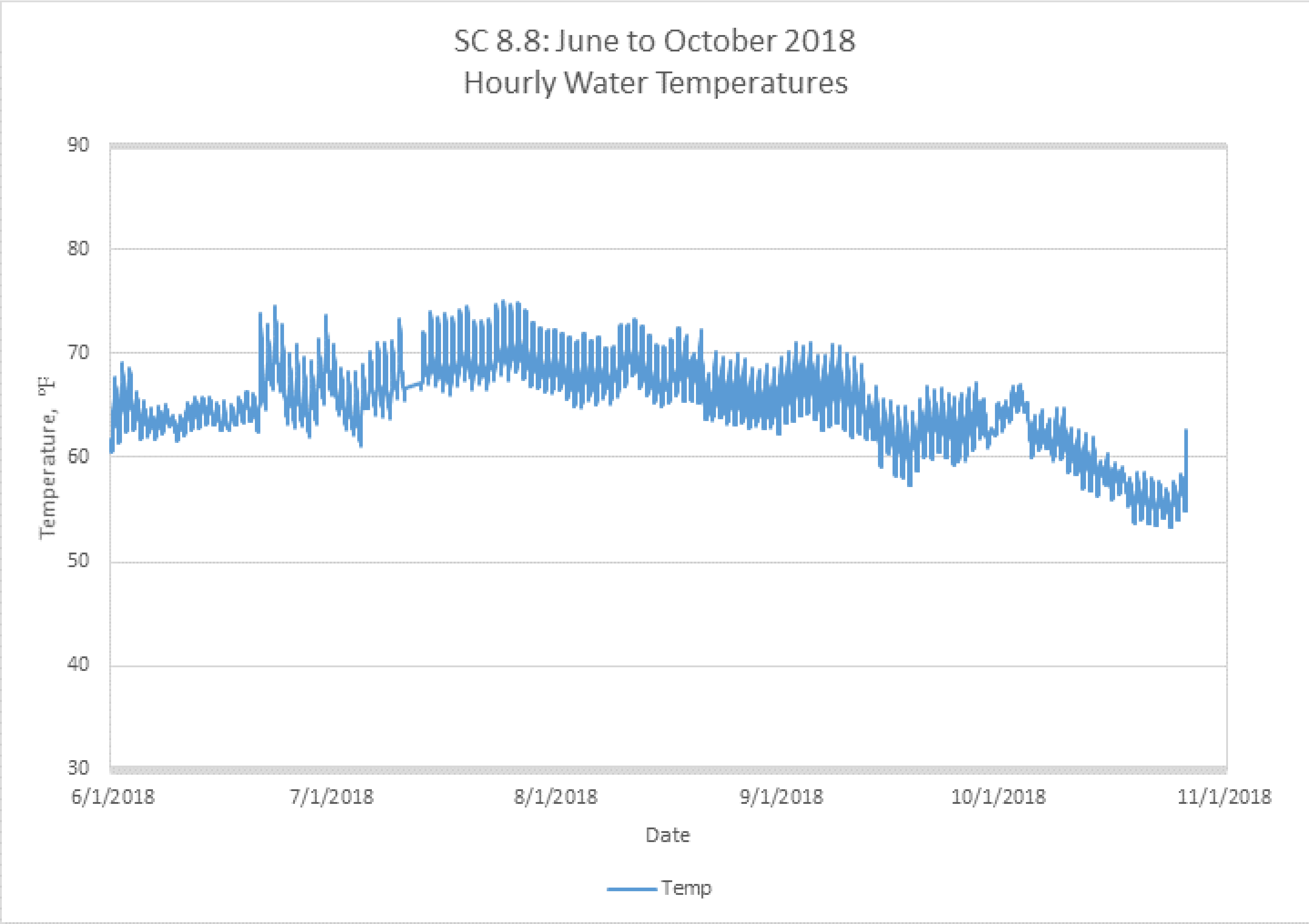

SC 8.6: June to October 2018
Daily Water Temperature Summary
90
80
70
60
50
40
30
Temperature, °F
6/1/2018
7/1/2018
8/1/2018
9/1/2018
10/1/2018
11/1/2018
Date
Daily Median Temp
Max Daily Temp
Min Daily Temp
Seven Day Moving Average of Max Water Temperature


SC 8.7: June to October 2018
Hourly Water Temperatures
90
80
70
60
50
40
30
Temperature, °F
6/1/2018
7/1/2018
8/1/2018
9/1/2018
10/1/2018
11/1/2018
Date
Temp

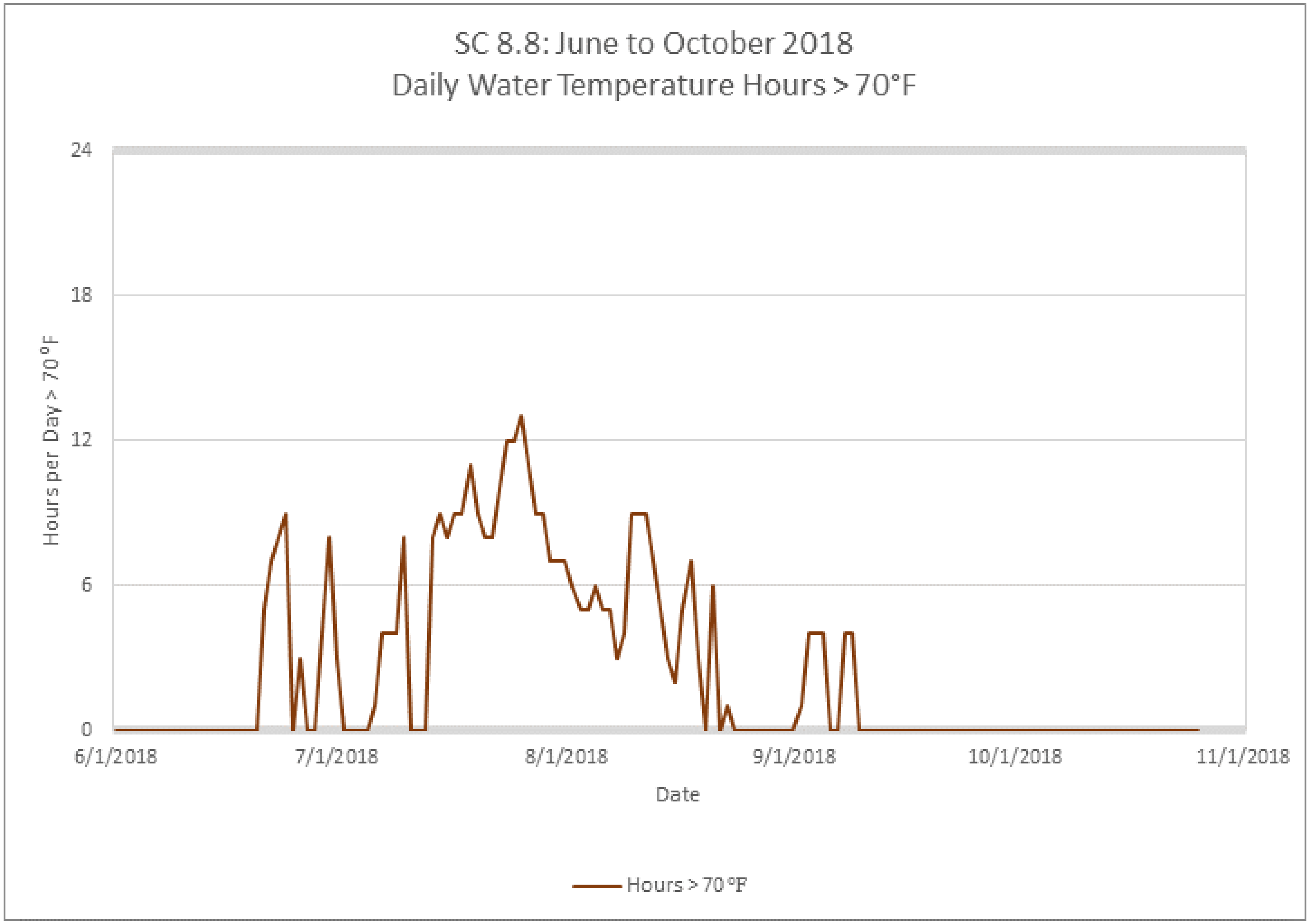

SC 8.7: June to October 2018
Daily Water Temperature Hours > 70°F
24
18
12
6
0
Hours per Day > 70°F
6/1/2018
7/1/2018
8/1/2018
9/1/2018
10/1/2018
11/1/2018
Date
Hours > 70 °F



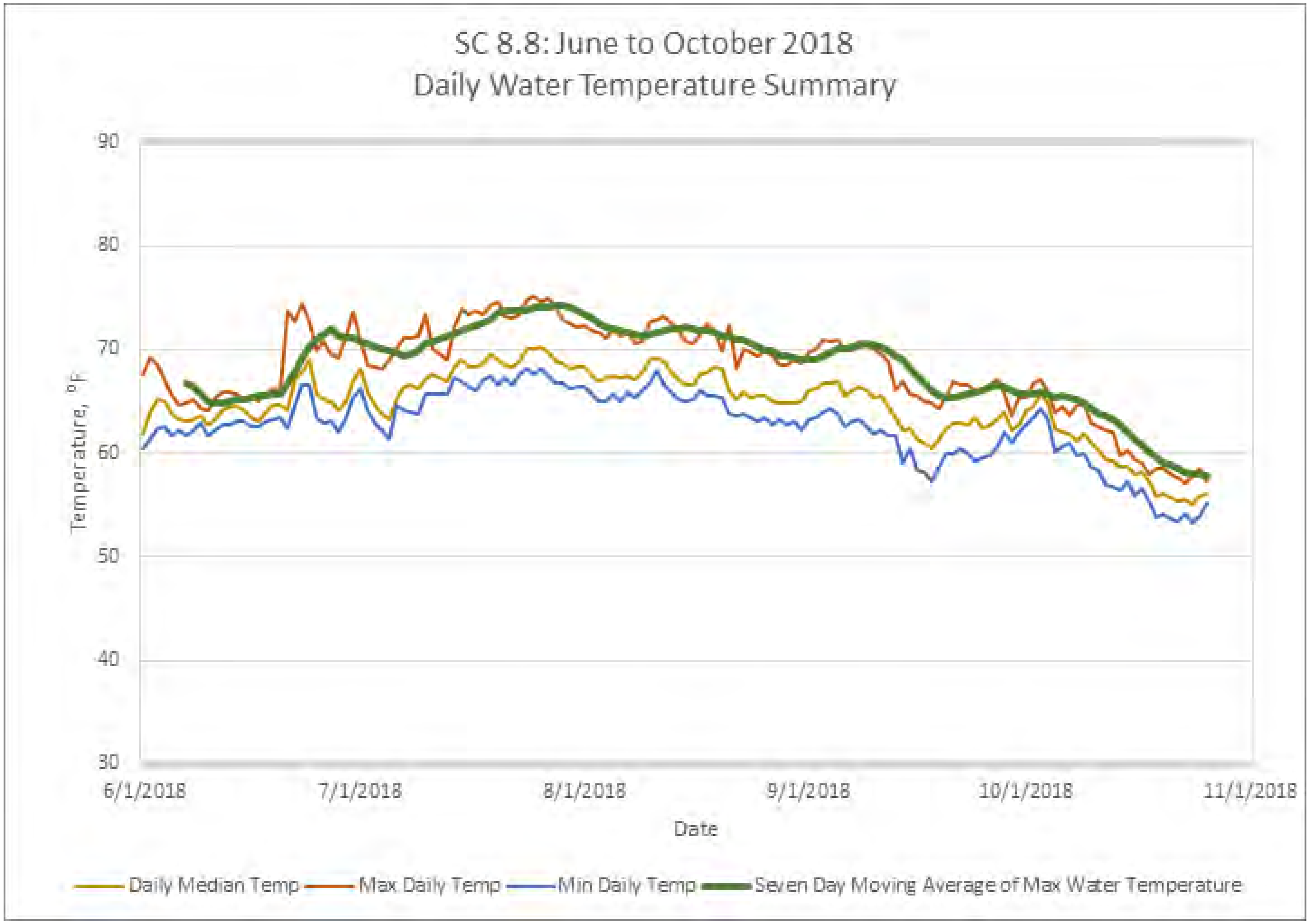
SC 8.7: June to October 2018
Daily Water Temperature Summary
90
80
70
60
50
40
30
Temperature, °F
6/1/2018
7/1/2018
8/1/2018
9/1/2018
10/1/2018
11/1/2018
Date
Daily Median Temp
Max Daily Temp
Min Daily Temp
Seven Day Moving Average of Max Water Temperature

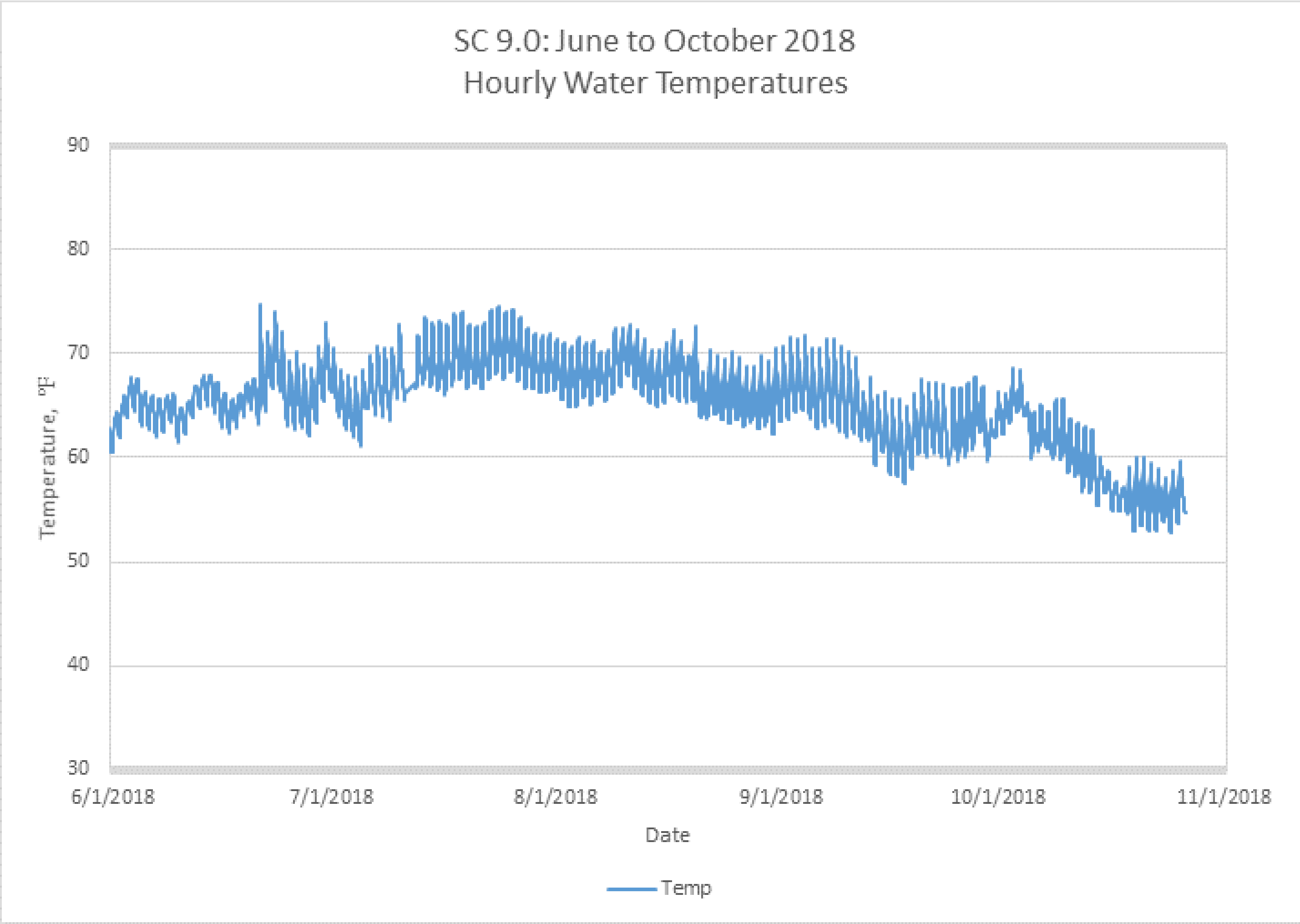


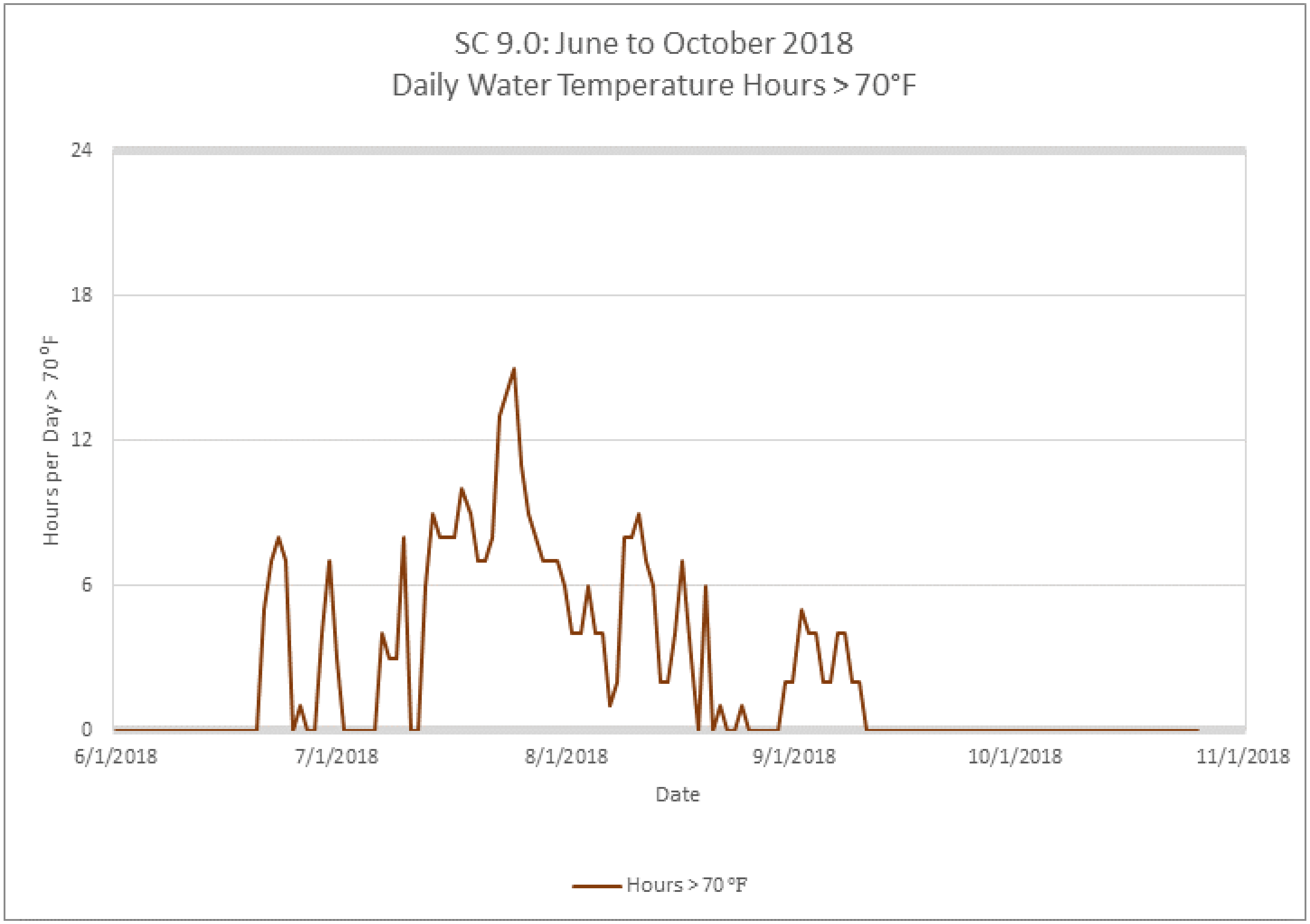
SC 8.8: June to October 2018
Hourly Water Temperatures
90
80
70
60
50
40
30
Temperature, °F
6/1/2018
7/1/2018
8/1/2018
9/1/2018
10/1/2018
11/1/2018
Date
Temp



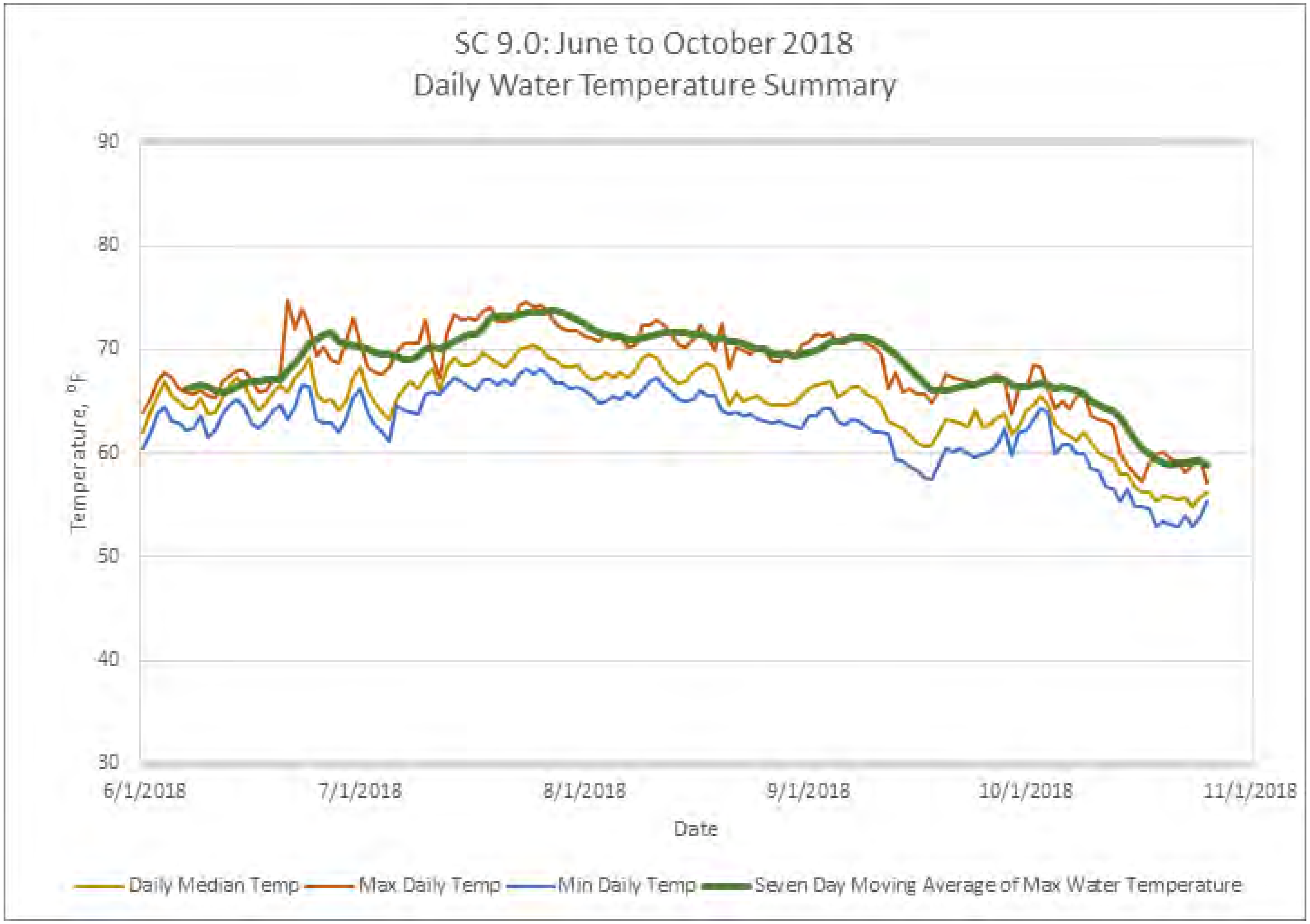
SC 8.8: June to October 2018
Daily Water Temperature Hours > 70°F
24
18
12
6
0
Hours per Day > 70°F
6/1/2018
7/1/2018
8/1/2018
9/1/2018
10/1/2018
11/1/2018
Date
Hours > 70 °F


SC 8.8: June to October 2018
Daily Water Temperature Summary
90
80
70
60
50
40
30
Temperature, °F
6/1/2018
7/1/2018
8/1/2018
9/1/2018
10/1/2018
11/1/2018
Date
Daily Median Temp
Max Daily Temp
Min Daily Temp
Seven Day Moving Average of Max Water Temperature

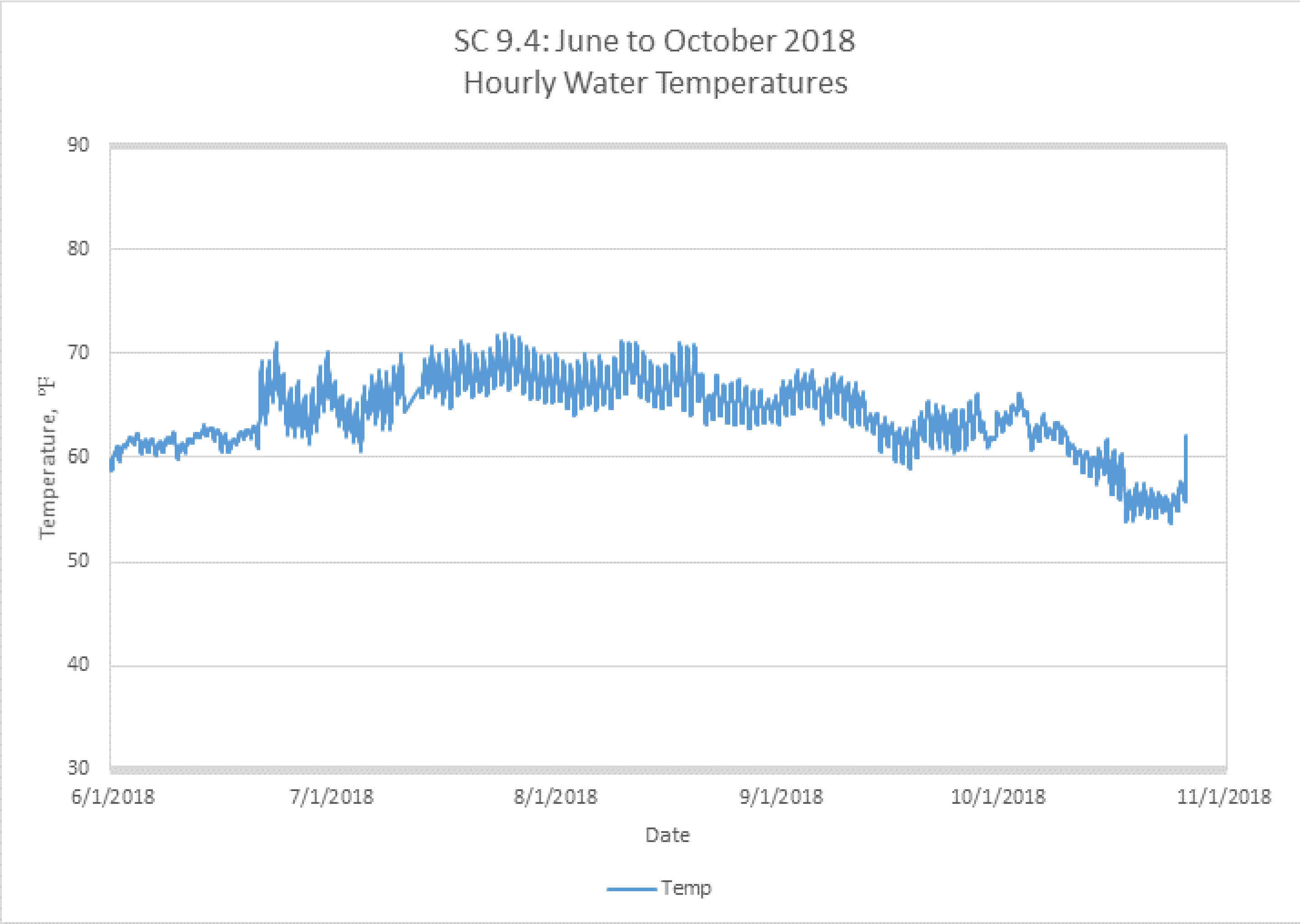

SC 9.0: June to October 2018
Hourly Water Temperatures
Temperature, °F
90
80
70
60
50
40
30
6/1/2018
7/1/2018
8/1/2018
9/1/2018
10/1/2018
11/1/2018
Date
Temp

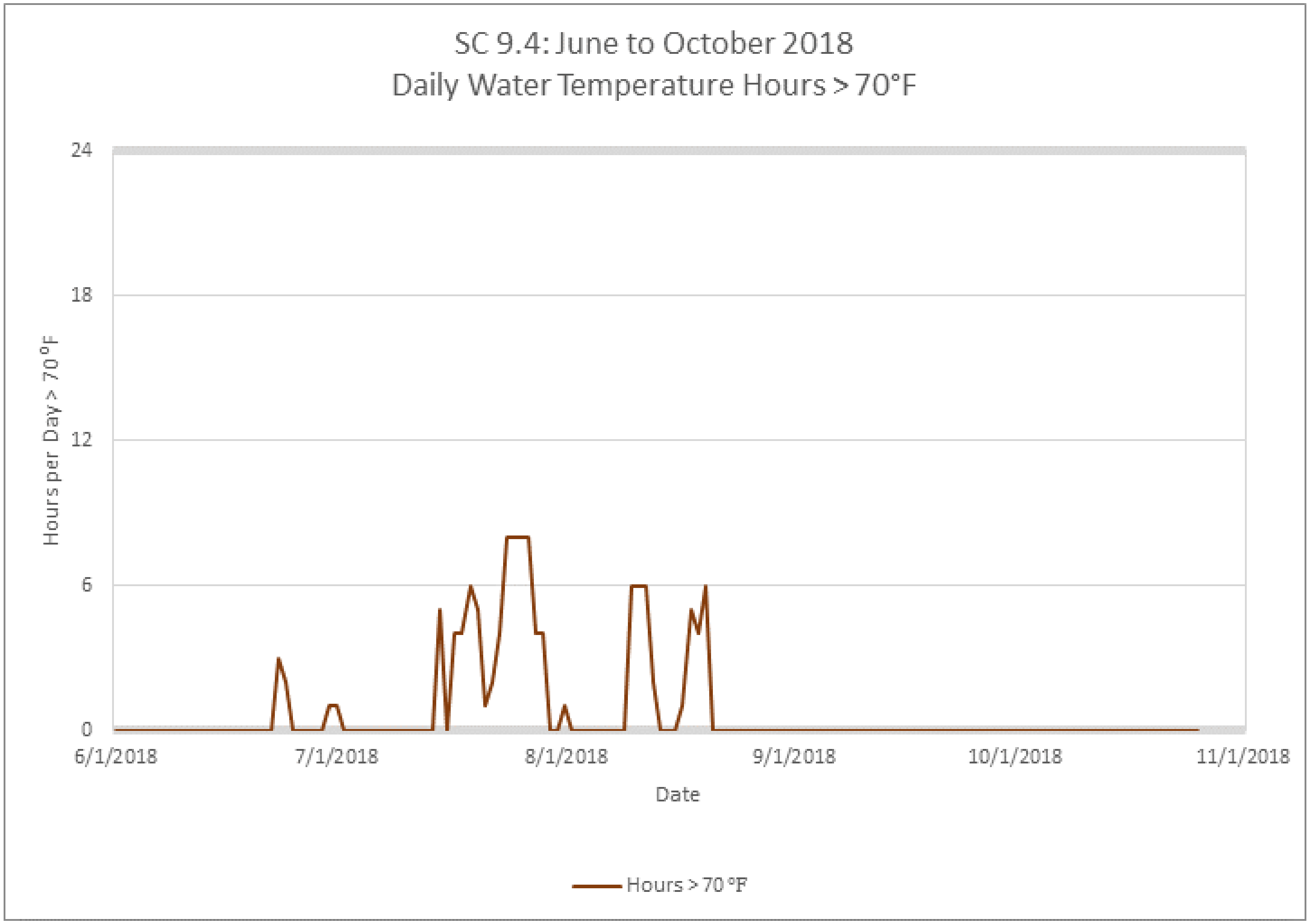


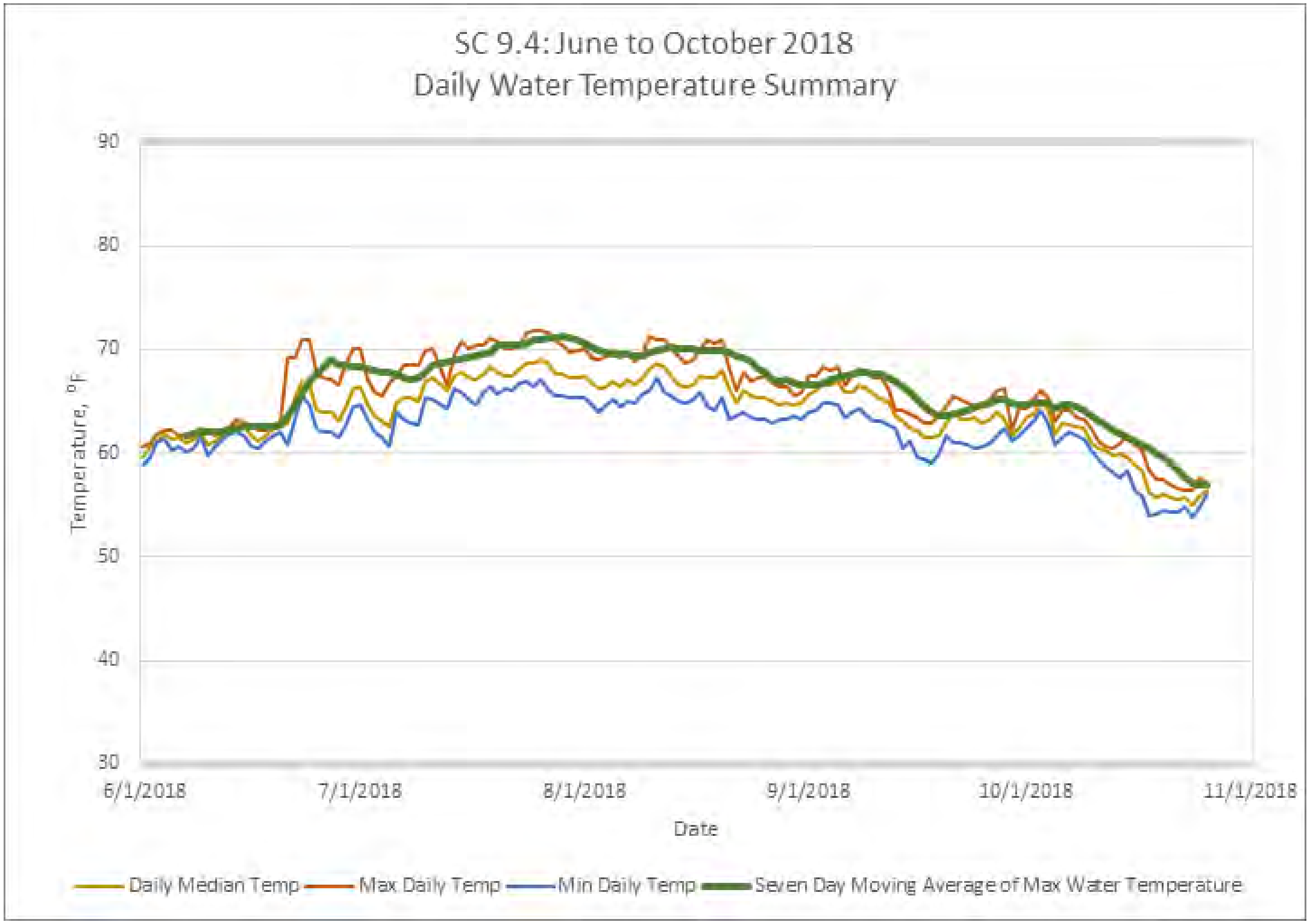
SC 9.0: June to October 2018
Daily Water Temperature Hours > 70°F
24
18
12
6
0
Hours per Day > 70°F
6/1/2018
7/1/2018
8/1/2018
9/1/2018
10/1/2018
11/1/2018
Date
Hours > 70 °F

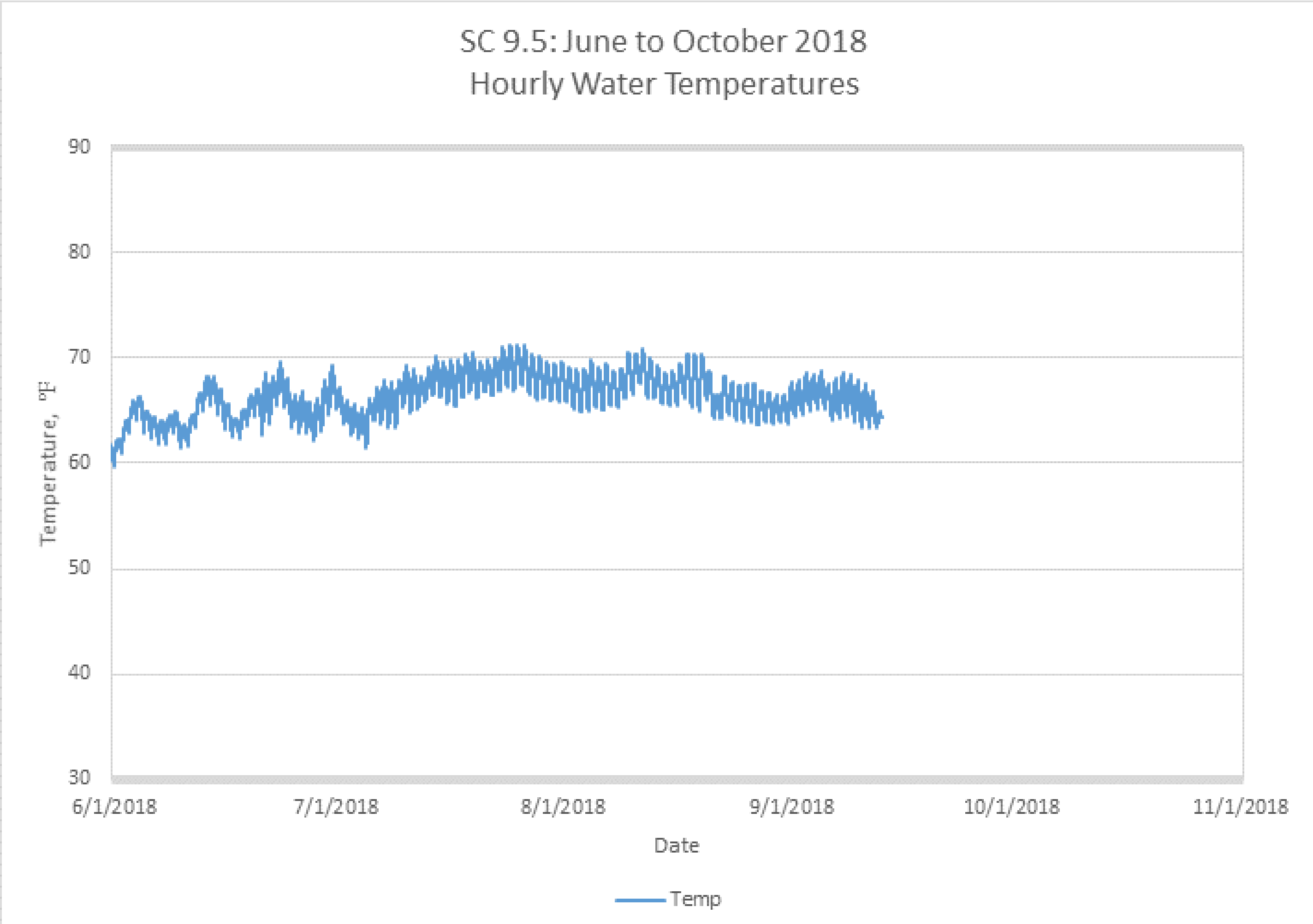


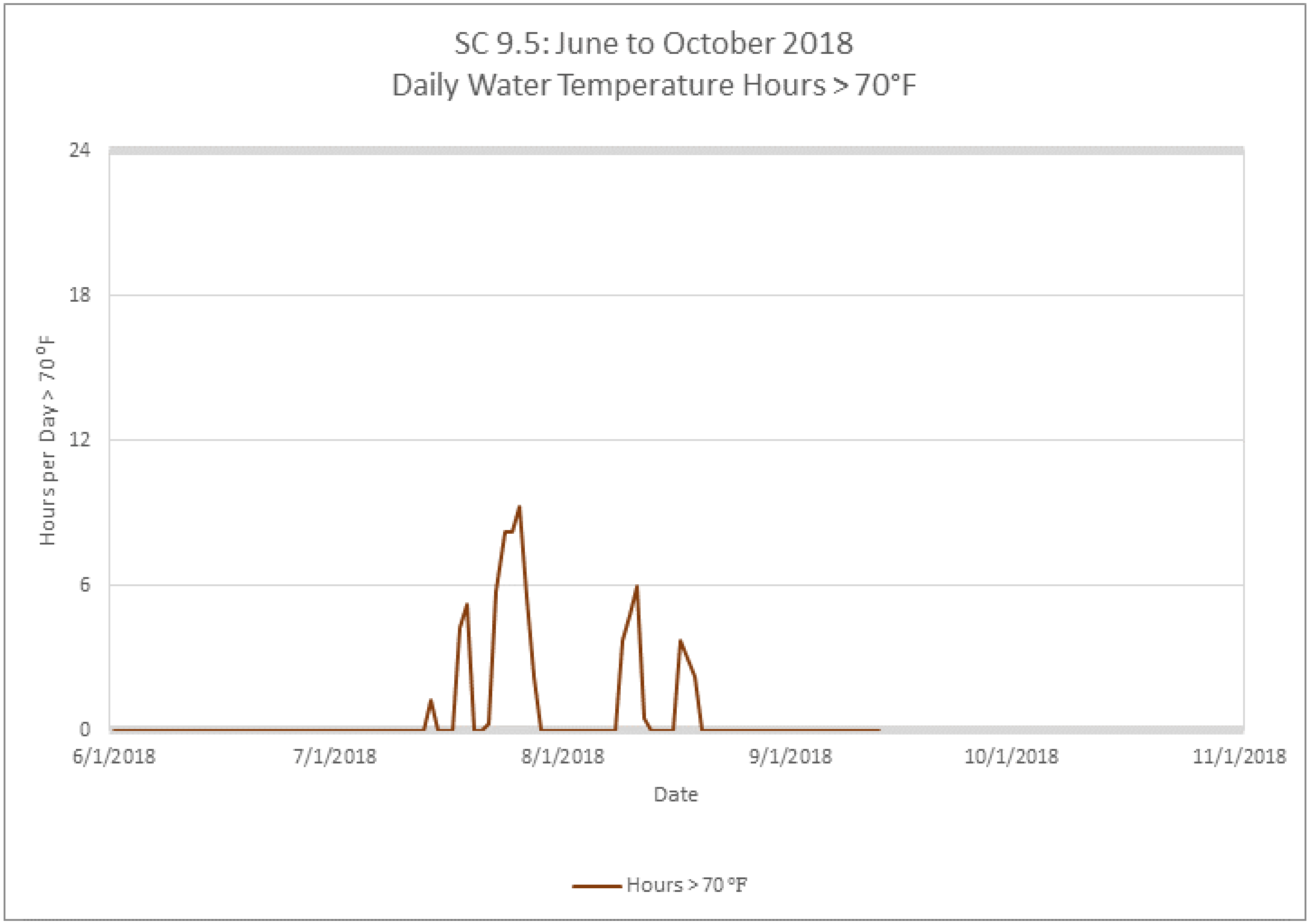
SC 9.0: June to October 2018
Daily Water Temperature Summary
90
80
70
60
50
40
30
Temperature, °F
6/1/2018
7/1/2018
8/1/2018
9/1/2018
10/1/2018
11/1/2018
Date
Daily Median Temp
Max Daily Temp
Min Daily Temp
Seven Day Moving Average of Max Water Temperature

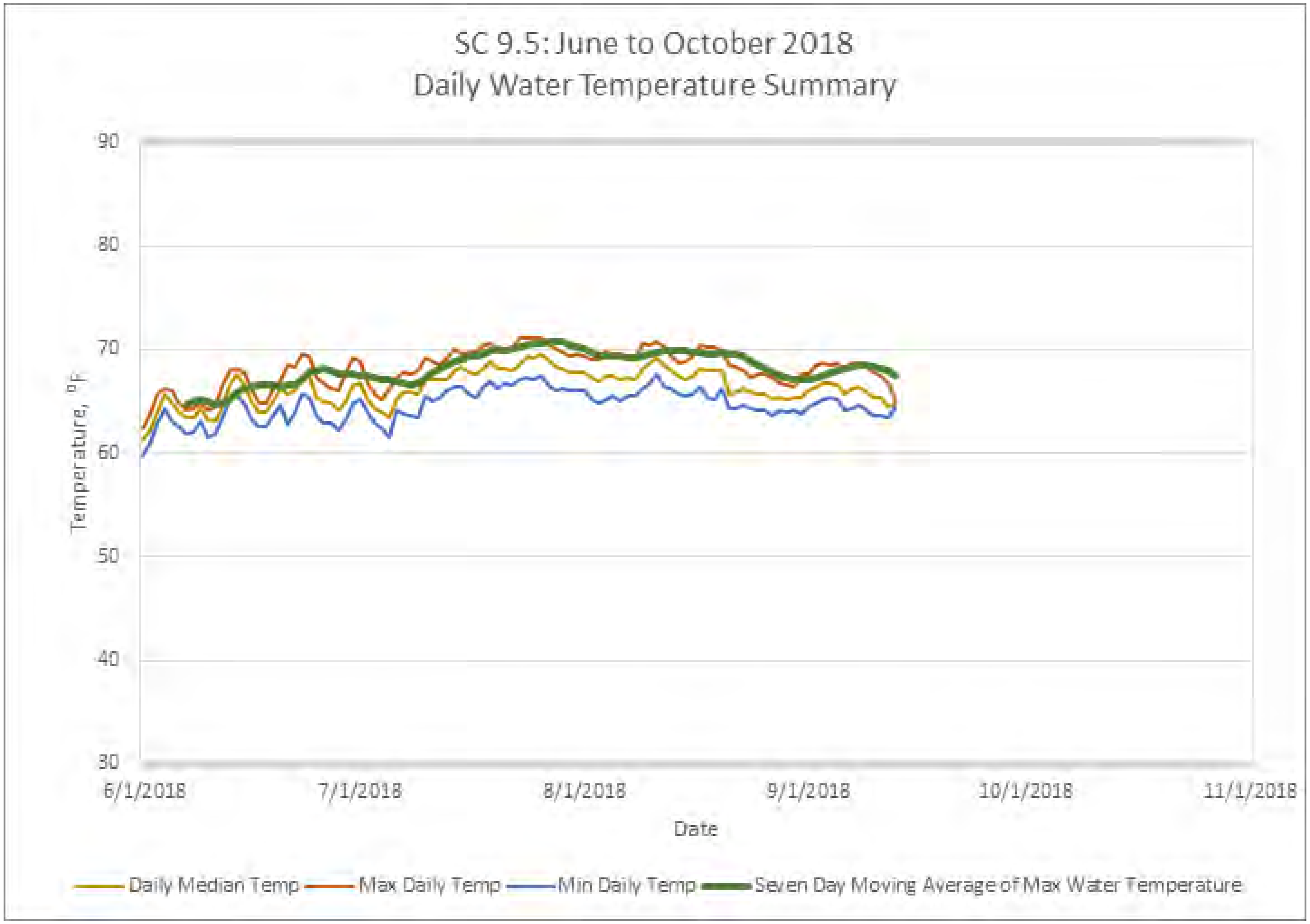

SC 9.4: June to October 2018
Hourly Water Temperatures
90
80
70
60
50
40
30
Temperature, °F
6/1/2018
7/1/2018
8/1/2018
9/1/2018
10/1/2018
11/1/2018
Date
Temp

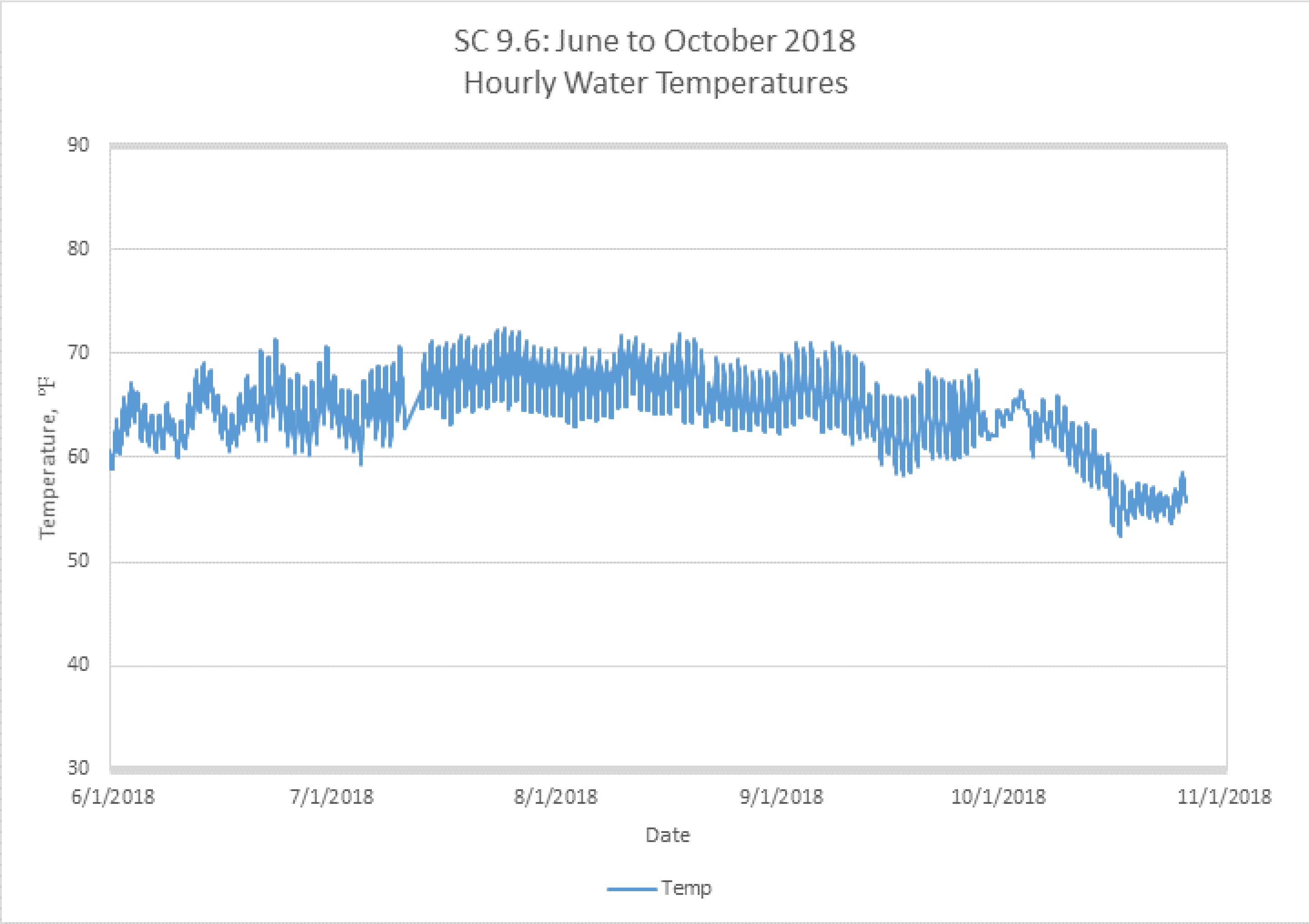

SC 9.4: June to October 2018
Daily Water Temperature Hours > 70°F
Hours per Day > 70°F
24
18
12
6
0
6/1/2018
7/1/2018
8/1/2018
9/1/2018
10/1/2018
11/1/2018
Date
Hours > 70 °F

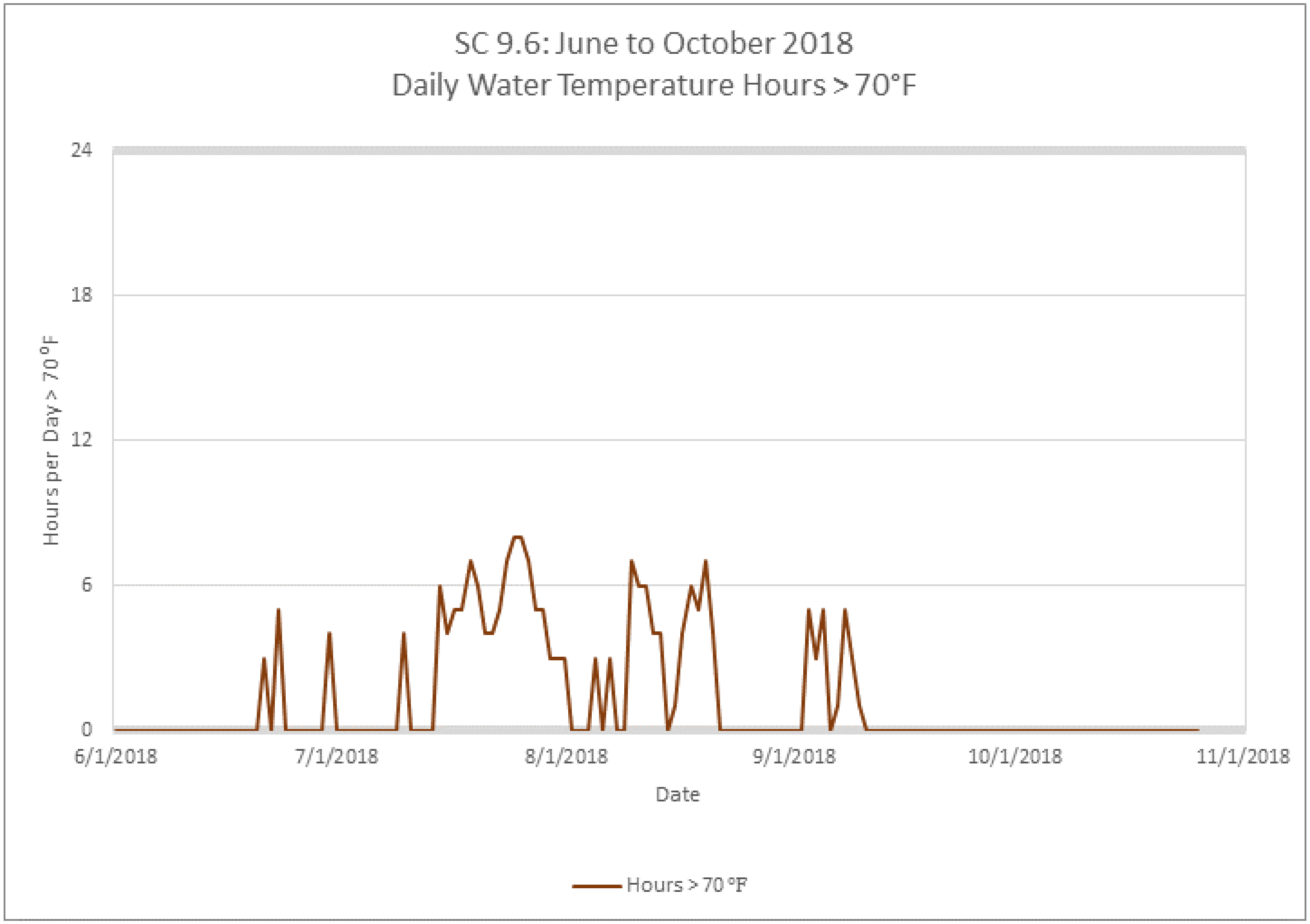

SC 9.4: June to October 2018
Daily Water Temperature Summary
90
80
70
60
50
40
30
Temperature, °F
6/1/2018
7/1/2018
8/1/2018
9/1/2018
10/1/2018
11/1/2018
Date
Daily Median Temp
Max Daily Temp
Min Daily Temp
Seven Day Moving Average of Max Water Temperature

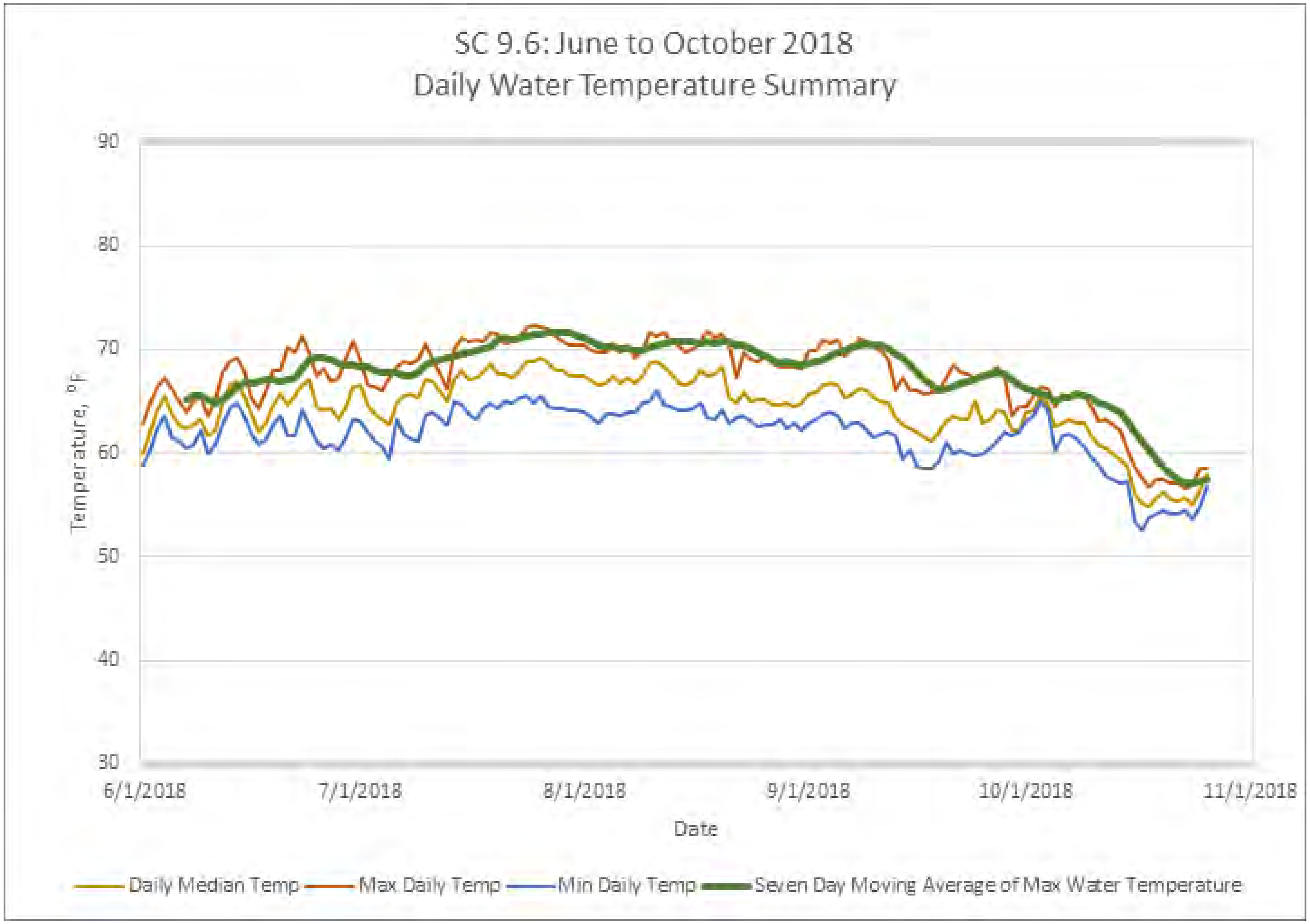

SC 9.5: June to October 2018
Hourly Water Temperatures
Temperature, °F
90
80
70
60
50
40
30
6/1/2018
7/1/2018
8/1/2018
9/1/2018
10/1/2018
11/1/2018
Date
Temp

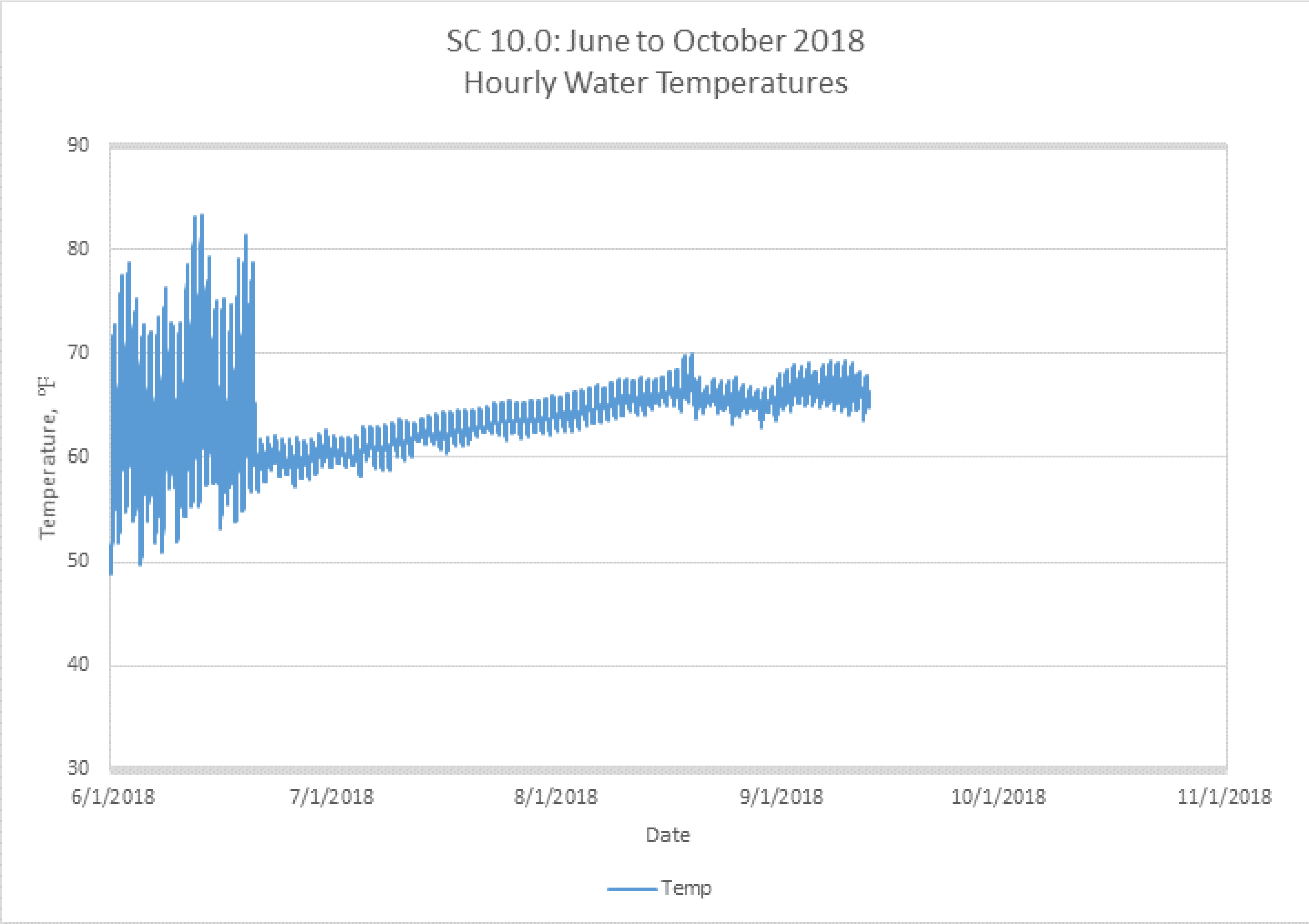

SC 9.5: June to October 2018
Daily Water Temperature Hours > 70°F
24
18
12
6
0
Hours per Day > 70°F
6/1/2018
7/1/2018
8/1/2018
9/1/2018
10/1/2018
11/1/2018
Date
Hours > 70 °F

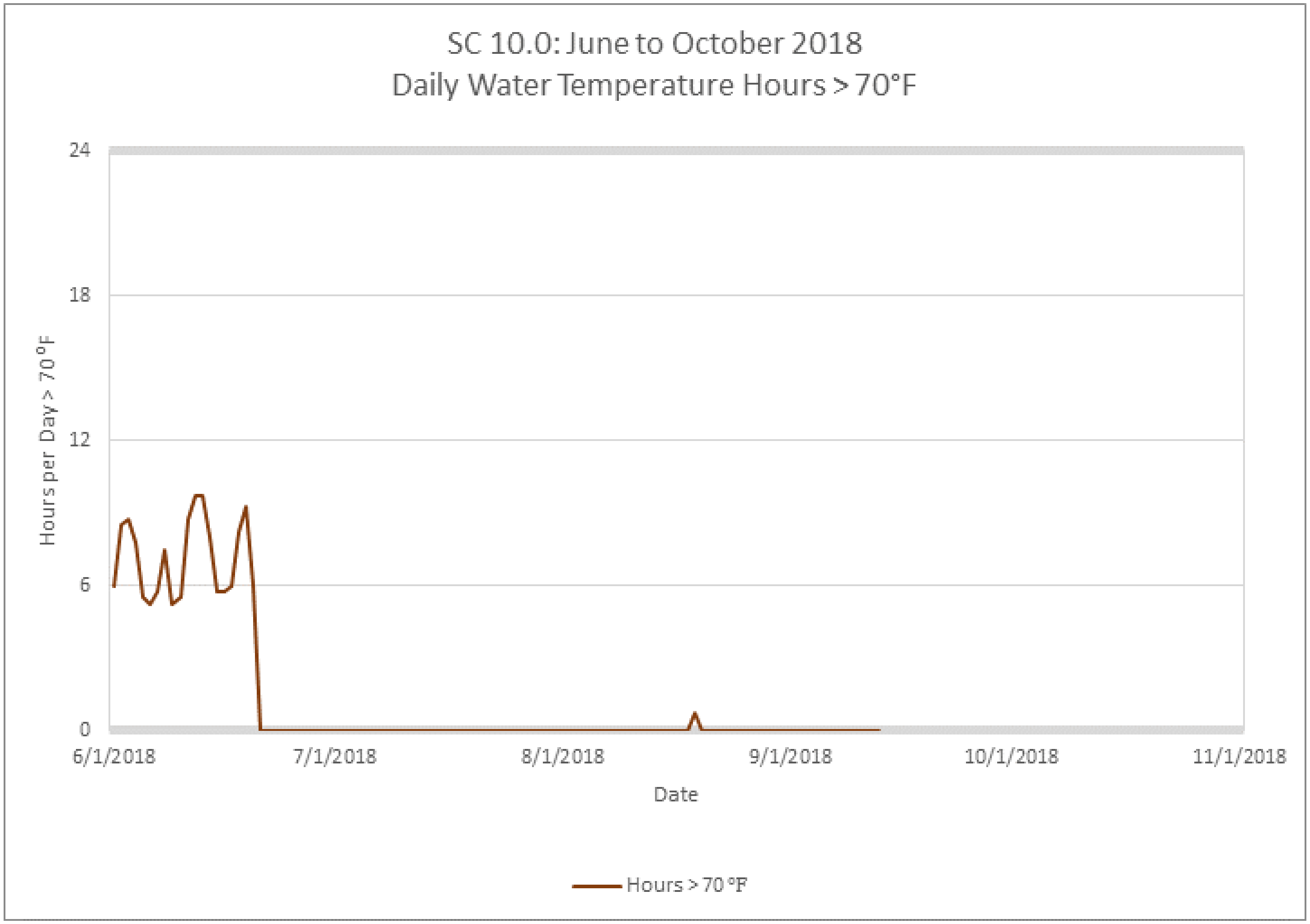

SC 9.5: June to October 2018
Daily Water Temperature Summary
90
80
70
60
50
40
30
Temperature, °F
6/1/2018
7/1/2018
8/1/2018
9/1/2018
10/1/2018
11/1/2018
Date
Daily Median Temp
Max Daily Temp
Min Daily Temp
Seven Day Moving Average of Max Water Temperature

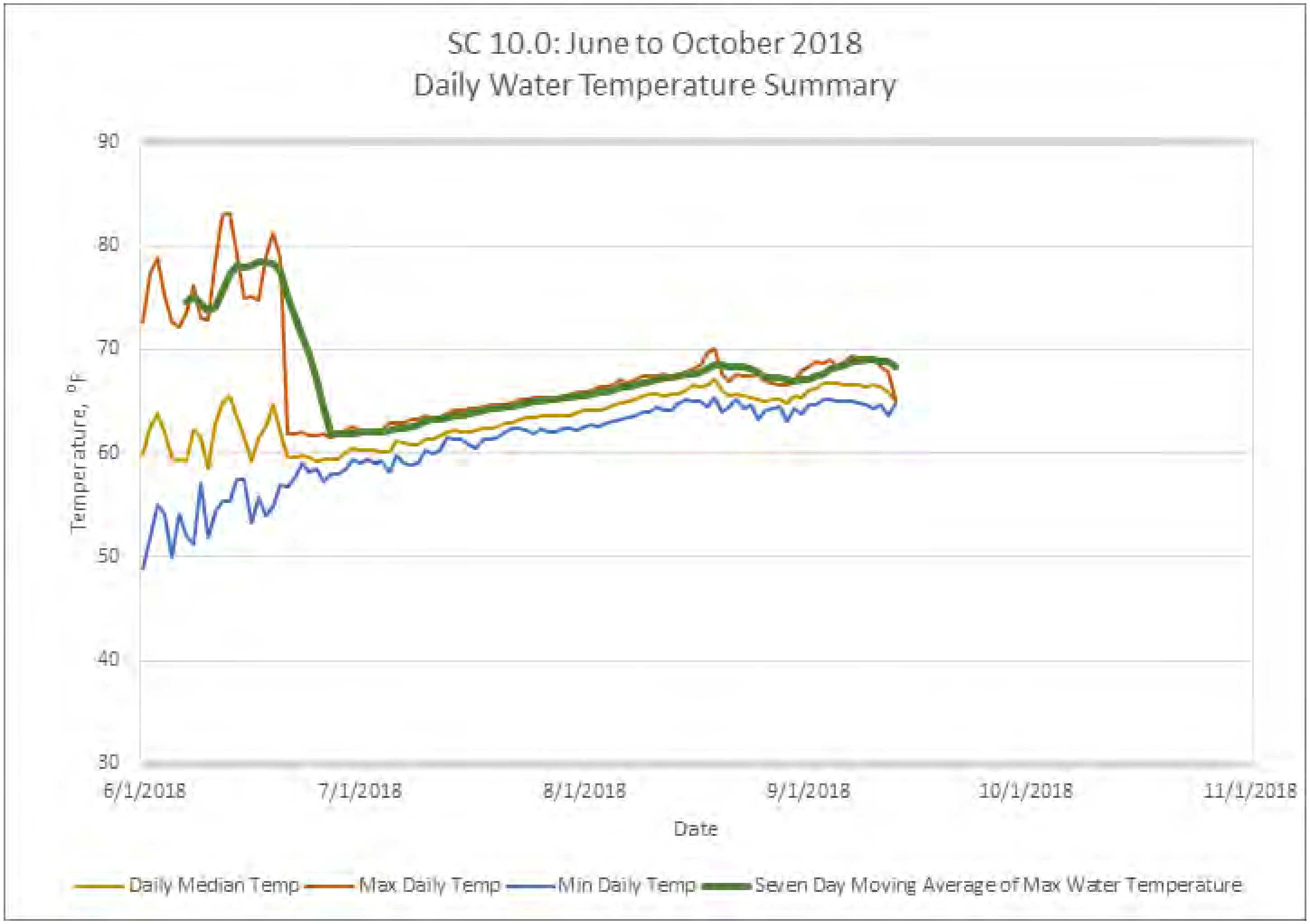

SC 9.6: June to October 2018
Hourly Water Temperatures
90
80
70
60
50
40
30
Temperature, °F
6/1/2018
7/1/2018
8/1/2018
9/1/2018
10/1/2018
11/1/2018
Date
Temp

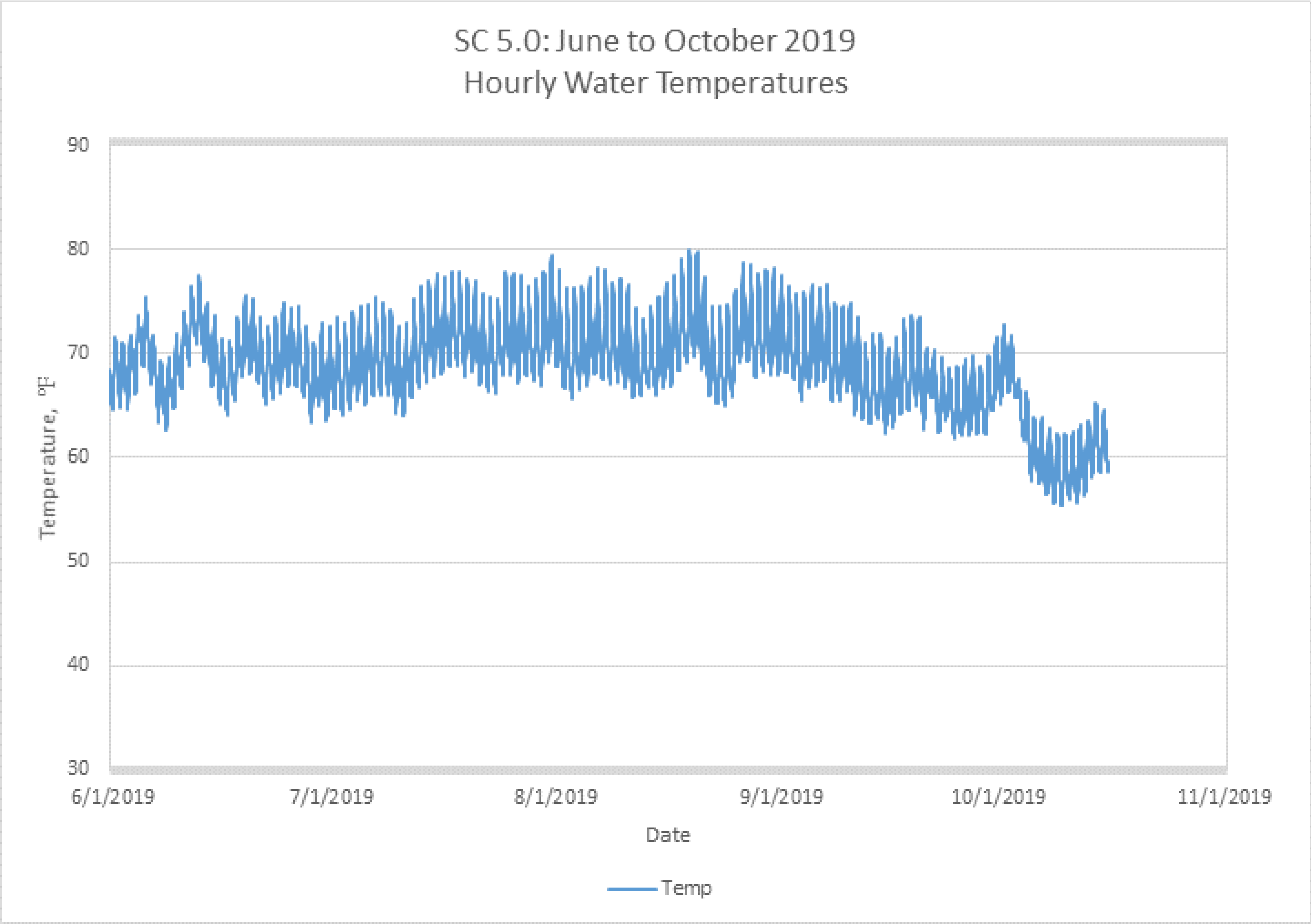

SC 9.6: June to October 2018
Daily Water Temperature Hours > 70°F
24
18
12
6
0
Hours per Day > 70°F
6/1/2018
7/1/2018
8/1/2018
9/1/2018
10/1/2018
11/1/2018
Date
Hours > 70 °F

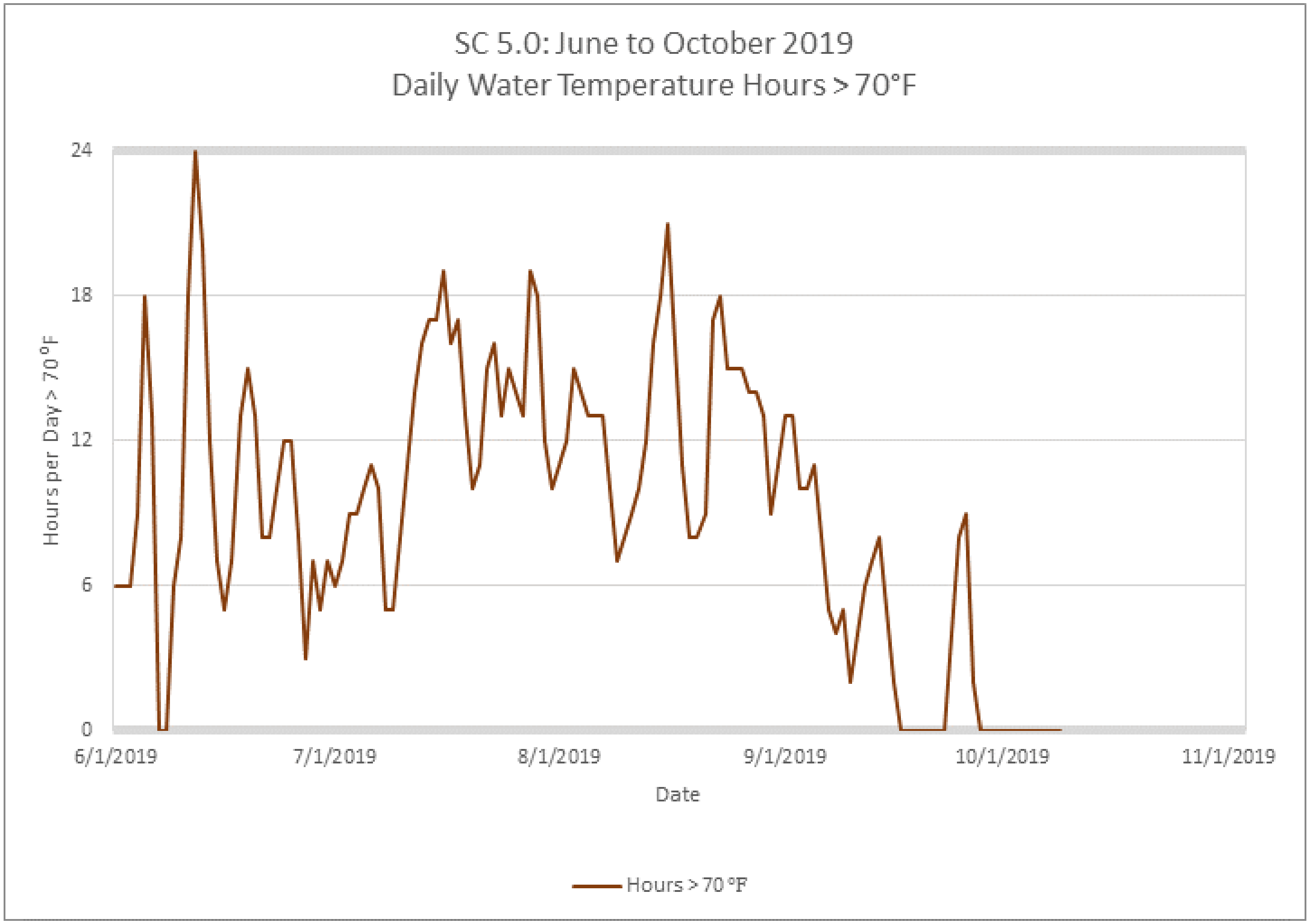

SC 9.6: June to October 2018
Daily Water Temperature Summary
90
80
70
60
50
40
30
Temperature, °F
6/1/2018
7/1/2018
8/1/2018
9/1/2018
10/1/2018
11/1/2018
Date
Daily Median Temp
Max Daily Temp
Min Daily Temp
Seven Day Moving Average of Max Water Temperature

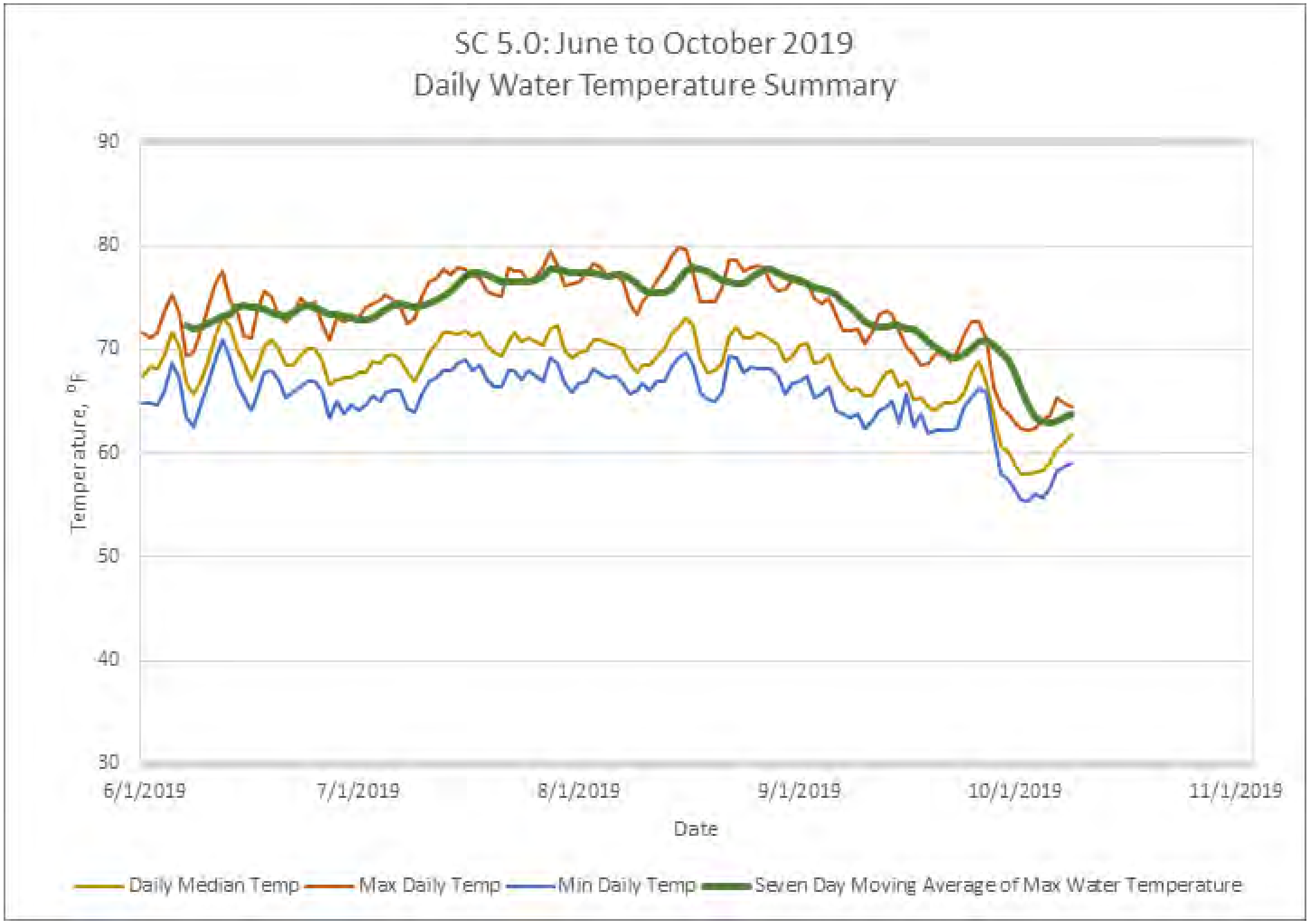

SC 10.0: June to October 2018
Hourly Water Temperatures
90
80
70
60
50
40
30
Temperature, °F
6/1/2018
7/1/2018
8/1/2018
9/1/2018
10/1/2018
11/1/2018
Date
Temp


SC 10.0: June to October 2018
Daily Water Temperature Hours > 70°F
24
18
12
6
0
Hours per Day > 70°F
6/1/2018
7/1/2018
8/1/2018
9/1/2018
10/1/2018
11/1/2018
Date
Hours > 70 °F

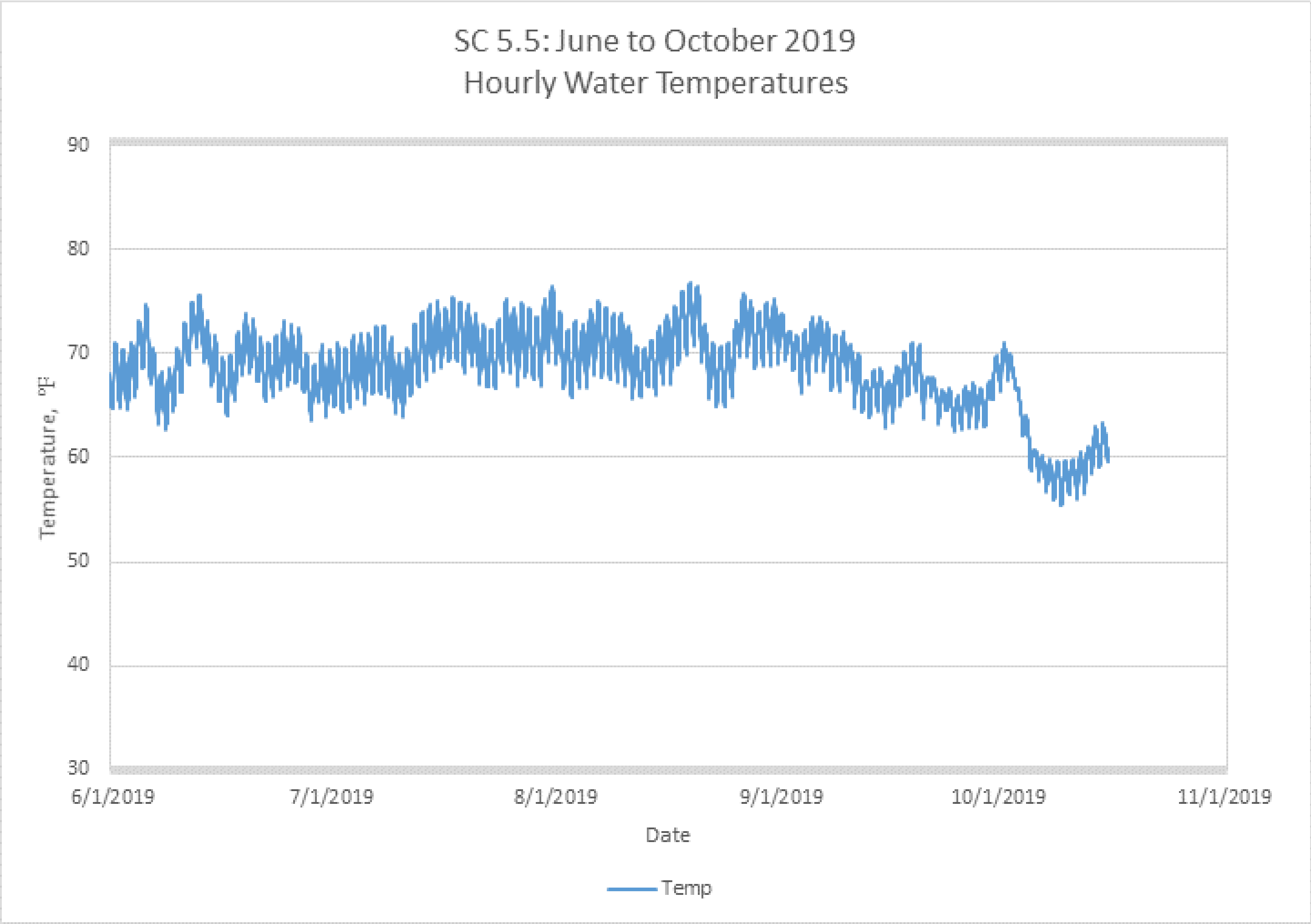

SC 10.0: June to October 2018
Daily Water Temperature Summary
90
80
70
60
50
40
30
Temperature, °F
6/1/2018
7/1/2018
8/1/2018
9/1/2018
10/1/2018
11/1/2018
Date
Daily Median Temp
Max Daily Temp
Min Daily Temp
Seven Day Moving Average of Max Water Temperature

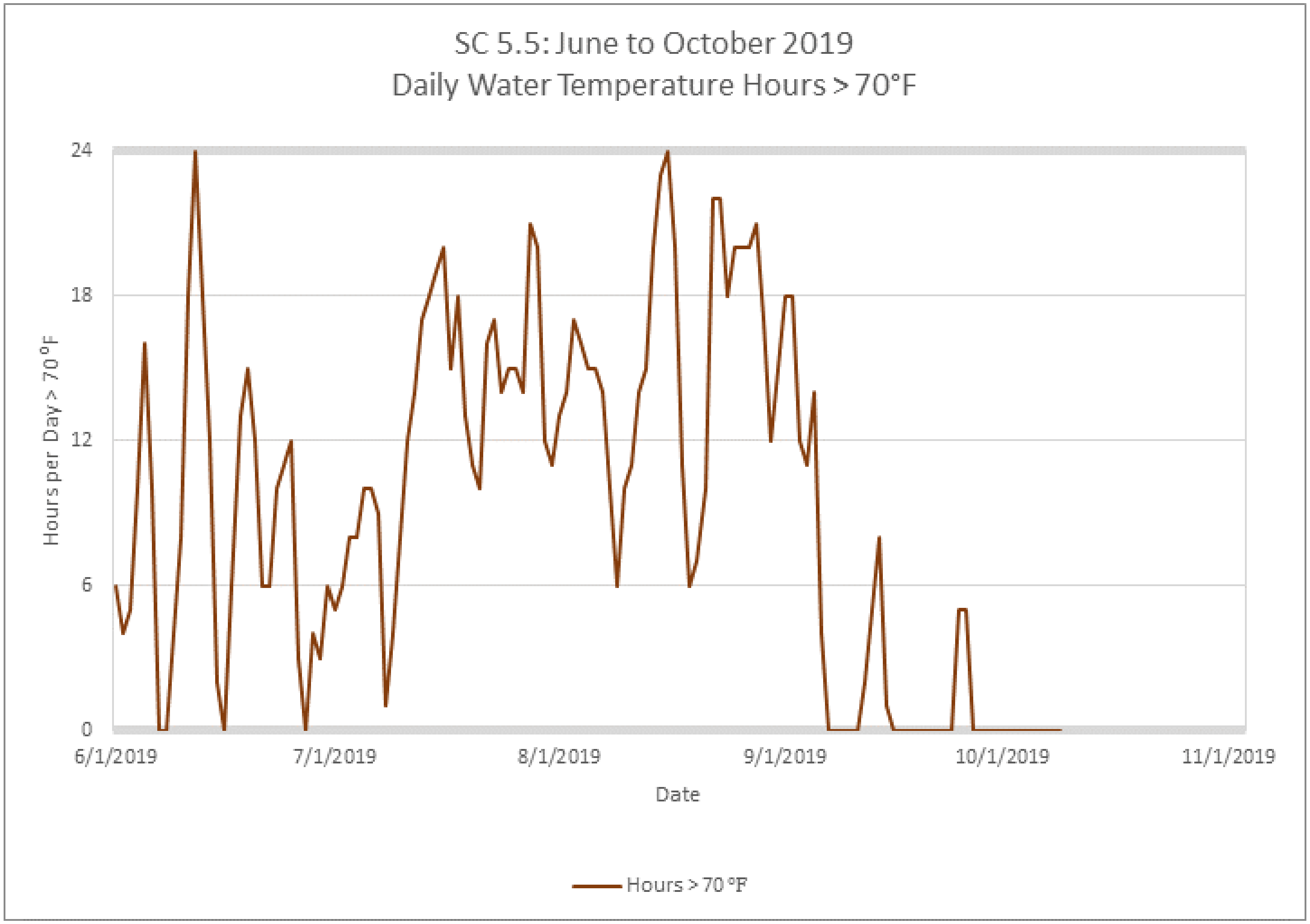

SC 5.0: June to October 2019
Hourly Water Temperatures
90
80
70
60
50
40
30
Temperature, °F
6/1/2019
7/1/2019
8/1/2019
9/1/2019
10/1/2019
11/1/2019
Date
Temp


SC 5.0: June to October 2019
Daily Water Temperature Hours > 70°F
24
18
12
6
0
Hours per Day > 70°F
6/1/2019
7/1/2019
8/1/2019
9/1/2019
10/1/2019
11/1/2019
Date
Hours > 70 °F

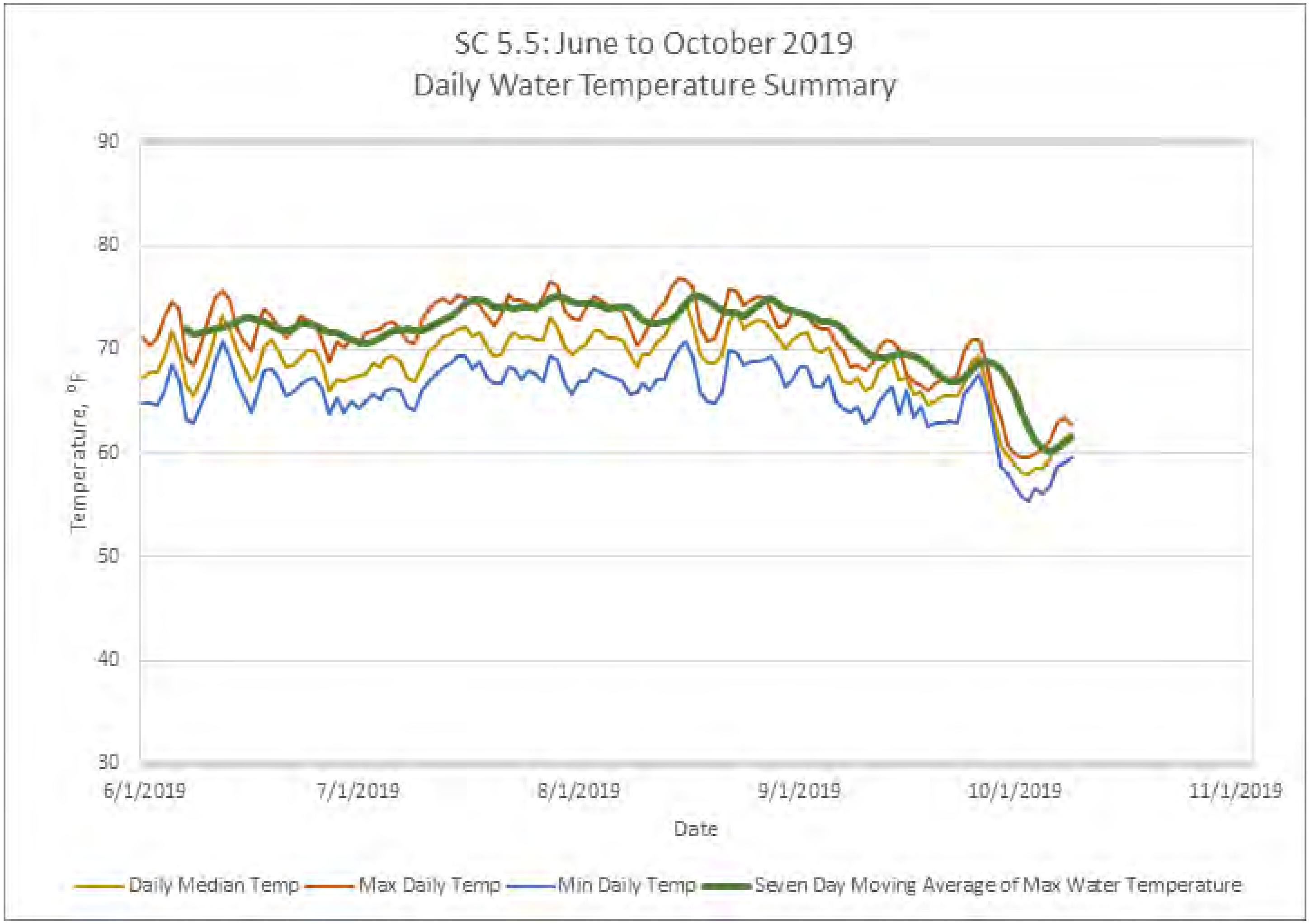


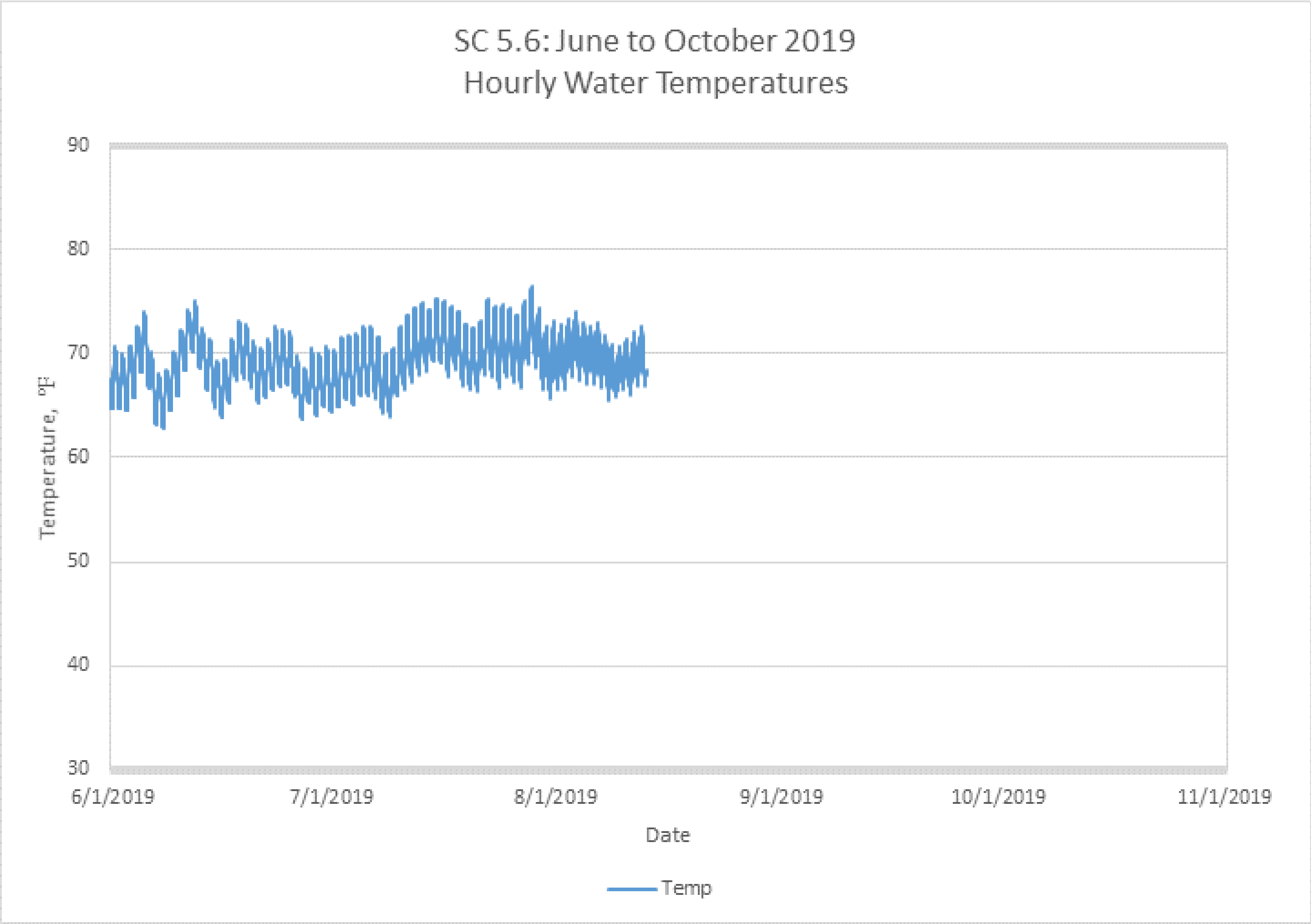
SC 5.0: June to October 2019
Daily Water Temperature Summary
90
80
70
60
50
40
30
Temperature, °F
6/1/2019
7/1/2019
8/1/2019
9/1/2019
10/1/2019
11/1/2019
Date
Daily Median Temp
Max Daily Temp
Min Daily Temp
Seven Day Moving Average of Max Water Temperature


SC 5.5: June to October 2019
Hourly Water Temperatures
90
80
70
60
50
40
30
Temperature, °F
6/1/2019
7/1/2019
8/1/2019
9/1/2019
10/1/2019
11/1/2019
Date
Temp

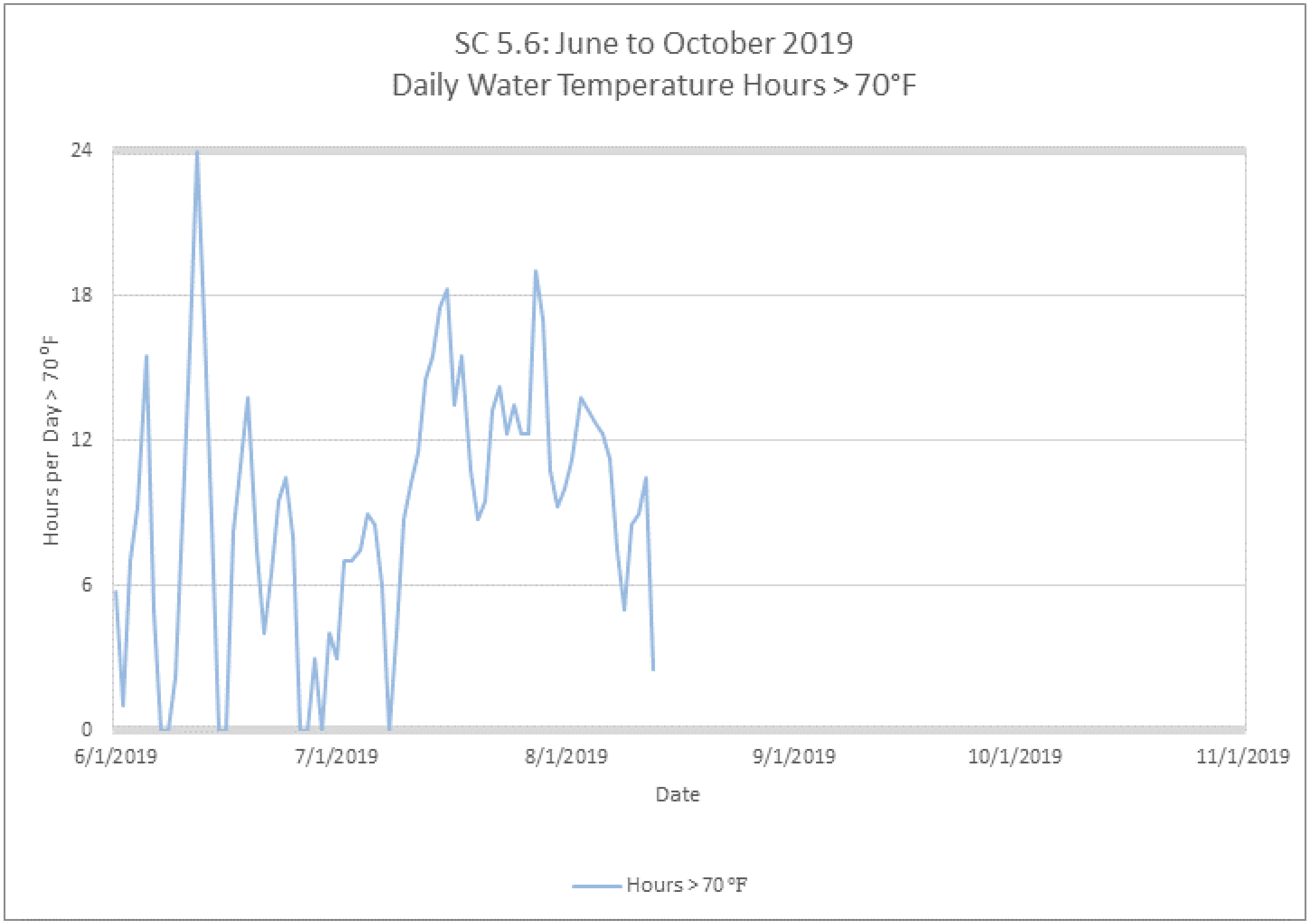


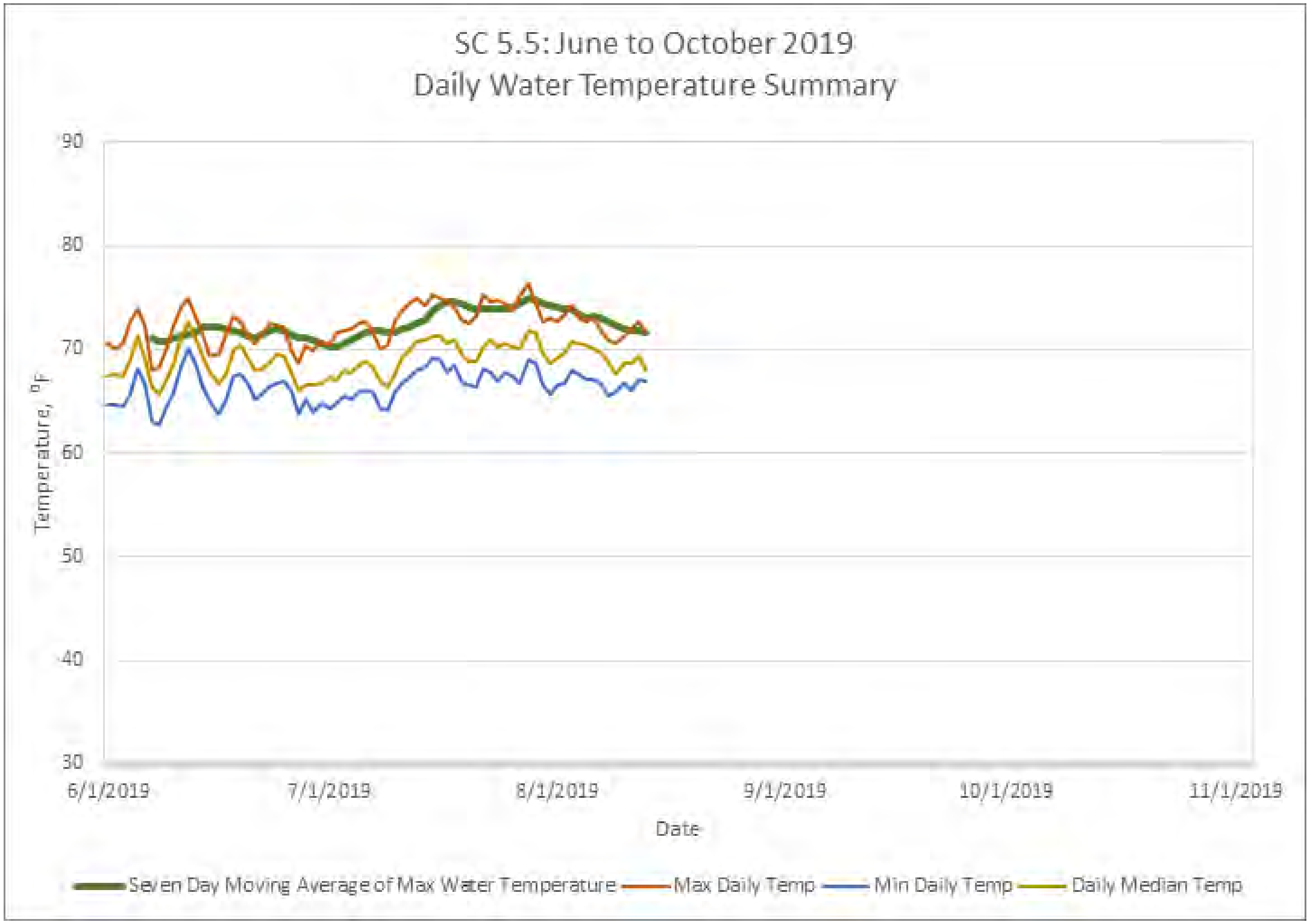
SC 5.5: June to October 2019
Daily Water Temperature Hours > 70°F
24
18
12
6
0
Hours per Day > 70°F
6/1/2019
7/1/2019
8/1/2019
9/1/2019
10/1/2019
11/1/2019
Date
Hours > 70 °F

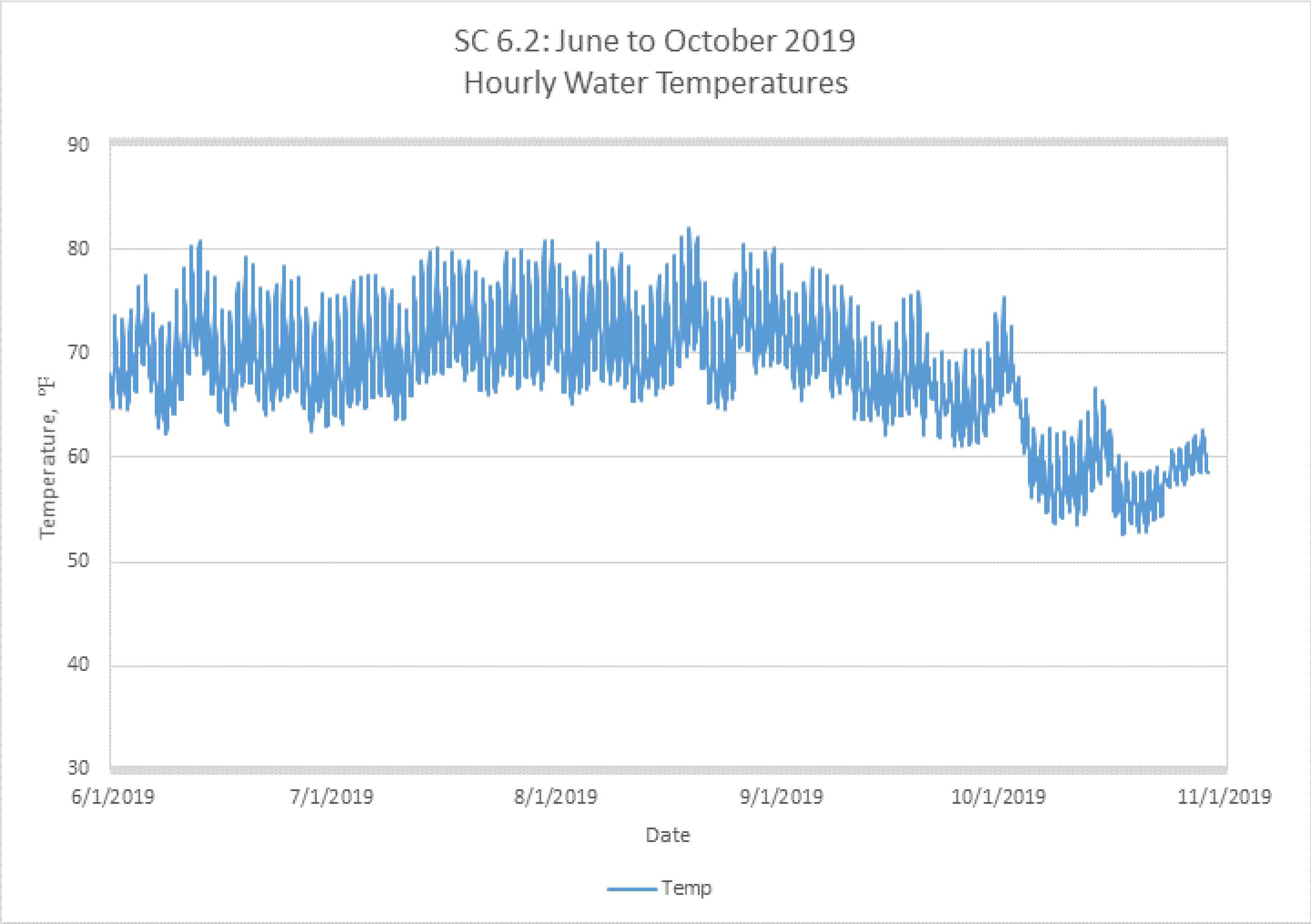

SC 5.5: June to October 2019
Daily Water Temperature Summary
90
80
70
60
50
40
30
Temperature, °F
6/1/2019
7/1/2019
8/1/2019
9/1/2019
10/1/2019
11/1/2019
Date
Daily Median Temp
Max Daily Temp
Min Daily Temp
Seven Day Moving Average of Max Water Temperature

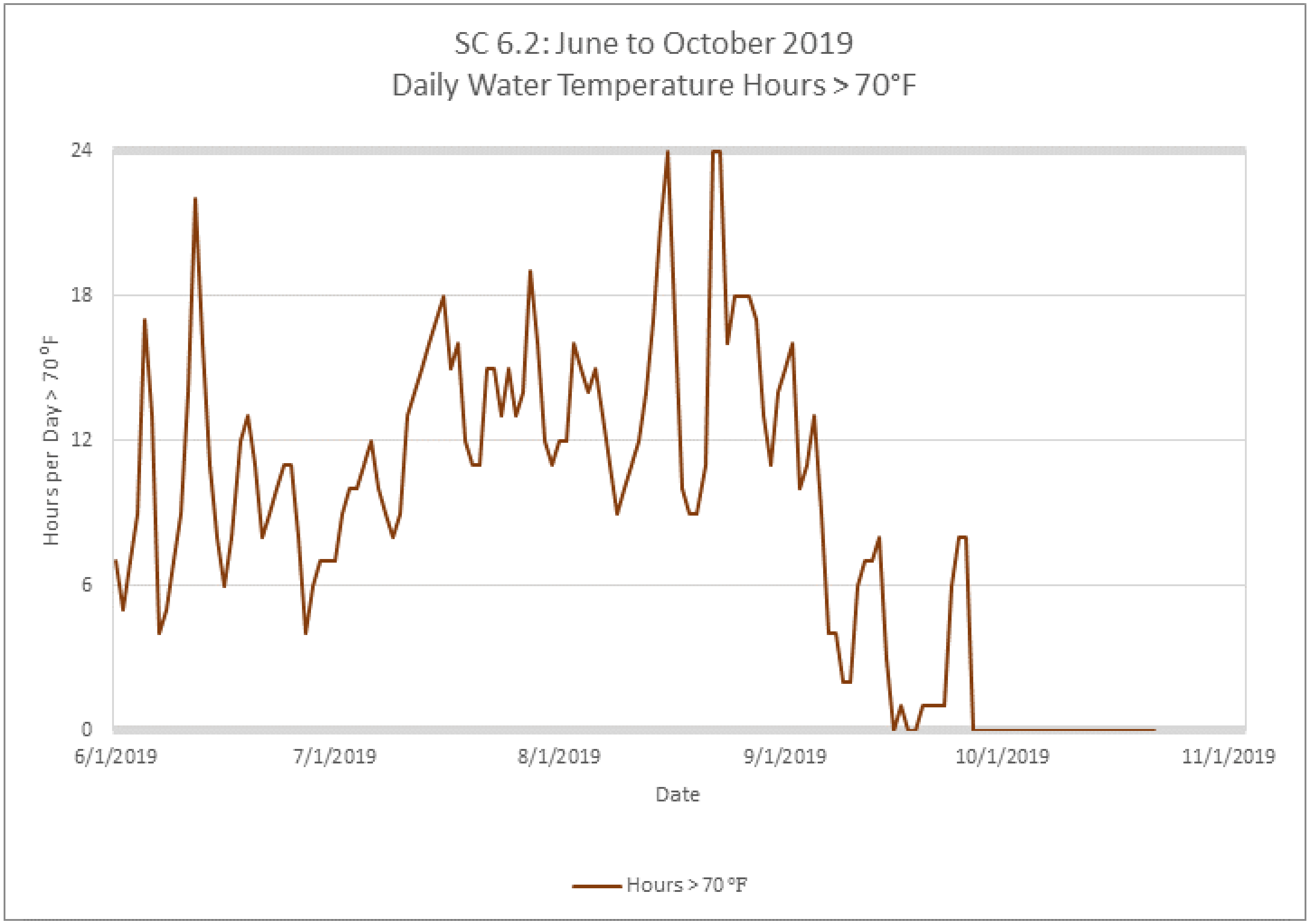


SC 5.6: June to October 2019
Hourly Water Temperatures
90
80
70
60
50
40
30
Temperature, °F
6/1/2019
7/1/2019
8/1/2019
9/1/2019
10/1/2019
11/1/2019
Date
Temp

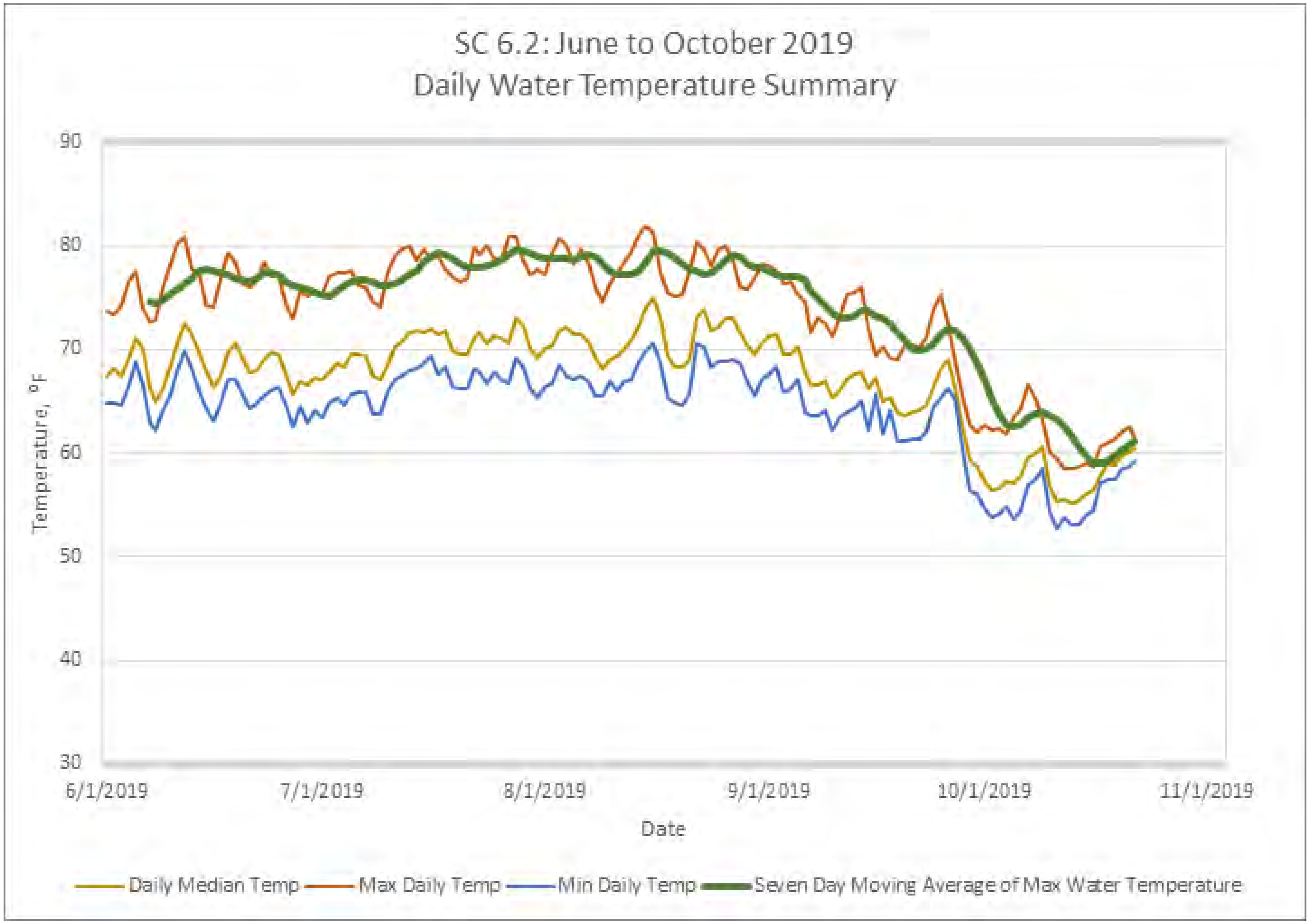

SC 5.6: June to October 2019
Daily Water Temperature Hours > 70°F
24
18
12
6
0
Hours per Day > 70°F
6/1/2019
7/1/2019
8/1/2019
9/1/2019
10/1/2019
11/1/2019
Date
Hours > 70 °F

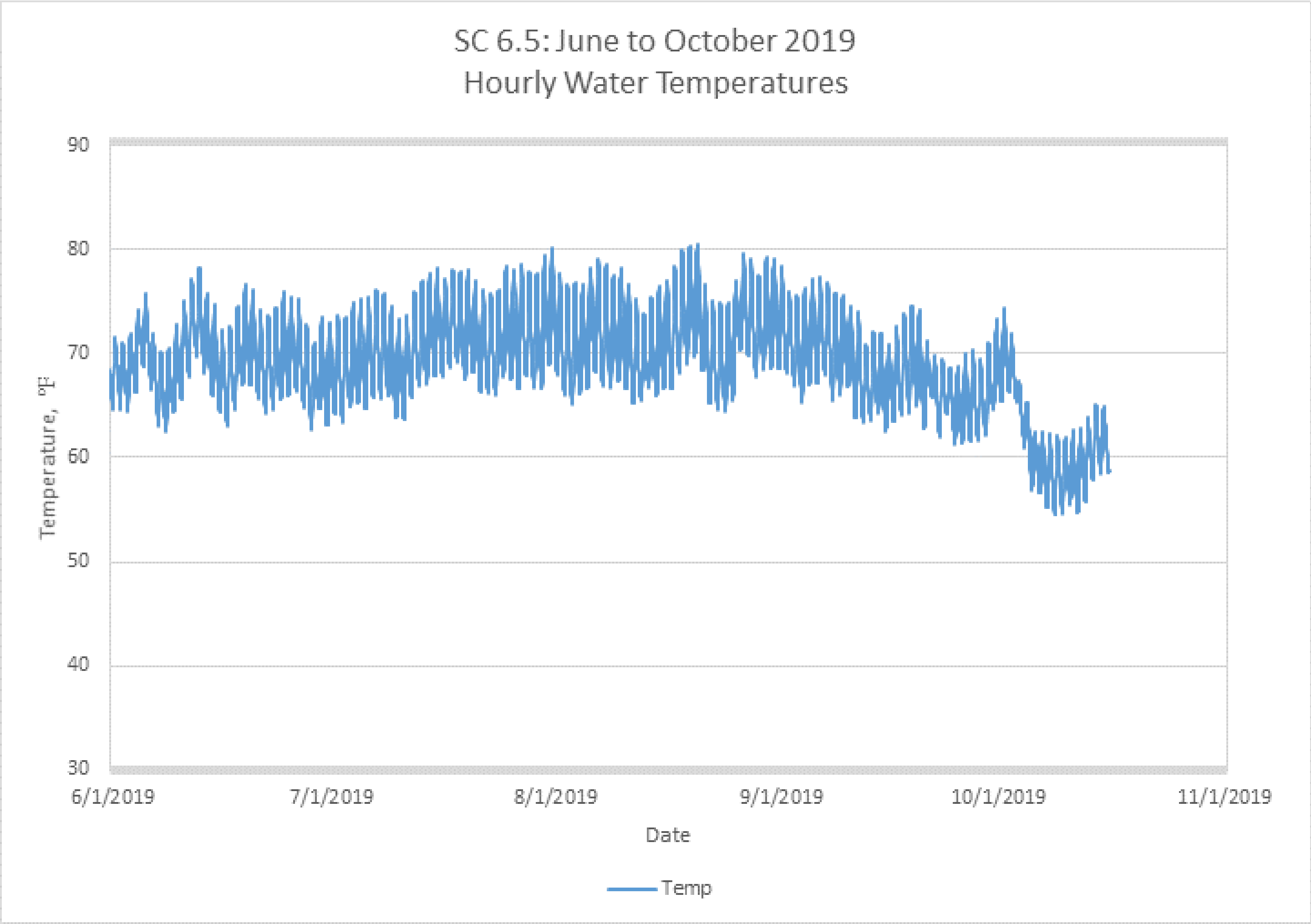

SC 5.5: June to October 2019
Daily Water Temperature Summary
90
80
70
60
50
40
30
Temperature, °F
6/1/2019
7/1/2019
8/1/2019
9/1/2019
10/1/2019
11/1/2019
Date
Seven Day Moving Average of Max Water Temperature
Max Daily Temp
Min Daily Temp
Daily Median Temp


SC 6.2: June to October 2019
Hourly Water Temperatures
90
80
70
60
50
40
30
Temperature, °F
6/1/2019
7/1/2019
8/1/2019
9/1/2019
10/1/2019
11/1/2019
Date
Temp



SC 6.2: June to October 2019
Daily Water Temperature Hours > 70°F
24
18
12
6
0
Hours per Day > 70°F
6/1/2019
7/1/2019
8/1/2019
9/1/2019
10/1/2019
11/1/2019
Date
Hours > 70 °F


SC 6.2: June to October 2019
Daily Water Temperature Summary
90
80
70
60
50
40
30
Temperature, °F
6/1/2019
7/1/2019
8/1/2019
9/1/2019
10/1/2019
11/1/2019
Date
Daily Median Temp
Max Daily Temp
Min Daily Temp
Seven Day Moving Average of Max Water Temperature



SC 6.5: June to October 2019
Hourly Water Temperatures
90
80
70
60
50
40
30
Temperature, °F
6/1/2019
7/1/2019
8/1/2019
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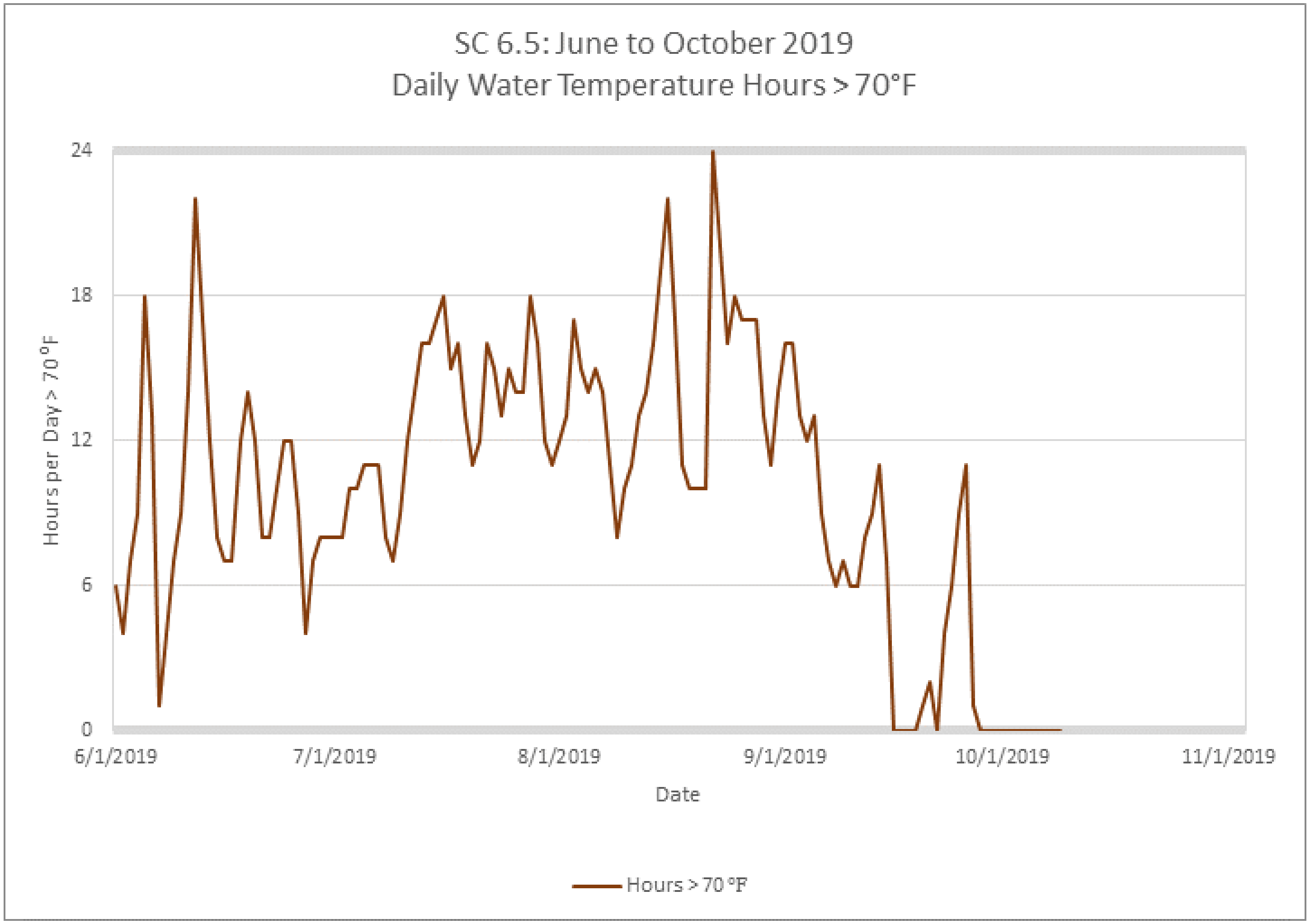
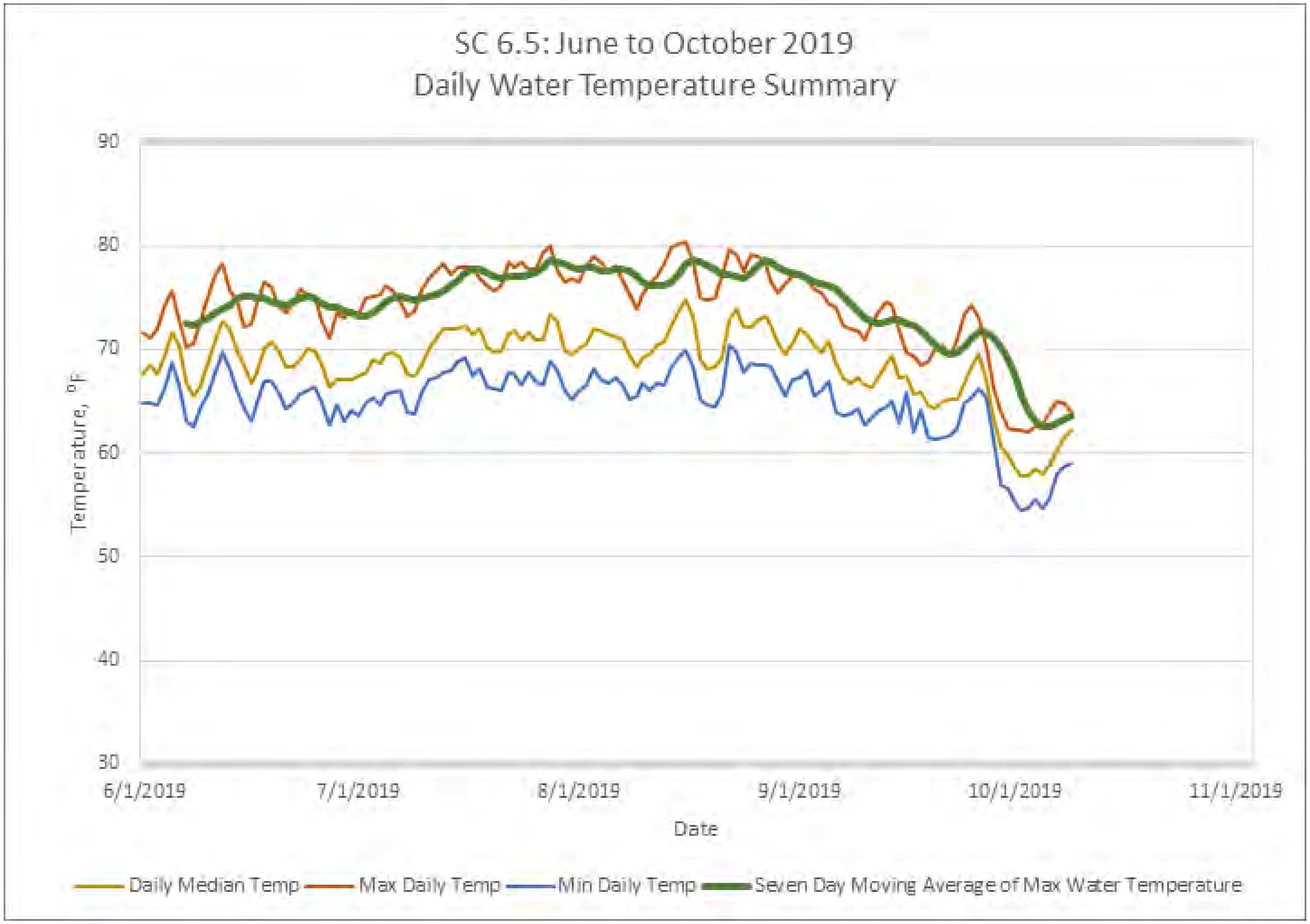
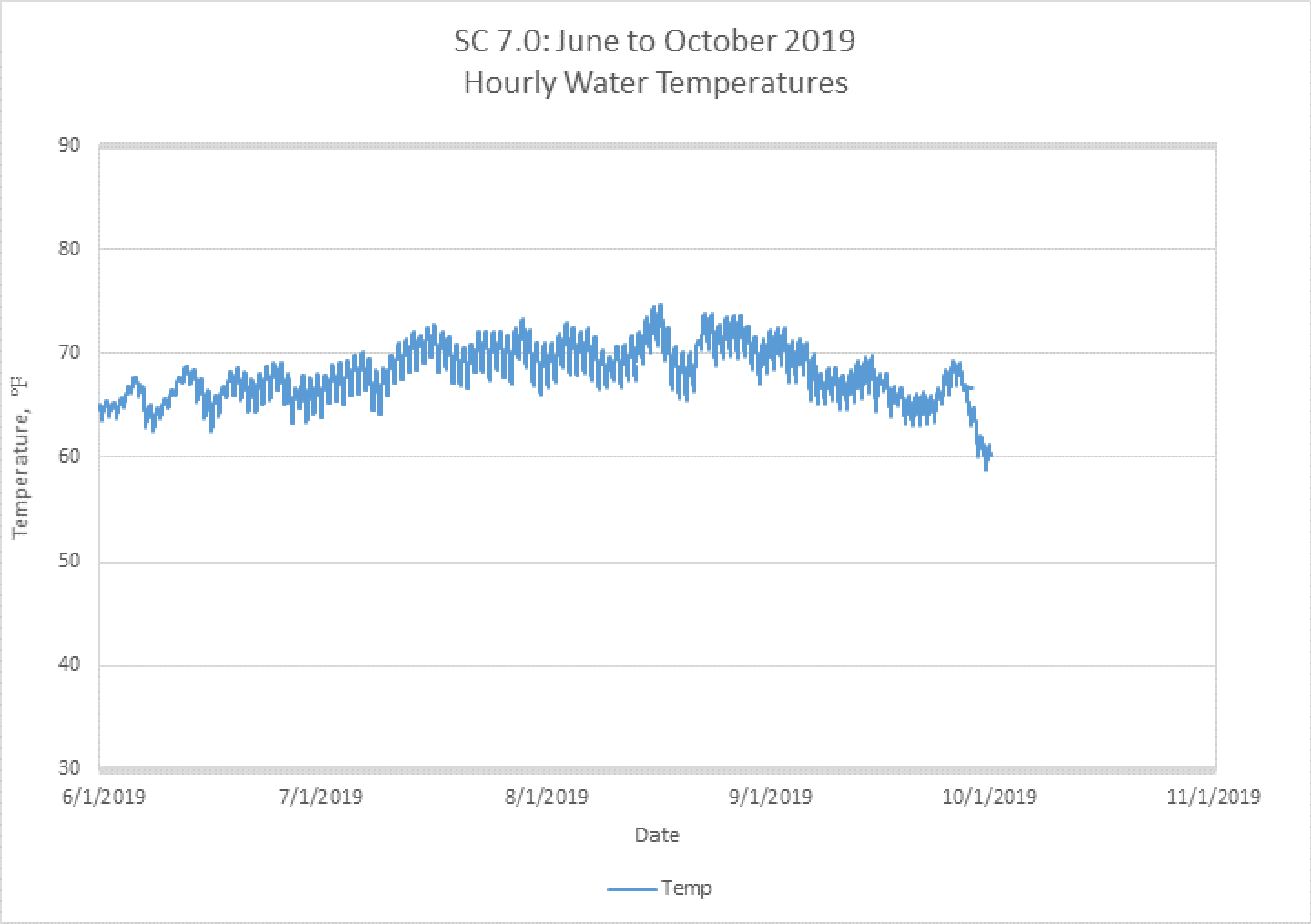
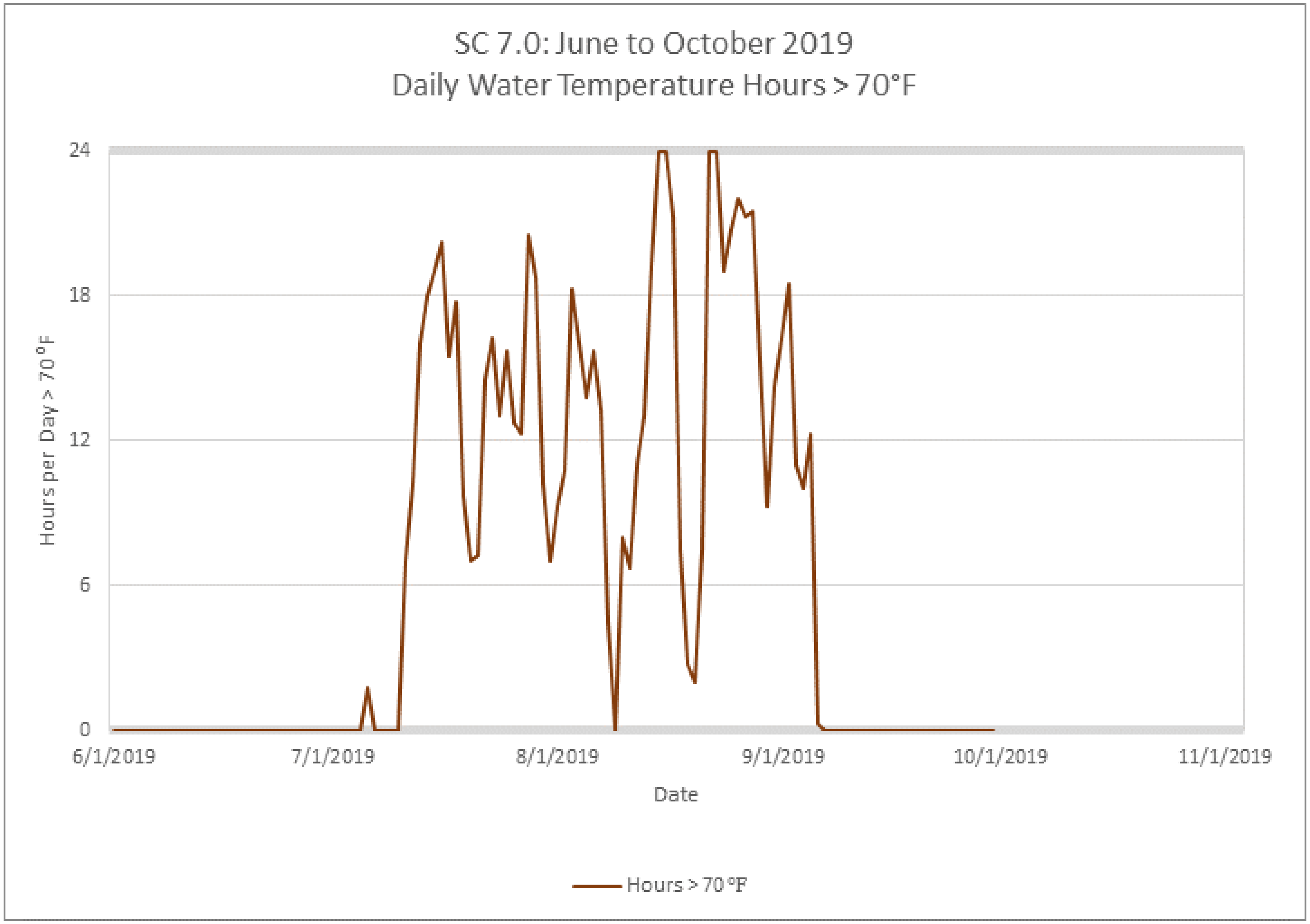
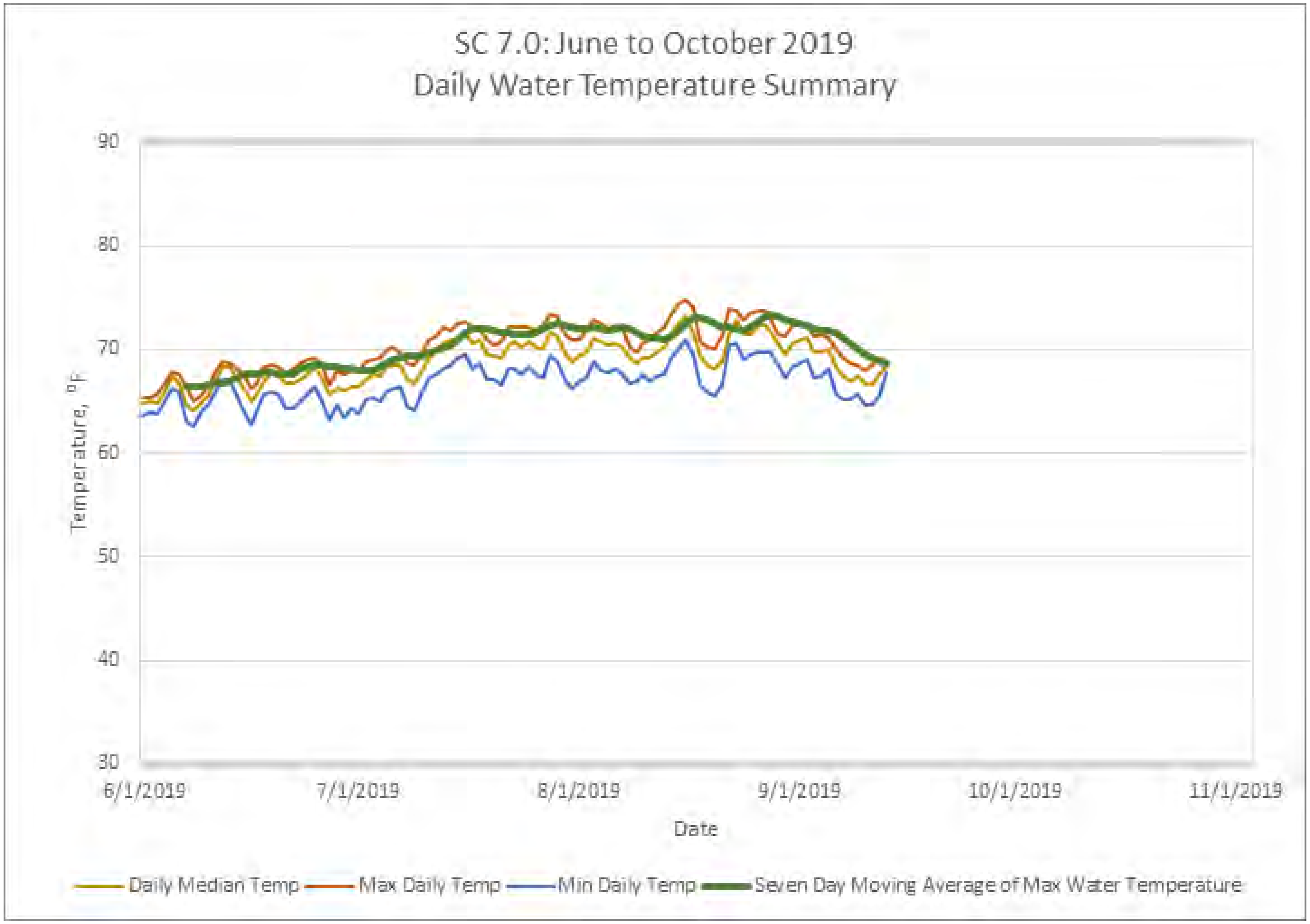
10/1/2019
11/1/2019
Date
Temp

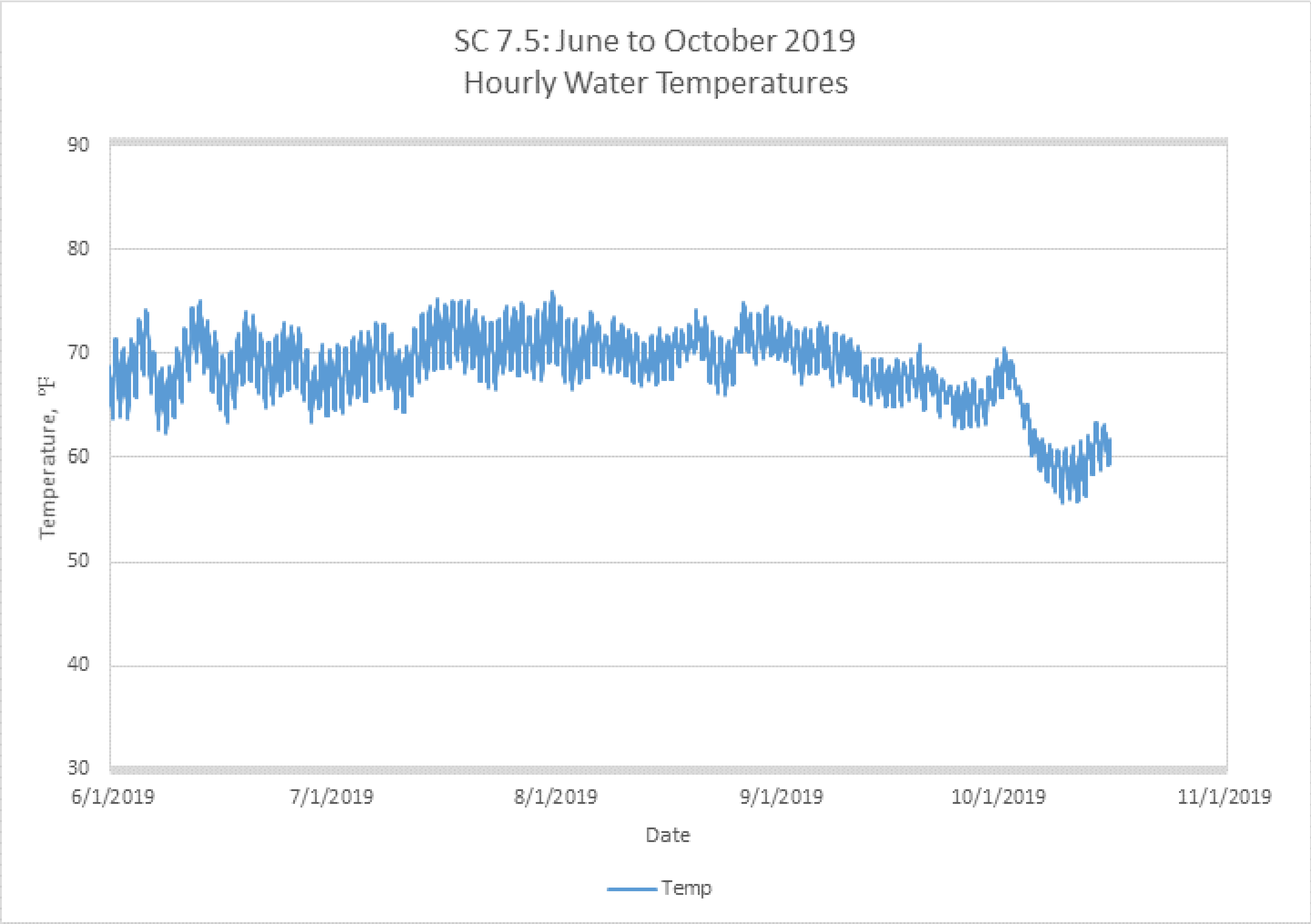

SC 6.5: June to October 2019
Daily Water Temperature Hours > 70°F
24
18
12
6
0
Hours per Day > 70°F
6/1/2019
7/1/2019
8/1/2019
9/1/2019
10/1/2019
11/1/2019
Date
Hours > 70 °F


SC 6.5: June to October 2019
Daily Water Temperature Summary
90
80
70
60
50
40
30
Temperature, °F
6/1/2019
7/1/2019
8/1/2019
9/1/2019
10/1/2019
11/1/2019
Date
Daily Median Temp
Max Daily Temp
Min Daily Temp
Seven Day Moving Average of Max Water Temperature

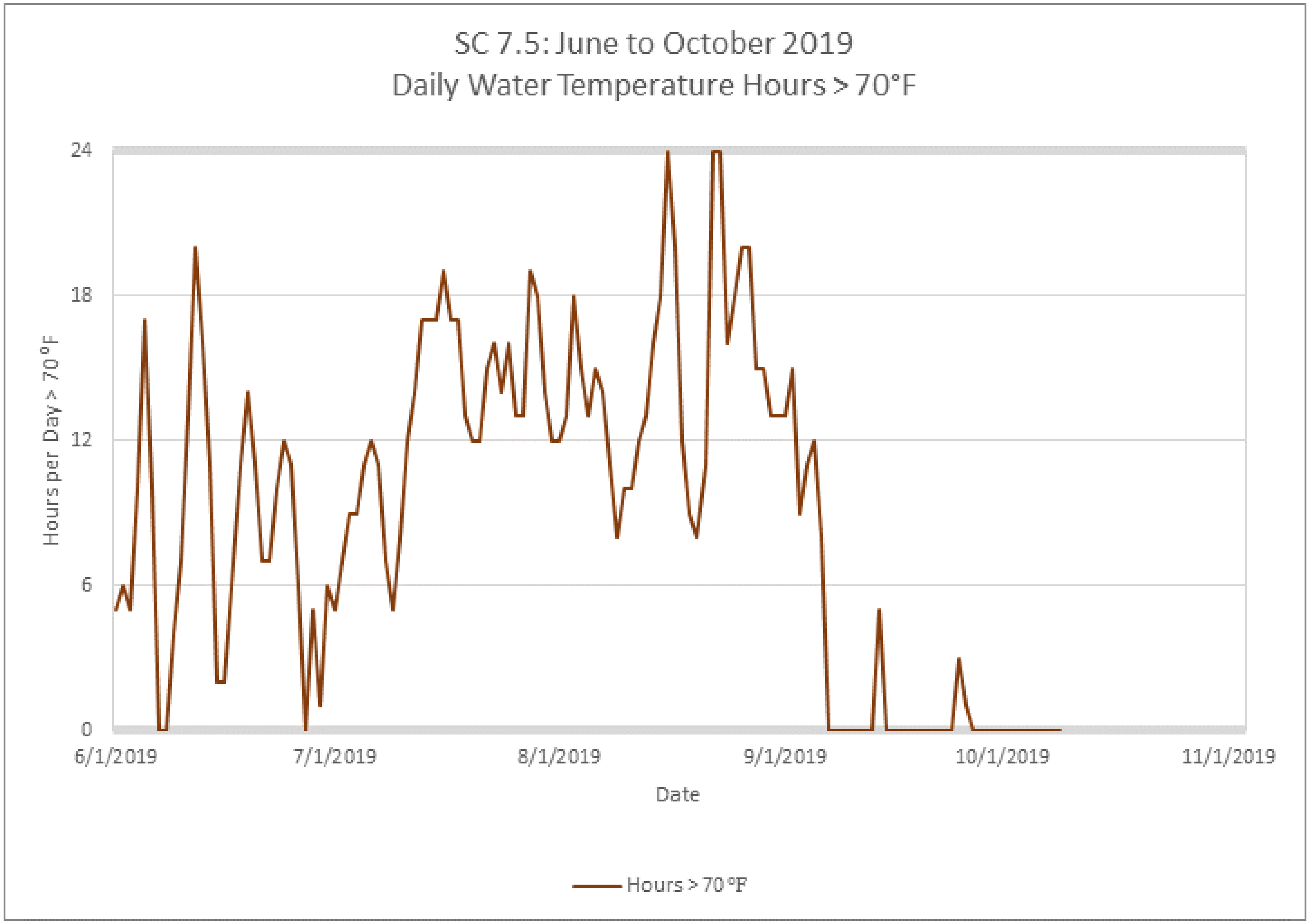

SC 7.0: June to October 2019
Hourly Water Temperatures
90
80
70
60
50
40
30
Temperature, °F
6/1/2019
7/1/2019
8/1/2019
9/1/2019
10/1/2019
11/1/2019
Date
Temp

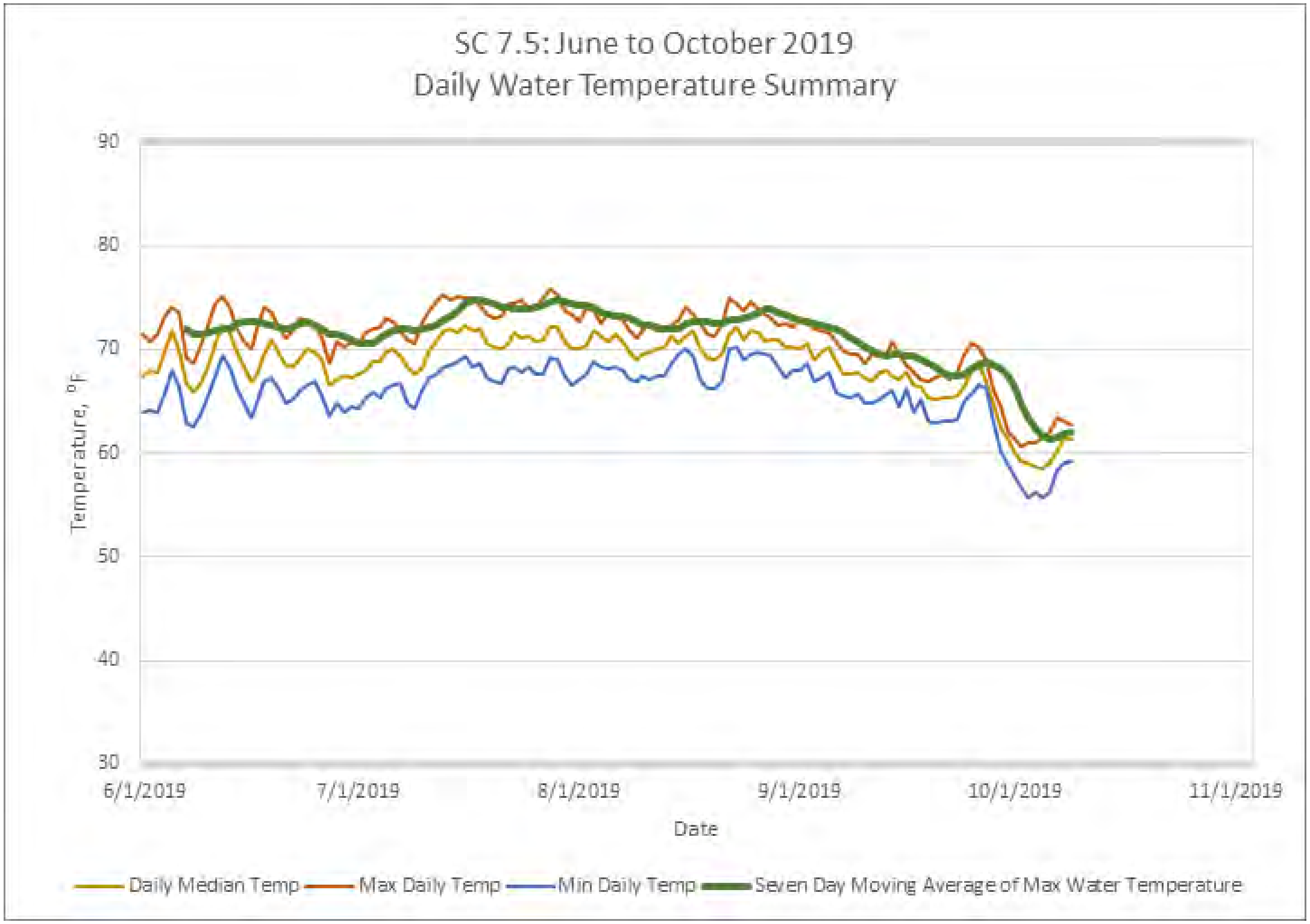

SC 7.0: June to October 2019
Daily Water Temperature Hours > 70°F
24
18
12
6
0
Hours per Day > 70°F
6/1/2019
7/1/2019
8/1/2019
9/1/2019
10/1/2019
11/1/2019
Date
Hours > 70 °F


SC 7.0: June to October 2019
Daily Water Temperature Summary
90
80
70
60
50
40
30
Temperature, °F
6/1/2019
7/1/2019
8/1/2019
9/1/2019
10/1/2019
11/1/2019
Date
Daily Median Temp
Max Daily Temp
Min Daily Temp
Seven Day Moving Average of Max Water Temperature

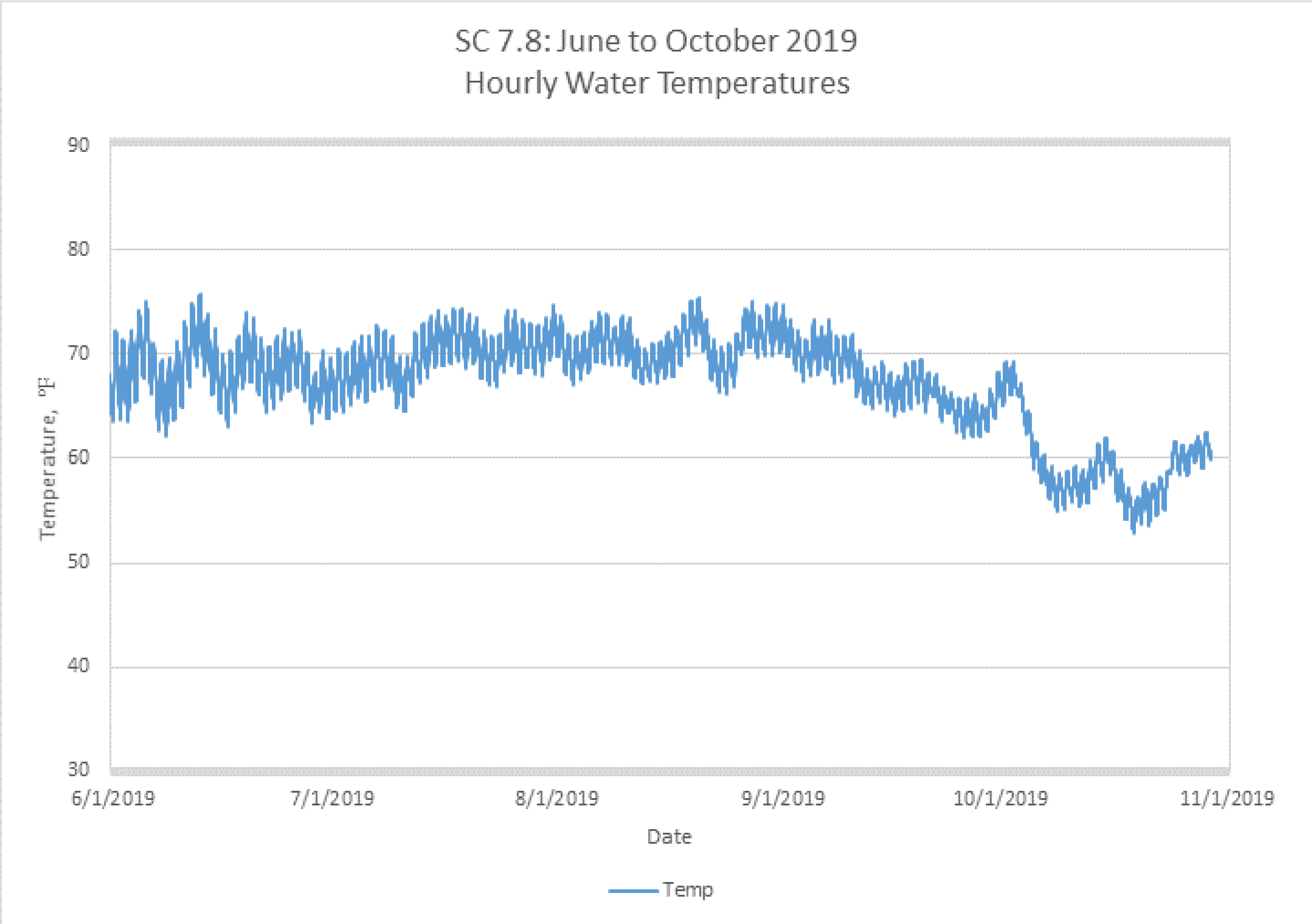


SC 7.5: June to October 2019
Hourly Water Temperatures
90
80
70
60
50
40
30
Temperature, °F
6/1/2019
7/1/2019
8/1/2019
9/1/2019
10/1/2019
11/1/2019
Date
Temp

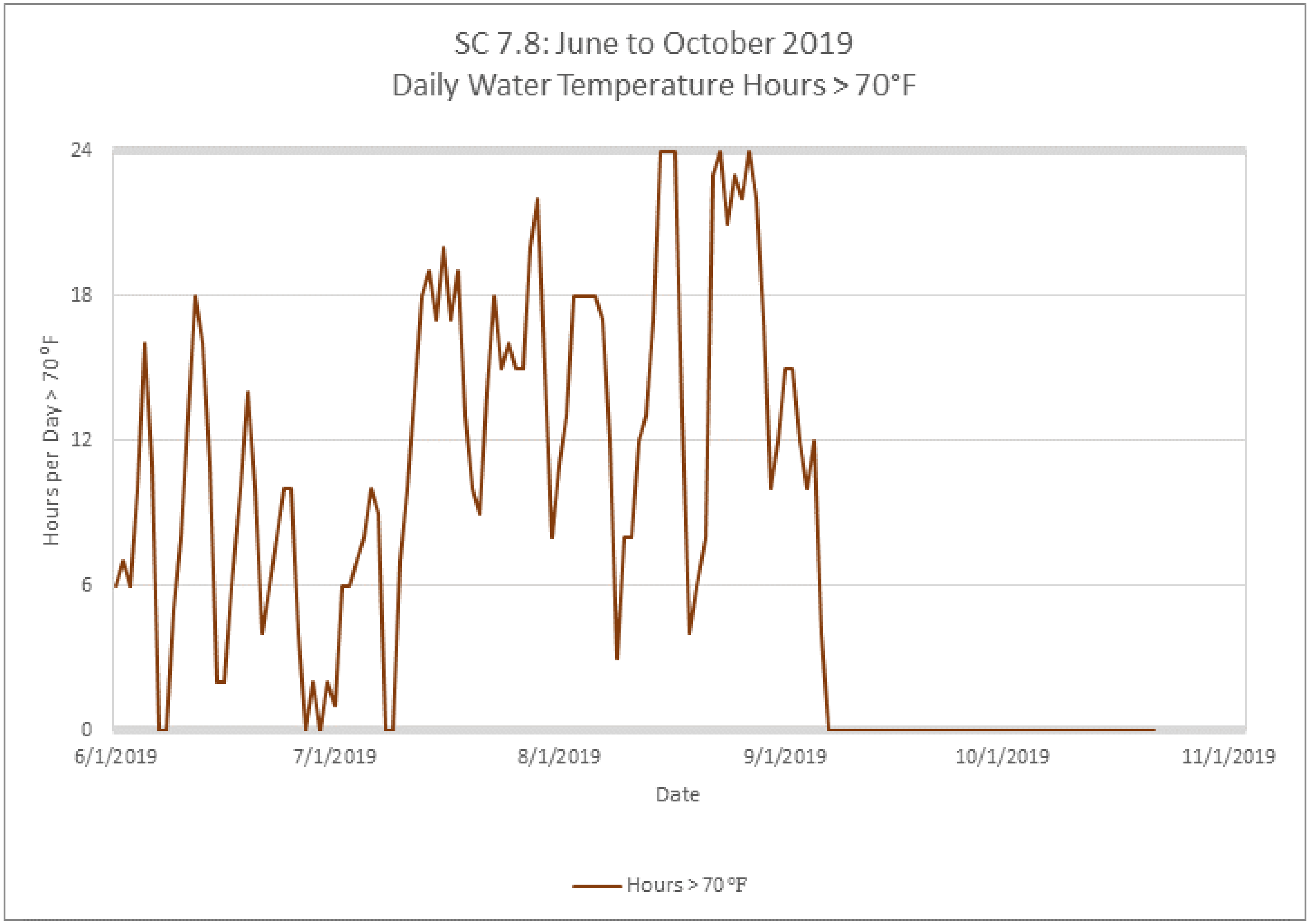

SC 7.5: June to October 2019
Daily Water Temperature Hours > 70°F
24
18
12
6
0
Hours per Day > 70°F
6/1/2019
7/1/2019
8/1/2019
9/1/2019
10/1/2019
11/1/2019
Date
Hours > 70 °F



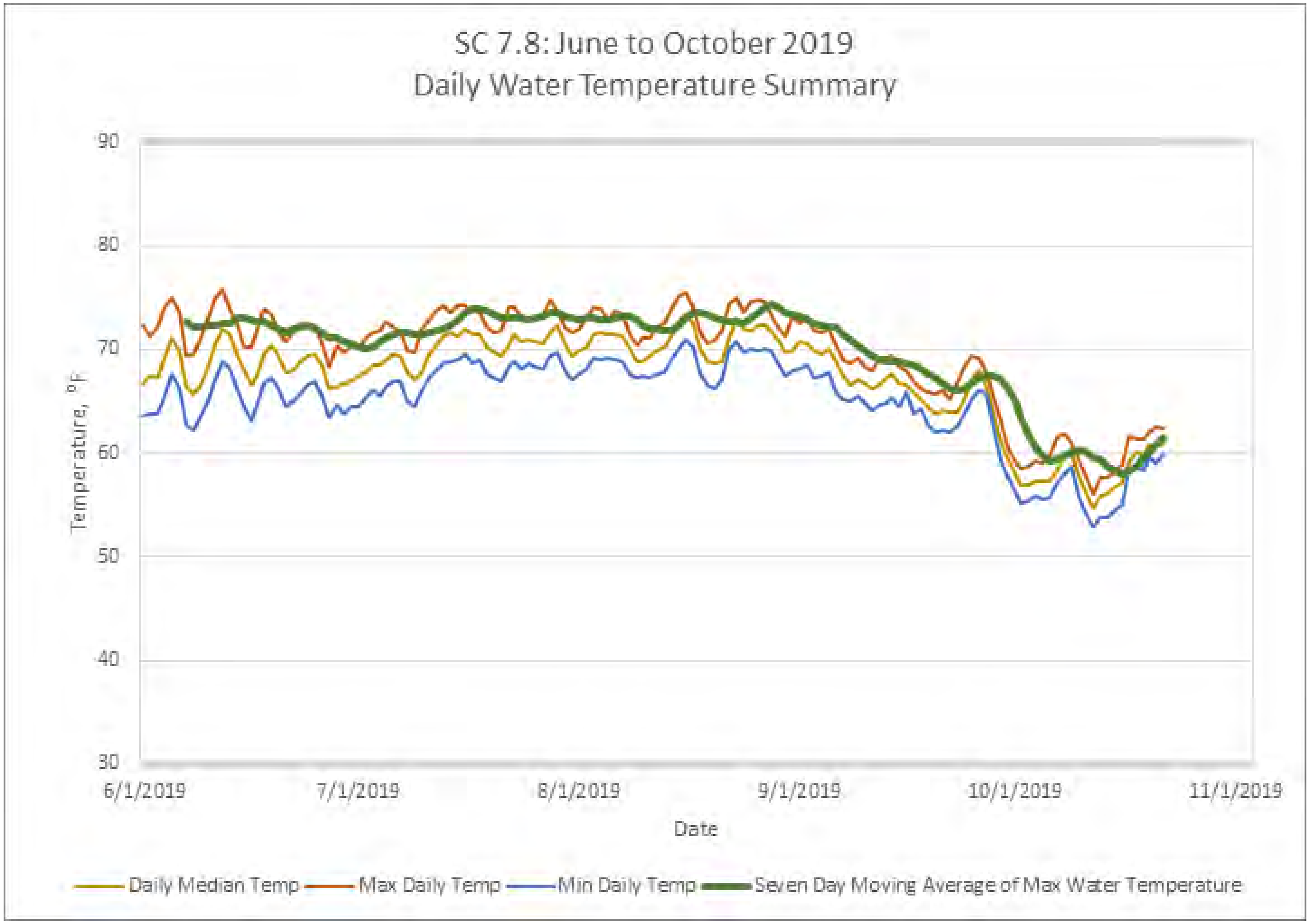
SC 7.5: June to October 2019
Daily Water Temperature Summary
90
80
70
60
50
40
30
Temperature, °F
6/1/2019
7/1/2019
8/1/2019
9/1/2019
10/1/2019
11/1/2019
Date
Daily Median Temp
Max Daily Temp
Min Daily Temp
Seven Day Moving Average of Max Water Temperature

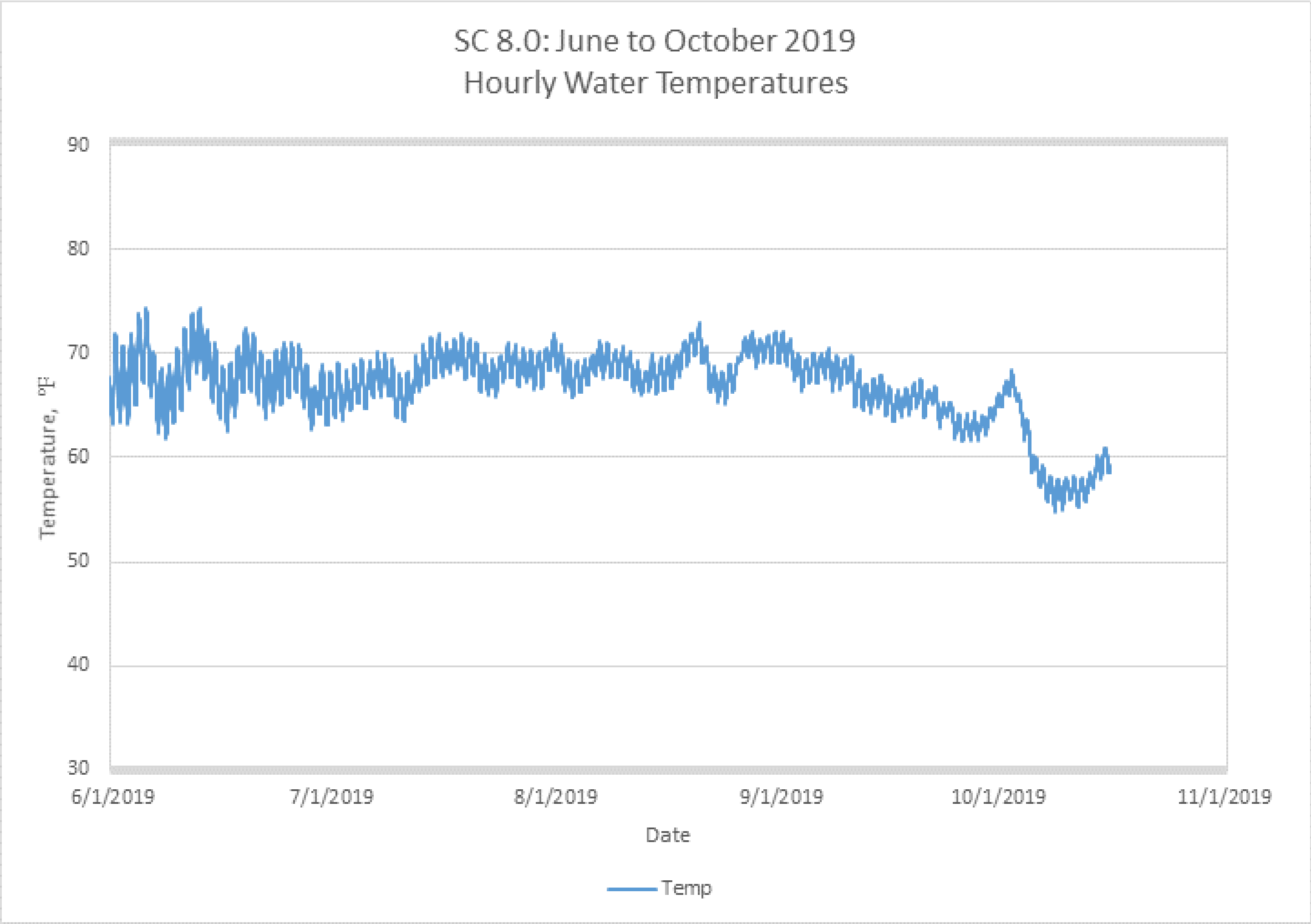


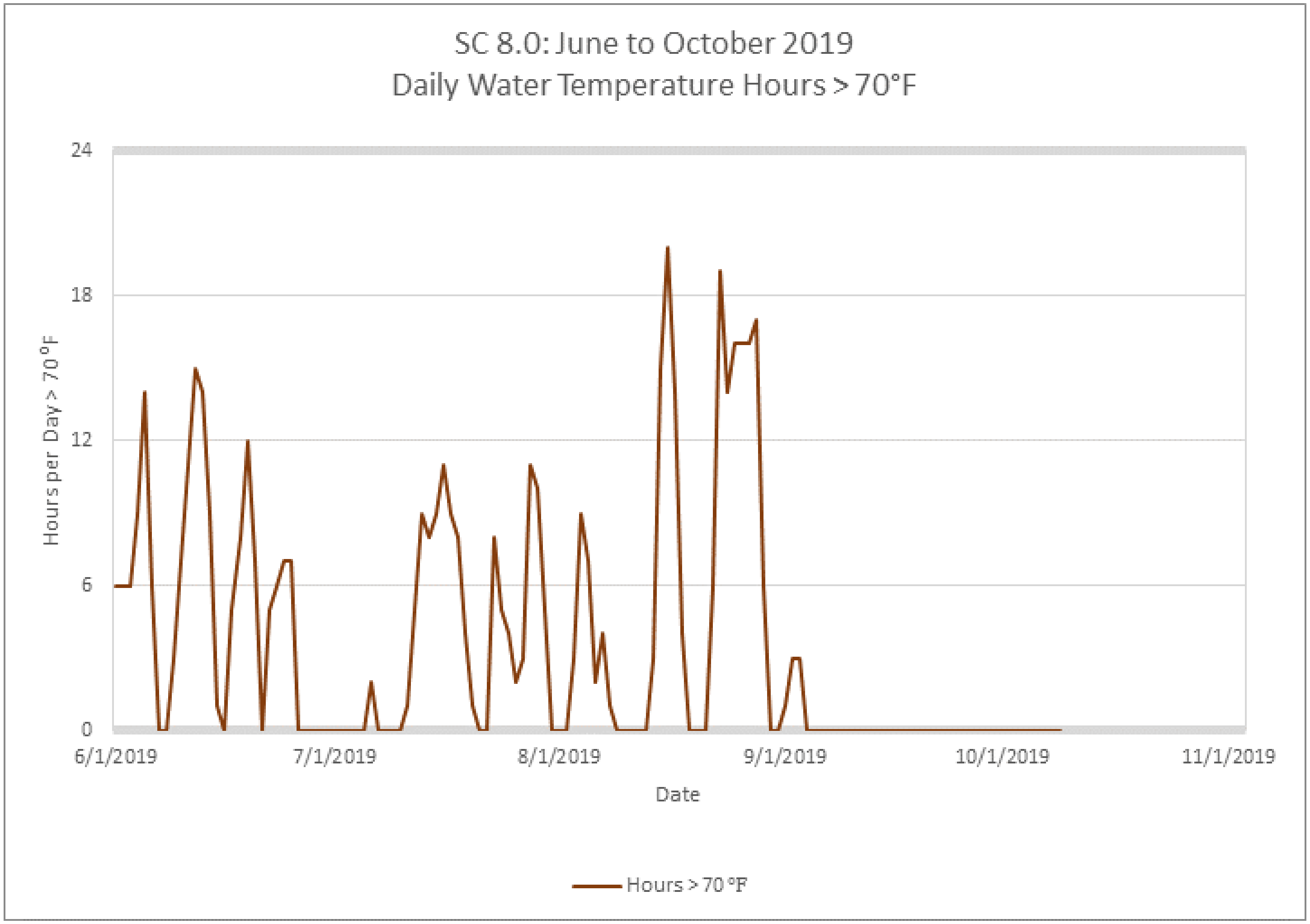
SC 7.8: June to October 2019
Hourly Water Temperatures
90
80
70
60
50
40
30
Temperature, °F
6/1/2019
7/1/2019
8/1/2019
9/1/2019
10/1/2019
11/1/2019
Date
Temp



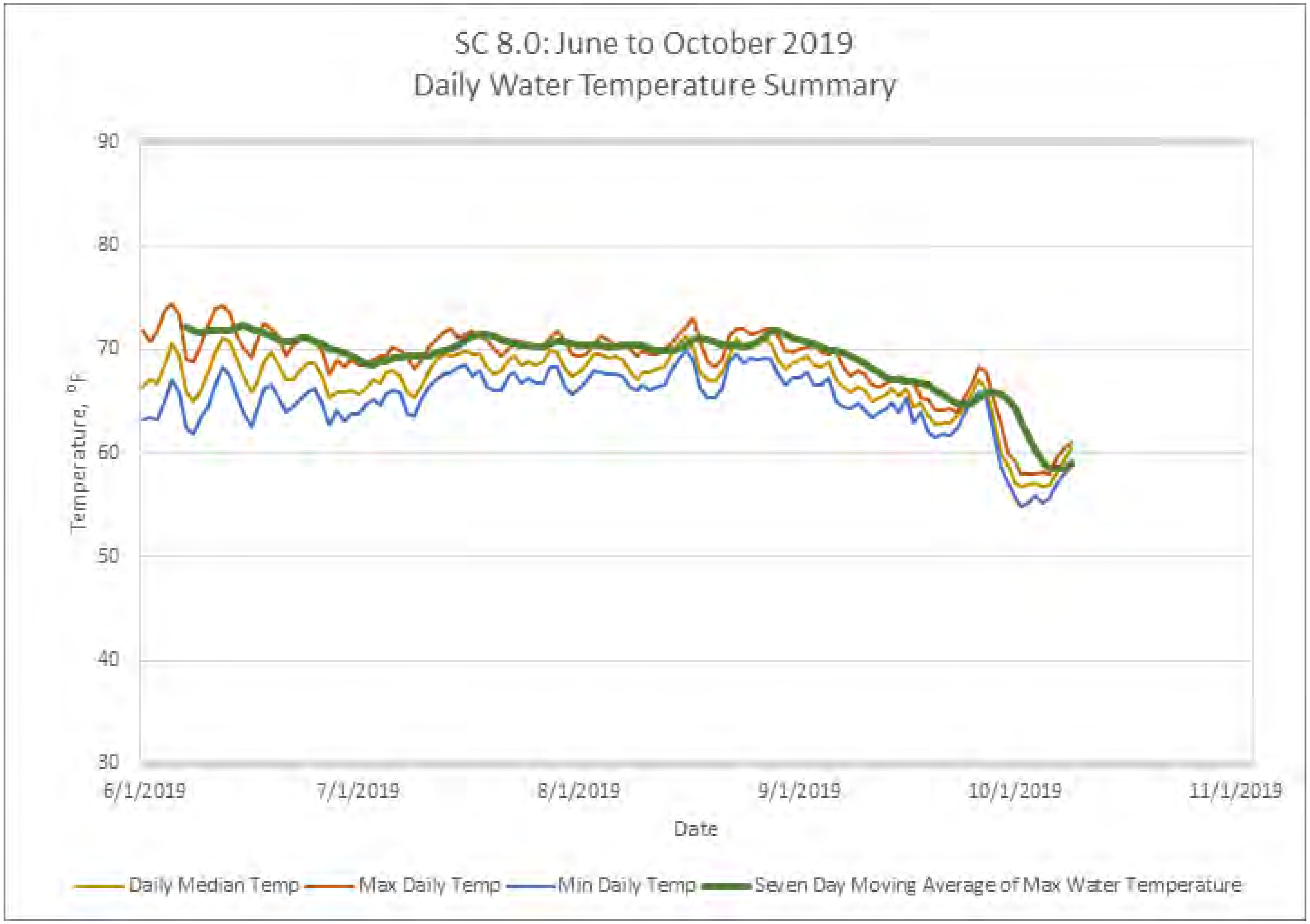
SC 7.8: June to October 2019
Daily Water Temperature Hours > 70°F
24
18
12
6
0
Hours per Day > 70°F
6/1/2019
7/1/2019
8/1/2019
9/1/2019
10/1/2019
11/1/2019
Date
Hours > 70°F


SC 7.8: June to October 2019
Daily Water Temperature Summary
Temperature, °F
90
80
70
60
50
40
30
6/1/2019
7/1/2019
8/1/2019
9/1/2019
10/1/2019
11/1/2019
Date
Daily Median Temp
Max Daily Temp
Min Daily Temp
Seven Day Moving Average of Max Water Temperature

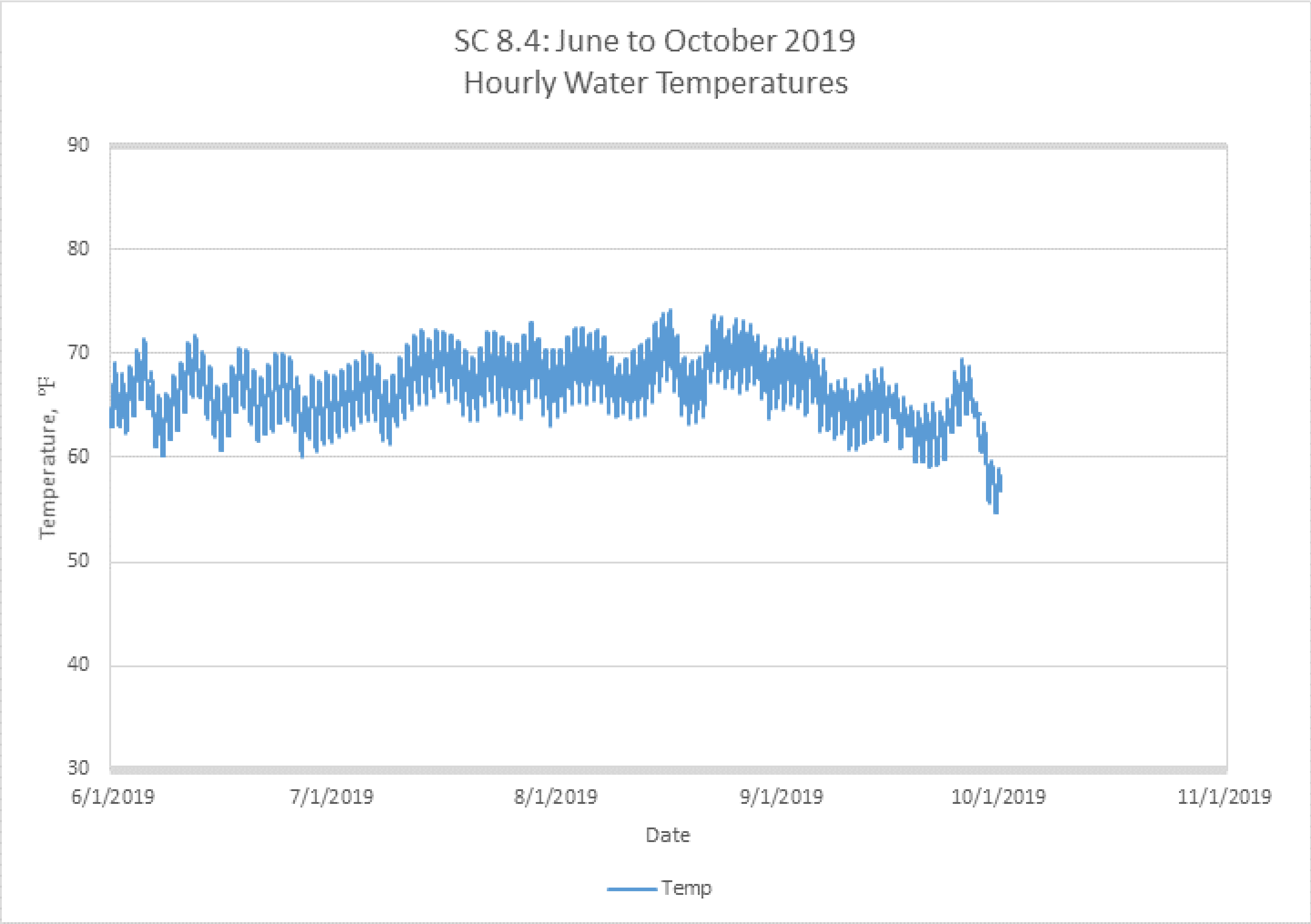

SC 8.0: June to October 2019
Hourly Water Temperatures
90
80
70
60
50
40
30
Temperature, °F
6/1/2019
7/1/2019
8/1/2019
9/1/2019
10/1/2019
11/1/2019
Date
Temp

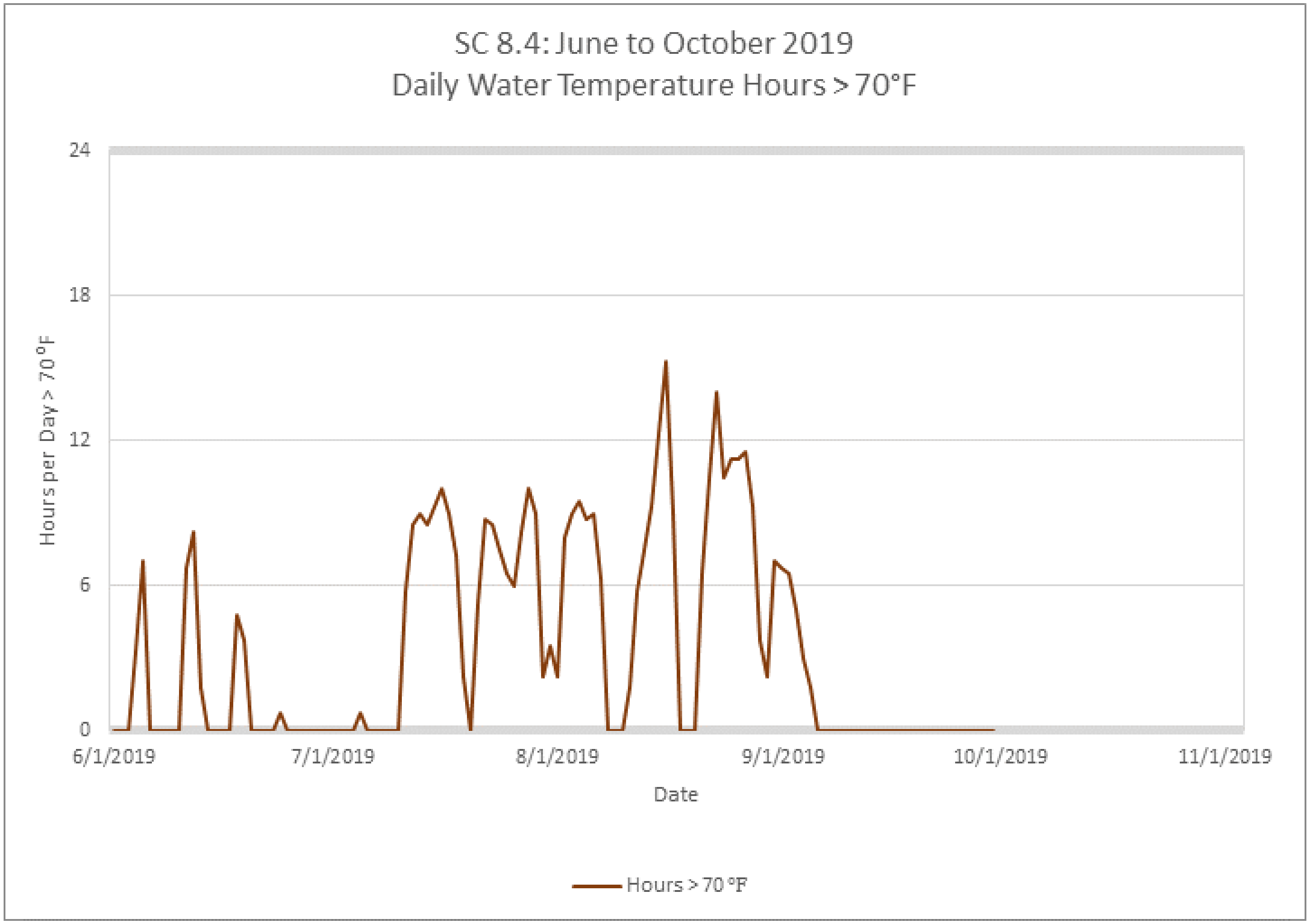


SC 8.0: June to October 2019
Daily Water Temperature Hours > 70°F
24
18
12
6
0
Hours per Day > 70°F
6/1/2019
7/1/2019
8/1/2019
9/1/2019
10/1/2019
11/1/2019
Date
Hours > 70 °F

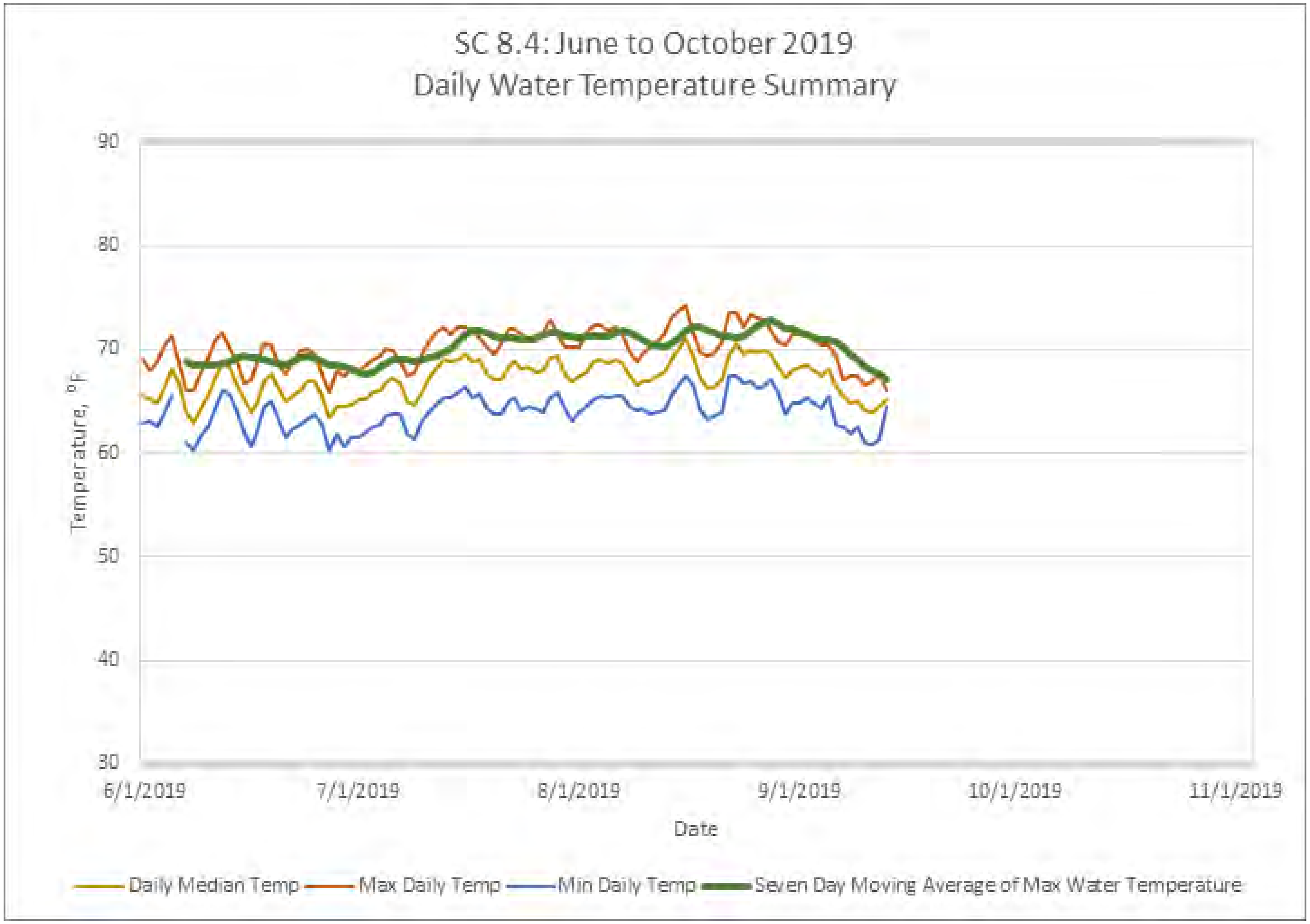


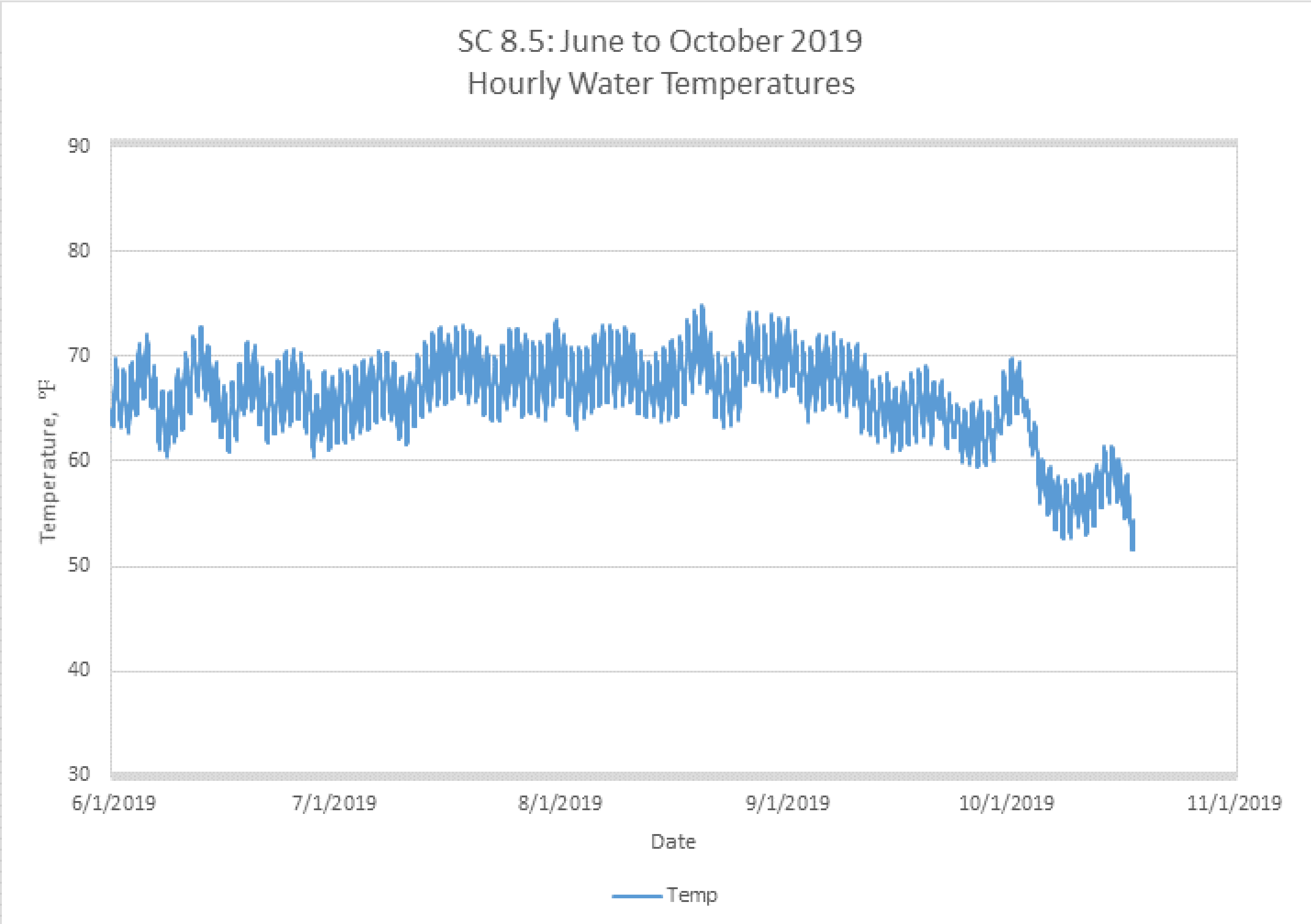
SC 8.0: June to October 2019
Daily Water Temperature Summary
90
80
70
60
50
40
30
Temperature, °F
6/1/2019
7/1/2019
8/1/2019
9/1/2019
10/1/2019
11/1/2019
Date
Daily Median Temp
Max Daily Temp
Min Daily Temp
Seven Day Moving Average of Max Water Temperature

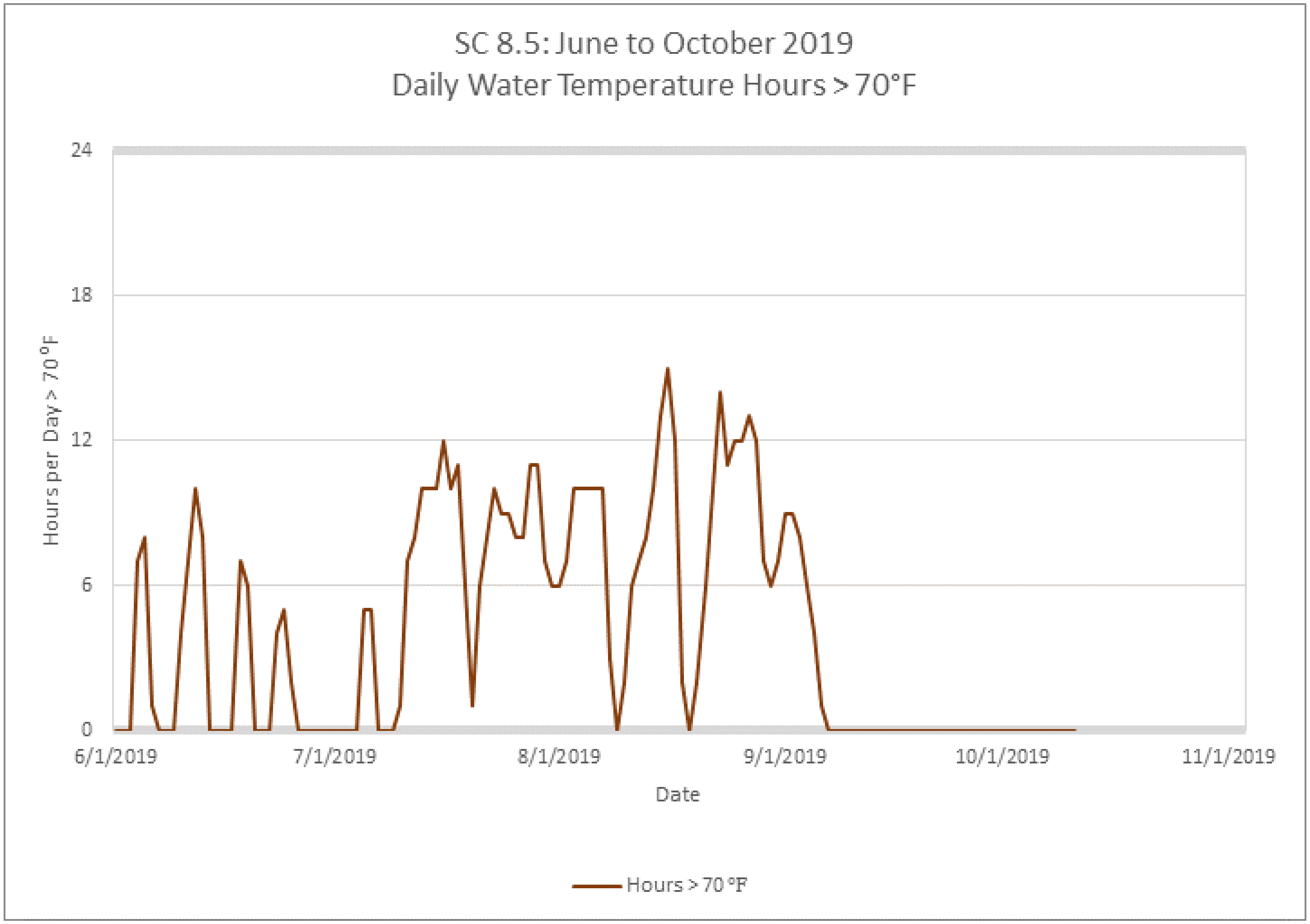

SC 8.4: June to October 2019
Hourly Water Temperatures
90
80
70
60
50
40
30
Temperature, °F
6/1/2019
7/1/2019
8/1/2019
9/1/2019
10/1/2019
11/1/2019
Date
Temp



SC 8.4: June to October 2019
Daily Water Temperature Hours > 70°F
24
18
12
6
0
Hours per Day > 70°F
6/1/2019
7/1/2019
8/1/2019
9/1/2019
10/1/2019
11/1/2019
Date
Hours > 70 °F


SC 8.4: June to October 2019
Daily Water Temperature Summary
90
80
70
60
50
40
30
Temperature, °F
6/1/2019
7/1/2019
8/1/2019
9/1/2019
10/1/2019
11/1/2019
Date
Daily Median Temp
Max Daily Temp
Min Daily Temp
Seven Day Moving Average of Max Water Temperature


SC 8.5: June to October 2019
Hourly Water Temperatures
90
80
70
60
50
40
30
Temperature, °F
6/1/2019
7/1/2019
8/1/2019
9/1/2019
10/1/2019
11/1/2019
Date
Temp



SC 8.5: June to October 2019
Daily Water Temperature Hours > 70°F
Hours per Day > 70°F
24
18
12
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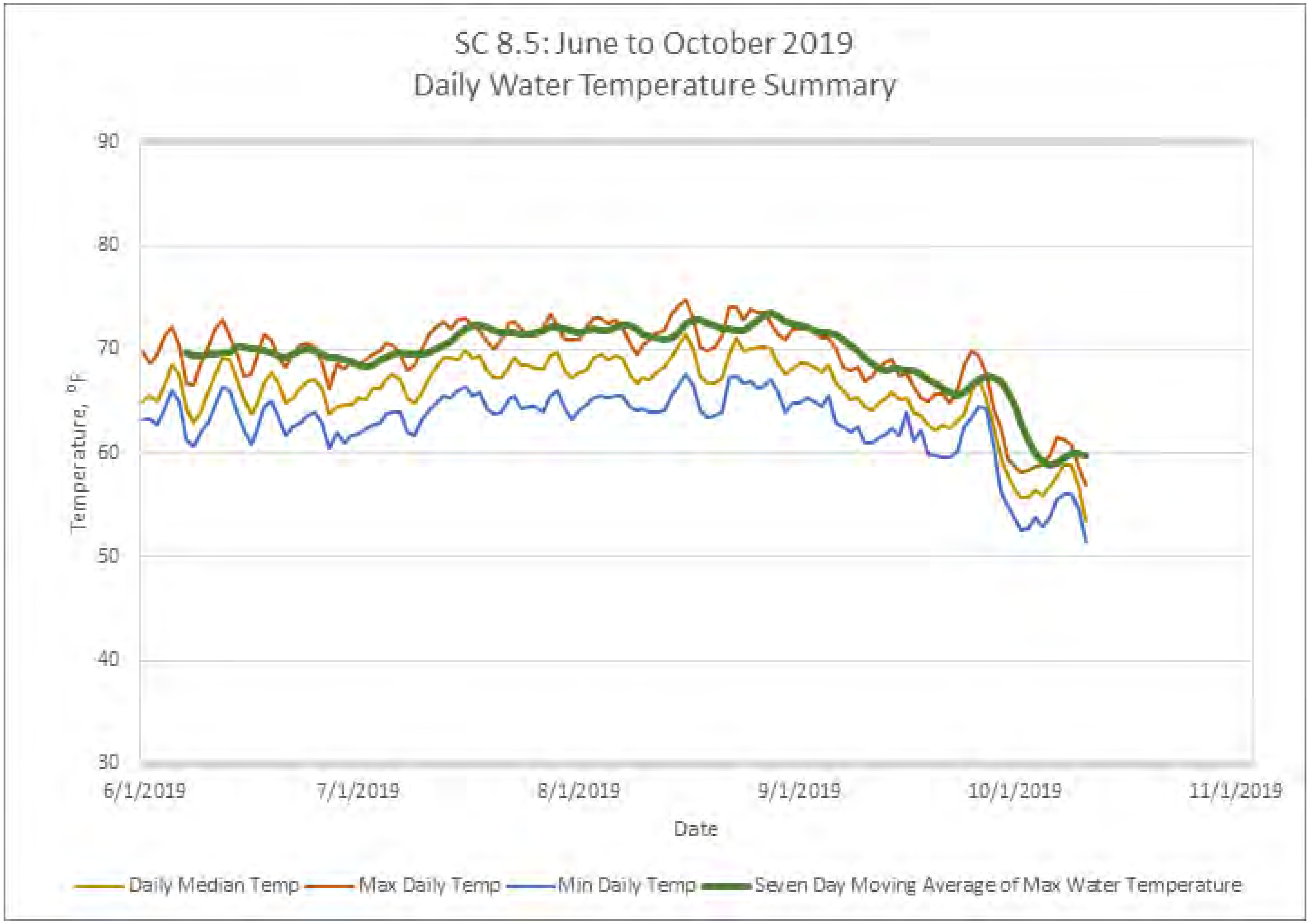
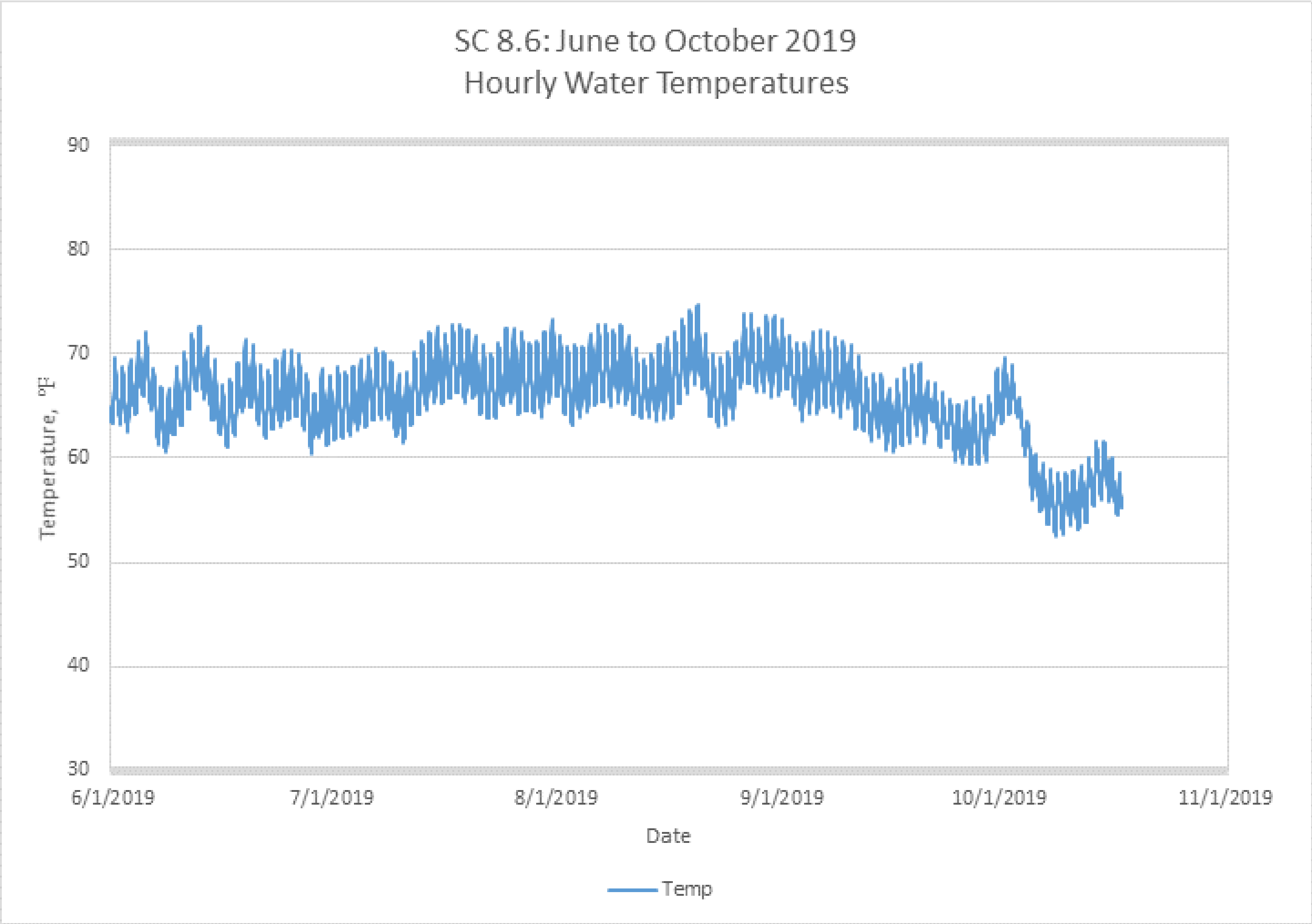
0
6/1/2019
7/1/2019
8/1/2019
9/1/2019
10/1/2019
11/1/2019
Date
Hours > 70 °F


SC 8.5: June to October 2019
Daily Water Temperature Summary
90
80
70
60
50
40
30
Temperature, °F
6/1/2019
7/1/2019
8/1/2019
9/1/2019
10/1/2019
11/1/2019
Date
Daily Median Temp
Max Daily Temp
Min Daily Temp
Seven Day Moving Average of Max Water Temperature


SC 8.6: June to October 2019
Hourly Water Temperatures
90
80
70
60
50
40
30
Temperature, °F
6/1/2019
7/1/2019
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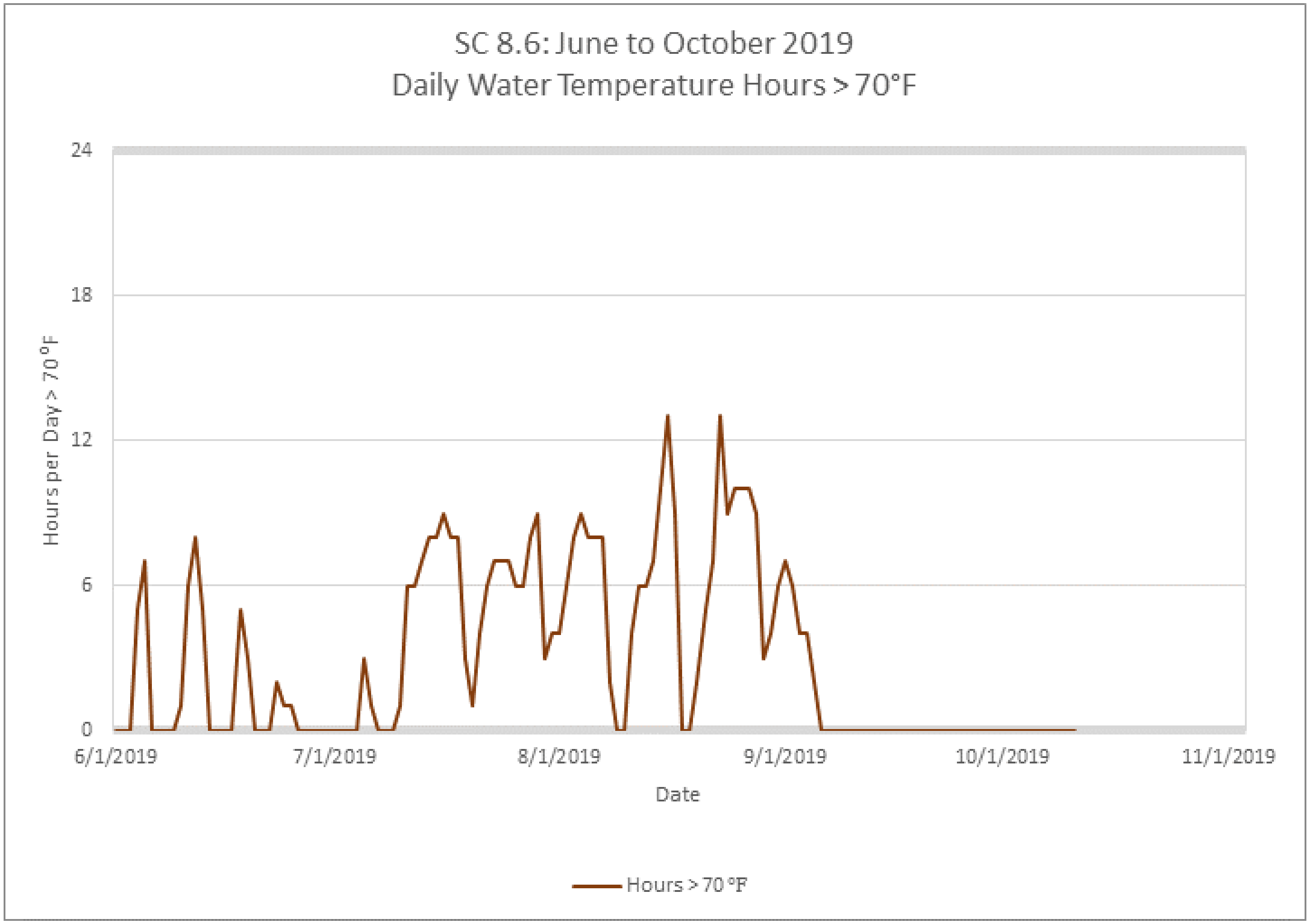
11/1/2019
Date
Temp



SC 8.6: June to October 2019
Daily Water Temperature Hours > 70°F
24
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Hours per Day > 70°F
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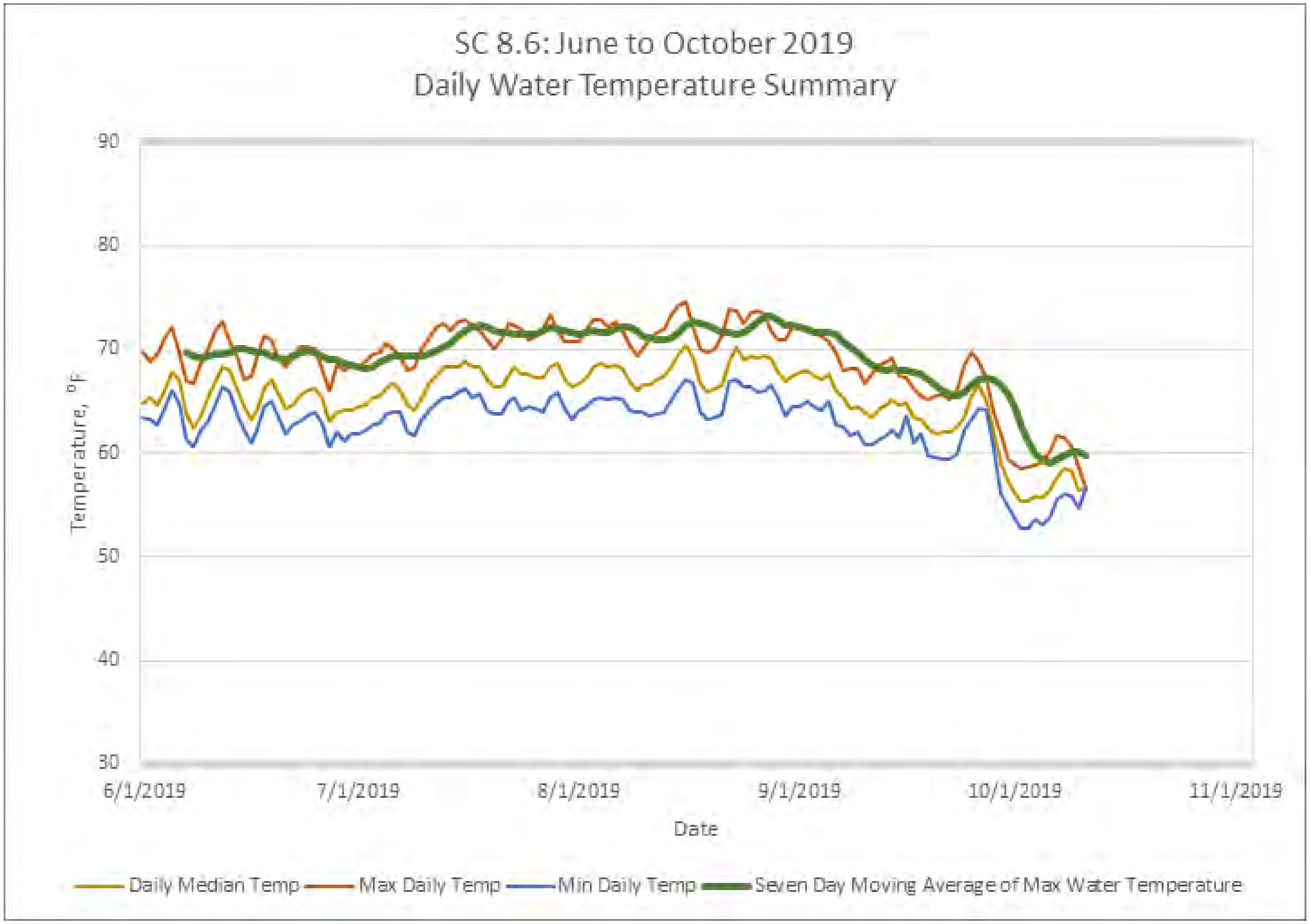
9/1/2019
10/1/2019
11/1/2019
Date
Hours > 70 °F



SC 8.6: June to October 2019
Daily Water Temperature Summary
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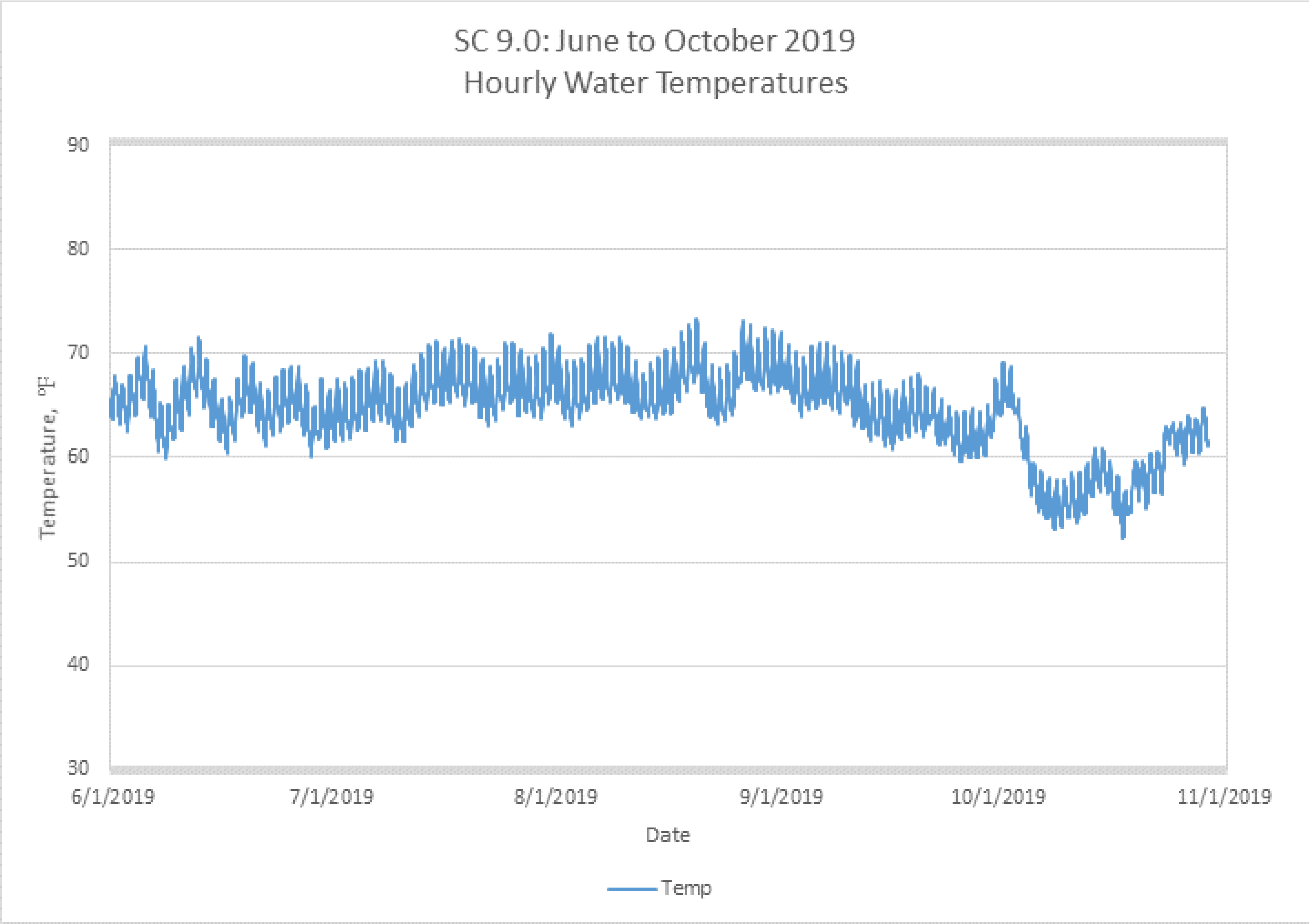
Temperature, °F
6/1/2019
7/1/2019
8/1/2019
9/1/2019
10/1/2019
11/1/2019
Date
Daily Median Temp
Max Daily Temp
Min Daily Temp
Seven Day Moving Average of Max Water Temperature


SC 9.0: June to October 2019
Hourly Water Temperatures
90
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Temperature, °F
6/1/2019
7/1/2019
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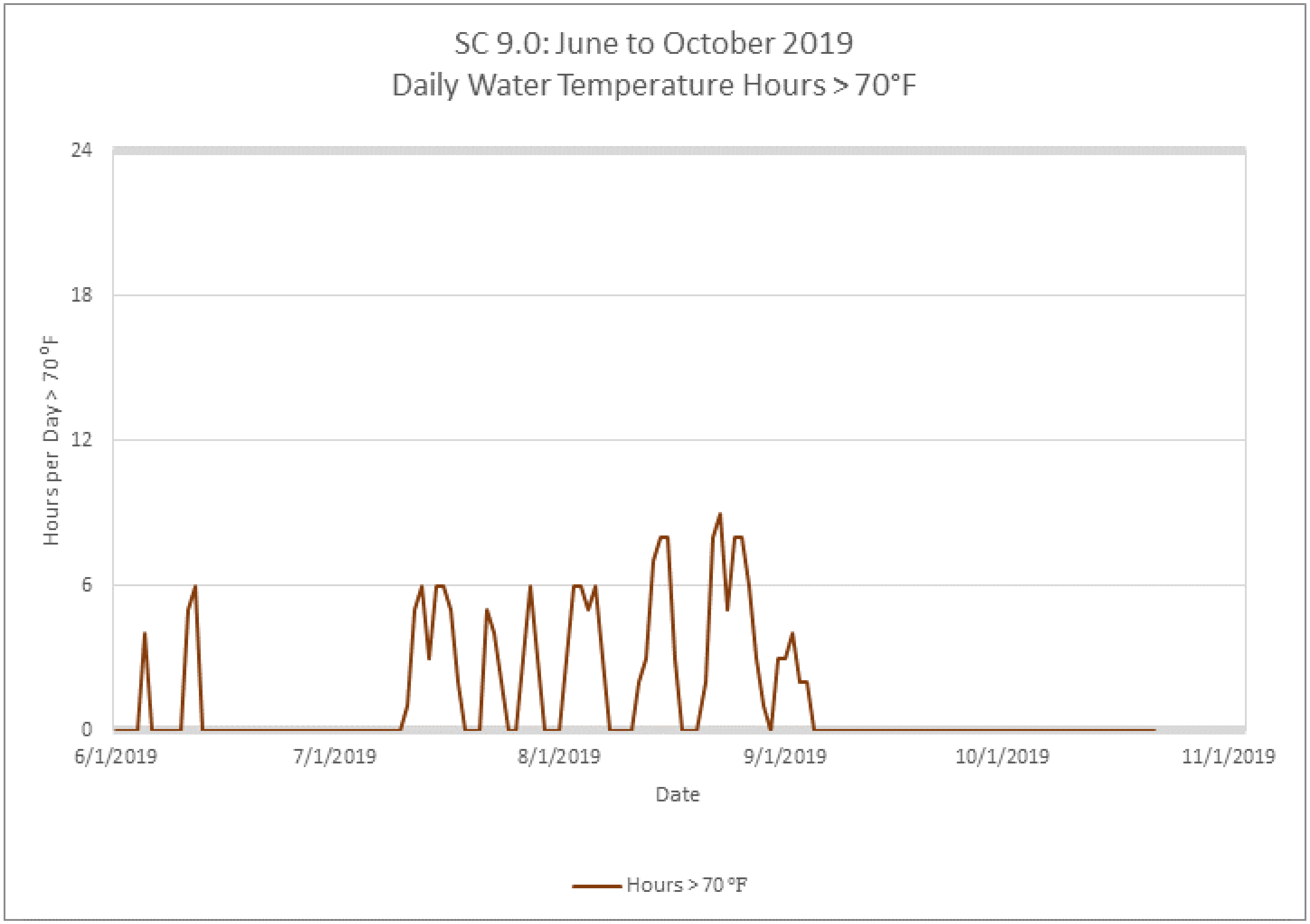
11/1/2019
Date
Temp


SC 9.0: June to October 2019
Daily Water Temperature Hours > 70°F
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Hours per Day > 70°F
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7/1/2019
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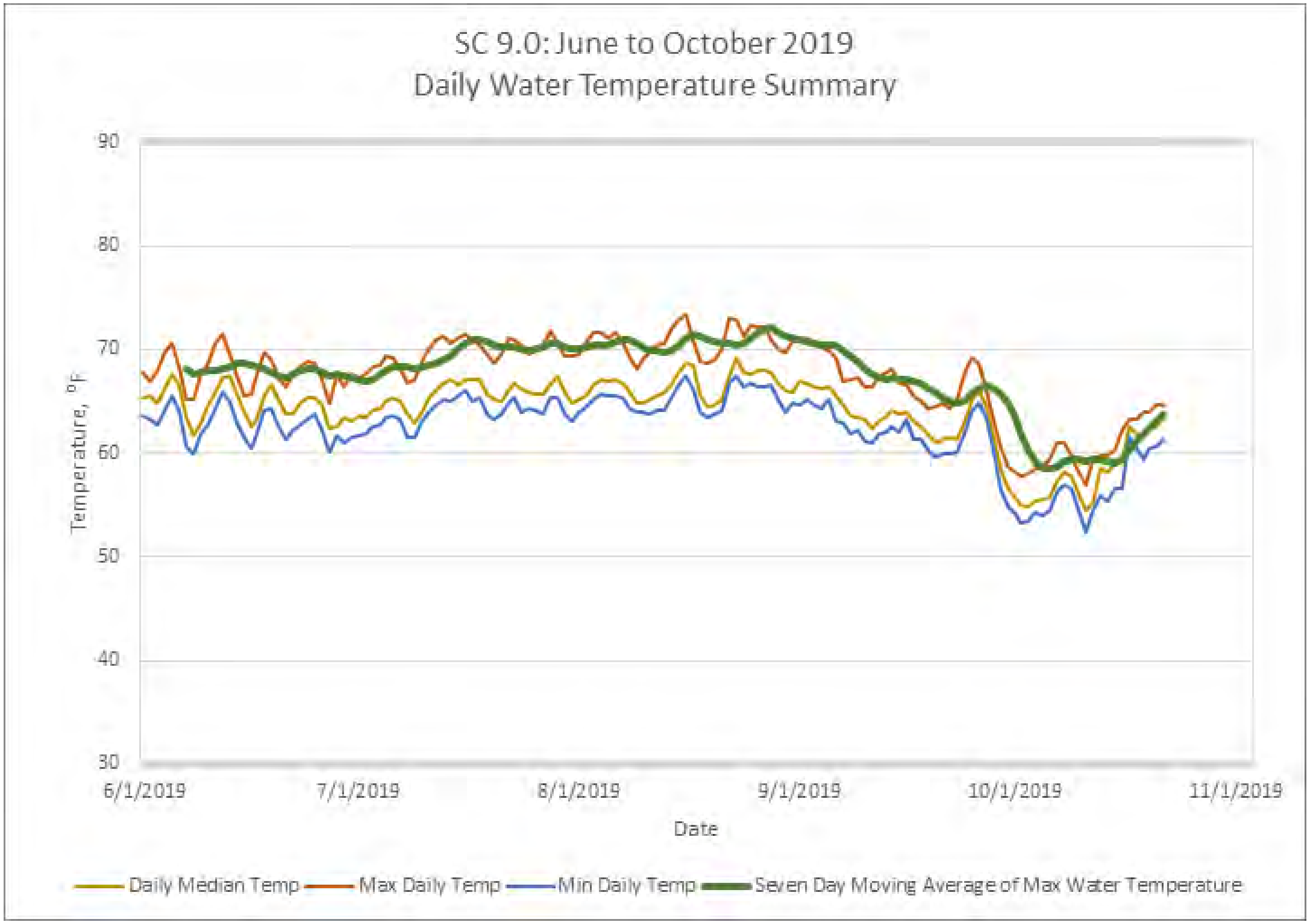
9/1/2019
10/1/2019
11/1/2019
Date
Hours > 70 °F



SC 9.0: June to October 2019
Daily Water Temperature Summary
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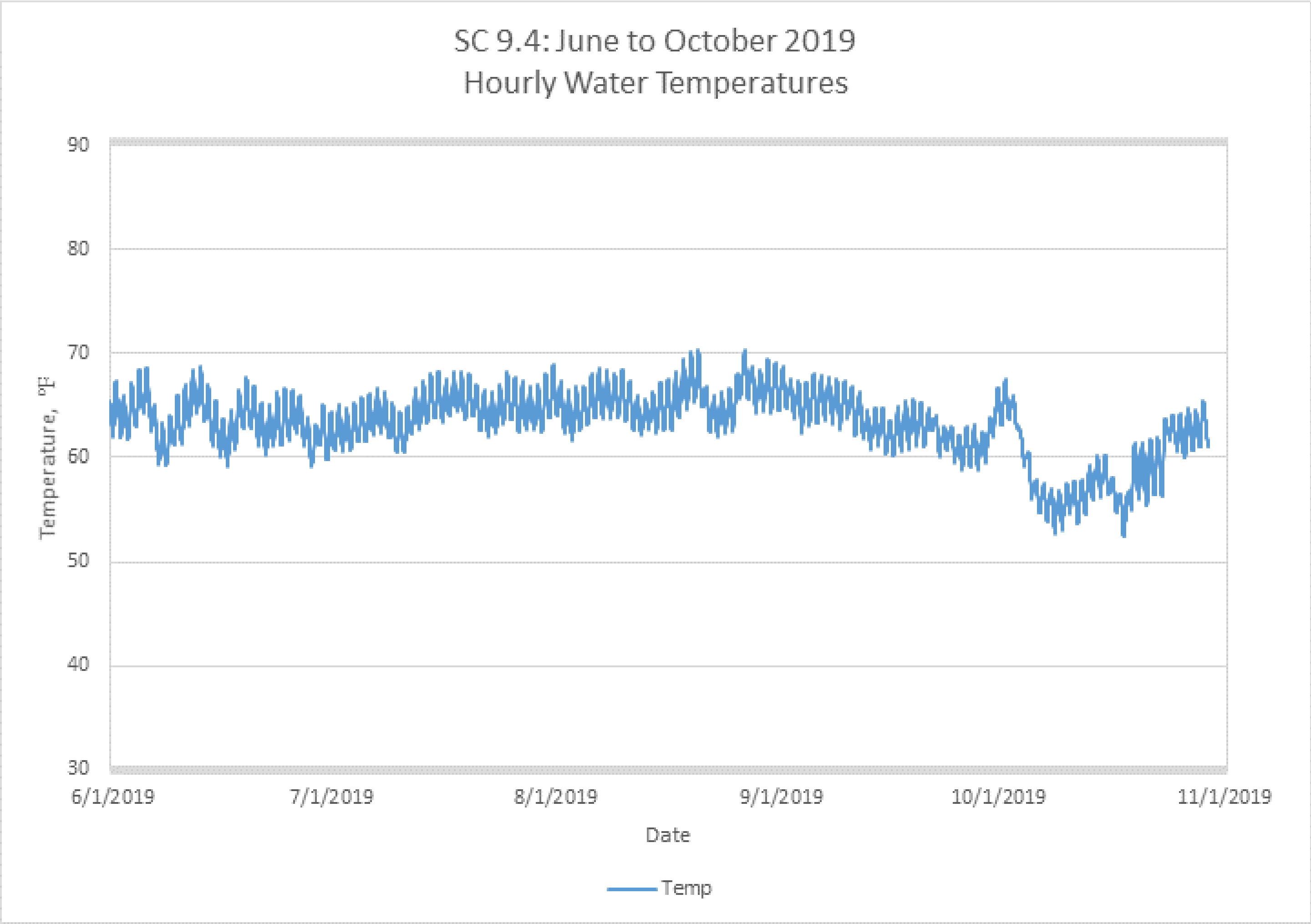
Temperature, °F
6/1/2019
7/1/2019
8/1/2019
9/1/2019
10/1/2019
11/1/2019
Date
Daily Median Temp
Max Daily Temp
Min Daily Temp
Seven Day Moving Average of Max Water Temperature


SC 9.4: June to October 2019
Hourly Water Temperatures
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Temperature, °F
6/1/2019
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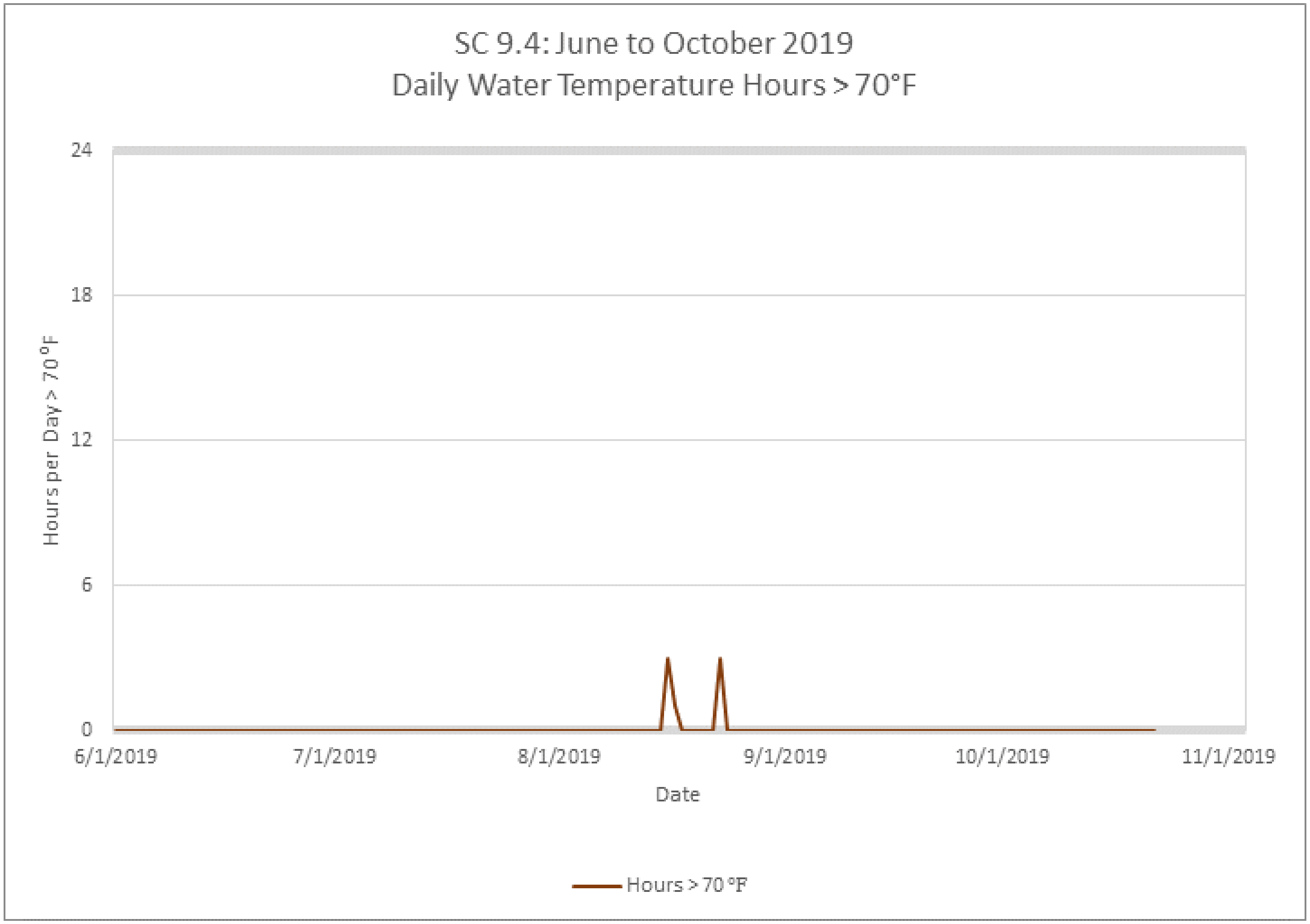
11/1/2019
Date
Temp



SC 9.4: June to October 2019
Daily Water Temperature Hours > 70°F
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Hours per Day > 70°F
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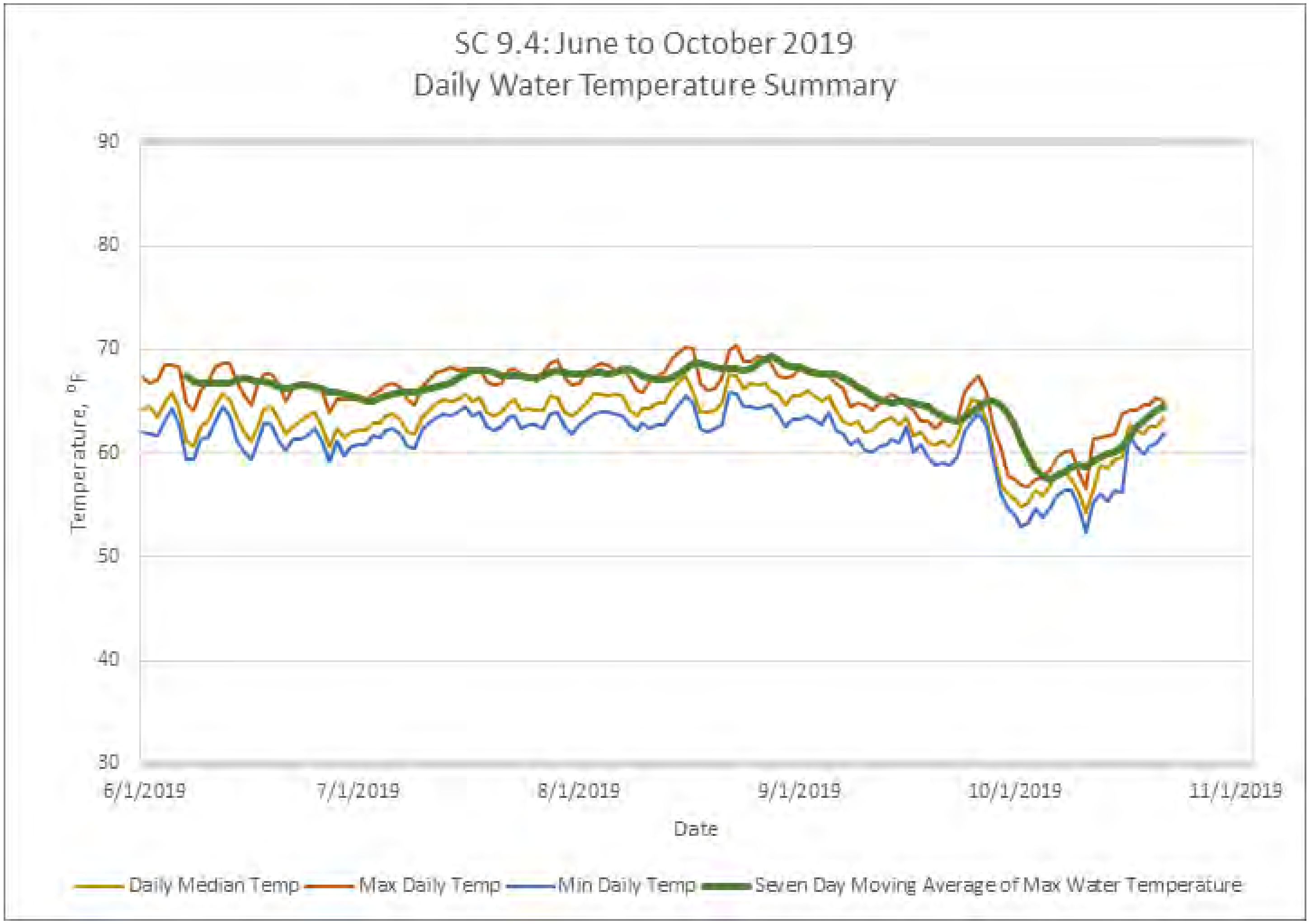
9/1/2019
10/1/2019
11/1/2019
Date
Hours > 70 °F


SC 9.4: June to October 2019
Daily Water Temperature Summary
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Temperature, °F
6/1/2019
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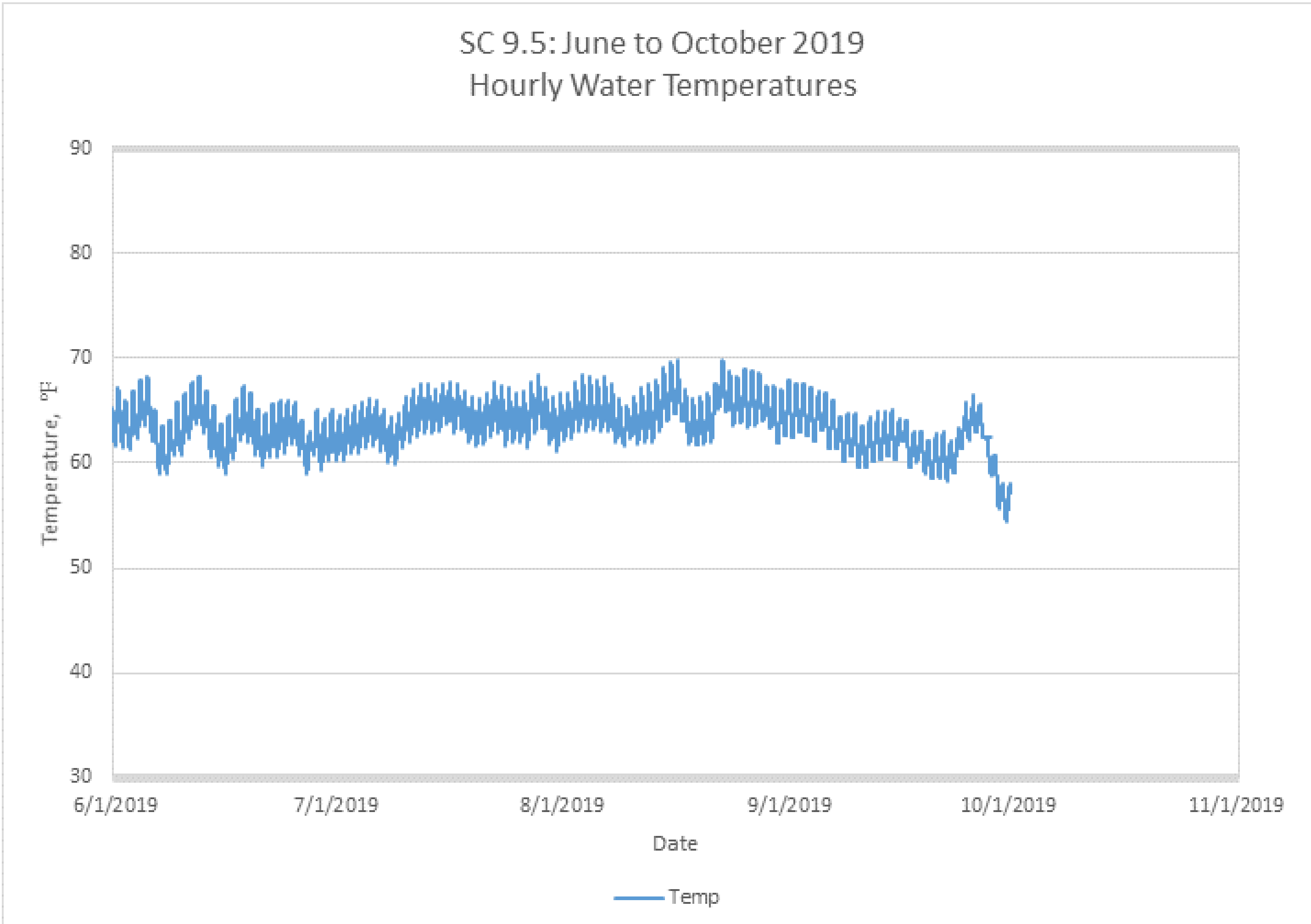
9/1/2019
10/1/2019
11/1/2019
Date
Daily Median Temp
Max Daily Temp
Min Daily Temp
Seven Day Moving Average of Max Water Temperature


SC 9.5: June to October 2019
Hourly Water Temperatures
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Temperature, °F
6/1/2019
7/1/2019
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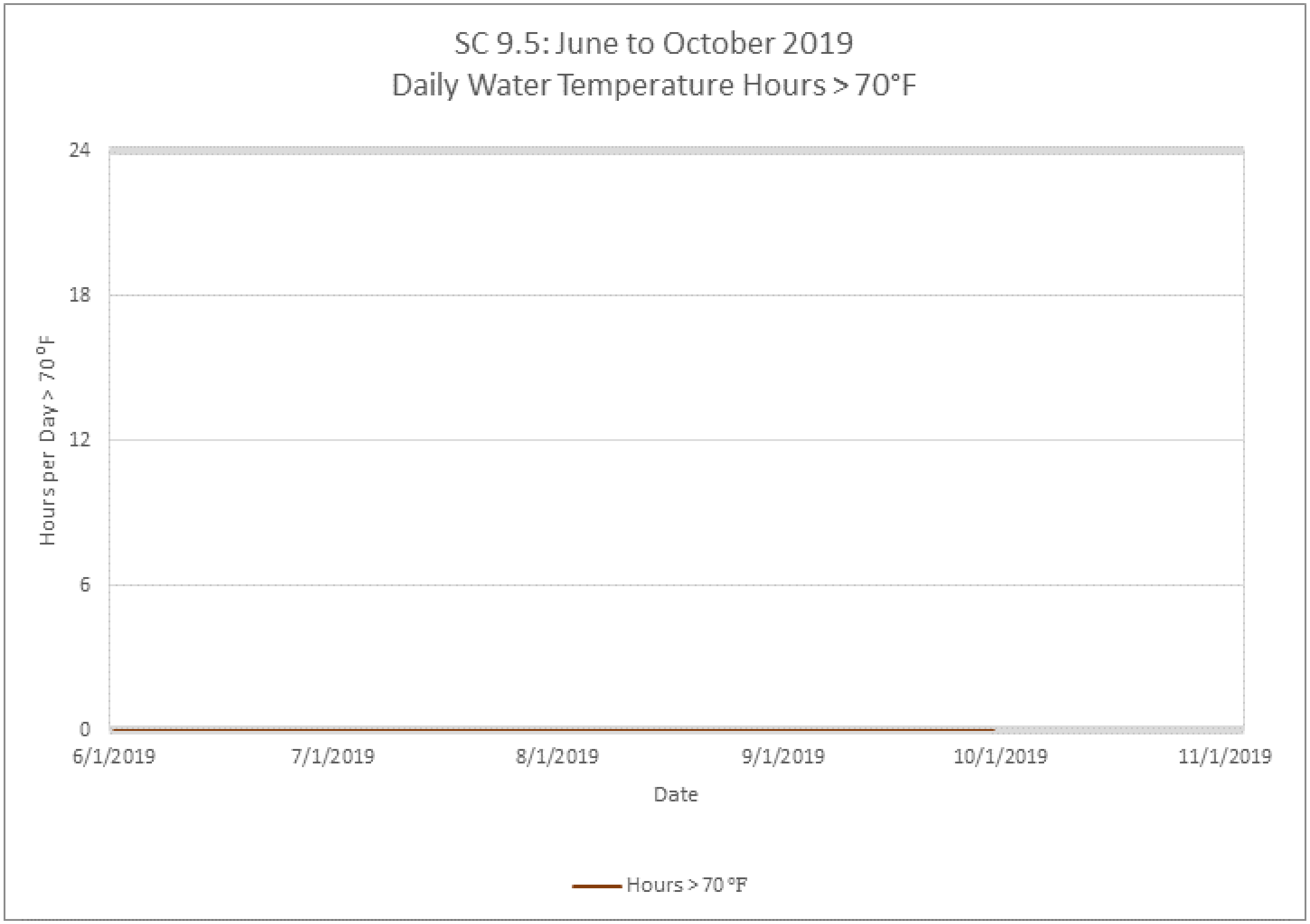
11/1/2019
Date
Temp


SC 9.5: June to October 2019
Daily Water Temperature Hours > 70°F
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Hours per Day > 70°F
6/1/2019
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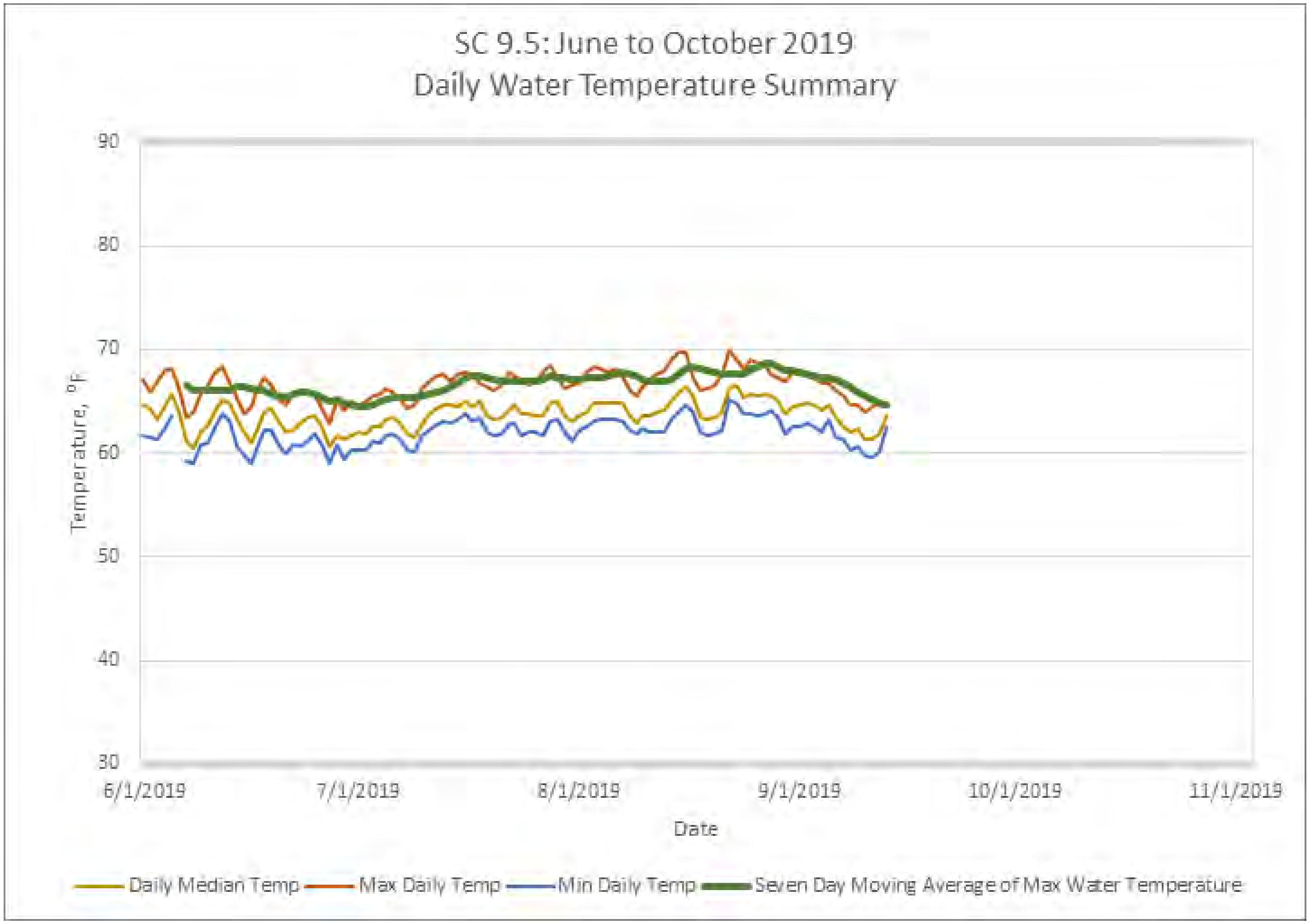
9/1/2019
10/1/2019
11/1/2019
Date
Hours > 70 °F



SC 9.5: June to October 2019
Daily Water Temperature Summary
90
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Temperature, °F
6/1/2019
7/1/2019
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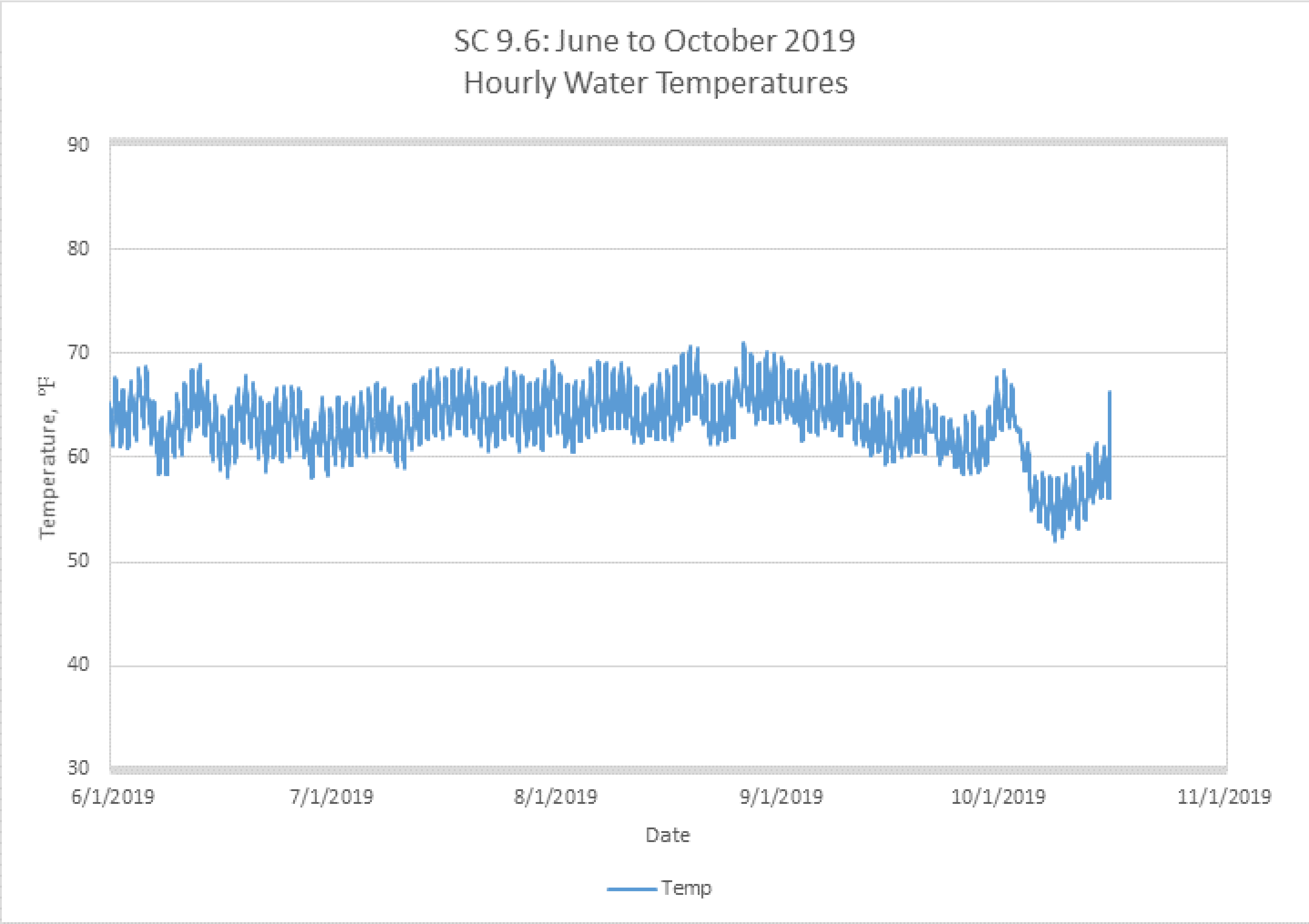
9/1/2019
10/1/2019
11/1/2019
Date
Daily Median Temp
Max Daily Temp
Min Daily Temp
Seven Day Moving Average of Max Water Temperature



SC 9.6: June to October 2019
Hourly Water Temperatures
90
80
70
60
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30
Temperature, °F
6/1/2019
7/1/2019
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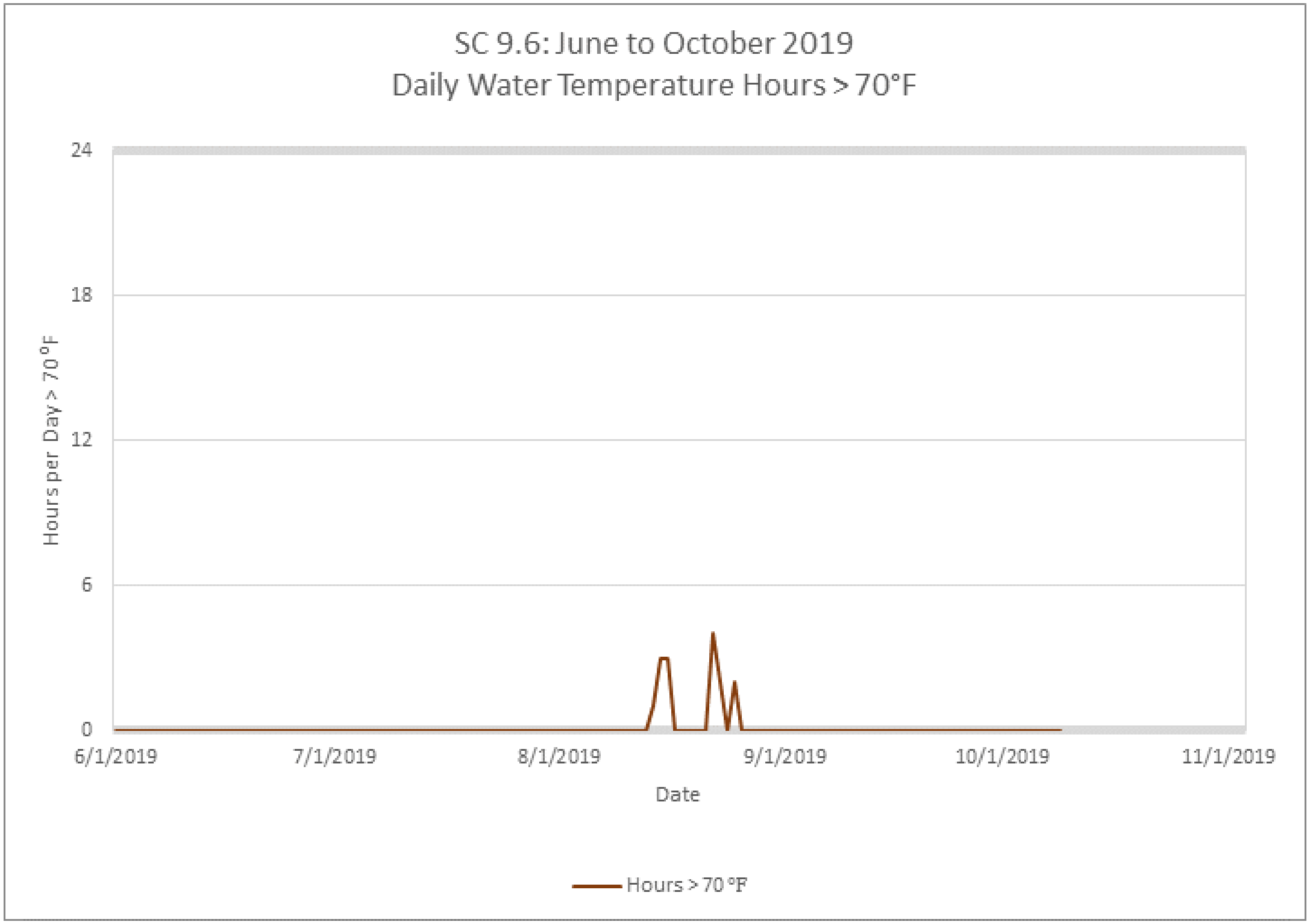
11/1/2019
Date
Temp


SC 9.6: June to October 2019
Daily Water Temperature Hours > 70°F
24
18
12
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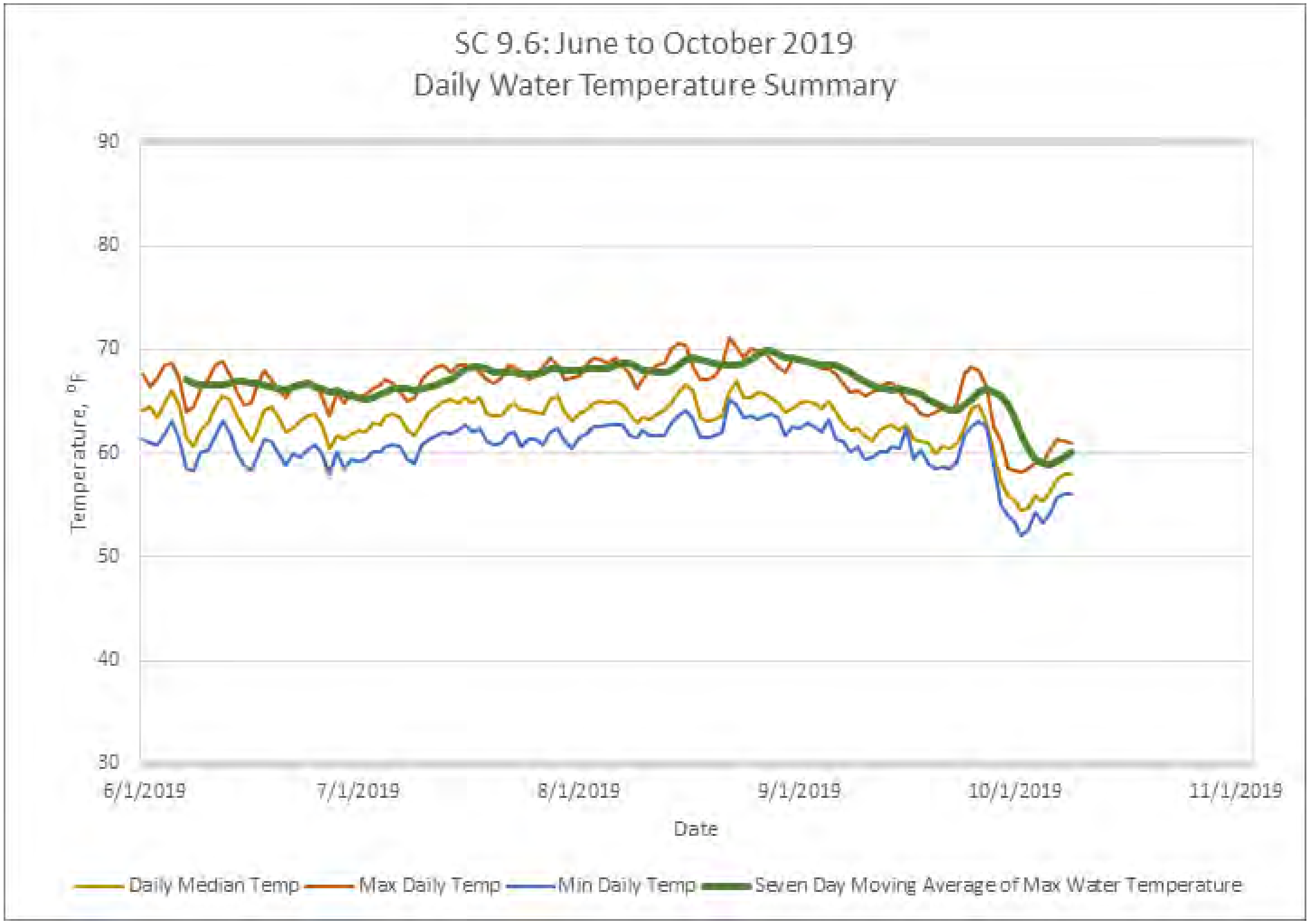
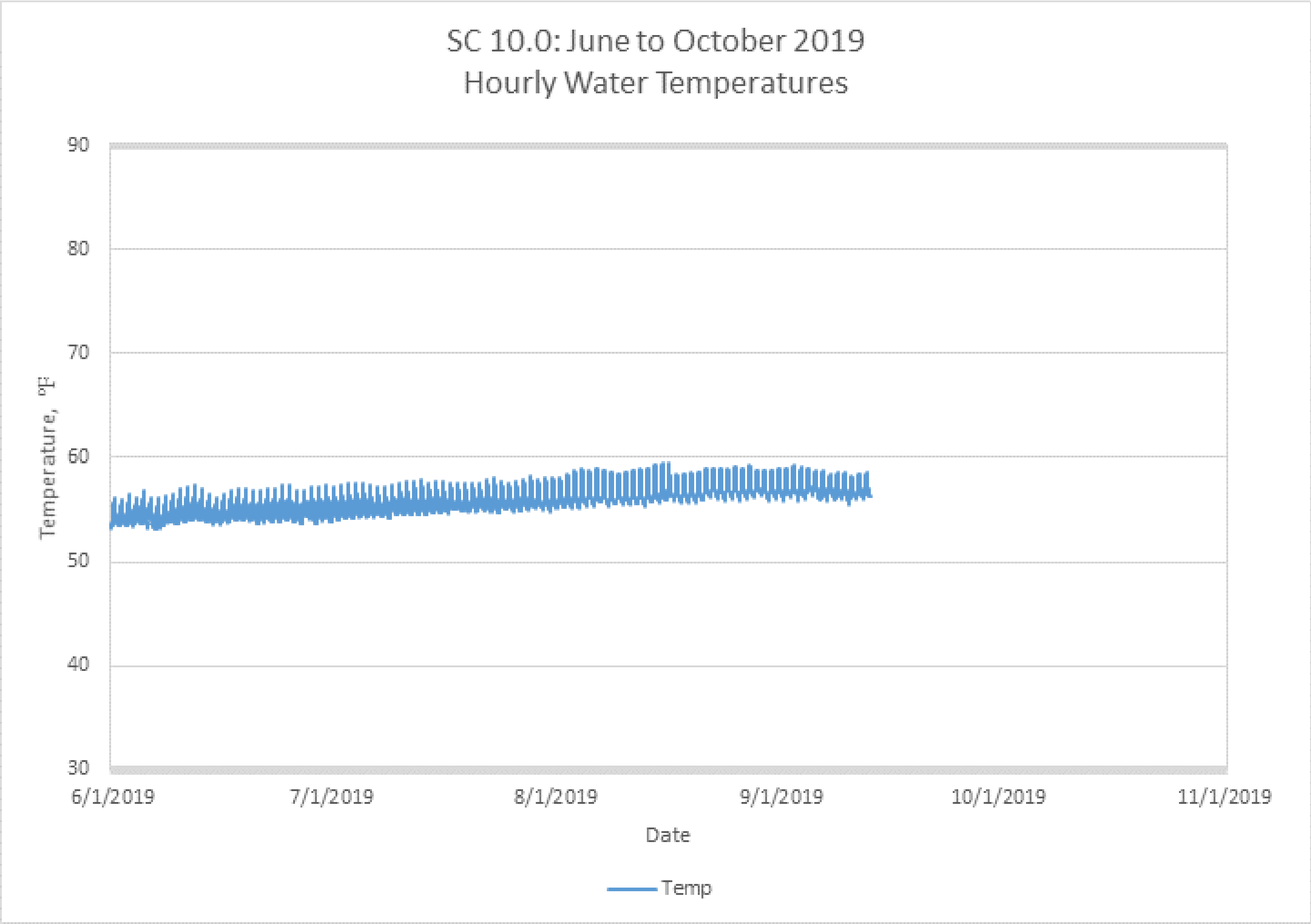
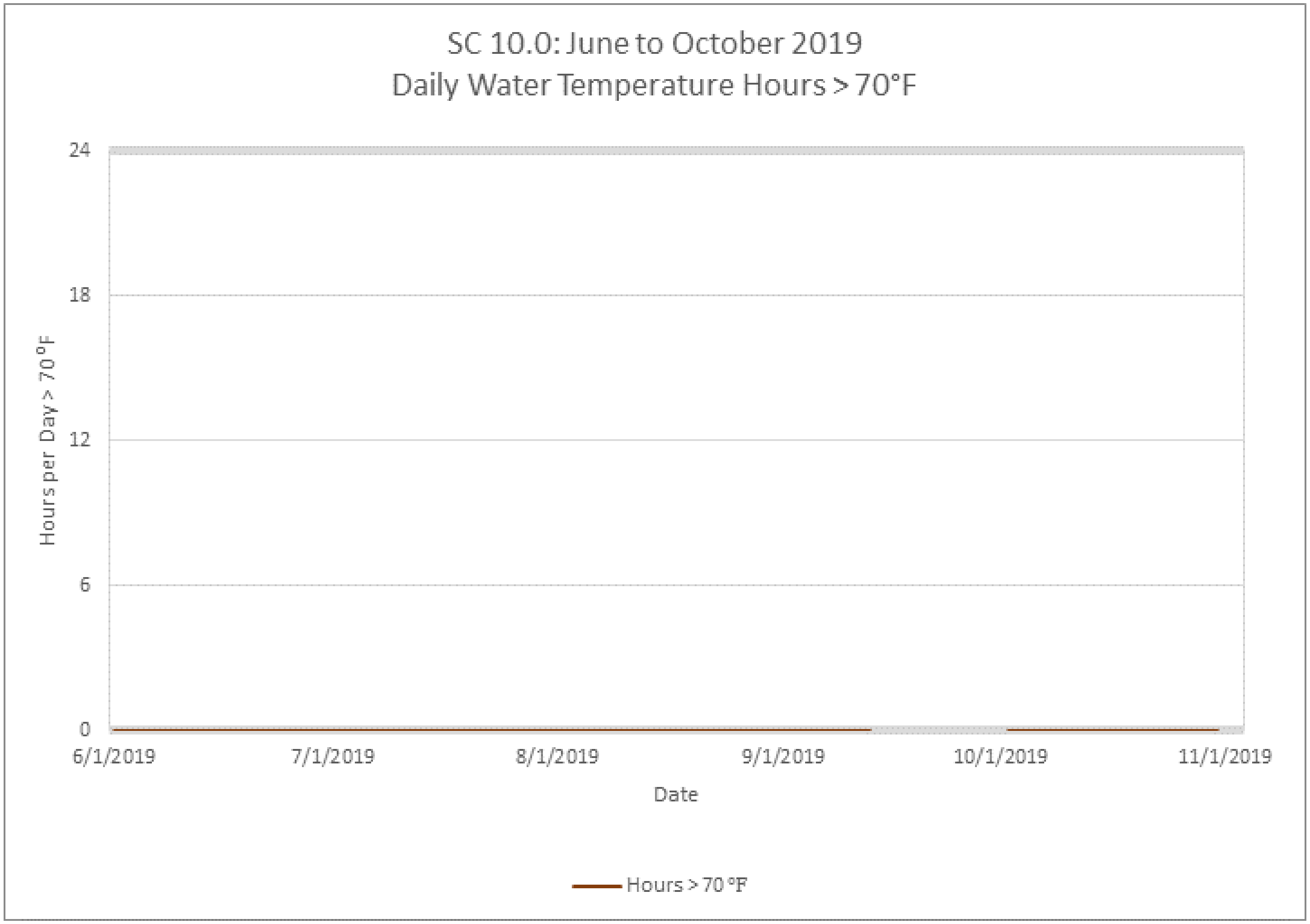
Hours per Day > 70°F
6/1/2019
7/1/2019
8/1/2019
9/1/2019
10/1/2019
11/1/2019
Date
Hours > 70 °F

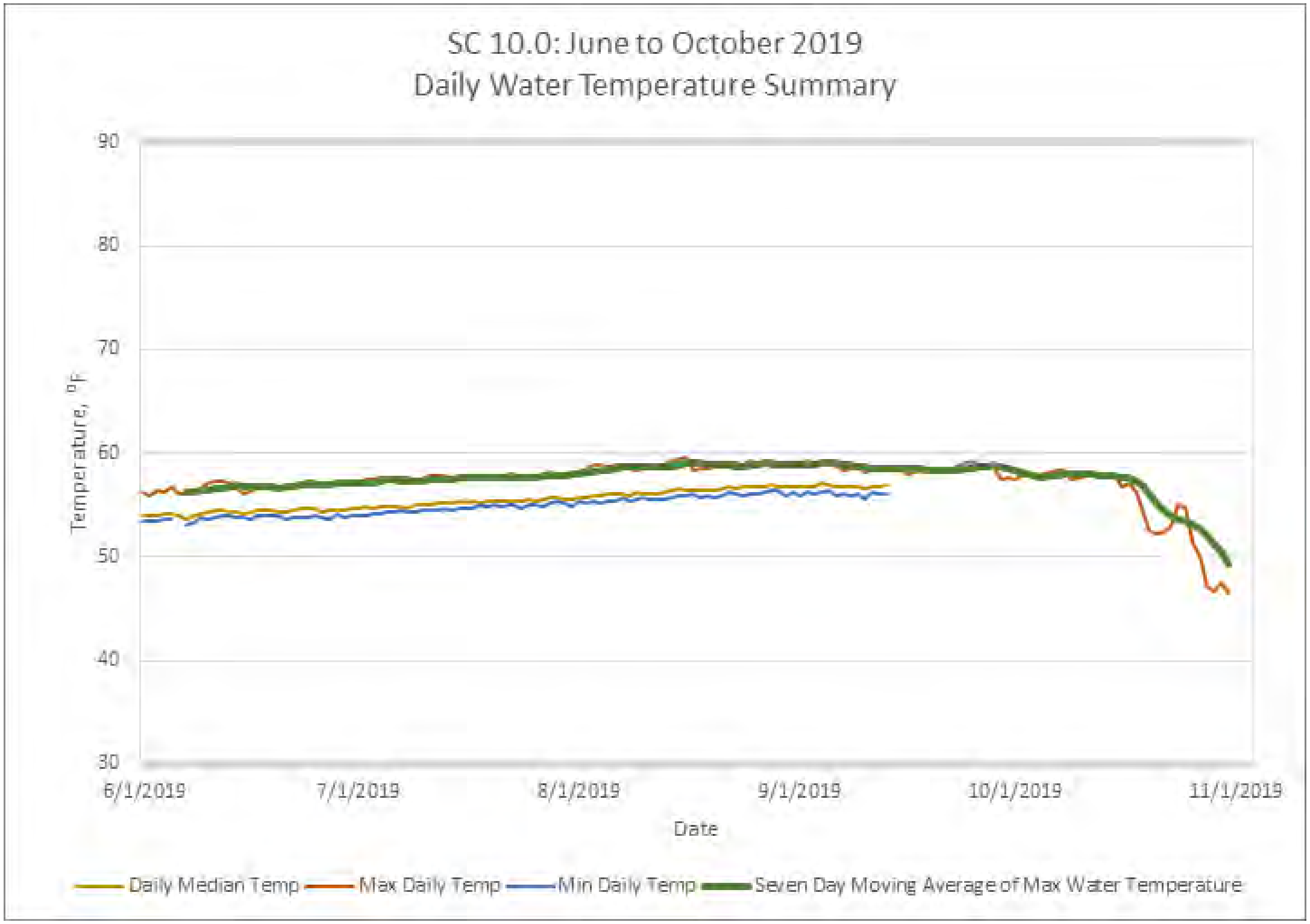


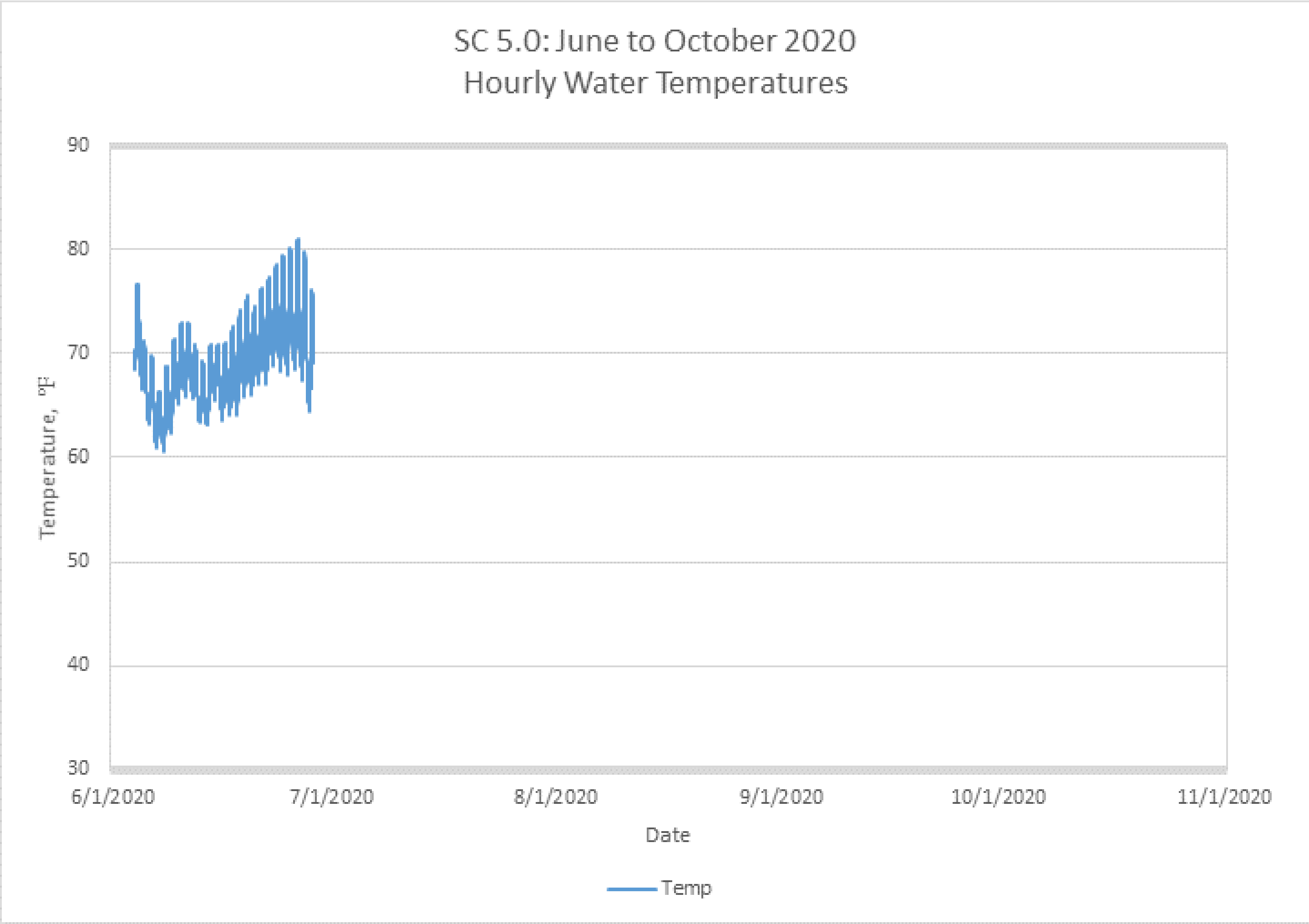
SC 9.6: June to October 2019
Daily Water Temperature Summary
90
80
70
60
50
40
30
Temperature, °F
6/1/2019
7/1/2019
8/1/2019
9/1/2019
10/1/2019
11/1/2019
Date
Daily Median Temp
Max Daily Temp
Min Daily Temp
Seven Day Moving Average of Max Water Temperature

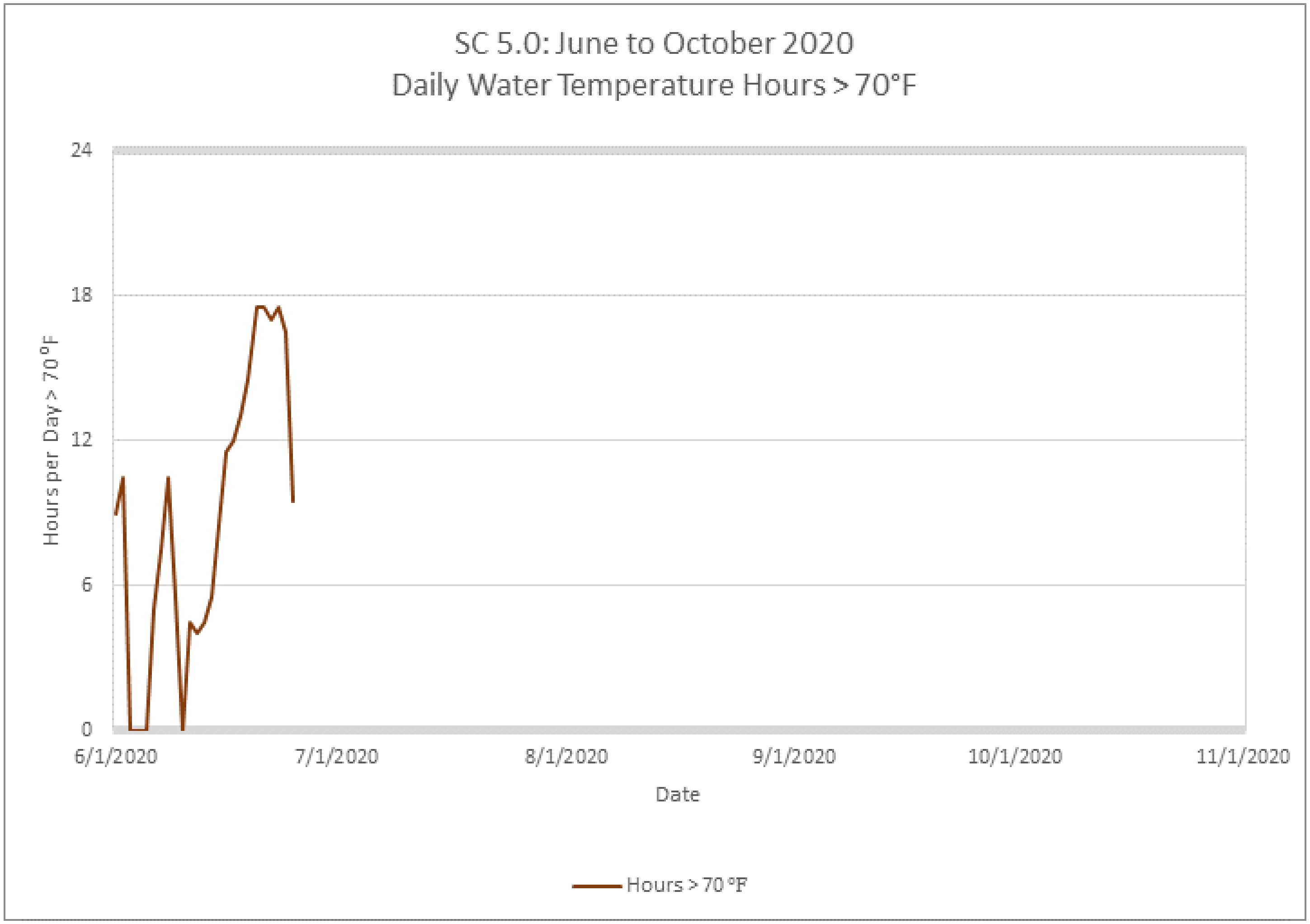


SC 10.0: June to October 2019
Hourly Water Temperatures
90
80
70
60
50
40
30
Temperature, °F
6/1/2019
7/1/2019
8/1/2019
9/1/2019
10/1/2019
11/1/2019
Date
Temp


SC 10.0: June to October 2019
Daily Water Temperature Hours > 70°F
Hours per Day > 70°F
24
18
12
6
0
6/1/2019
7/1/2019
8/1/2019
9/1/2019
10/1/2019
11/1/2019
Date
Hours > 70 °F


SC 10.0: June to October 2019
Daily Water Temperature Summary
90
80
70
60
50
40
30
Temperature, °F
6/1/2019
7/1/2019
8/1/2019
9/1/2019
10/1/2019
11/1/2019
Date
Daily Median Temp
Max Daily Temp
Min Daily Temp
Seven Day Moving Average of Max Water Temperature


SC 5.0: June to October 2020
Hourly Water Temperatures
90
80
70
60
50
40
30
Temperature, °F
6/1/2020
7/1/2020
8/1/2020
9/1/2020
10/1/2020
11/1/2020
Date
Temp


SC 5.0: June to October 2020
Daily Water Temperature Hours > 70°F
Hours per Day > 70°F
24
18
12
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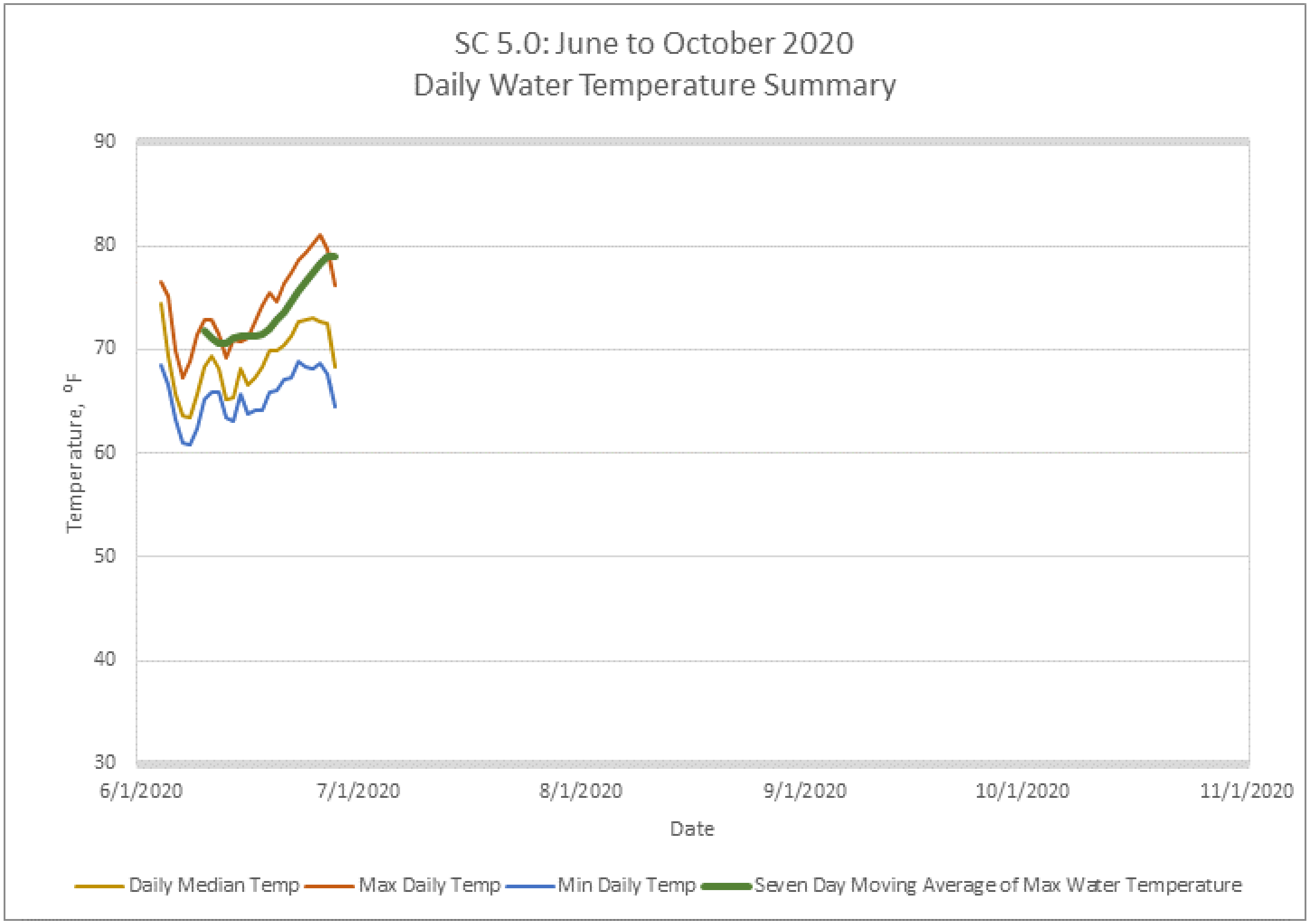
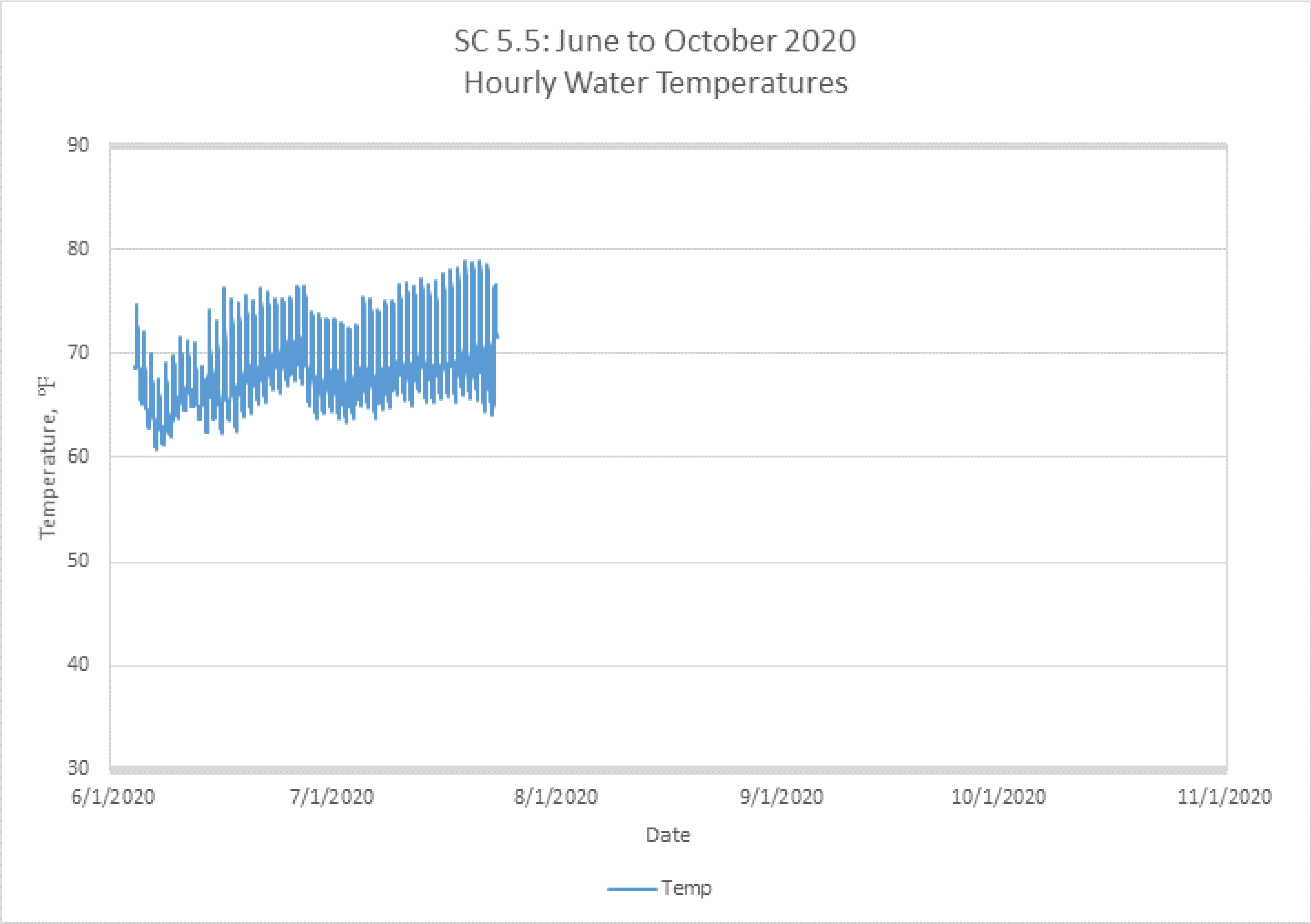
6/1/2020
7/1/2020
8/1/2020
9/1/2020
10/1/2020
11/1/2020
Date
Hours > 70 °F


SC 5.0: June to October 2020
Daily Water Temperature Summary
90
80
70
60
50
40
30
Temperature, °F
6/1/2020
7/1/2020
8/1/2020
9/1/2020
10/1/2020
11/1/2020
Date
Daily Median Temp
Max Daily Temp
Min Daily Temp
Seven Day Moving Average of Max Water Temperature


SC 5.5: June to October 2020
Hourly Water Temperatures
90
80
70
60
50
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30
Temperature, °F
6/1/2020
7/1/2020
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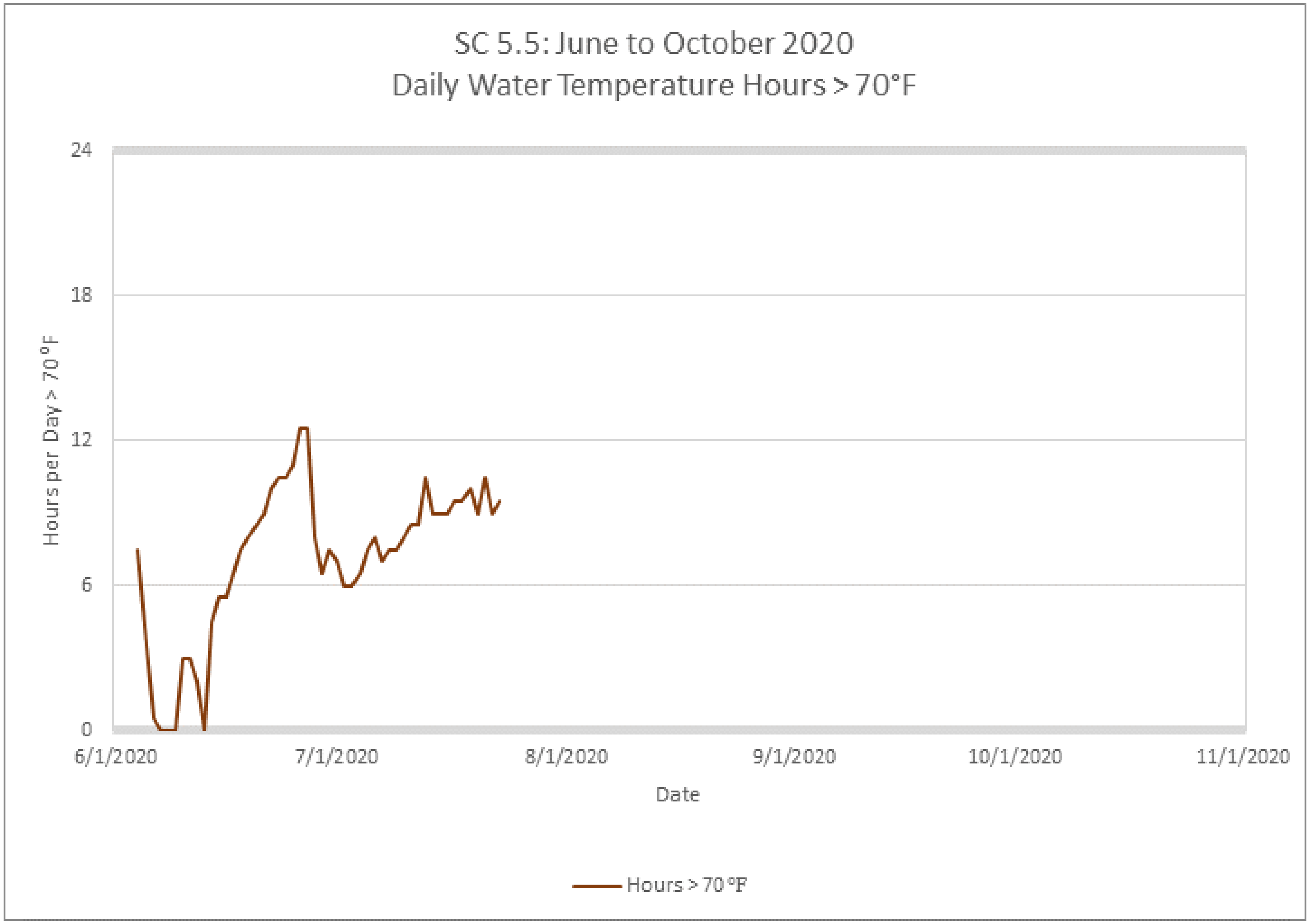
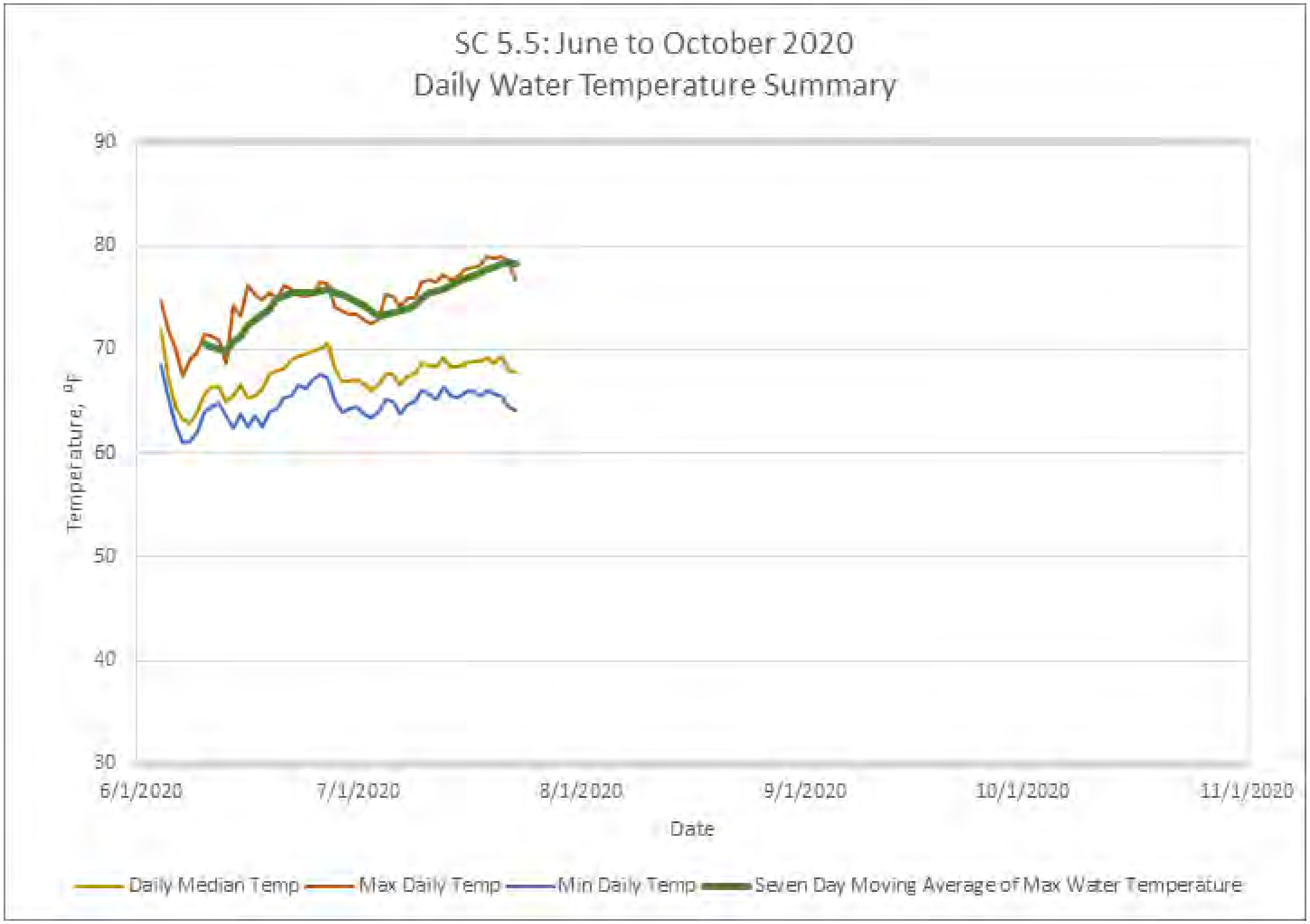
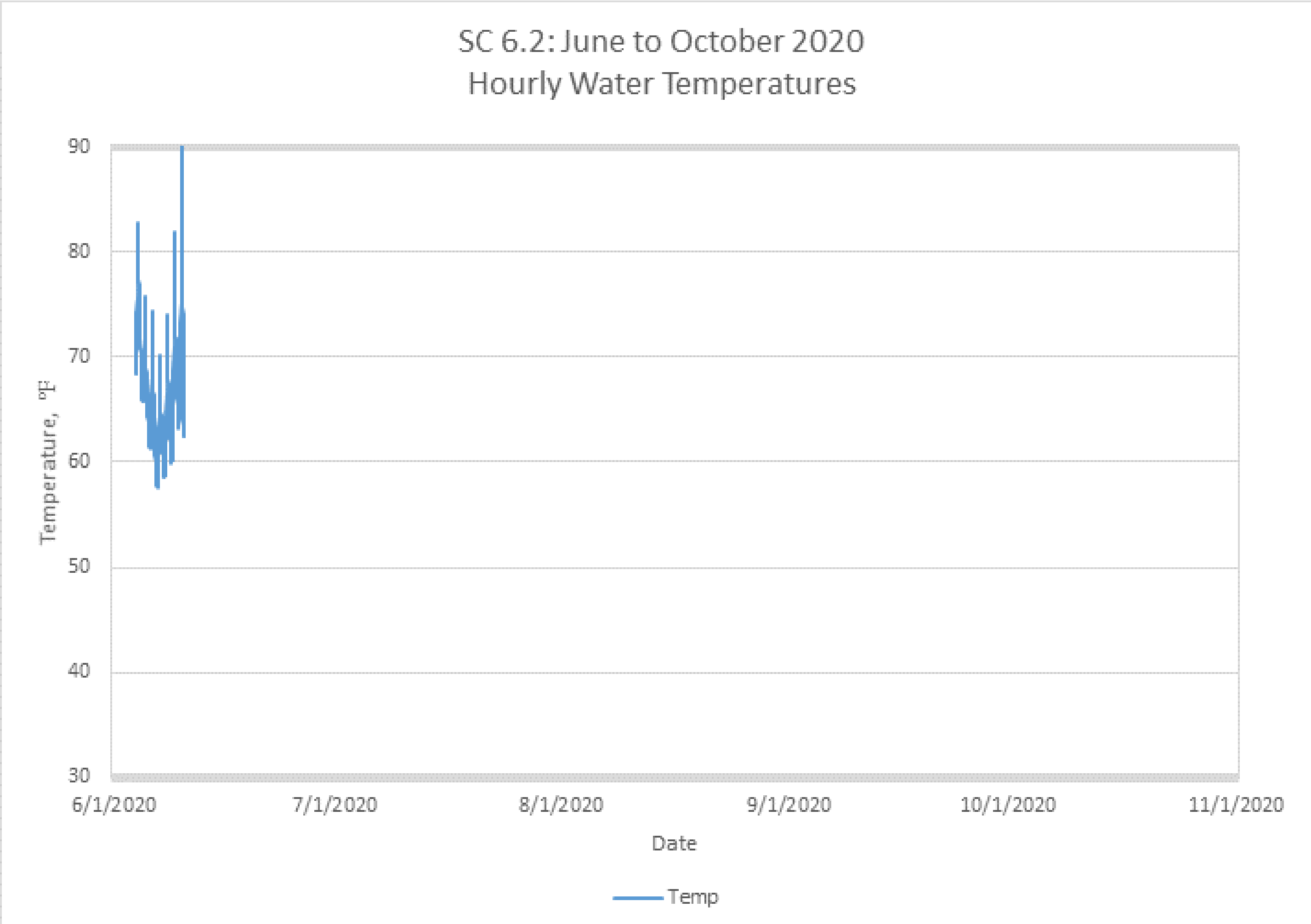
11/1/2020
Date
Temp


SC 5.5: June to October 2020
Daily Water Temperature Hours > 70°F
24
18
12
6
0
Hours per Day > 70°F
6/1/2020
7/1/2020
8/1/2020
9/1/2020
10/1/2020
11/1/2020
Date
Hours > 70 °F


SC 5.5: June to October 2020
Daily Water Temperature Summary
90
80
70
60
50
40
30
Temperature, °F
6/1/2020
7/1/2020
8/1/2020
9/1/2020
10/1/2020
11/1/2020
Date
Daily Median Temp
Max Daily Temp
Min Daily Temp
Seven Day Moving Average of Max Water Temperature


SC 6.2: June to October 2020
Hourly Water Temperatures
90
80
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60
50
40
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Temperature, °F
6/1/2020
7/1/2020
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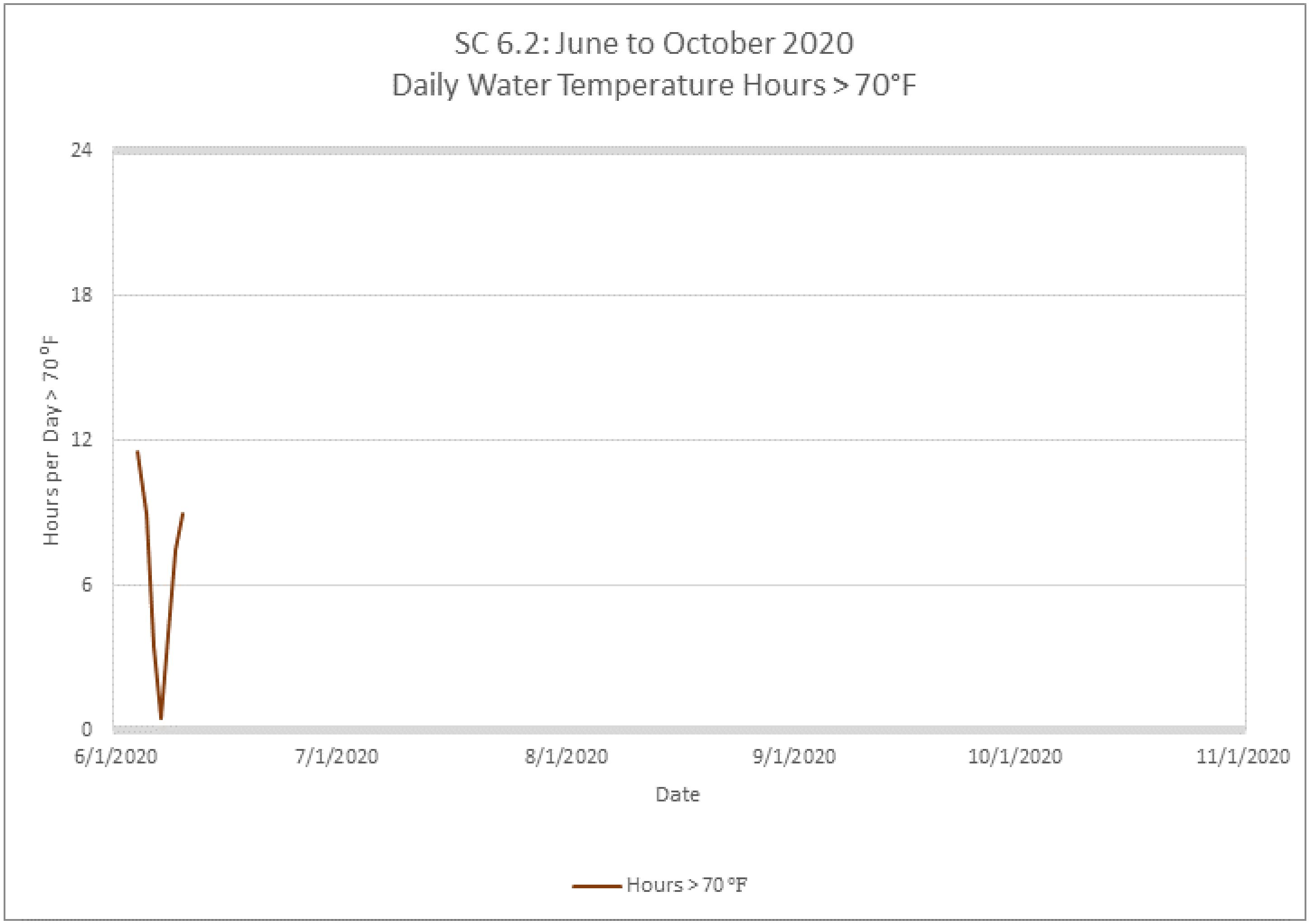
11/1/2020
Date
Temp



SC 6.2: June to October 2020
Daily Water Temperature Hours > 70°F
24
18
12
6
0
Hours per Day > 70°F
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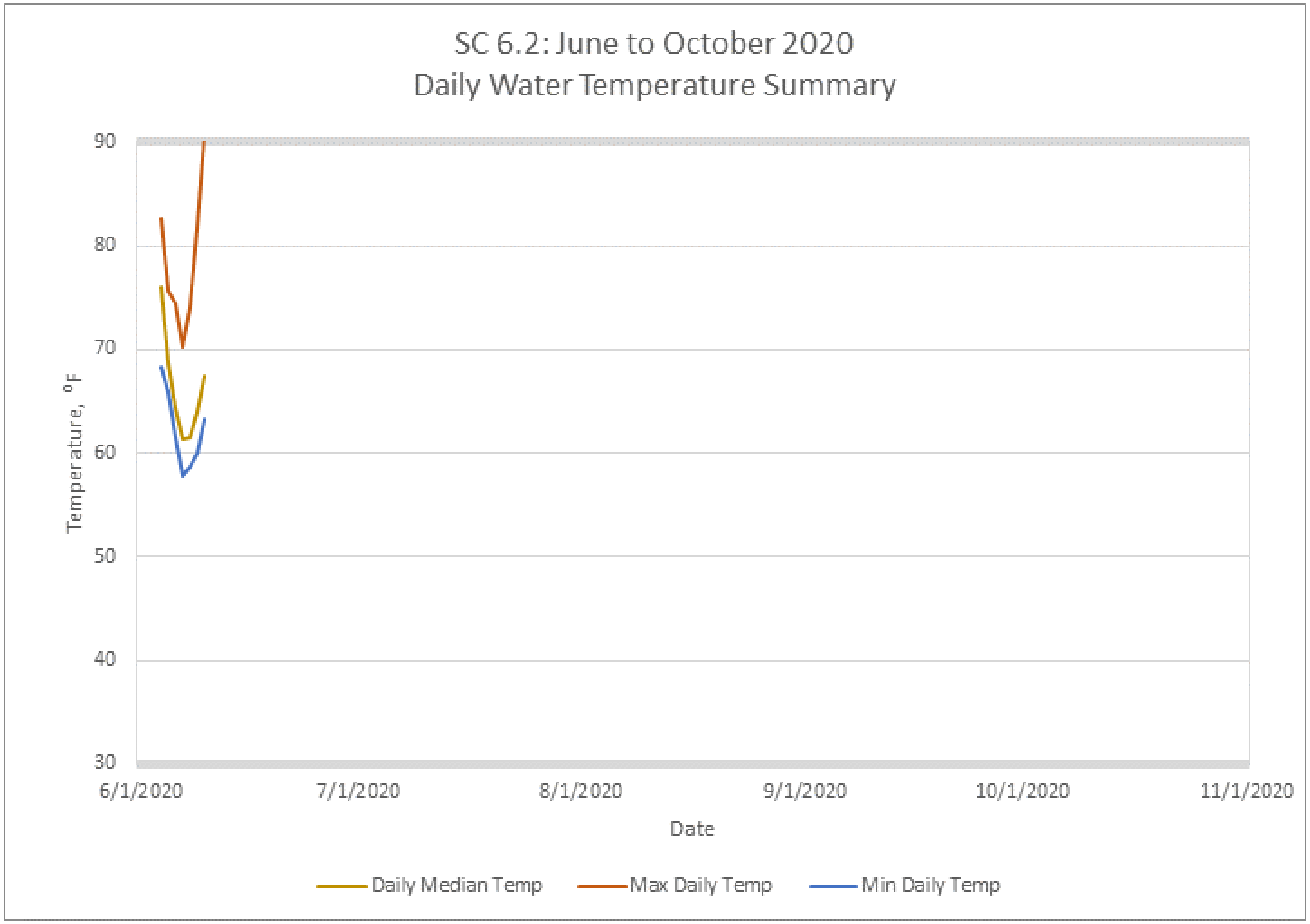
7/1/2020
8/1/2020
9/1/2020
10/1/2020
11/1/2020
Date
Hours > 70 °F



SC 6.2: June to October 2020
Daily Water Temperature Summary
90
80
70
60
50
40
30
Temperature, °F
6/1/2020
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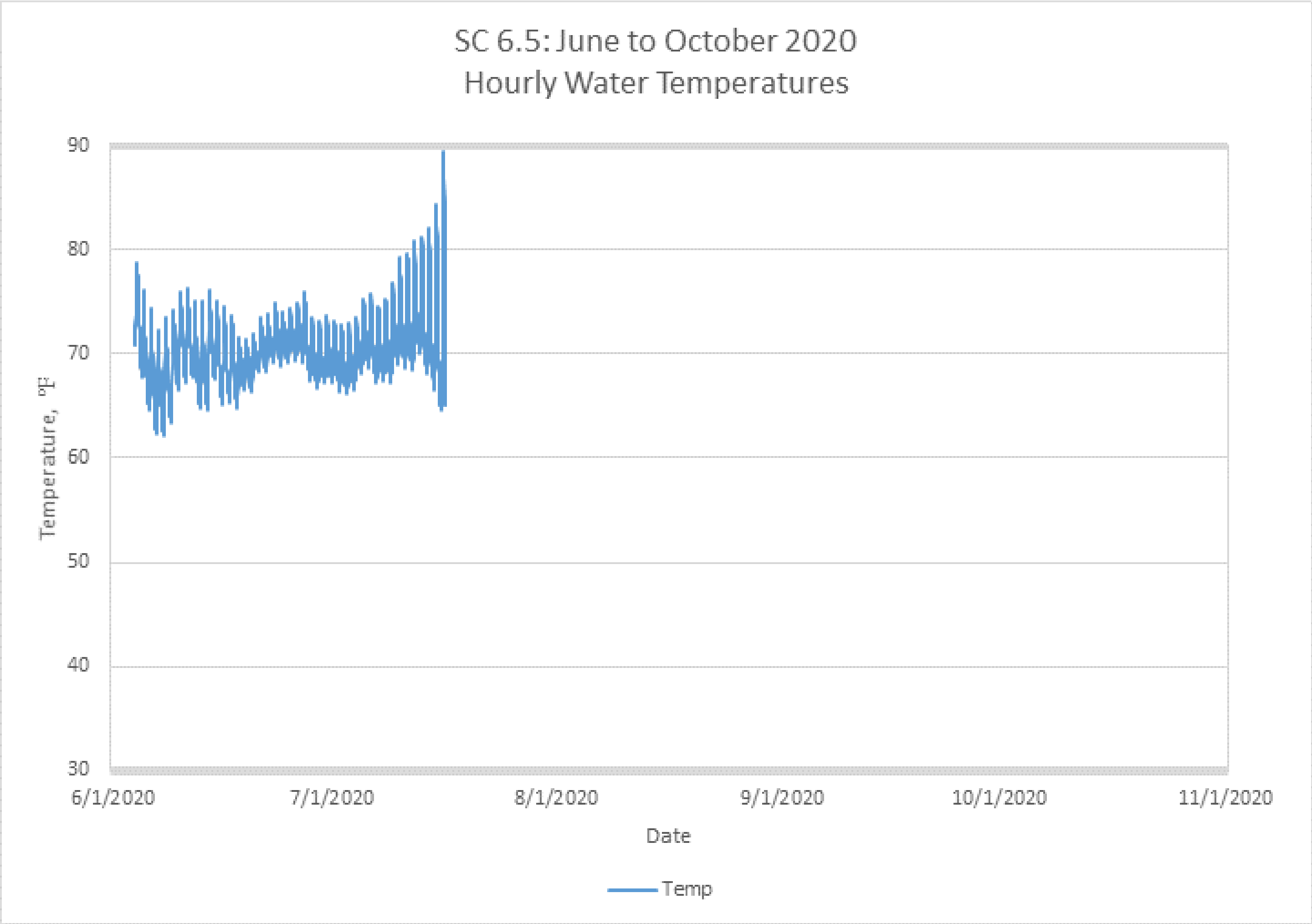
8/1/2020
9/1/2020
10/1/2020
11/1/2020
Date
Daily Median Temp
Max Daily Temp
Min Daily Temp


SC 6.5: June to October 2020
Hourly Water Temperatures
90
80
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Temperature, °F
6/1/2020
7/1/2020
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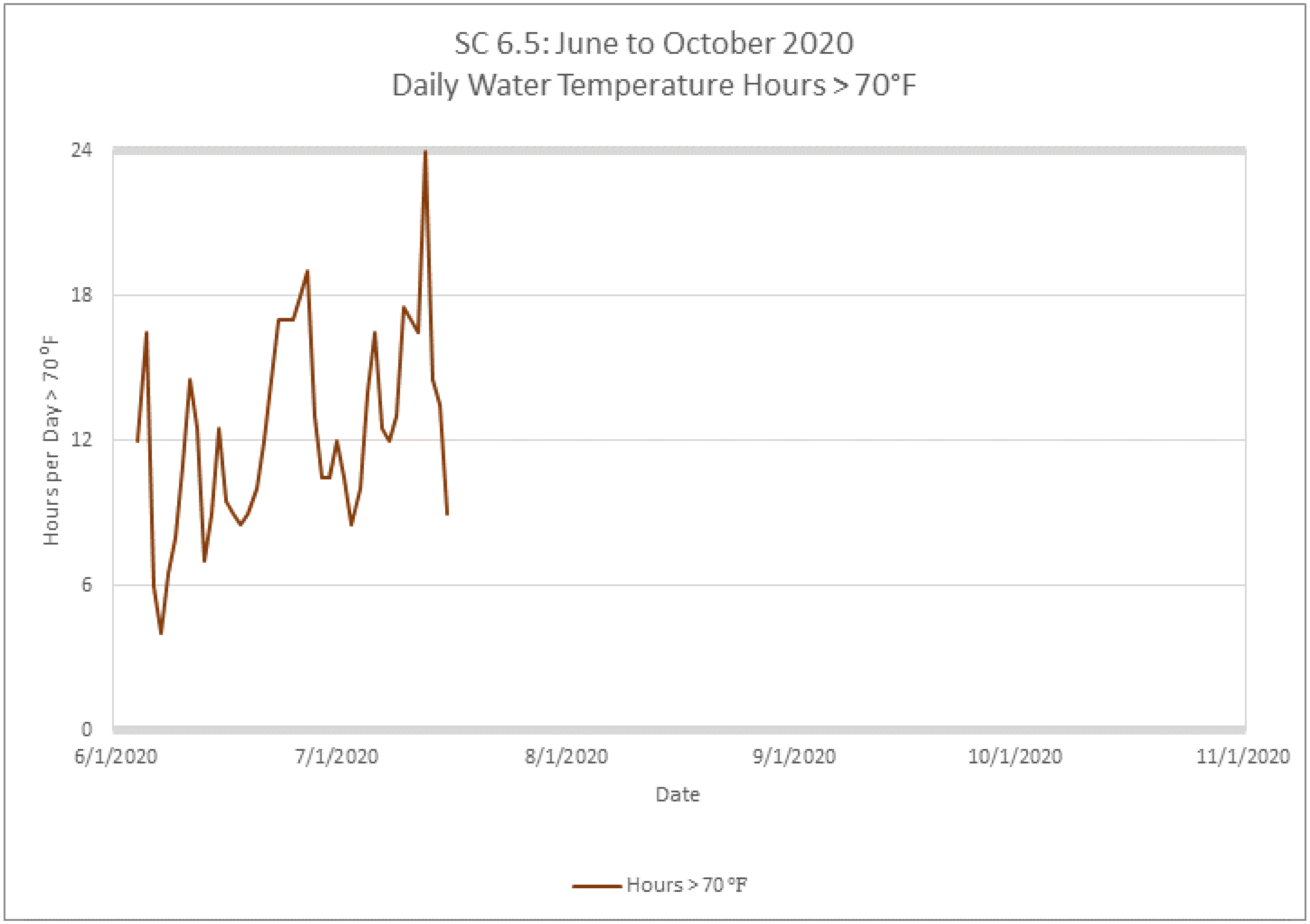
11/1/2020
Date
Temp



SC 6.5: June to October 2020
Daily Water Temperature Hours > 70°F
Hours per Day > 70°F
24
18
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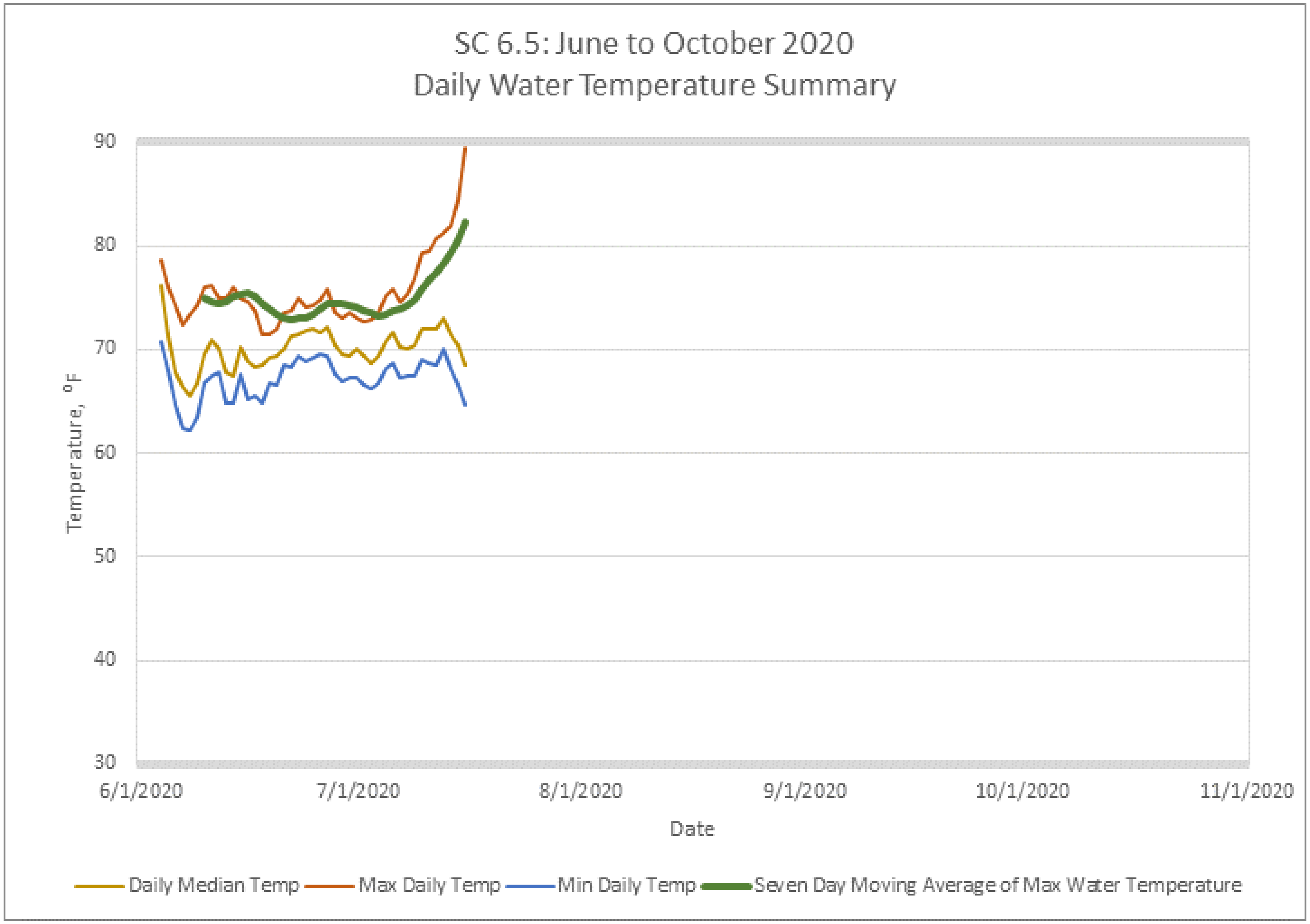
7/1/2020
8/1/2020
9/1/2020
10/1/2020
11/1/2020
Date
Hours > 70 °F



SC 6.5: June to October 2020
Daily Water Temperature Summary
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80
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60
50
40
30
Temperature, °F
6/1/2020
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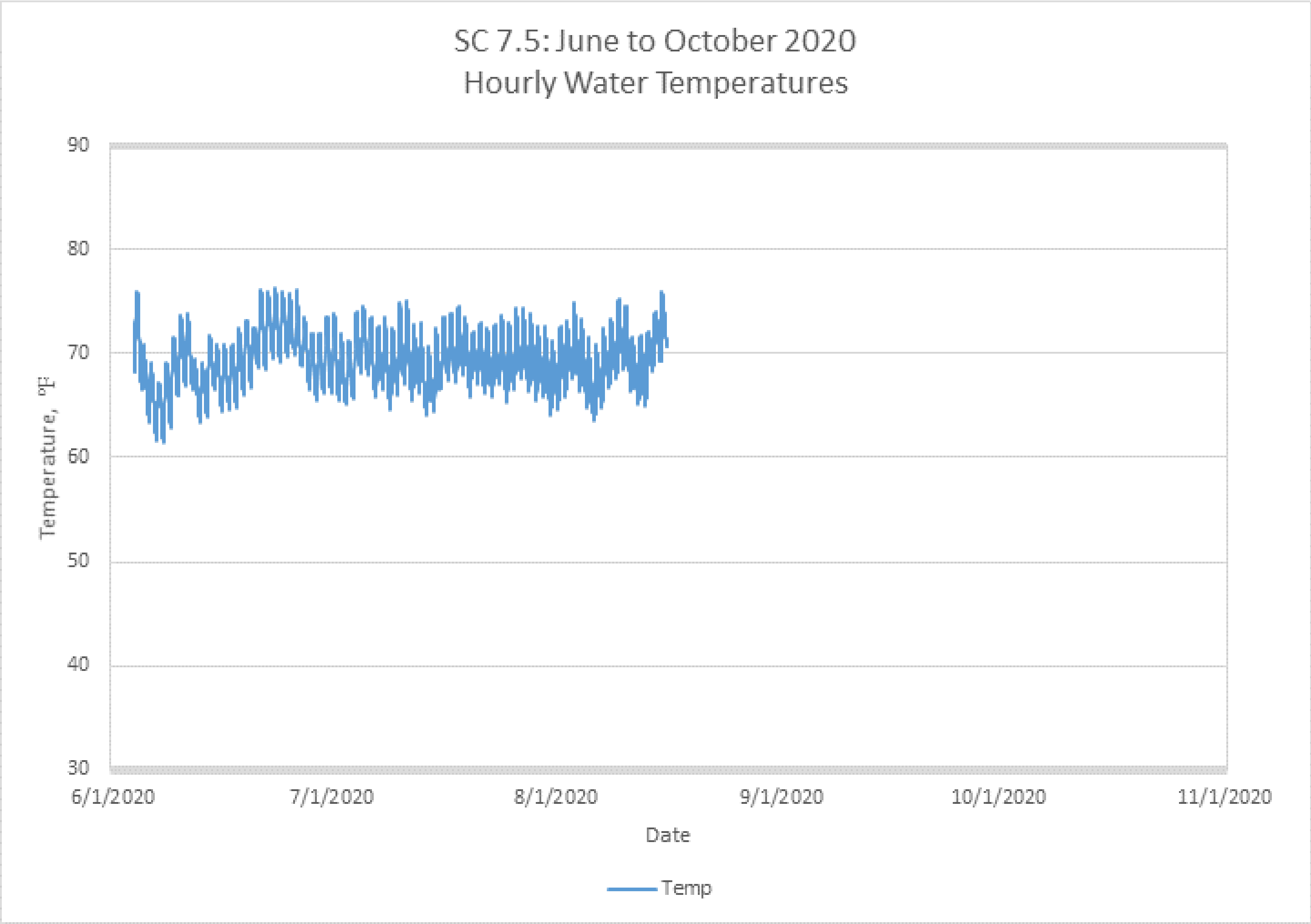
9/1/2020
10/1/2020
11/1/2020
Date
Daily Median Temp
Max Daily Temp
Min Daily Temp
Seven Day Moving Average of Max Water Temperature


SC 7.5: June to October 2020
Hourly Water Temperatures
90
80
70
60
50
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Temperature, °F
6/1/2020
7/1/2020
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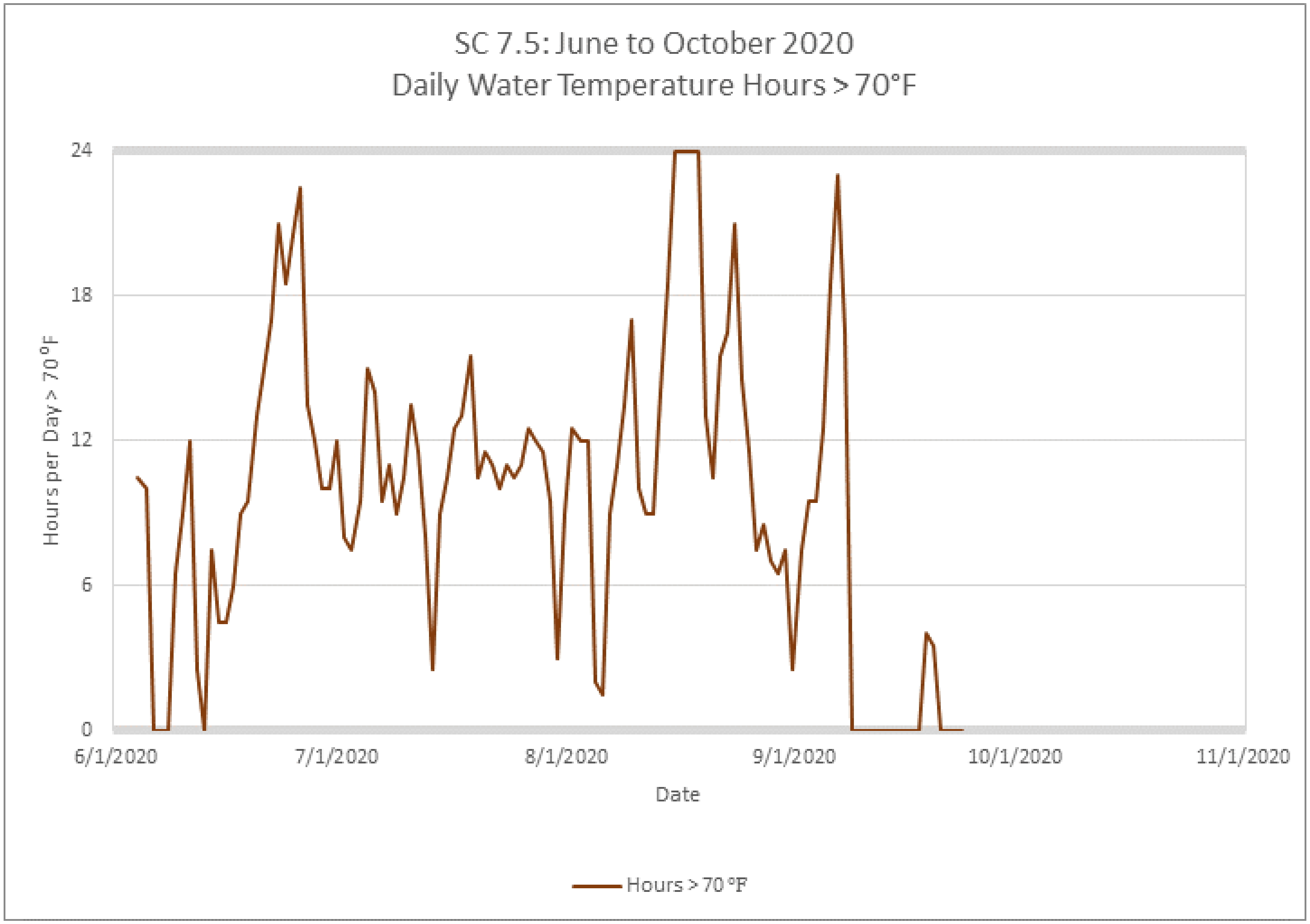
11/1/2020
Date
Temp


SC 7.5: June to October 2020
Daily Water Temperature Hours > 70°F
Hours per Day > 70°F
24
18
12
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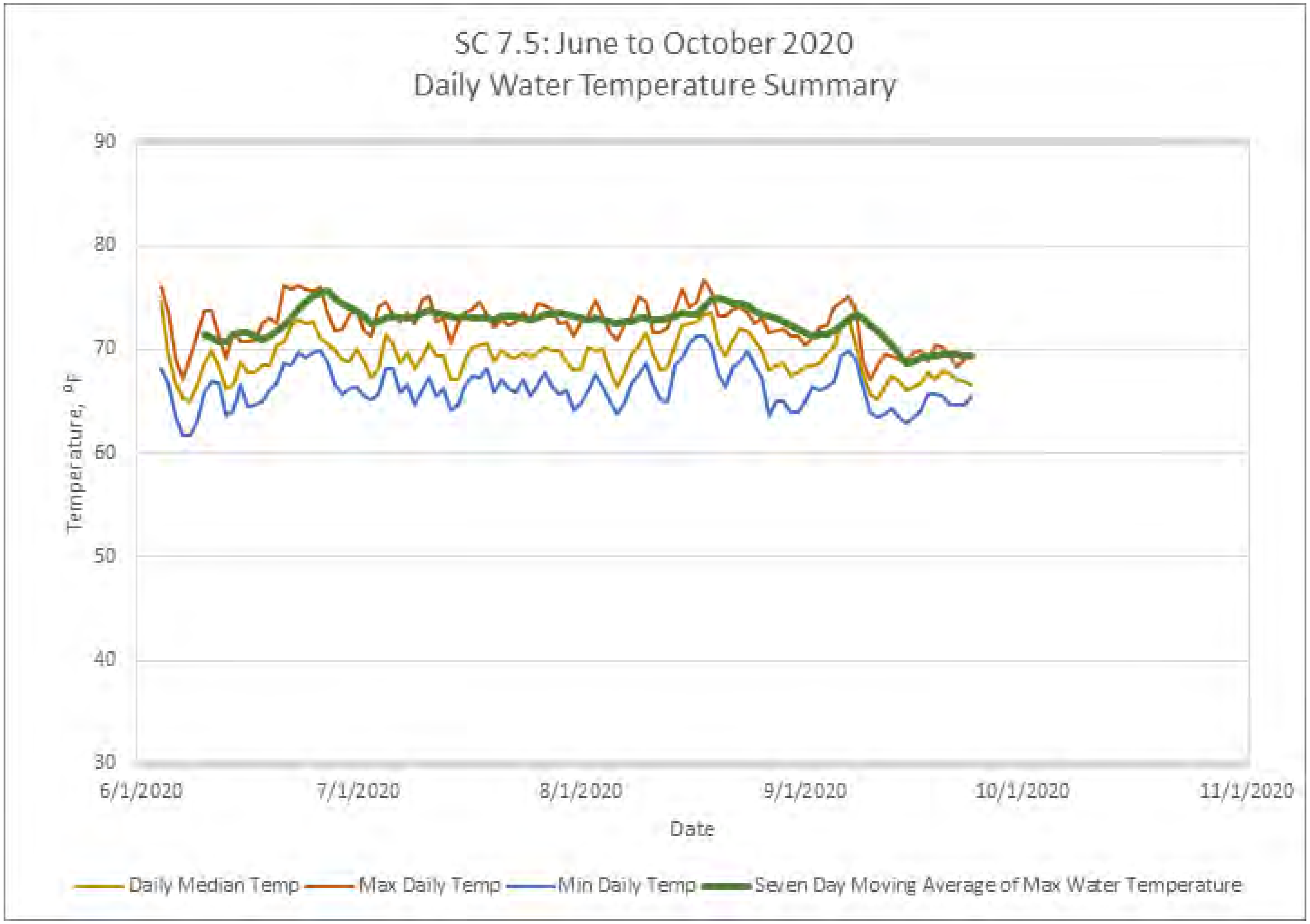
6/1/2020
7/1/2020
8/1/2020
9/1/2020
10/1/2020
11/1/2020
Date
Hours > 70 °F



SC 7.5: June to October 2020
Daily Water Temperature Summary
90
80
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30
Temperature, °F
6/1/2020
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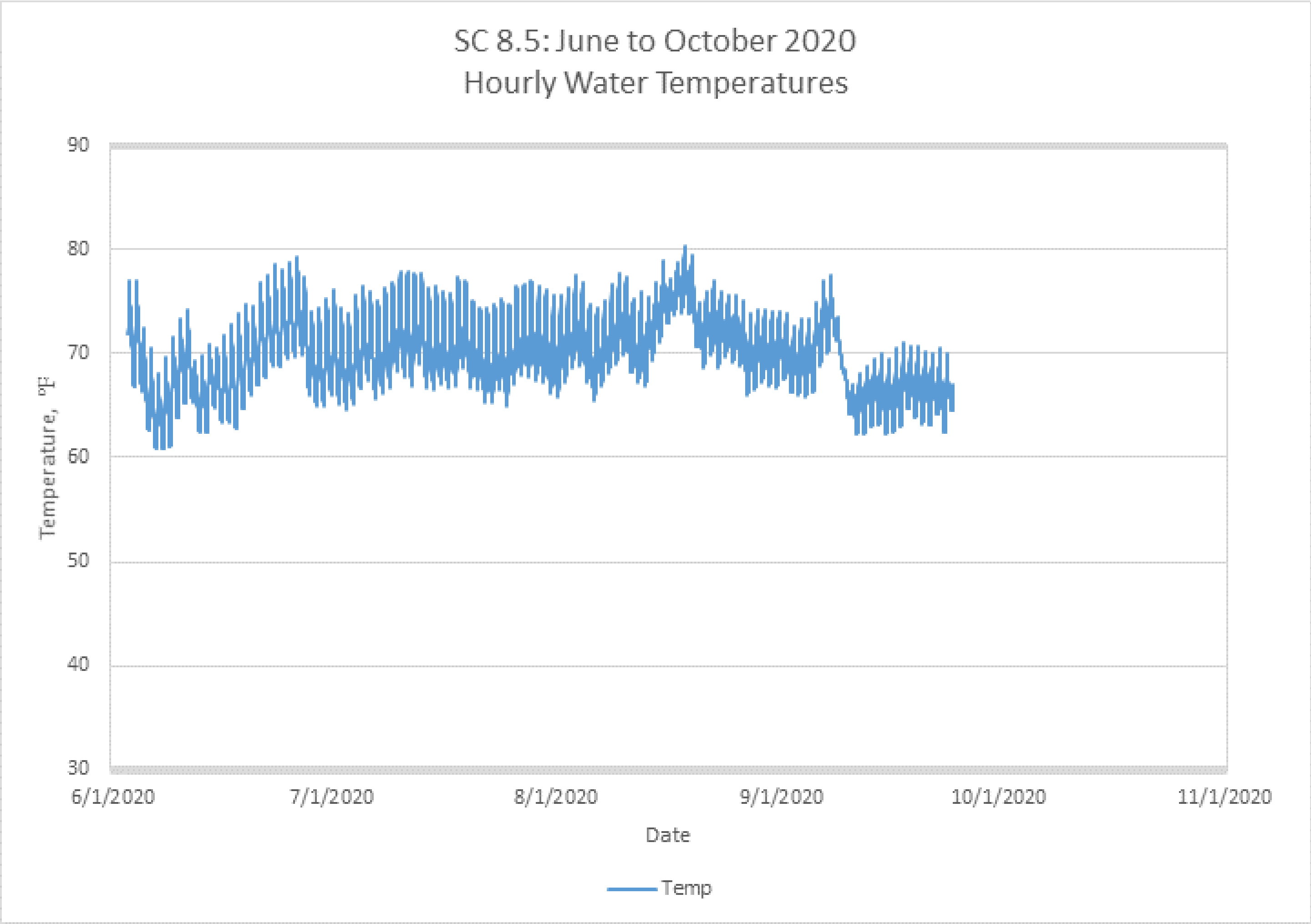
9/1/2020
10/1/2020
11/1/2020
Date
Daily Median Temp
Max Daily Temp
Min Daily Temp
Seven Day Moving Average of Max Water Temperature



SC 8.5: June to October 2020
Hourly Water Temperatures
90
80
70
60
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Temperature, °F
6/1/2020
7/1/2020
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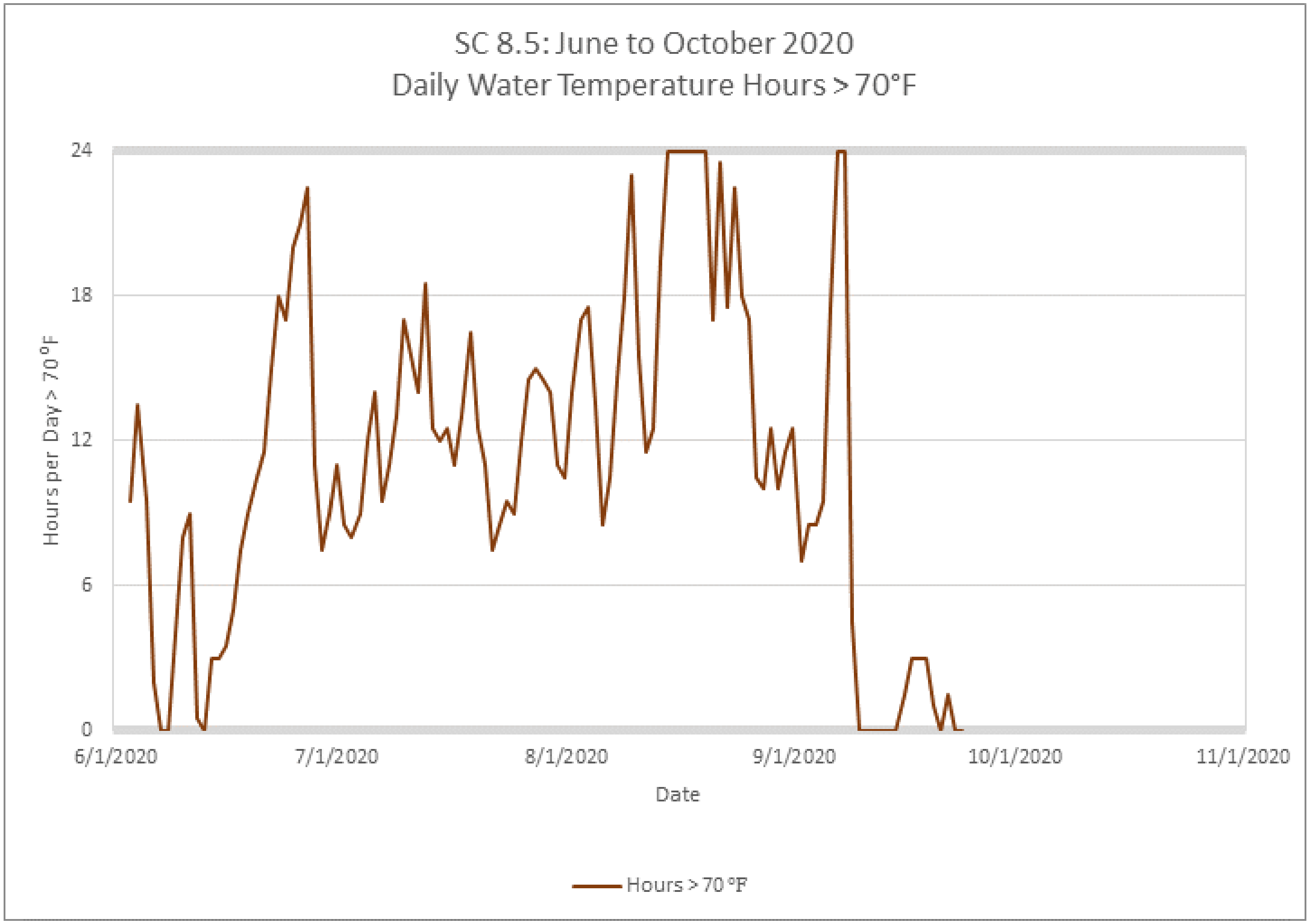
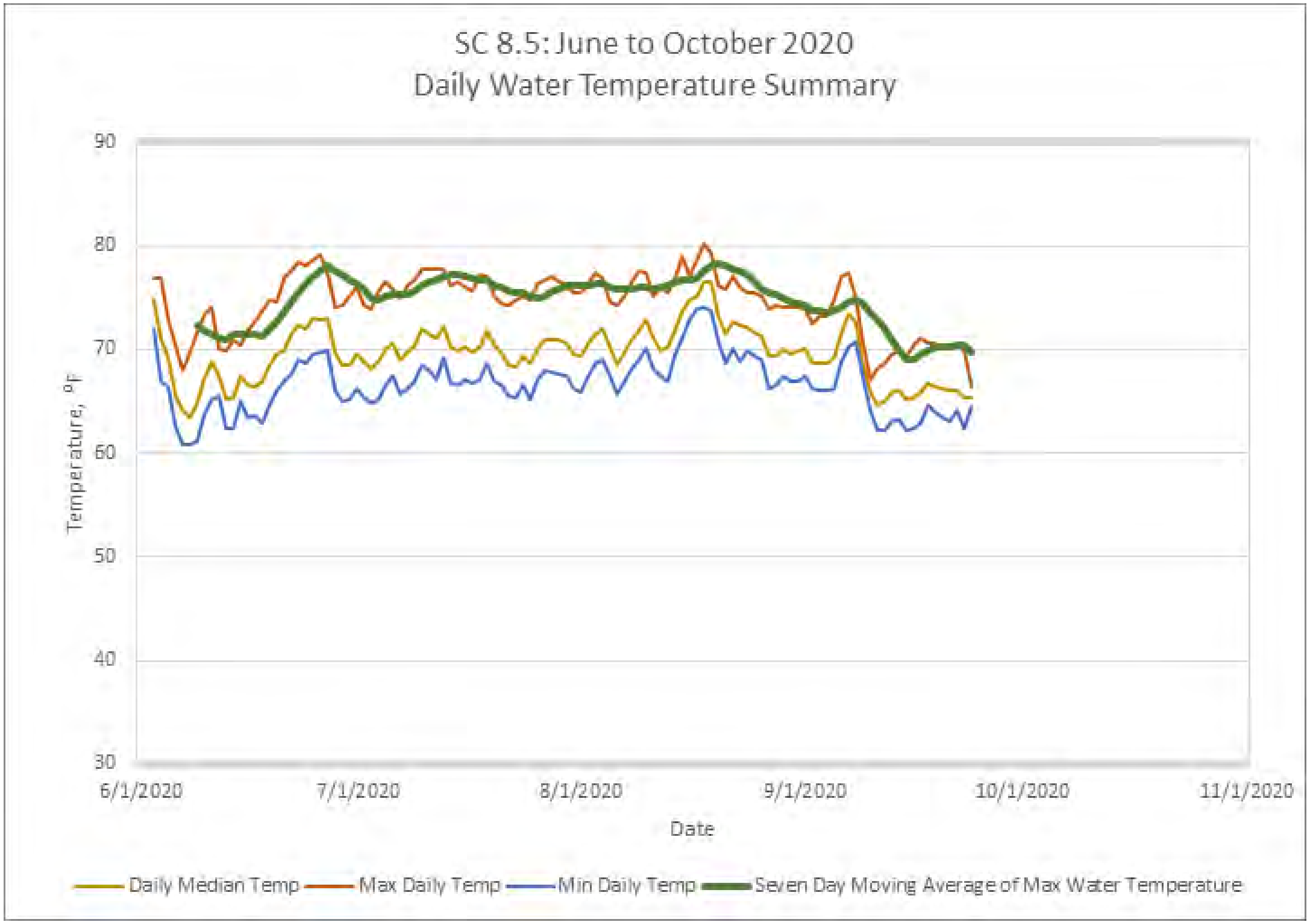
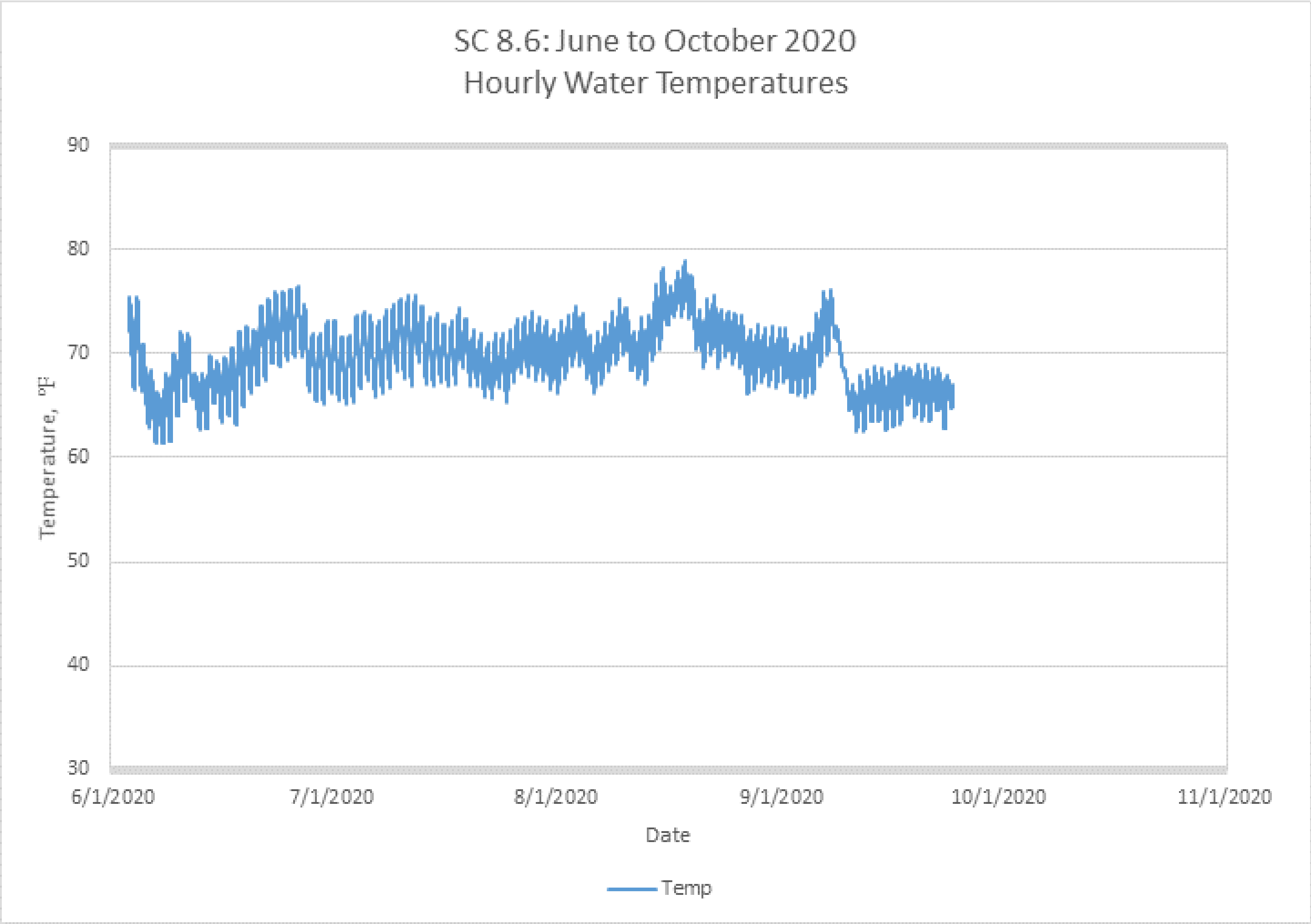
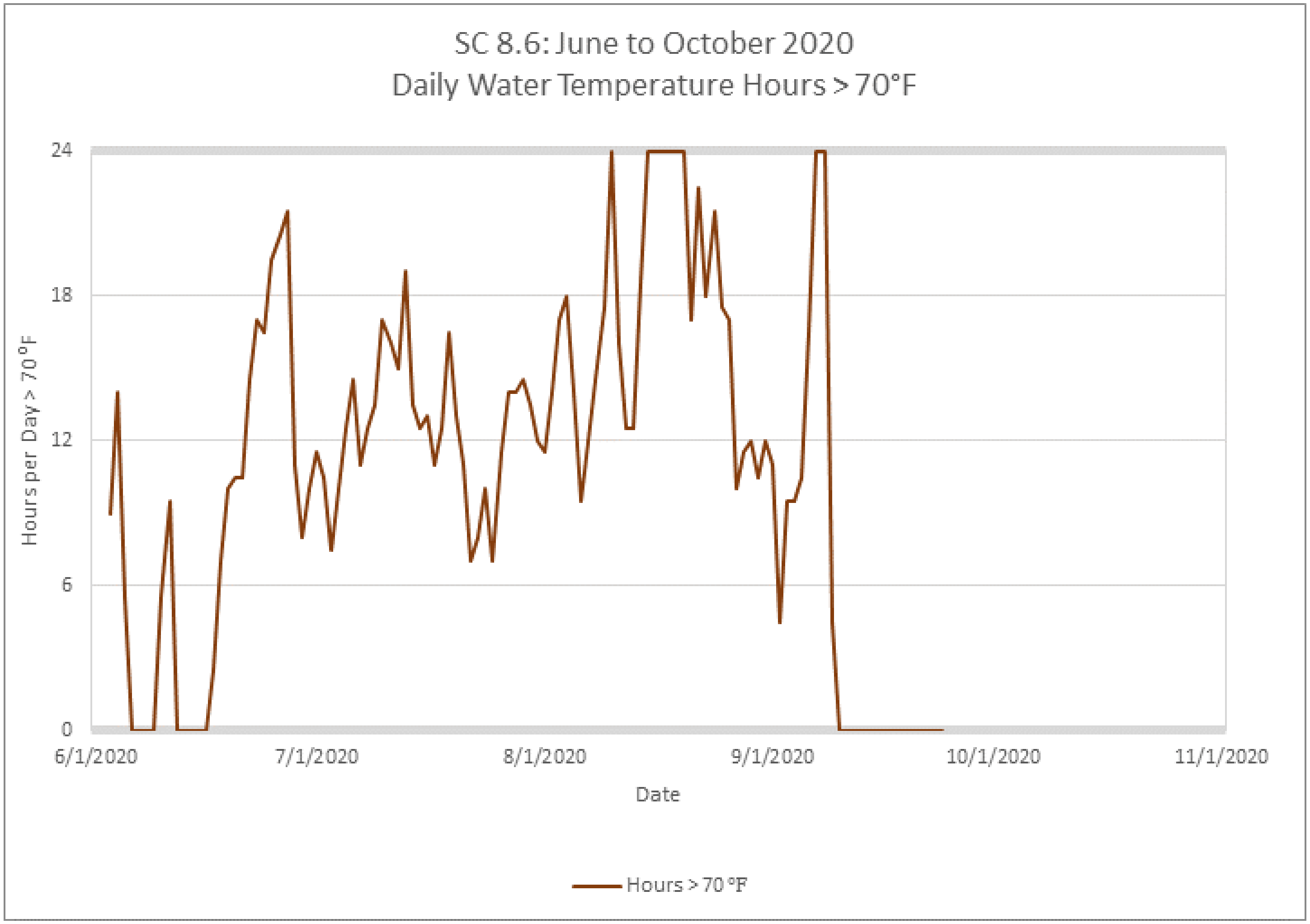
11/1/2020
Date
Temp

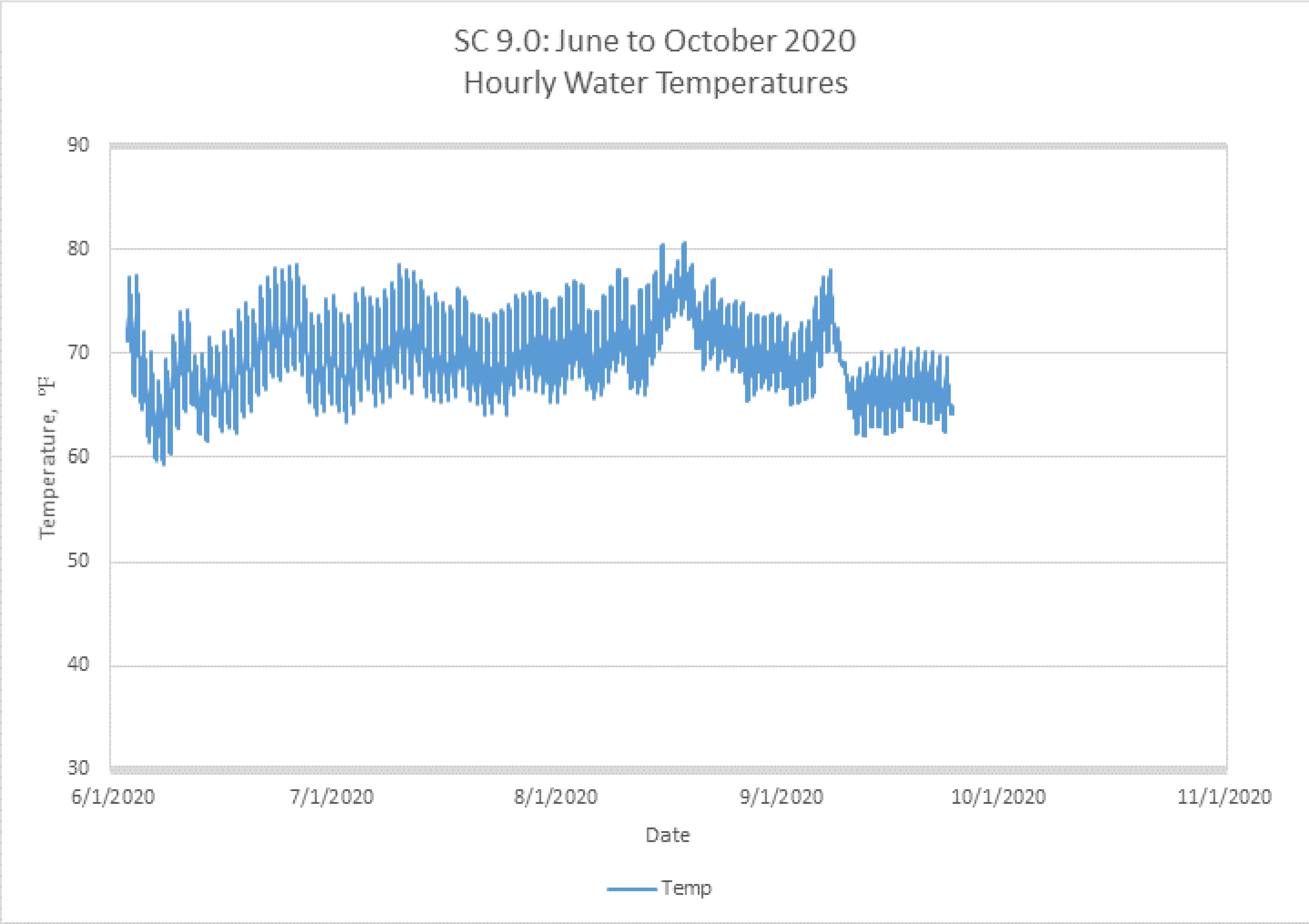

SC 8.5: June to October 2020
Daily Water Temperature Hours > 70°F
24
18
12
6
0
Hours per Day > 70°F
6/1/2020
7/1/2020
8/1/2020
9/1/2020
10/1/2020
11/1/2020
Date
Hours > 70 °F

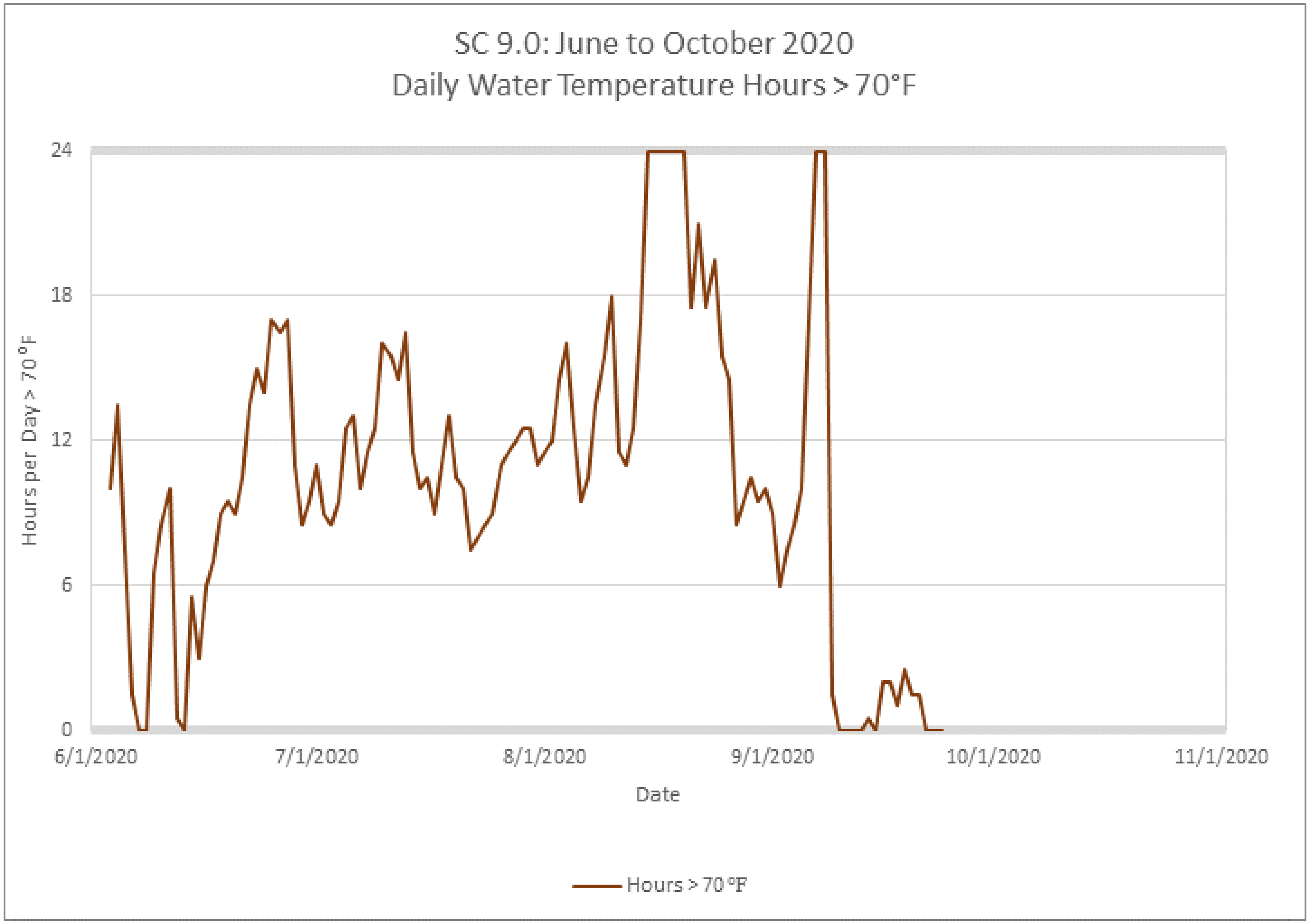

SC 8.5: June to October 2020
Daily Water Temperature Summary
90
80
70
60
50
40
30
Temperature, °F
6/1/2020
7/1/2020
8/1/2020
9/1/2020
10/1/2020
11/1/2020
Date
Daily Median Temp
Max Daily Temp
Min Daily Temp
Seven Day Moving Average of Max Water Temperature


SC 8.6: June to October 2020
Hourly Water Temperatures
90
80
70
60
50
40
30
Temperature, °F
6/1/2020
7/1/2020
8/1/2020
9/1/2020
10/1/2020
11/1/2020
Date
Temp


SC 8.6: June to October 2020
Daily Water Temperature Hours > 70°F
24
18
12
6
0
Hours per Day > 70°F
6/1/2020
7/1/2020
8/1/2020
9/1/2020
10/1/2020
11/1/2020
Date
Hours > 70 °F

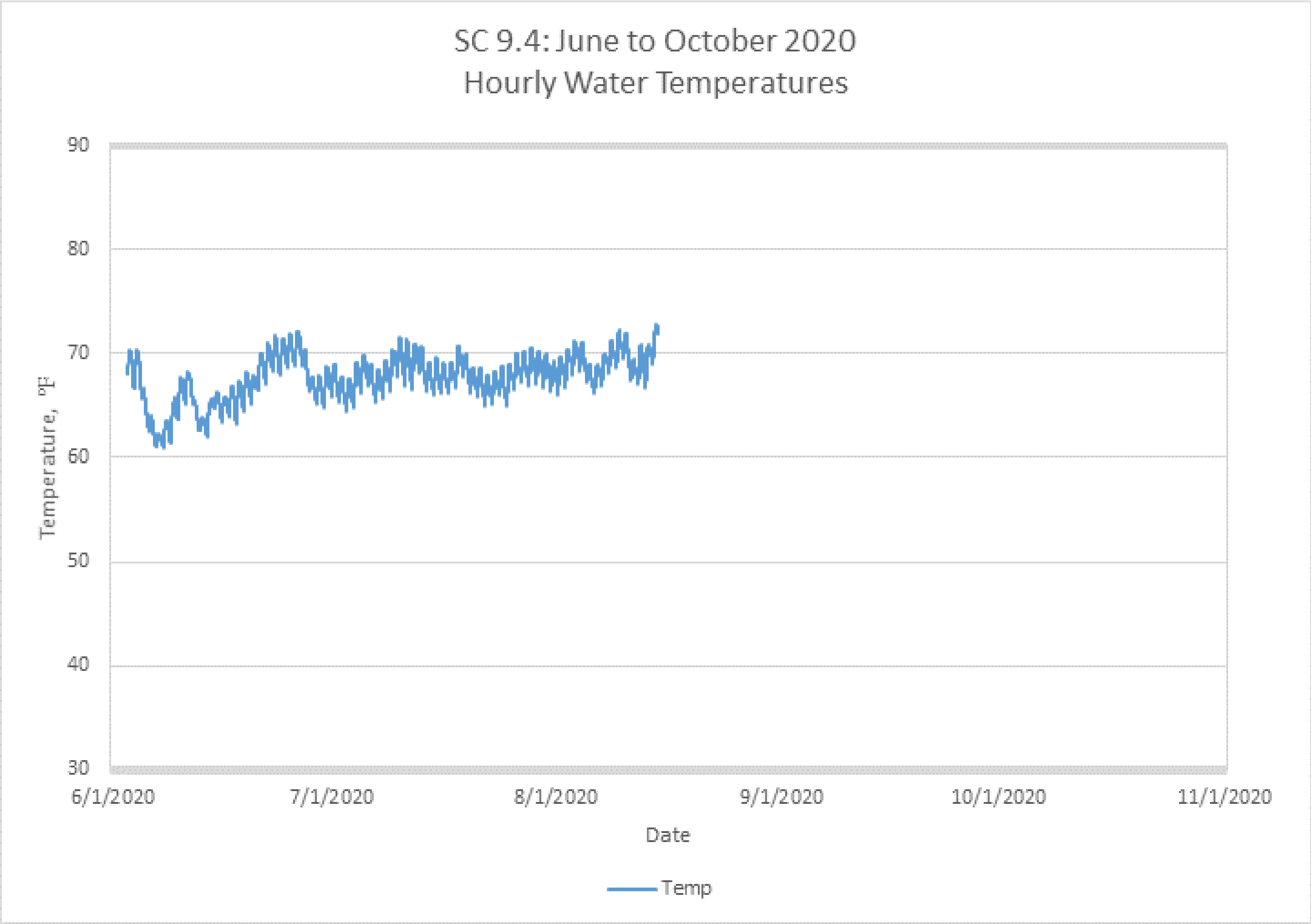
SC 8.6: June to October 2020
Daily Water Temperature Summary
90
80
70
60
50
40
30
Temperature, °F
6/1/2020
7/1/2020
8/1/2020
9/1/2020
10/1/2020
11/1/2020
Date
Daily Median Temp
Max Daily Temp
Min Daily Temp
Seven Day Moving Average of Max Water Temperature


SC 9.0: June to October 2020
Hourly Water Temperatures
Temperature, °F
90
80
70
60
50
40
30
6/1/2020
7/1/2020
8/1/2020
9/1/2020
10/1/2020
11/1/2020
Date
Temp

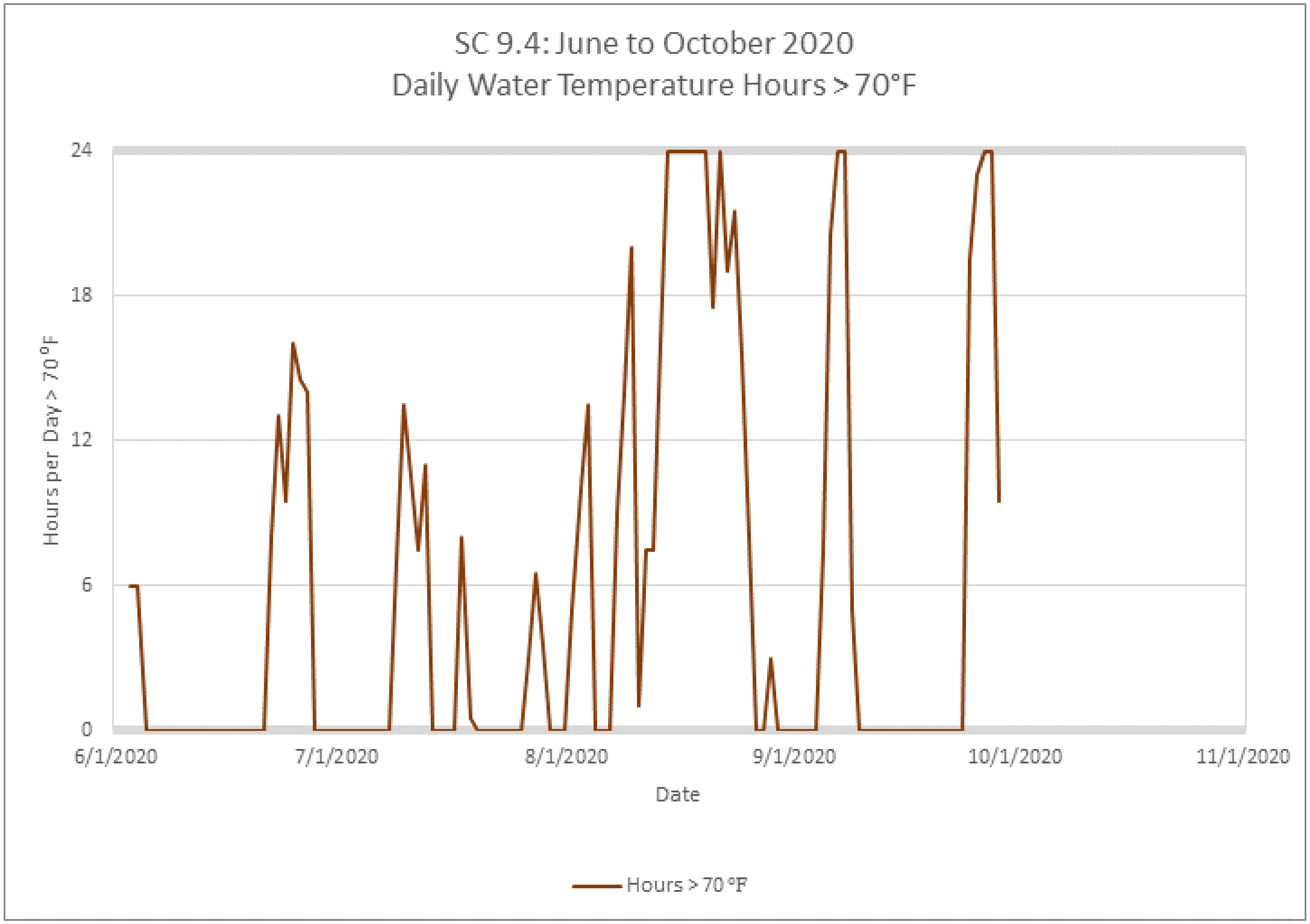


SC 9.0: June to October 2020
Daily Water Temperature Hours > 70°F
24
18
12
6
0
Hours per Day > 70°F
6/1/2020
7/1/2020
8/1/2020
9/1/2020
10/1/2020
11/1/2020
Date
Hours > 70 °F

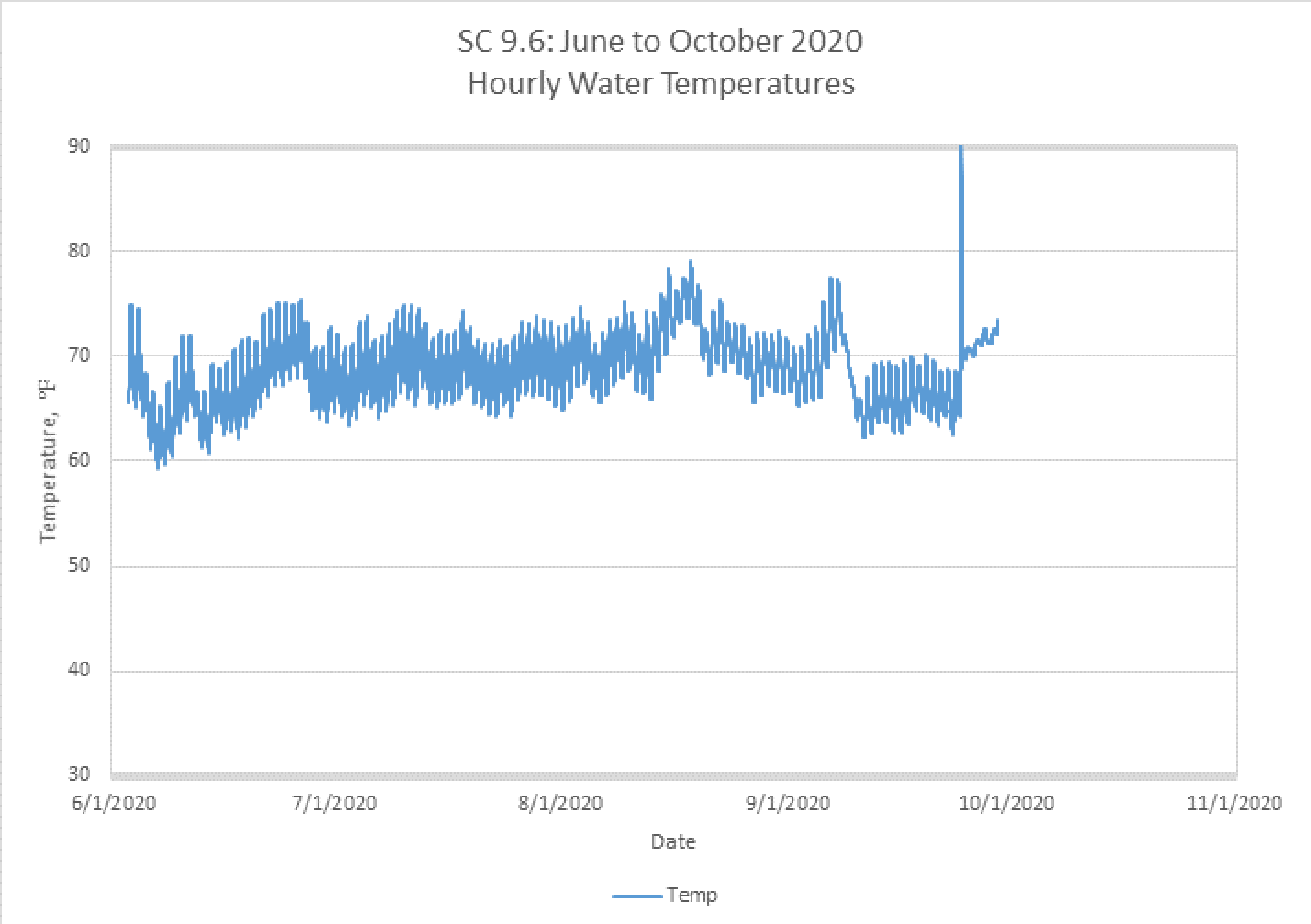

SC 9.0: June to October 2020
Daily Water Temperature Summary
90
80
70
60
50
40
30
Temperature, °F
6/1/2020
7/1/2020
8/1/2020
9/1/2020
10/1/2020
11/1/2020
Date
Daily Median Temp
Max Daily Temp
Min Daily Temp
Seven Day Moving Average of Max Water Temperature

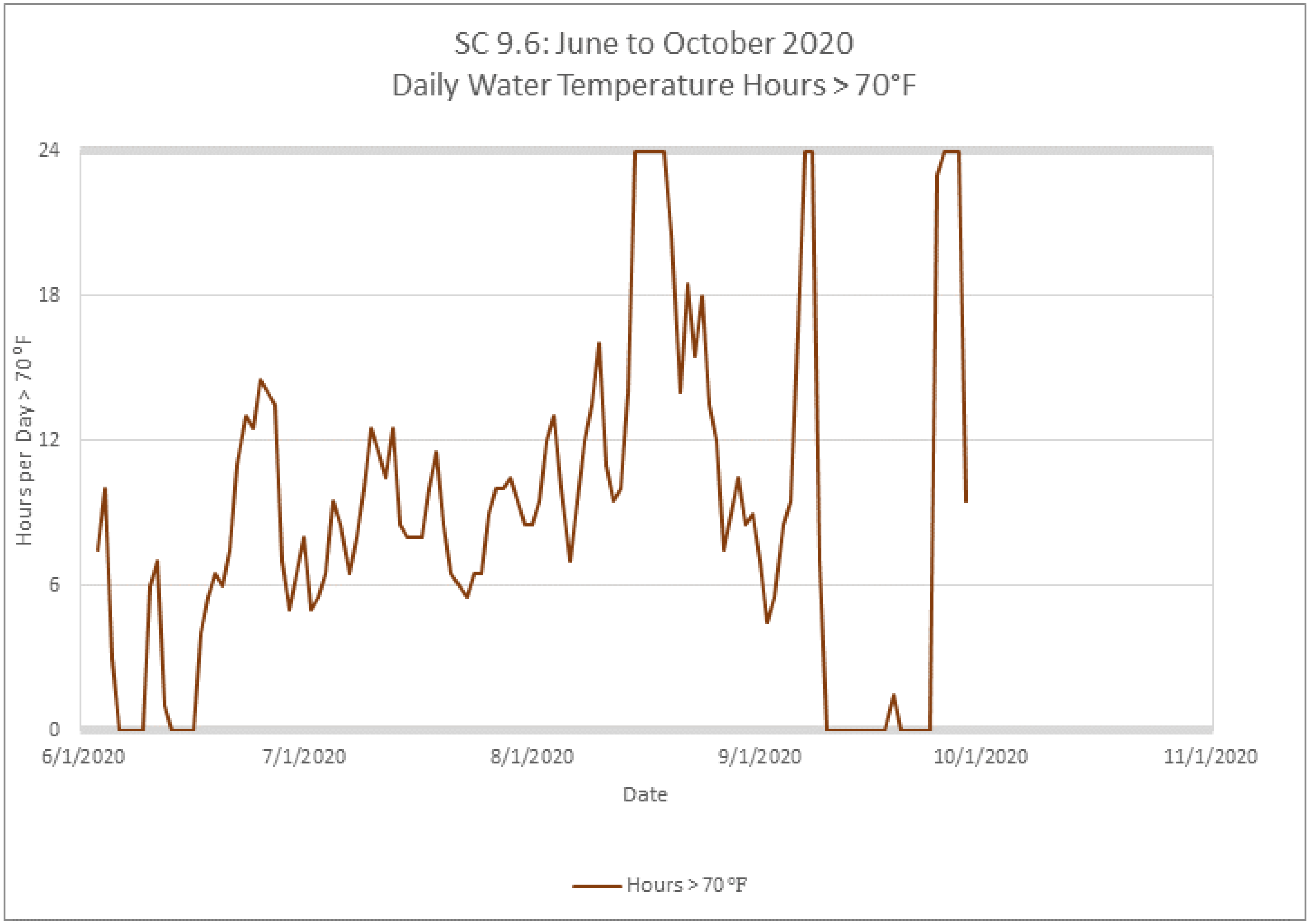


SC 9.4: June to October 2020
Hourly Water Temperatures
90
80
70
60
50
40
30
Temperature, °F
6/1/2020
7/1/2020
8/1/2020
9/1/2020
10/1/2020
11/1/2020
Date
Temp


SC 9.4: June to October 2020
Daily Water Temperature Hours > 70°F
24
18
12
6
0
Hours per Day > 70°F
6/1/2020
7/1/2020
8/1/2020
9/1/2020
10/1/2020
11/1/2020
Date
Hours > 70 °F

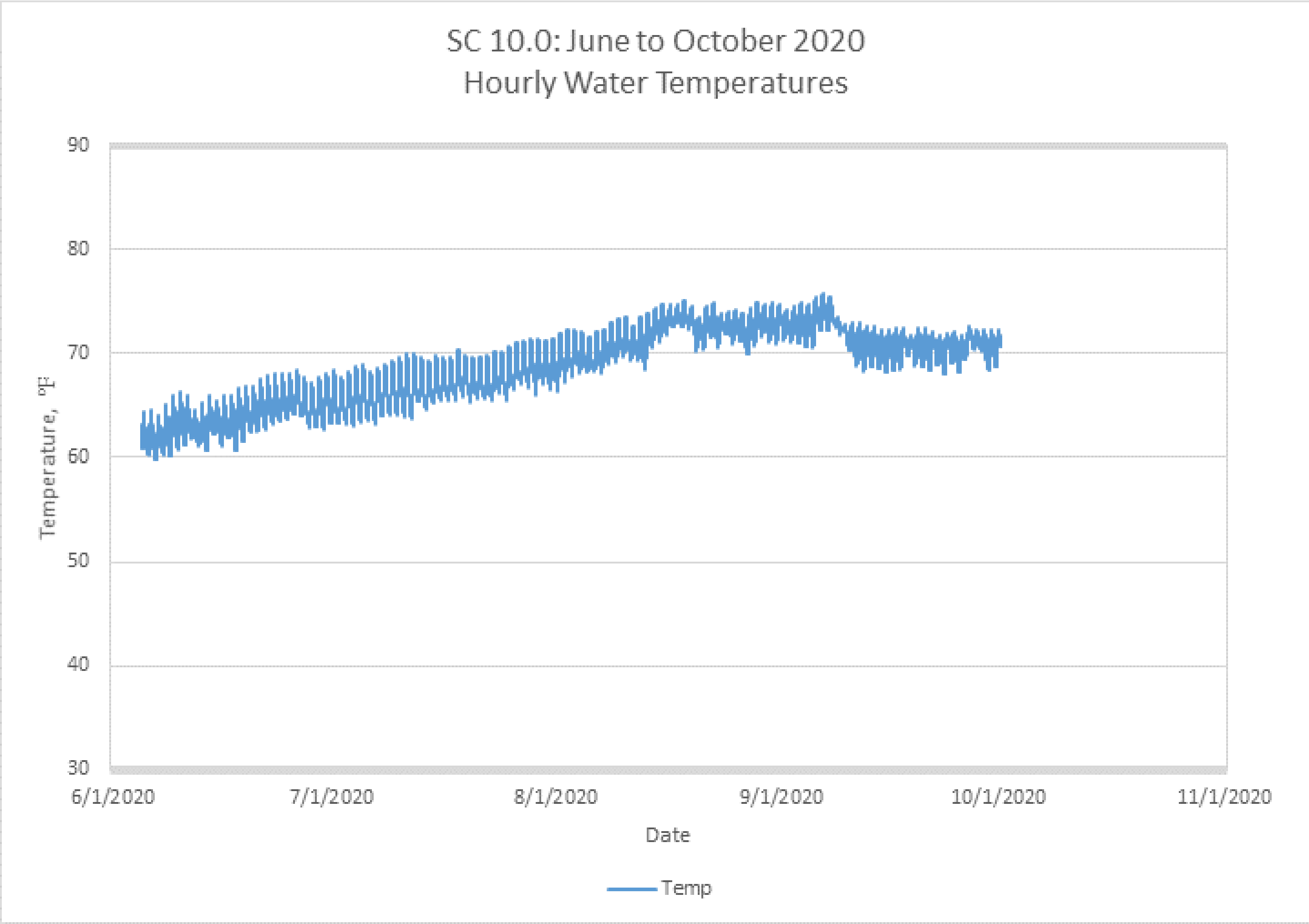
SC 9.4: June to October 2020
Daily Water Temperature Summary
90
80
70
60
50
40
30
Temperature, ºF
6/1/2020
7/1/2020
8/1/2020
9/1/2020
10/1/2020
11/1/2020
Date
Daily Median Temp
Max Daily Temp
Min Daily Temp
Seven Day Moving Average of Max Water Temperature


SC 9.6: June to October 2020
Hourly Water Temperatures
90
80
70
60
50
40
30
Temperature, °F
6/1/2020
7/1/2020
8/1/2020
9/1/2020
10/1/2020
11/1/2020
Date
Temp

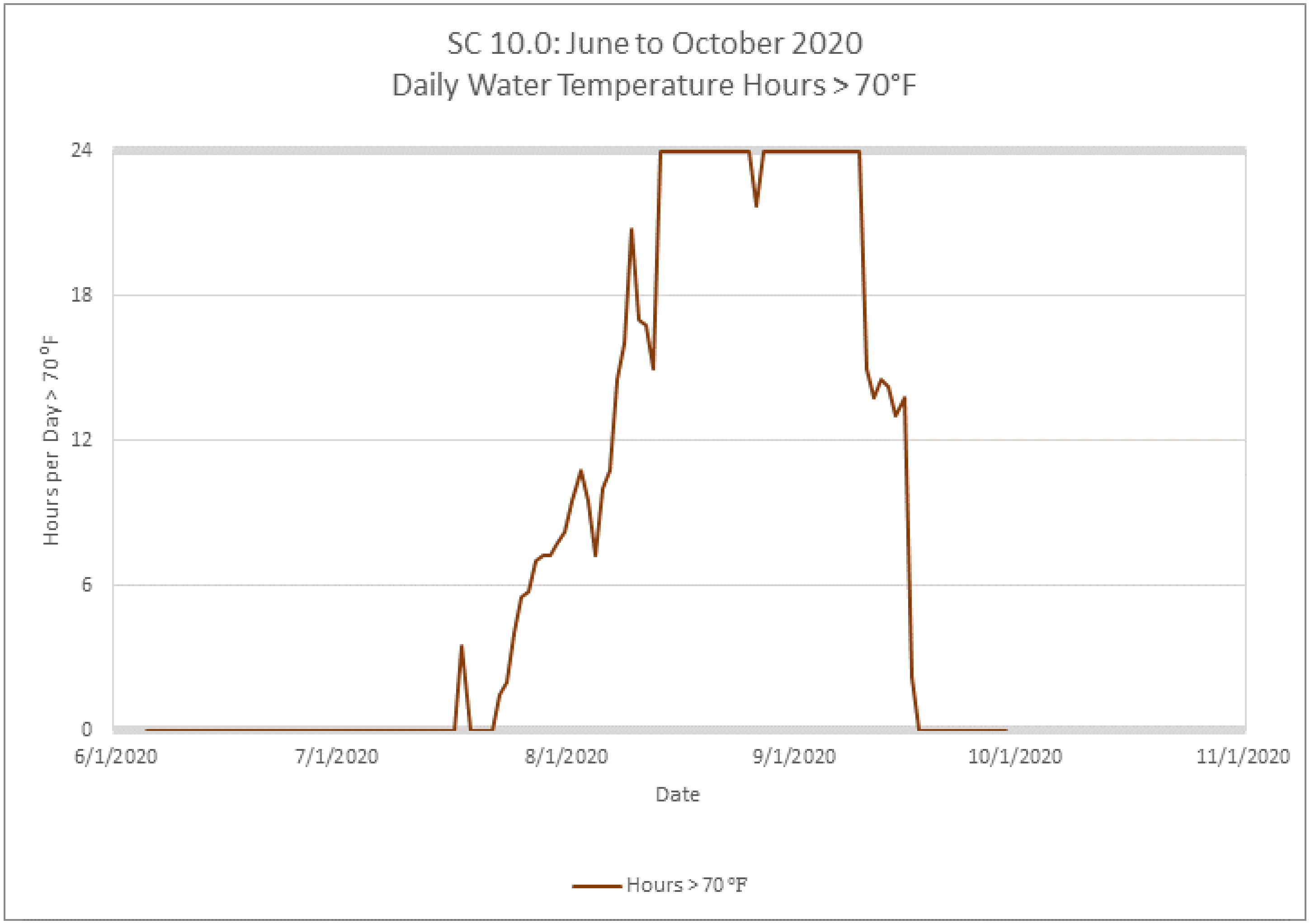


SC 9.6: June to October 2020
Daily Water Temperature Hours > 70°F
24
18
12
6
0
Hours per Day > 70°F
6/1/2020
7/1/2020
8/1/2020
9/1/2020
10/1/2020
11/1/2020
Date
Hours > 70 °F

SC 9.6: June to October 2020
Daily Water Temperature Summary
90
80
70
60
50
40
30
Temperature, ºF
6/1/2020
7/1/2020
8/1/2020
9/1/2020
10/1/2020
11/1/2020
Date
Daily Median Temp
Max Daily Temp
Min Daily Temp
Seven Day Moving Average of Max Water Temperature



SC 10.0: June to October 2020
Hourly Water Temperatures
90
80
70
60
50
40
30
Temperature, °F
6/1/2020
7/1/2020
8/1/2020
9/1/2020
10/1/2020
11/1/2020
Date
Temp


SC 10.0: June to October 2020
Daily Water Temperature Hours > 70°F
Hours per Day > 70°F
24
18
12
6
0
6/1/2020
7/1/2020
8/1/2020
9/1/2020
10/1/2020
11/1/2020
Date
Hours > 70 °F


SC 10.0: June to October 2020
Daily Water Temperature Summary
90
80
70
60
50
40
30
Temperature, °F
6/1/2020
7/1/2020
8/1/2020
9/1/2020
10/1/2020
11/1/2020
Date
Daily Median Temp
Max Daily Temp
Min Daily Temp
Seven Day Moving Average of Max Water Temperature

Appendix C

Spatial Stream Network Model

Suisun Creek

3300 Industrial Blvd., Suite 100
West Sacramento, CA 95691
(916) 231-1681
www.fishsciences.net

CRAMER FISH SCIENCES®
An Employee Owned Consulting Company

MEMORANDUM

Date: November 27, 2018

To: Laurel Marcus, California Land Stewardship Institute.

From: Michael Beakes, PhD, Jesse Weisenfeld, MS, and Rocko Brown, PhD

Subject: Spatial Stream Network Modeling of Suisun Creek

INTRODUCTION

Cramer Fish Sciences (CFS) worked collaboratively with the California Land Stewardship Institute (CLSI) to develop a spatial stream network model (SSN) that was used to test hypotheses associated with the impacts of climate, land use, and water releases from Lake Curry on water temperatures in Suisun Creek. We quantified how these factors independently and collectively altered water temperatures in the creek; and *O. mykiss* habitat by extension. This modeling framework also provided a means through which CLSI can make predictions about the impacts of future land-use and climate change on water temperatures and explore the relative benefit of different mitigation strategies (e.g., riparian restoration vs. increased water releases).

SSN models allow users to maximize the strength and utility of data collected in the field and remotely and leverage those data to generate robust predictions about habitat conditions throughout an entire watershed. There are two primary benefits of developing an SSN model for Suisun Creek. First, by accounting for spatial autocorrelation and the nested nature of rivers, an SSN model allowed us to predict and evaluate habitat conditions (i.e., water temperatures) in areas of Suisun Creek that are inaccessible (e.g., landowner restrictions) or haven't previously been monitored. Second, the SSN model improved our understanding of how the surrounding landscape, flow conditions, and climate impact instream temperatures because the model allows us to spatially link characteristics of the drainage basin (e.g., aspect, canopy cover, geology) to instream habitat conditions.

METHODS

Data Sources and Key Factors

The primary goal of this analysis was to evaluate how altering discharge from Lake Curry affects downstream water temperatures in Suisun Creek. However, previous research has shown that air temperature and canopy cover are two of the dominant controls of water temperatures in streams and rivers. Without accounting for these key factors, it would be difficult to accurately assess how changing discharge from Lake Curry alters downstream creek temperatures.

We built an SSN model (Peterson and Ver Hoef 2010, Ver Hoef et al. 2012), for Suisun Creek using historical stream temperature data collected by the CLSI. We developed a spatial generalized linear model using the SSN model framework to test the collective effects of air temperature, canopy cover, and Lake Curry discharge on stream temperatures in Suisun Creek. This modelling framework also allowed us to consider the spatial autocorrelation inherent in these data. Our approach allowed us to conduct a robust evaluation of how altering discharge from Lake Curry changes downstream temperatures in Suisun Creek while accounting for other key factors.

We focused this analysis on temperature data from 2006 and 2017 that were collected along 11 miles of the mainstem of Suisun Creek downstream of Lake Curry. Water temperature data collected during this time coincides with records of mean daily discharge from Lake Curry. Collectively these data represent 3,388 daily maximum temperature records (°F) collected from 30 unique monitoring locations. We obtained spatially explicit mean daily air temperature records from the PRISM Climate Group that is based out of Oregon State University (http://prism.oregonstate.edu/). Estimates of canopy cover throughout the Suisun Creek watershed were either obtained from point measurements taken at the time of water temperature logger deployment or from professional judgement of areal imagery. Discharge data from Lake Curry was provided by the City of Vallejo lake operations management staff.

Statistical Analysis and Hypothesis Testing

Our analysis tests the impact of mean daily air temperature, canopy cover, and Lake Curry discharge on daily maximum water temperatures in Suisun Creek. Previous research has shown that these three factors play a vital role in shaping the thermal regime of streams and rivers. In addition to these primary effects we also tested an interaction between air temperature and stream flow to evaluate if the relative impact of flow changes as air temperature changes. The three specific null hypotheses this analysis aimed to address include:

H_1: Mean air temperature has no impact on water temperatures in Suisun Creek

H_2: Canopy cover has no impact on water temperatures in Suisun Creek

H_3: Discharge rate from Lake Curry has no impact on water temperatures in Suisun Creek.

Prediction Scenarios

One of the key benefits of modelling these temperature data in the SSN framework is that it provides a mechanism for predicting water temperatures throughout the stream network. Furthermore, this framework allows us to make these predictions of how altering air temperature, canopy cover, and/or discharge rate from Lake Curry will impact stream temperatures. We examined how daily maximum water temperatures would change at approximately 70 sites stratified uniformly along the mainstem of Suisun Creek under several different scenarios. These scenarios are described below and include variations in air temperature, canopy cover, and discharge rate.

Scenarios:

1. Current conditions; mean daily air temperatures in July, current canopy cover, and 2 CFS discharge.
2. Increase in mean daily air temperatures by 2.8°C from July mean (estimated A1B impact from climate warming), current canopy cover, and 2 CFS discharge.
3. Decrease in canopy cover; mean daily air temperatures in July, 0% canopy cover, and 2 cfs discharge.

4. Increase in canopy cover; mean daily air temperatures in July, 100% canopy cover, and 2 cfs discharge.
5. Lake discharge at 1 cfs; mean daily air temperatures in July, current canopy cover.
6. Lake discharge at 4 cfs; mean daily air temperatures in July, current canopy cover.
7. Lake discharge at 6 cfs; mean daily air temperatures in July, current canopy cover.

The factors in each of these scenarios are expected to change through time due to climate change, habitat restoration or degradation, and water management decisions. Our aim was to predict how each of these scenarios will translate to changes in stream temperature in Suisun Creek. Doing so will provide insight into how water management and/or habitat restoration can be used to mitigate the impacts of climate warming and/or habitat degradation.

Climate is expected to warm over the next century. The total degree of warming varies among model projections from 1.8 – 4.0°C (Solomon et al. 2007). Even if radiative forcing agents were held constant at year 2000 levels, a further warming trend would occur in the next two decades at a rate of about 0.2°C (Solomon et al. 2007). There is a wealth of research that suggests this warming trend will also increase temperatures in streams and rivers. To evaluate the potential impacts of climate warming on stream temperatures in Suisun Creek we ran SSN model predictions assuming a A1B climate warming projections at approximately 2.8°C, or 5°F (Solomon et al. 2007).

Research has linked climate warming and natural landscape perturbations to rising temperatures in freshwaters (Isaak et al. 2010, Holsinger et al. 2014). For example, Isaak et al. (2010) found that solar radiation increases linked to wildfires in the Boise River basin accounted for ~9% percent of the basin-scale warming. We would expect changes to the riparian corridor and canopy cover in Suisun Creek to have direct impacts on the thermal regime of the creek.

The thermal mass of water plays a key role in how rapidly external factors such as air temperature and solar radiation can warm water temperatures. Increasing thermal capacity and discharge makes rivers and streams less sensitive to atmospheric influences (Smith and Lavis 1975, Ozaki et al. 2003, Webb et al. 2003, 2008). As such, increasing the volume of water in Suisun Creek will decrease the relative impact of increasing air temperature or solar inputs on increasing water temperatures.

Model Domains

Using all the data within the study area is advantageous as more observed temperature data is available to evaluate statistical relationships. However, CLSI is mostly concerned with the upper ~5.5 miles of Suisun creek. Therefore, two model domains were explored to analyze the relative effects with regard to the length of channel below Lake Curry. The first, segment scale model, spans ~12 miles from the dam down to SC-1. The second, reach scale model, spans from the dam down to SC-5.5. The reach scale model used 19 stations compared to the full 30 used in the segment scale model.

RESULTS

Segment Scale Model

We identified potential outliers while examining the residual fit from the initial model fit. Data with error greater than two studentized residuals from the mean model fit (i.e., outside the 95%

distribution of error) were classified as outliers and removed from the dataset. In total, these outliers constituted approximately 6% of the total data modelled. We refit the SSN model to the revised dataset excluding these outliers.

The parameters we included in the segment scale SSN model explained approximately 52% of the variation in observed maximum stream temperature data. We found that air temperature, canopy cover, and lake discharge significantly impacted maximum water temperatures in Suisun Creek (Table 1; SSN GLM $P < 0.05$). In general, increasing air temperature elevated stream temperatures. Whereas increasing canopy cover or discharge from Lake Curry decreased stream temperatures (Figure 1). Based on the model coefficients from the fit segment scale SSN model we estimate that increasing air temperature by 10°F would increase daily maximum water temperatures by approximately 3.4°F. An increase canopy cover by 10 percent would decrease maximum water temperatures by approximately 0.8°F on average. We found a significant interaction between air temperature and discharge from Lake Curry (Table 1), which suggest that the impact of air temperature on water temperatures depends on the discharge rate from Lake Curry and vice versa (Figure 1). These results also indicate that the cooling effect of increasing discharge is greater at higher air temperatures relative to lower air temperatures (Figure 1).

Table 1: Parameter estimates from SSN model fit.

Model Main Effects	Coefficient Estimate	Estimate SE	t-value	P value
Intercept	53.870	2.104	25.607	< 0.001
Mean Air Temperature	0.338	0.025	13.506	< 0.001
Canopy Cover	-0.081	0.007	-11.122	< 0.001
Lake Discharge	0.285	0.308	0.927	0.354
Air Temp:Lake Discharge	-0.010	0.004	-2.348	0.019

Covariance Model	Parameter	Estimate
Exponential Taildown	parsill	4.18
Exponential Taildown	range	1214.54
Nugget	parsill	4.85

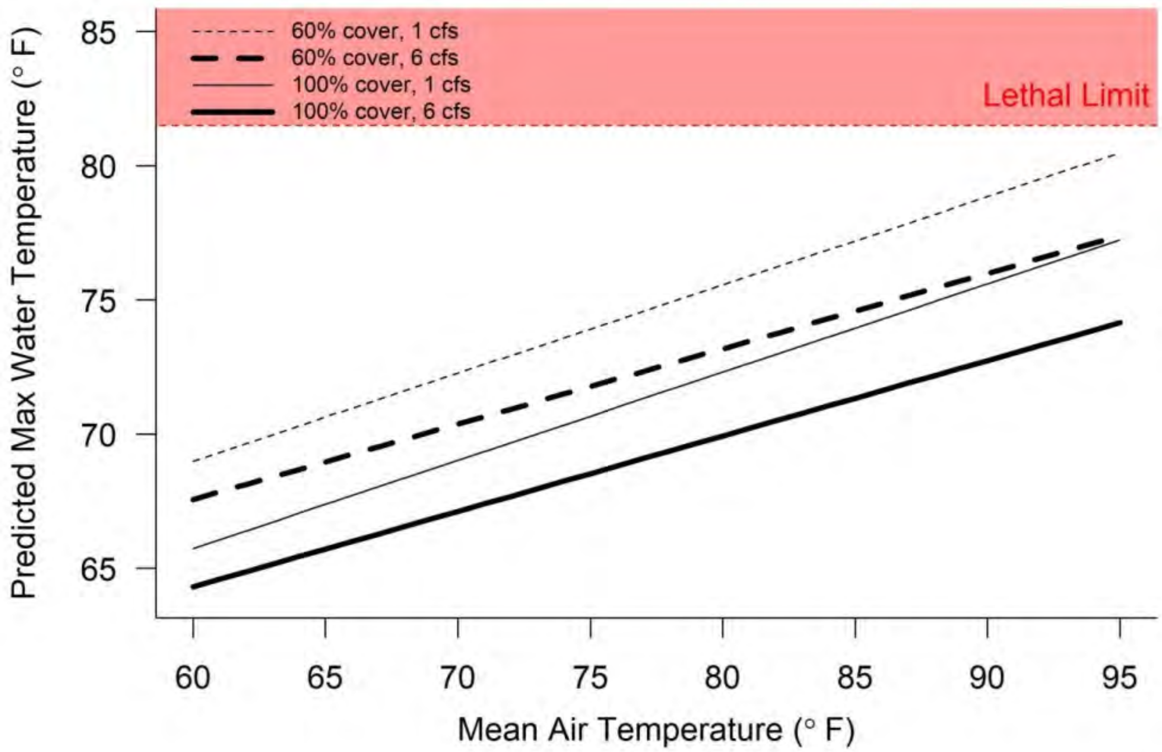


Figure 1: The plot above illustrates the estimated linear relationship between mean daily air temperature, canopy cover, and discharge from Lake Curry, based on the segment scale model. The estimated relationship assumes canopy cover was 60% (dashed lines) or 100% (solid lines), and discharge was either 1 cfs (thin line) or 6 cfs (thick line). Critical thermal maximum water temperatures for *O. mykiss* are highlighted by a red polygon (Myrick and Check 2005). Note that water temperature at any point in Suisun Creek is also partly a function of upstream temperatures that are not illustrated here.

Segment Scale Prediction Scenario Summary

Point specific estimates of water temperature varied considerably among the prediction scenarios. Part of this variability is due to local impacts of air temperature, canopy cover, the interactive effects of air temperature and lake discharge, and spatial auto correlation. Here we focus our evaluation on average impacts across all prediction sites to glean generalities from each prediction scenario.

As can be seen in Table 2, scenario 4 had the lowest average temperature, reducing water temperature 2.47 °F from the baseline. Scenarios 6 and 7 also decreased water temperature from the baseline at 1.7 and 0.85 °F, respectively. Scenario 1 predicted no change from the baseline, while scenarios 5,2, and 3 predicted increased water temperatures.

Table 2: Generalized results across prediction sites from each modeled scenario. Values reported are of predicted daily maximum water temperature. Scenarios are ranked from coolest to warmest average temperature.

Rank	Scenario	Average (°F)	SD (°F)	Max (°F)	Δ From Baseline (°F)
1	4	70.10	0.87	72.38	-2.47
2	7	70.87	2.52	77.97	-1.70
3	6	71.72	2.53	78.83	-0.85
4	1	72.57	2.54	79.68	0.00
5	5	73.00	2.55	80.11	0.43
6	2	74.17	2.54	81.28	1.60
7	3	78.22	0.87	80.50	5.65

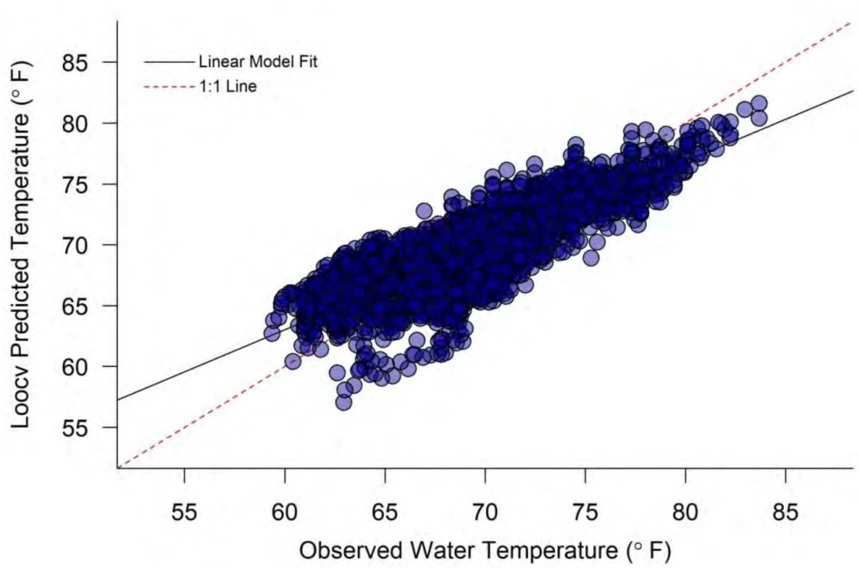


Figure 2: The plot above illustrates a comparison between observed and predicted water temperatures from the leave one out cross validation.

Segment Scale Model Validation

We tested the SSN model's predictive ability via leave-one-out cross validation ("loocv"). This method of cross validation essentially removes a random data point from the data set, refits the model parameters, and then predicts the value of the missing data point. This process of leaving one data point out, refitting, and prediction is completed for all data in the modelled dataset. Comparing the resulting predicted values to the observed values provides a method for measure the model's predictive performance.

In general, predictions from the SSN model aligned relatively well with the observed data the model was fit to (Figure 2). We fit a linear model to these predicted and observed data and estimated the R^2 was approximately 0.69. It is important to note, however, that the intercept in this model was significantly different from zero which suggests the relationship between observed and predicted data wasn't 1:1 (Figure 2). The SSN model tended to overestimate water temperatures when water temperatures were cold (i.e., < 65 °F) and under estimate water temperatures when water temperatures were hot (i.e., > 75 °F). Predicted and observed temperatures were relatively close to 1:1 between 65 – 75 °F.

Reach Scale Model

The results of the reach scale SSN GLM indicated that the interaction term between air temperature and dam discharge was no longer significant, so we reran the model without the interaction term to improve model fit. The parameters used for upper watershed model explained slightly less (49%) of the observed maximum stream temperature data compared to the segment scale SSN model Similar to the segment scale SSN model, air temperature and canopy cover significantly impacted maximum water temperatures in the Upper Reach of Suisun Creek (Table 3; SSN GLM $P < 0.05$). However, lake discharge, which was not significant in the segment scale SSN GLM, was significant. Although the pattern of air temperature and canopy cover's effect was similar to the original model, they differed in how maximum water temperatures were altered. Based on the new model coefficients from the upper watershed SSN model, increasing air temperature by 10°F would have a smaller increase in daily maximum water temperatures (~2.5°F) compared to the original model coefficients (Table 1 and 3). An increase in canopy cover by 10 percent would have a larger decrease in maximum water temperatures (~1.6°F), while increasing lake discharge by 1 cfs would decrease maximum water temperature by 0.38°F in the upper watershed (Table 3). There is no interaction term in this model, which means the cooling effect from increasing discharge is constant across all temperatures and canopy cover levels. In other words, lake discharge had a cooling effect at both hot and cool air temperatures – the amount of cooling was the same (Figure 3).

Table 3: Parameter estimates from updated upper watershed SSN model fit

Model Main Effects	Coefficient Estimate	Estimate SE	t-value	P value
Intercept	67.232	1.202	55.96	< 0.001
Mean Air Temperature	0.249	0.006	39.74	< 0.001
Canopy Cover	-0.164	0.0108	-15.12	< 0.001
Lake Discharge	-0.380	0.0298	-12.74	< 0.001

Covariance Model	Parameter	Estimate
Exponential Taildown	parsill	4.744
Exponential Taildown	range	< 0.001
Nugget	parsill	4.81

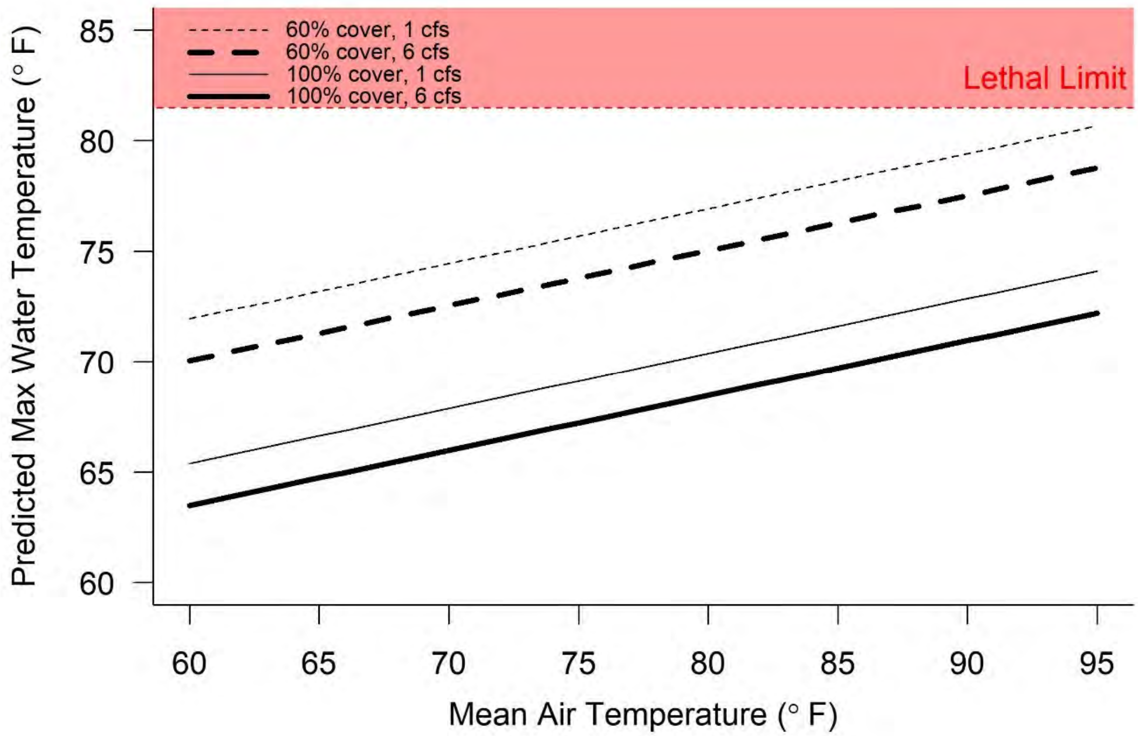


Figure 3: The plot above illustrates the estimated linear relationship between mean daily air temperature, canopy cover, and discharge from Lake Curry, based on the reach scale model. The estimated relationship assumes canopy cover was 60% (dashed lines) or 100% (solid lines), and discharge was either 1 cfs (thin line) or 6 cfs (thick line). Critical thermal maximum water temperatures for *O. mykiss* are highlighted by a red polygon (Myrick and Check 2005). Note that water temperature at any point in Suisun Creek is also partly a function of upstream temperatures that are not illustrated here.

Upper Reach Prediction Scenario Summary

The upper reach prediction scenarios ranked in the same order as scenarios using the entire watershed. However, average temperatures and max temperatures increased for all scenarios (Table 2), while standard deviations of average water temperatures increased for 5 of the 7 scenarios.

As can be seen in Table 4, scenario 4 had the lowest average temperature, reducing water temperature by 5.02 °F from the baseline. Scenarios 6 and 7 also decreased average water temperature from the baseline by 1.88 and 0.76 °F, respectively. Scenario 1 predicted no change from the baseline, while scenarios 5, 2, and 3 predicted increased water temperatures.

Table 4: Generalized results across prediction sites from each modeled scenario for the upper watershed model. Values reported are of predicted daily maximum water temperature. Scenarios are ranked from coolest to warmest average temperature.

Rank	Scenario	Average (°F)	SD (°F)	Max (°F)	Δ From Baseline (°F)
1	4	68.70	0.42	69.33	-5.02
2	7	72.18	4.68	84.26	-1.55
3	6	72.95	4.67	85.01	-0.77
4	1	73.73	4.67	85.75	0.00
5	5	74.11	4.66	86.12	1.16
6	2	74.83	4.67	86.86	1.88
7	3	85.21	0.42	85.84	10.38

Upper Reach Model Validation

Similar to the original result, the leave-one-out cross validation for the upper watershed model predictions from the SSN model matched observed data although the R^2 was slightly lower (~0.65, Figure 4). This is most likely due to having less temperature observations due to a smaller model domain (e.g. the reach model is a subset of the segment model).

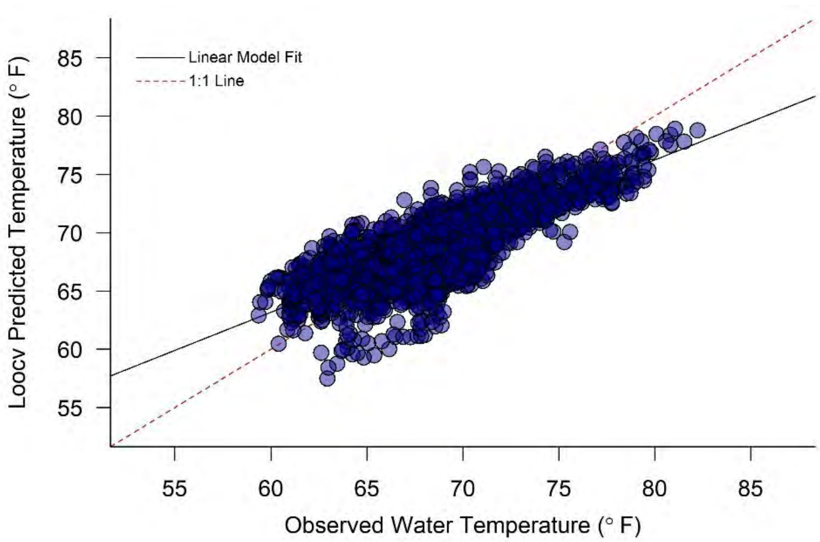


Figure 4: The plot above illustrates a comparison between observed and predicted water temperatures from the leave one out cross validation for the upper watershed model.

CONCLUSIONS

The SSN model we developed in this project identified that mean air temperature significantly impacts water temperatures at both the segment and reach scale. This result rejects the null hypothesis for H_1. Further, increasing discharge rate from Lake Curry and increasing canopy cover significantly decreased stream temperatures in Suisun Creek at the reach scale. This rejects the null hypotheses for H_2 and H_3.

IMPLICATIONS FOR WATER MANAGEMENT

There is broad agreement within the scientific community that air temperature is considered a very good predictor of water temperature (Stefan and Preud'homme 1993, Caissie 2006, Webb and Nobilis 2007, Webb et al. 2008, Kaushal et al. 2010). In fact, some biological and water quality research of streams often use air temperature as a surrogate for water temperature because water temperature data are sometime scarce or are relatively difficult to obtain (Smith 1981, Stefan and Preud'homme 1993, Webb et al. 2008). It is therefore reasonable to assume that climate warming over the next century will invariably warm stream temperatures in Suisun Creek as the model predicted.

It is important to highlight that we identified a significant interaction between air temperature and lake discharge. This significant interaction means that increasing discharge rate from Lake Curry, even for short periods of time (e.g., pulse flow), will decrease stream temperatures and the relative benefit of this elevated discharge rate will increase as air temperatures increase. Therefore, pulses during very hot periods could provide the greatest cooling benefit to the stream.

Shading provided by riparian vegetation, tall trees, and steep terrain may control the amount of shortwave radiation that reaches streams and rivers, which influences stream temperatures (Allen 2008). Riparian restoration is a potential tool that can be applied in Suisun Creek to decrease stream temperatures and/or mitigate for the expected impacts from climate warming. Small streams, such as Suisun Creek, are considered more vulnerable to the thermal effects of increasing solar radiation because they have a low thermal capacity relative to larger systems (Moore et al. 2005, Caissie 2006). Increasing the water volume in small tributaries will increase their thermal mass and therefore reduce their vulnerability to warming temperatures. Using pulse flows as a mitigating mechanism to buffer change in response to heat waves in small watersheds such as Suisun Creek is likely to be an effective management tool for resident *O. mykiss*.

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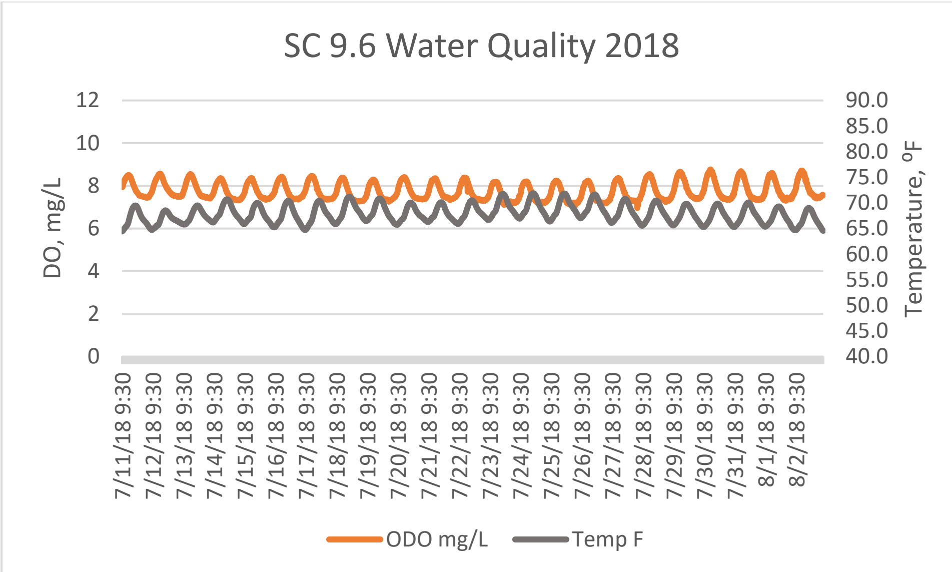
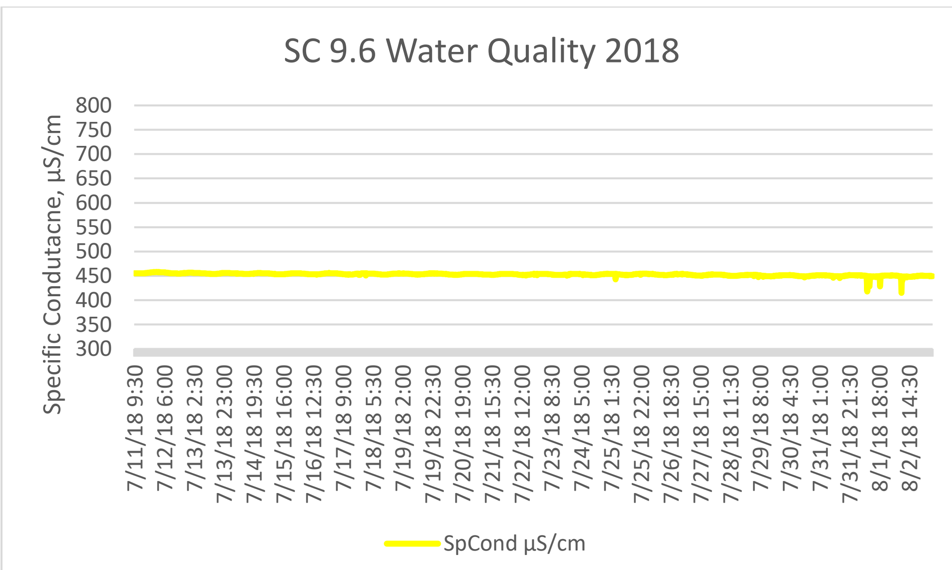
Appendix D

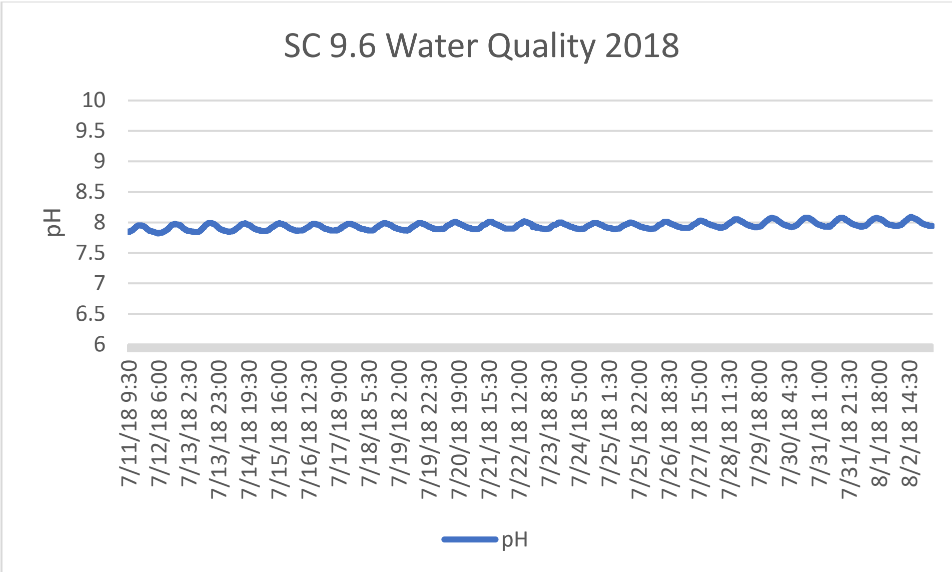
Water Quality Graphs 2017-2020 Suisun Creek

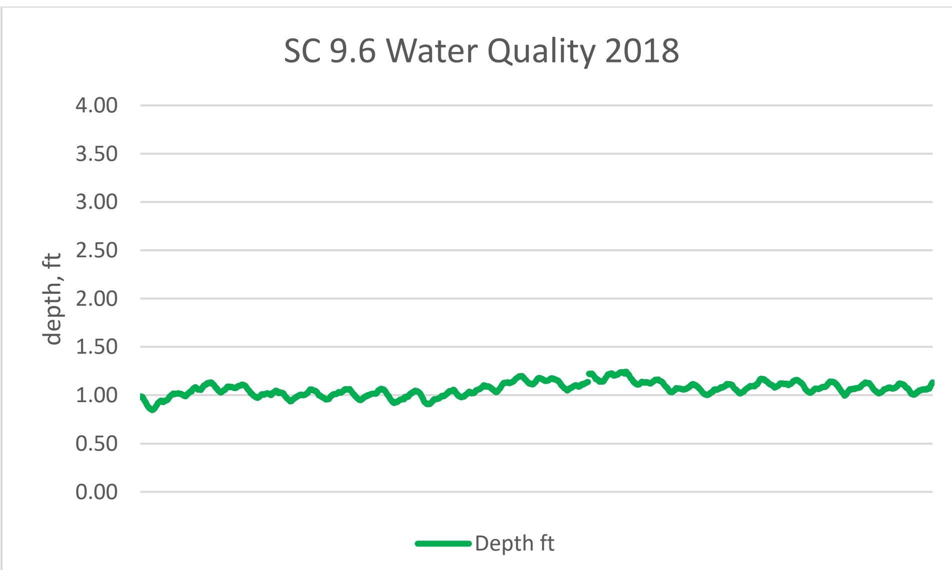


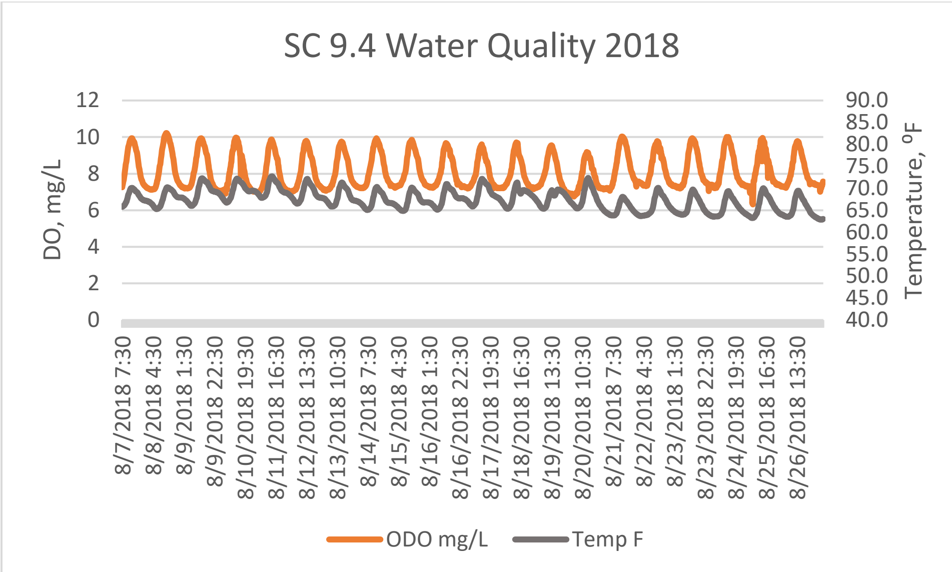
SC 9.6 Water Quality 2018
DO, mg/L
Temperature, °F
12
10
8
6
4
2
0
90.0
85.0
80.0
75.0
70.0
65.0
60.0
55.0
50.0
45.0
40.0
7/11/18 9:30
7/12/18 9:30
7/13/18 9:30
7/14/18 9:30
7/15/18 9:30
7/16/18 9:30
7/17/18 9:30
7/18/18 9:30
7/19/18 9:30
7/20/18 9:30
7/21/18 9:30
7/22/18 9:30
7/23/18 9:30
7/24/18 9:30
7/25/18 9:30
7/26/18 9:30
7/27/18 9:30
7/28/18 9:30
7/29/18 9:30
7/30/18 9:30
7/31/18 9:30
8/1/18 9:30
8/2/18 9:30
ODO mg/L
Temp F



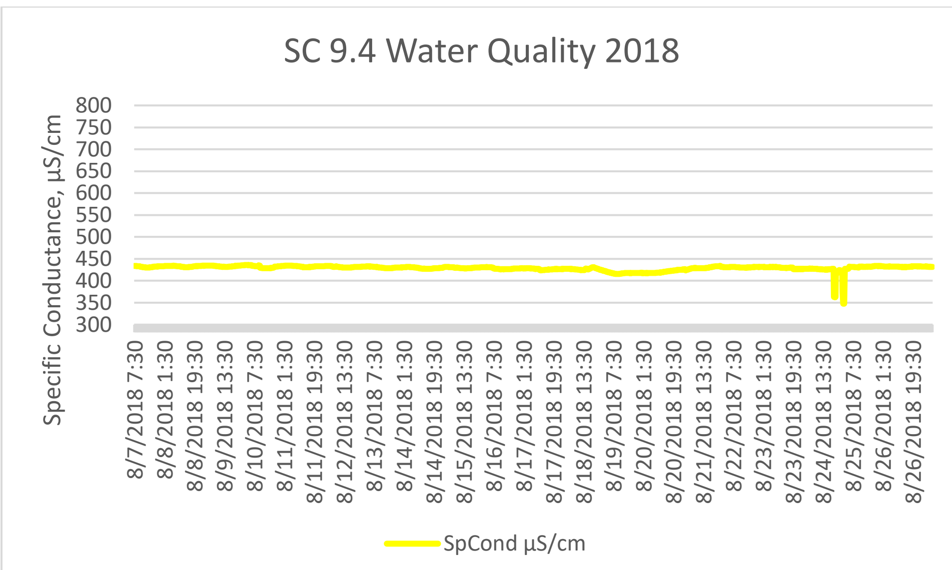
SC 9.6 Water Quality 2018
Specific Condutacne, µS/cm
800
750
700
650
600
550
500
450
400
350
300
7/11/18 9:30
7/12/18 6:00
7/13/18 2:30
7/13/18 23:00
7/14/18 19:30
7/15/18 16:00
7/16/18 12:30
7/17/18 9:00
7/18/18 5:30
7/19/18 2:00
7/19/18 22:30
7/20/18 19:00
7/21/18 15:30
7/22/18 12:00
7/23/18 8:30
7/24/18 5:00
7/25/18 1:30
7/25/18 22:00
7/26/18 18:30
7/27/18 15:00
7/28/18 11:30
7/29/18 8:00
7/30/18 4:30
7/31/18 1:00
7/31/18 21:30
8/1/18 18:00
8/2/18 14:30
SpCond µS/cm


SC 9.6 Water Quality 2018
pH
10
9.5
9
8.5
8
7.5
7
6.5
6
7/11/18 9:30
7/12/18 6:00
7/13/18 2:30
7/13/18 23:00
7/14/18 19:30
7/15/18 16:00
7/16/18 12:30
7/17/18 9:00
7/18/18 5:30
7/19/18 2:00
7/19/18 22:30
7/20/18 19:00
7/21/18 15:30
7/22/18 12:00
7/23/18 8:30
7/24/18 5:00
7/25/18 1:30
7/25/18 22:00
7/26/18 18:30
7/27/18 15:00
7/28/18 11:30
7/29/18 8:00
7/30/18 4:30
7/31/18 1:00
7/31/18 21:30
8/1/18 18:00
8/2/18 14:30
pH

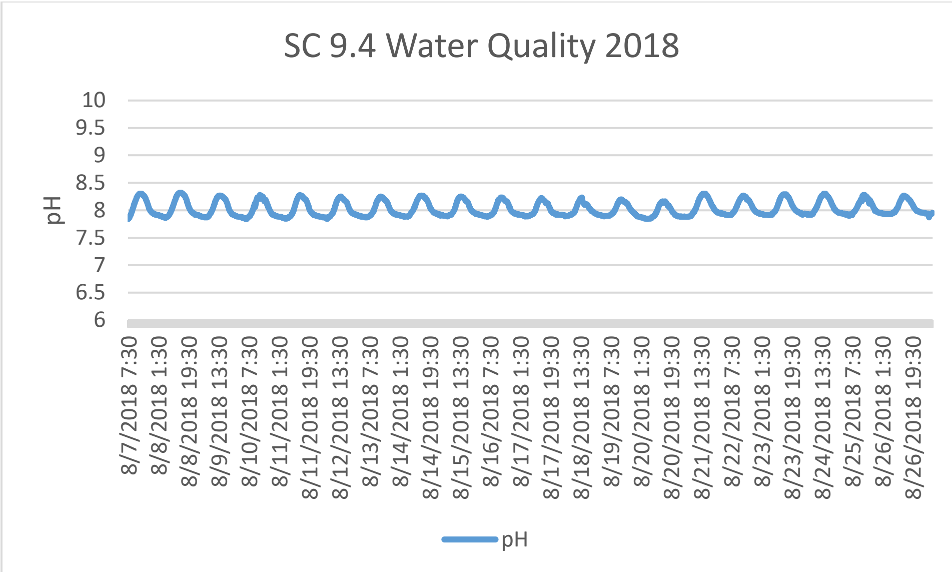

SC 9.6 Water Quality 2018
depth, ft
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
Depth ft

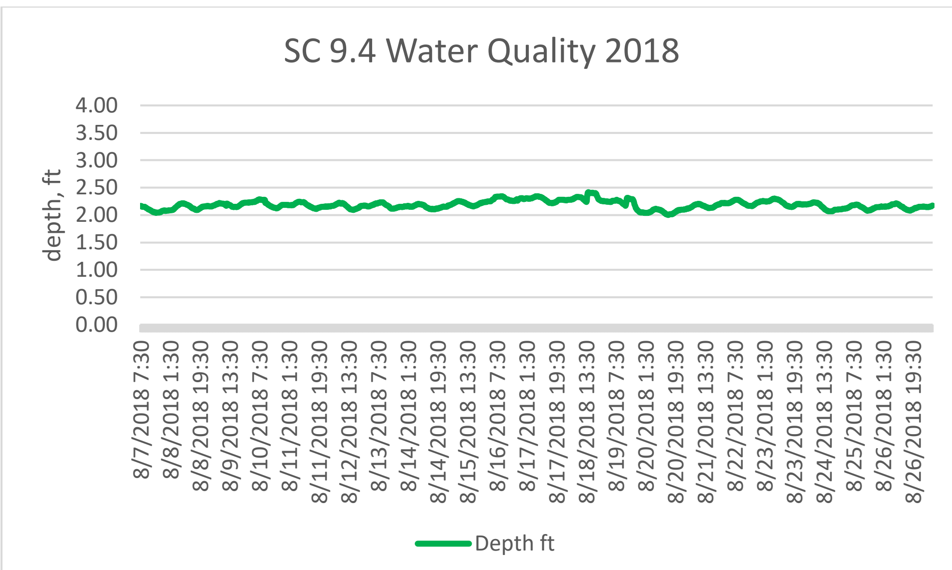


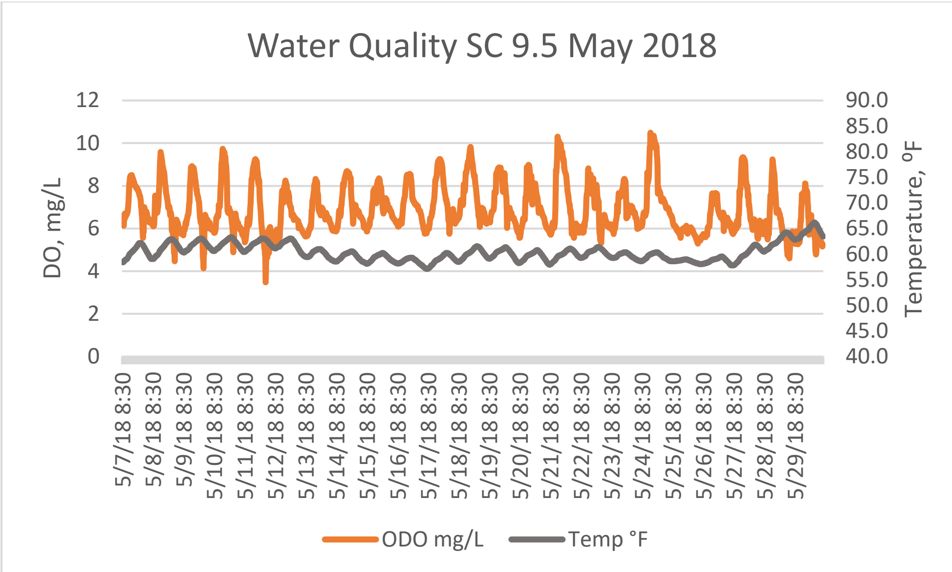
SC 9.4 Water Quality 2018
DO, mg/L
Temperature, °F
12
10
8
6
4
2
0
90.0
85.0
80.0
75.0
70.0
65.0
60.0
55.0
50.0
45.0
40.0
8/7/2018 7:30
8/8/2018 4:30
8/9/2018 1:30
8/9/2018 22:30
8/10/2018 19:30
8/11/2018 16:30
8/12/2018 13:30
8/13/2018 10:30
8/14/2018 7:30
8/15/2018 4:30
8/16/2018 1:30
8/16/2018 22:30
8/17/2018 19:30
8/18/2018 16:30
8/19/2018 13:30
8/20/2018 10:30
8/21/2018 7:30
8/22/2018 4:30
8/23/2018 1:30
8/23/2018 22:30
8/24/2018 19:30
8/25/2018 16:30
8/26/2018 13:30
ODO mg/L
Temp F

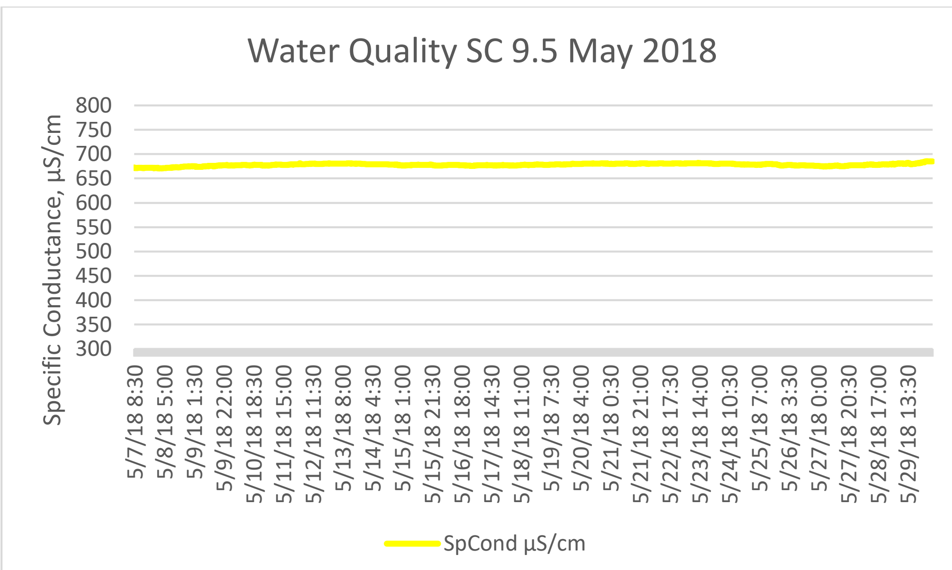


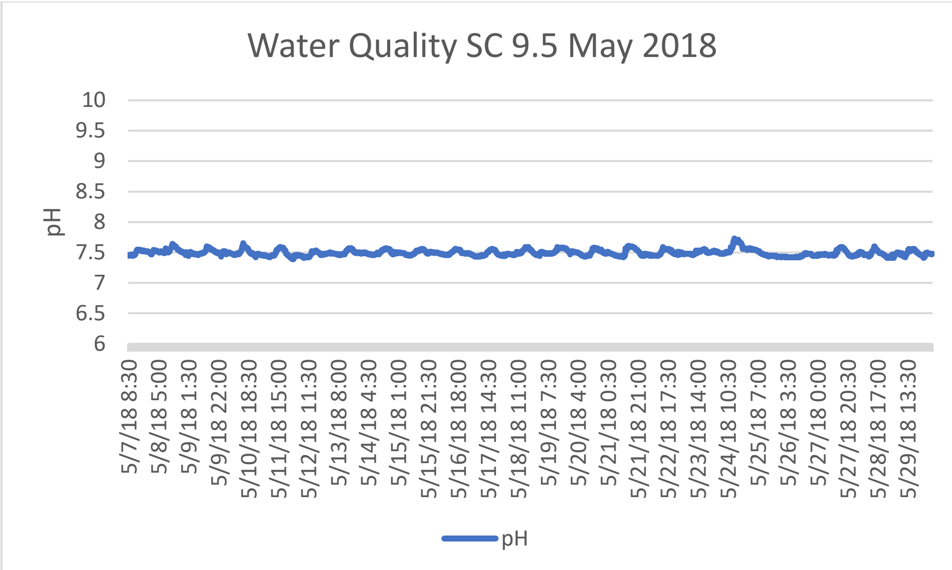
SC 9.4 Water Quality 2018
Specific Conductance, µS/cm
800
750
700
650
600
550
500
450
400
350
300
8/7/2018 7:30
8/8/2018 1:30
8/8/2018 19:30
8/9/2018 13:30
8/10/2018 7:30
8/11/2018 1:30
8/11/2018 19:30
8/12/2018 13:30
8/13/2018 7:30
8/14/2018 1:30
8/14/2018 19:30
8/15/2018 13:30
8/16/2018 7:30
8/17/2018 1:30
8/17/2018 19:30
8/18/2018 13:30
8/19/2018 7:30
8/20/2018 1:30
8/20/2018 19:30
8/21/2018 13:30
8/22/2018 7:30
8/23/2018 1:30
8/23/2018 19:30
8/24/2018 13:30
8/25/2018 7:30
8/26/2018 1:30
8/26/2018 19:30
SpCond µS/cm

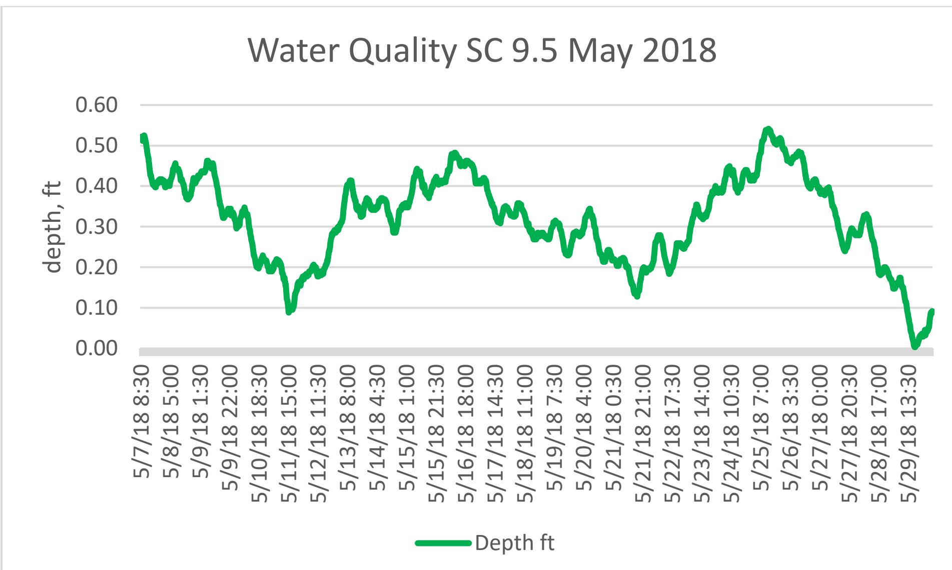

SC 9.4 Water Quality 2018
pH
10
9.5
9
8.5
8
7.5
7
6.5
6
8/7/2018 7:30
8/8/2018 1:30
8/8/2018 19:30
8/9/2018 13:30
8/10/2018 7:30
8/11/2018 1:30
8/11/2018 19:30
8/12/2018 13:30
8/13/2018 7:30
8/14/2018 1:30
8/14/2018 19:30
8/15/2018 13:30
8/16/2018 7:30
8/17/2018 1:30
8/17/2018 19:30
8/18/2018 13:30
8/19/2018 7:30
8/20/2018 1:30
8/20/2018 19:30
8/21/2018 13:30
8/22/2018 7:30
8/23/2018 1:30
8/23/2018 19:30
8/24/2018 13:30
8/25/2018 7:30
8/26/2018 1:30
8/26/2018 19:30
pH

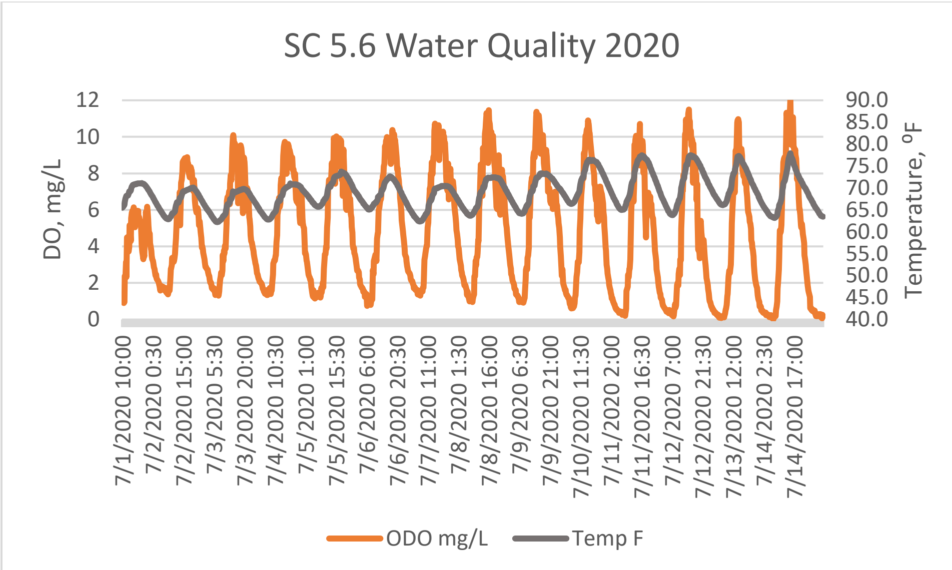

SC 9.4 Water Quality 2018
depth, ft
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
8/7/2018 7:30
8/8/2018 1:30
8/8/2018 19:30
8/9/2018 13:30
8/10/2018 7:30
8/11/2018 1:30
8/11/2018 19:30
8/12/2018 13:30
8/13/2018 7:30
8/14/2018 1:30
8/14/2018 19:30
8/15/2018 13:30
8/16/2018 7:30
8/17/2018 1:30
8/17/2018 19:30
8/18/2018 13:30
8/19/2018 7:30
8/20/2018 1:30
8/20/2018 19:30
8/21/2018 13:30
8/22/2018 7:30
8/23/2018 1:30
8/23/2018 19:30
8/24/2018 13:30
8/25/2018 7:30
8/26/2018 1:30
8/26/2018 19:30
Depth ft


Water Quality SC 9.5 May 2018
DO, mg/L
Temperature, °F
0
2
4
6
8
10
12
40.0
45.0
50.0
55.0
60.0
65.0
70.0
75.0
80.0
85.0
90.0
5/7/18 8:30
5/8/18 8:30
5/9/18 8:30
5/10/18 8:30
5/11/18 8:30
5/12/18 8:30
5/13/18 8:30
5/14/18 8:30
5/15/18 8:30
5/16/18 8:30
5/17/18 8:30
5/18/18 8:30
5/19/18 8:30
5/20/18 8:30
5/21/18 8:30
5/22/18 8:30
5/23/18 8:30
5/24/18 8:30
5/25/18 8:30
5/26/18 8:30
5/27/18 8:30
5/28/18 8:30
5/29/18 8:30
ODO mg/L
Temp °F

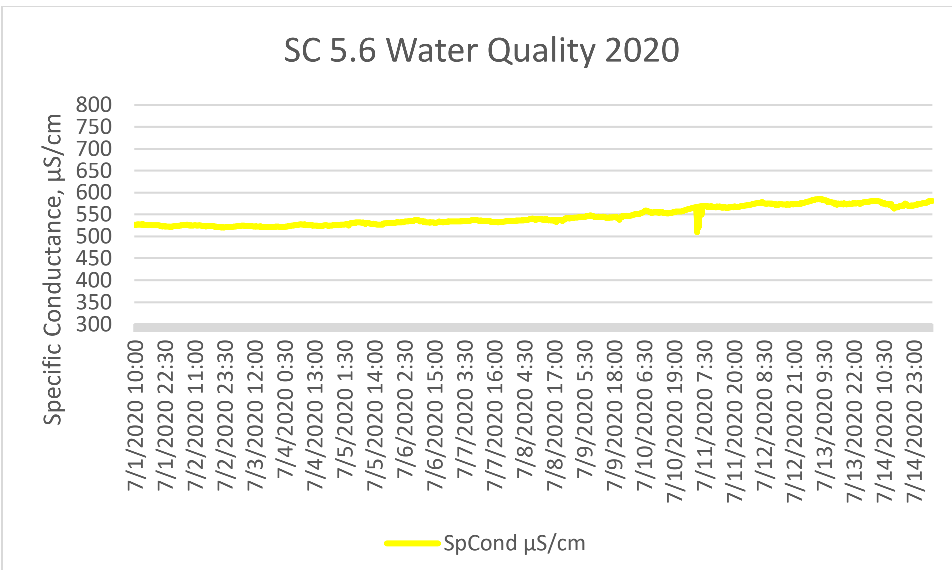

Water Quality SC 9.5 May 2018
Specific Conductance, µS/cm
300
350
400
450
500
550
600
650
700
750
800
5/7/18 8:30
5/8/18 5:00
5/9/18 1:30
5/9/18 22:00
5/10/18 18:30
5/11/18 15:00
5/12/18 11:30
5/13/18 8:00
5/14/18 4:30
5/15/18 1:00
5/15/18 21:30
5/16/18 18:00
5/17/18 14:30
5/18/18 11:00
5/19/18 7:30
5/20/18 4:00
5/21/18 0:30
5/21/18 21:00
5/22/18 17:30
5/23/18 14:00
5/24/18 10:30
5/25/18 7:00
5/26/18 3:30
5/27/18 0:00
5/27/18 20:30
5/28/18 17:00
5/29/18 13:30
SpCond µS/cm


Water Quality SC 9.5 May 2018
pH
10
9.5
9
8.5
8
7.5
7
6.5
6
5/7/18 8:30
5/8/18 5:00
5/9/18 1:30
5/9/18 22:00
5/10/18 18:30
5/11/18 15:00
5/12/18 11:30
5/13/18 8:00
5/14/18 4:30
5/15/18 1:00
5/15/18 21:30
5/16/18 18:00
5/17/18 14:30
5/18/18 11:00
5/19/18 7:30
5/20/18 4:00
5/21/18 0:30
5/21/18 21:00
5/22/18 17:30
5/23/18 14:00
5/24/18 10:30
5/25/18 7:00
5/26/18 3:30
5/27/18 0:00
5/27/18 20:30
5/28/18 17:00
5/29/18 13:30
pH

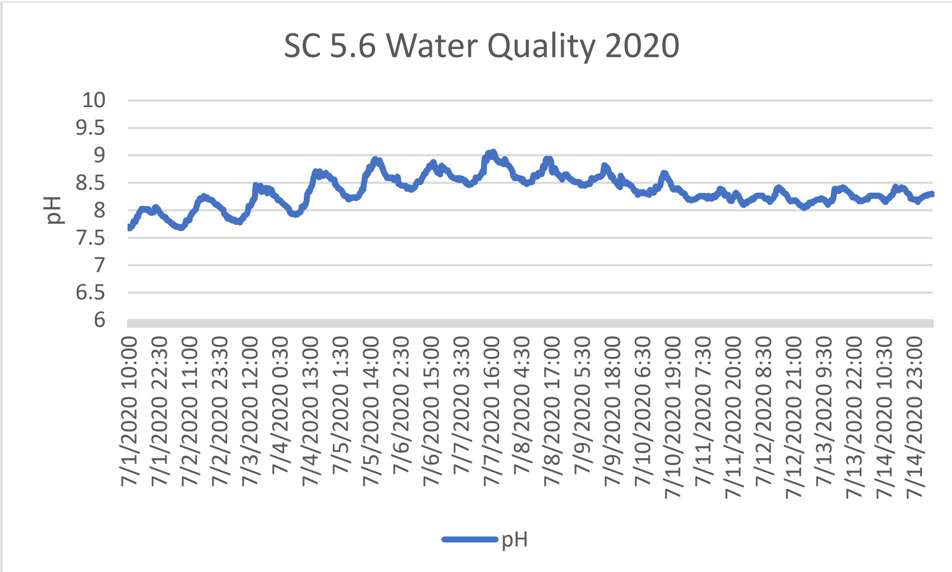

Water Quality SC 9.5 May 2018
depth, ft
0.60
0.50
0.40
0.30
0.20
0.10
0.00
5/7/18 8:30
5/8/18 5:00
5/9/18 1:30
5/9/18 22:00
5/10/18 18:30
5/11/18 15:00
5/12/18 11:30
5/13/18 8:00
5/14/18 4:30
5/15/18 1:00
5/15/18 21:30
5/16/18 18:00
5/17/18 14:30
5/18/18 11:00
5/19/18 7:30
5/20/18 4:00
5/21/18 0:30
5/21/18 21:00
5/22/18 17:30
5/23/18 14:00
5/24/18 10:30
5/25/18 7:00
5/26/18 3:30
5/27/18 0:00
5/27/18 20:30
5/28/18 17:00
5/29/18 13:30
Depth ft

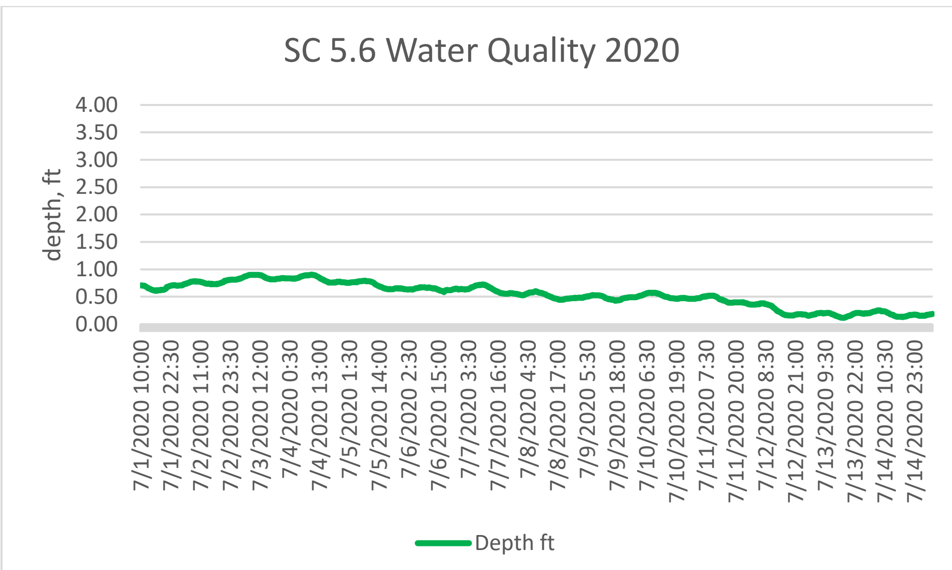


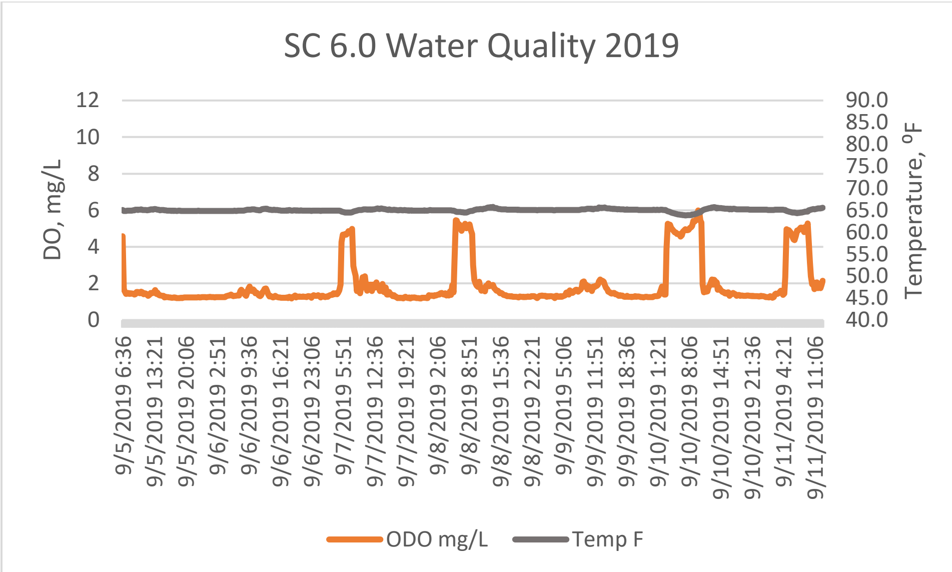
SC 5.6 Water Quality 2020
DO, mg/L
12
10
8
6
4
2
0
90.0
85.0
80.0
75.0
70.0
65.0
60.0
55.0
50.0
45.0
40.0
Temperature, °F
7/1/2020 10:00
7/2/2020 0:30
7/2/2020 15:00
7/3/2020 5:30
7/3/2020 20:00
7/4/2020 10:30
7/5/2020 1:00
7/5/2020 15:30
7/6/2020 6:00
7/6/2020 20:30
7/7/2020 11:00
7/8/2020 1:30
7/8/2020 16:00
7/9/2020 6:30
7/9/2020 21:00
7/10/2020 11:30
7/11/2020 2:00
7/11/2020 16:30
7/12/2020 7:00
7/12/2020 21:30
7/13/2020 12:00
7/14/2020 2:30
7/14/2020 17:00
ODO mg/L
Temp F

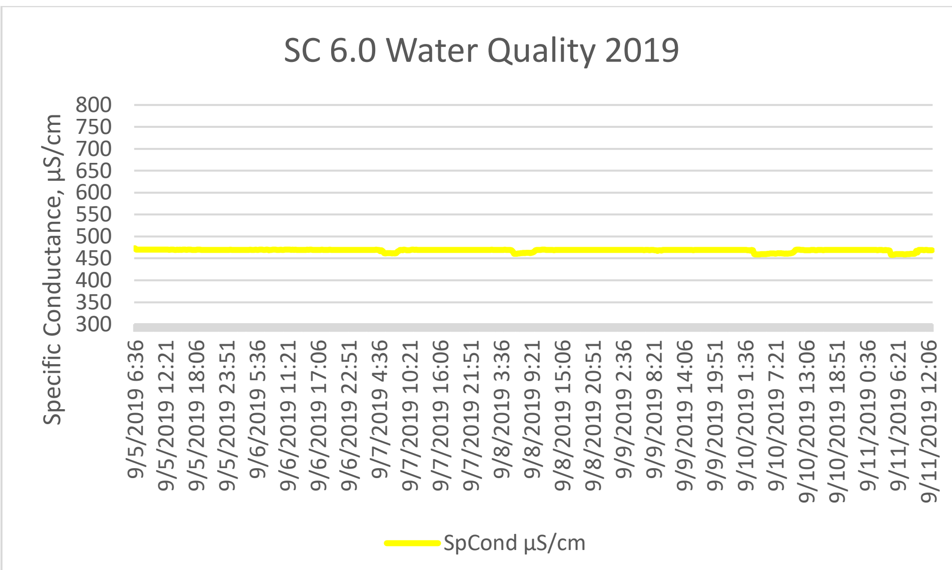


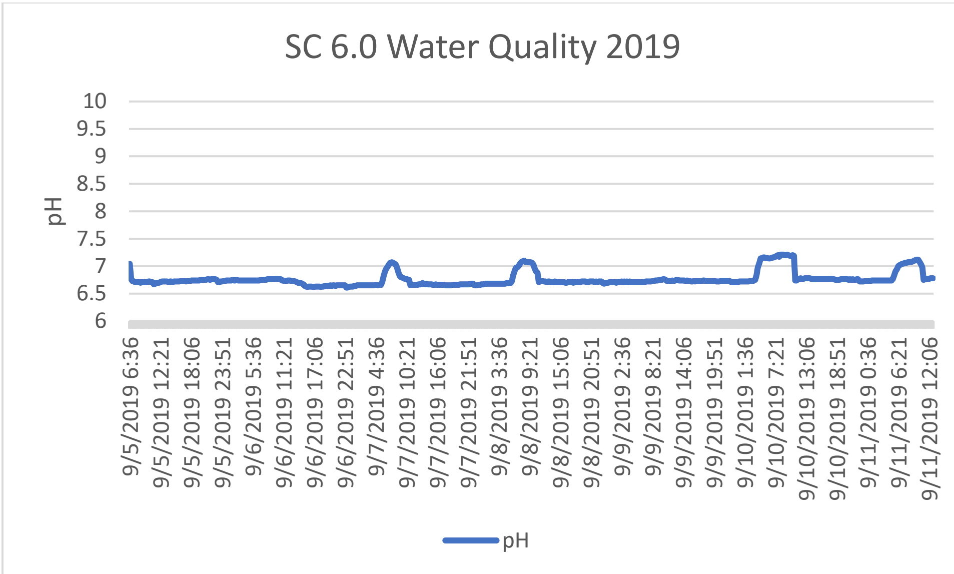
SC 5.6 Water Quality 2020
Specific Conductance, µS/cm
800
750
700
650
600
550
500
450
400
350
300
7/1/2020 10:00
7/1/2020 22:30
7/2/2020 11:00
7/2/2020 23:30
7/3/2020 12:00
7/4/2020 0:30
7/4/2020 13:00
7/5/2020 1:30
7/5/2020 14:00
7/6/2020 2:30
7/6/2020 15:00
7/7/2020 3:30
7/7/2020 16:00
7/8/2020 4:30
7/8/2020 17:00
7/9/2020 5:30
7/9/2020 18:00
7/10/2020 6:30
7/10/2020 19:00
7/11/2020 7:30
7/11/2020 20:00
7/12/2020 8:30
7/12/2020 21:00
7/13/2020 9:30
7/13/2020 22:00
7/14/2020 10:30
7/14/2020 23:00
SpCond µS/cm

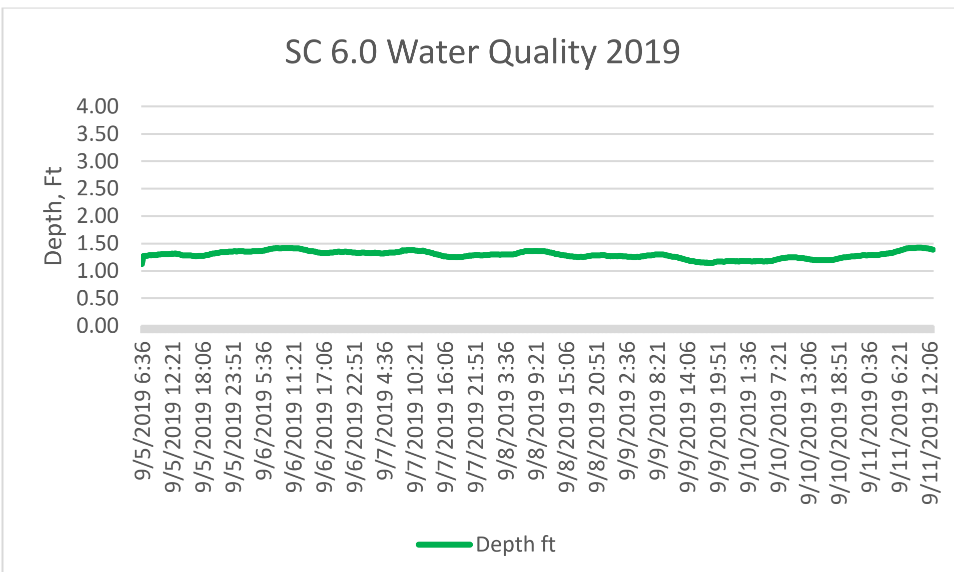

SC 5.6 Water Quality 2020
pH
10
9.5
9
8.5
8
7.5
7
6.5
6
7/1/2020 10:00
7/1/2020 22:30
7/2/2020 11:00
7/2/2020 23:30
7/3/2020 12:00
7/4/2020 0:30
7/4/2020 13:00
7/5/2020 1:30
7/5/2020 14:00
7/6/2020 2:30
7/6/2020 15:00
7/7/2020 3:30
7/7/2020 16:00
7/8/2020 4:30
7/8/2020 17:00
7/9/2020 5:30
7/9/2020 18:00
7/10/2020 6:30
7/10/2020 19:00
7/11/2020 7:30
7/11/2020 20:00
7/12/2020 8:30
7/12/2020 21:00
7/13/2020 9:30
7/13/2020 22:00
7/14/2020 10:30
7/14/2020 23:00
pH

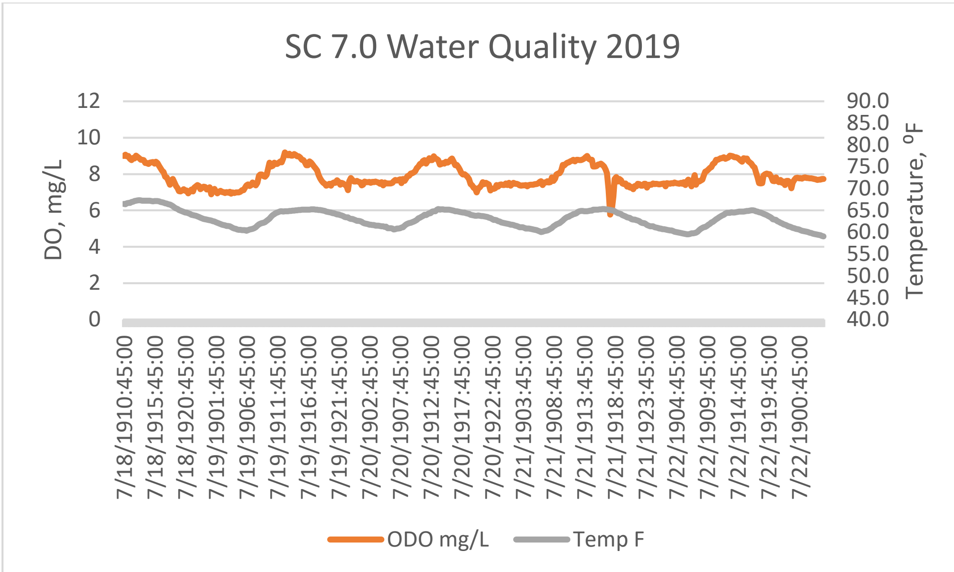

SC 5.6 Water Quality 2020
depth, ft
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
7/1/2020 10:00
7/1/2020 22:30
7/2/2020 11:00
7/2/2020 23:30
7/3/2020 12:00
7/4/2020 0:30
7/4/2020 13:00
7/5/2020 1:30
7/5/2020 14:00
7/6/2020 2:30
7/6/2020 15:00
7/7/2020 3:30
7/7/2020 16:00
7/8/2020 4:30
7/8/2020 17:00
7/9/2020 5:30
7/9/2020 18:00
7/10/2020 6:30
7/10/2020 19:00
7/11/2020 7:30
7/11/2020 20:00
7/12/2020 8:30
7/12/2020 21:00
7/13/2020 9:30
7/13/2020 22:00
7/14/2020 10:30
7/14/2020 23:00
Depth ft

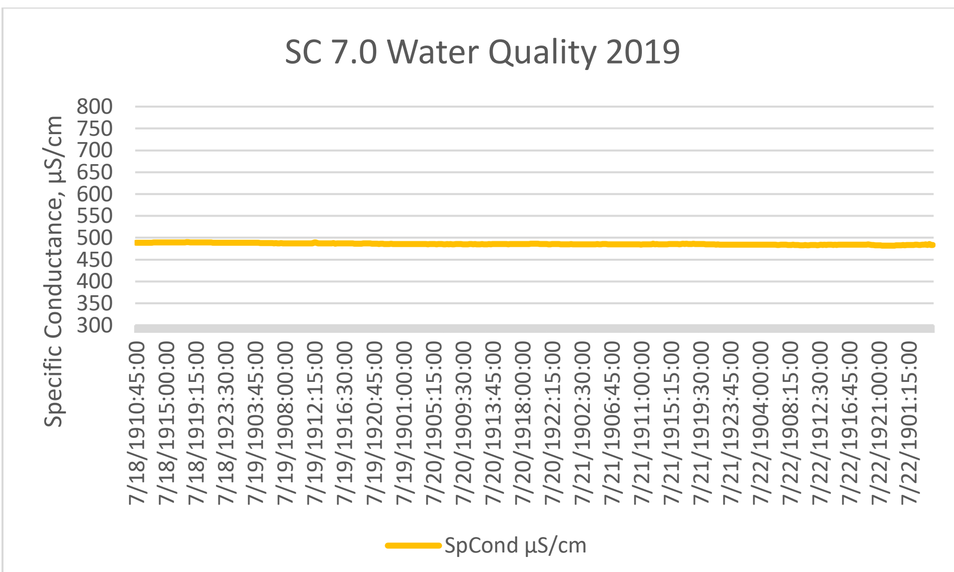

SC 6.0 Water Quality 2019
DO, mg/L
Temperature, °F
12
10
8
6
4
2
0
90.0
85.0
80.0
75.0
70.0
65.0
60.0
55.0
50.0
45.0
40.0
9/5/2019 6:36
9/5/2019 13:21
9/5/2019 20:06
9/6/2019 2:51
9/6/2019 9:36
9/6/2019 16:21
9/6/2019 23:06
9/7/2019 5:51
9/7/2019 12:36
9/7/2019 19:21
9/8/2019 2:06
9/8/2019 8:51
9/8/2019 15:36
9/8/2019 22:21
9/9/2019 5:06
9/9/2019 11:51
9/9/2019 18:36
9/10/2019 1:21
9/10/2019 8:06
9/10/2019 14:51
9/10/2019 21:36
9/11/2019 4:21
9/11/2019 11:06
ODO mg/L
Temp F

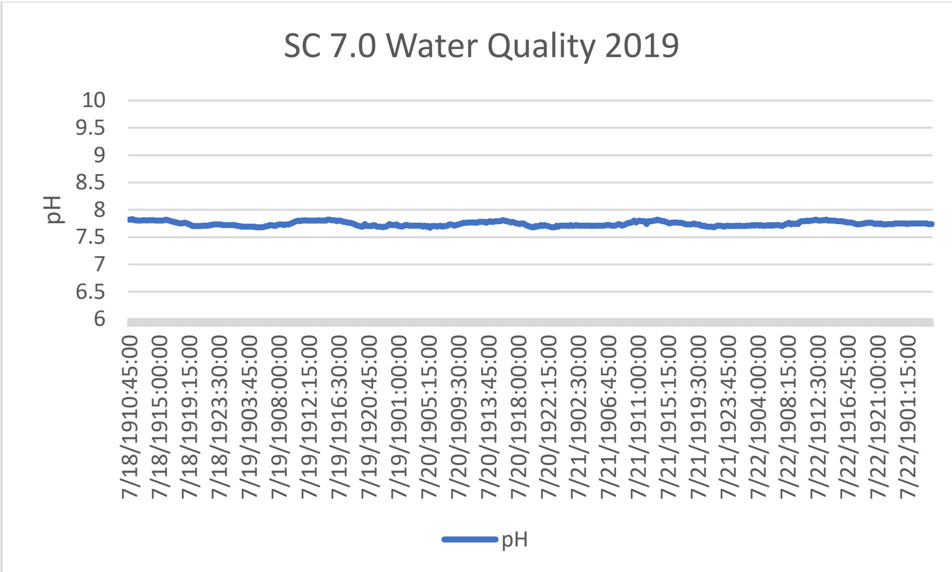

SC 6.0 Water Quality 2019
Specific Conductance, µS/cm
800
750
700
650
600
550
500
450
400
350
300
9/5/2019 6:36
9/5/2019 12:21
9/5/2019 18:06
9/5/2019 23:51
9/6/2019 5:36
9/6/2019 11:21
9/6/2019 17:06
9/6/2019 22:51
9/7/2019 4:36
9/7/2019 10:21
9/7/2019 16:06
9/7/2019 21:51
9/8/2019 3:36
9/8/2019 9:21
9/8/2019 15:06
9/8/2019 20:51
9/9/2019 2:36
9/9/2019 8:21
9/9/2019 14:06
9/9/2019 19:51
9/10/2019 1:36
9/10/2019 7:21
9/10/2019 13:06
9/10/2019 18:51
9/11/2019 0:36
9/11/2019 6:21
9/11/2019 12:06
SpCond µS/cm


SC 6.0 Water Quality 2019
pH
10
9.5
9
8.5
8
7.5
7
6.5
6
9/5/2019 6:36
9/5/2019 12:21
9/5/2019 18:06
9/5/2019 23:51
9/6/2019 5:36
9/6/2019 11:21
9/6/2019 17:06
9/6/2019 22:51
9/7/2019 4:36
9/7/2019 10:21
9/7/2019 16:06
9/7/2019 21:51
9/8/2019 3:36
9/8/2019 9:21
9/8/2019 15:06
9/8/2019 20:51
9/9/2019 2:36
9/9/2019 8:21
9/9/2019 14:06
9/9/2019 19:51
9/10/2019 1:36
9/10/2019 7:21
9/10/2019 13:06
9/10/2019 18:51
9/11/2019 0:36
9/11/2019 6:21
9/11/2019 12:06
pH

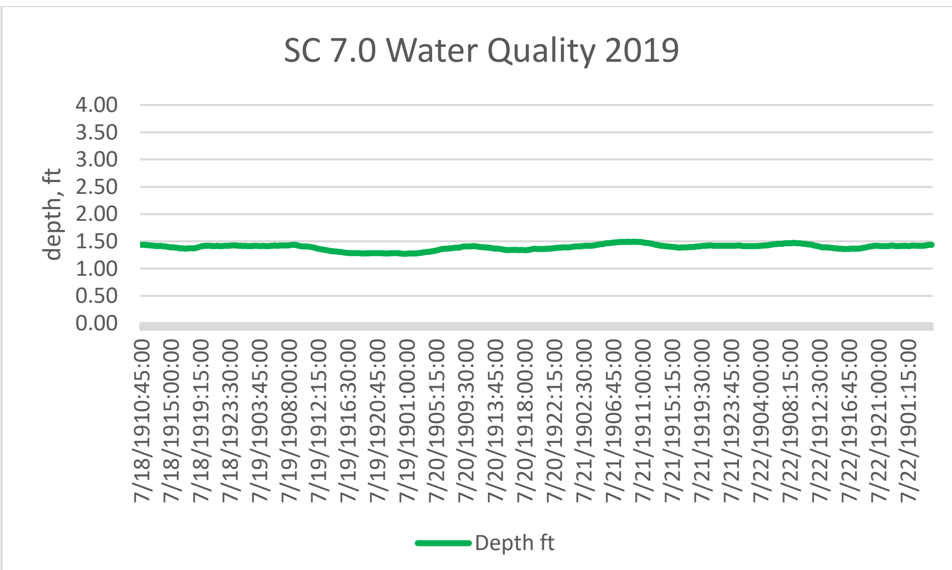

SC 6.0 Water Quality 2019
Depth, Ft
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
9/5/2019 6:36
9/5/2019 12:21
9/5/2019 18:06
9/5/2019 23:51
9/6/2019 5:36
9/6/2019 11:21
9/6/2019 17:06
9/6/2019 22:51
9/7/2019 4:36
9/7/2019 10:21
9/7/2019 16:06
9/7/2019 21:51
9/8/2019 3:36
9/8/2019 9:21
9/8/2019 15:06
9/8/2019 20:51
9/9/2019 2:36
9/9/2019 8:21
9/9/2019 14:06
9/9/2019 19:51
9/10/2019 1:36
9/10/2019 7:21
9/10/2019 13:06
9/10/2019 18:51
9/11/2019 0:36
9/11/2019 6:21
9/11/2019 12:06
Depth ft


SC 7.0 Water Quality 2019
DO, mg/L
Temperature, °F
12
10
8
6
4
2
0
90.0
85.0
80.0
75.0
70.0
65.0
60.0
55.0
50.0
45.0
40.0
7/18/1910:45:00
7/18/1915:45:00
7/18/1920:45:00
7/19/1901:45:00
7/19/1906:45:00
7/19/1911:45:00
7/19/1916:45:00
7/19/1921:45:00
7/20/1902:45:00
7/20/1907:45:00
7/20/1912:45:00
7/20/1917:45:00
7/20/1922:45:00
7/21/1903:45:00
7/21/1908:45:00
7/21/1913:45:00
7/21/1918:45:00
7/21/1923:45:00
7/22/1904:45:00
7/22/1909:45:00
7/22/1914:45:00
7/22/1919:45:00
7/22/1900:45:00
ODO mg/L
Temp F

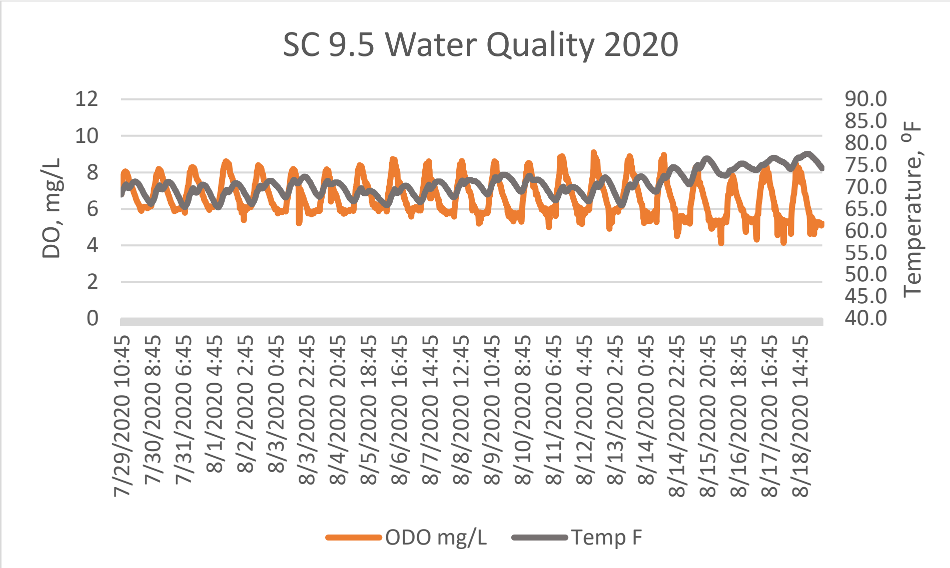

SC 7.0 Water Quality 2019
Specific Conductance, µS/cm
800
750
700
650
600
550
500
450
400
350
300
7/18/1910:45:00
7/18/1915:00:00
7/18/1919:15:00
7/18/1923:30:00
7/19/1903:45:00
7/19/1908:00:00
7/19/1912:15:00
7/19/1916:30:00
7/19/1920:45:00
7/19/1901:00:00
7/20/1905:15:00
7/20/1909:30:00
7/20/1913:45:00
7/20/1918:00:00
7/20/1922:15:00
7/21/1902:30:00
7/21/1906:45:00
7/21/1911:00:00
7/21/1915:15:00
7/21/1919:30:00
7/21/1923:45:00
7/22/1904:00:00
7/22/1908:15:00
7/22/1912:30:00
7/22/1916:45:00
7/22/1921:00:00
7/22/1901:15:00
SpCond µS/cm

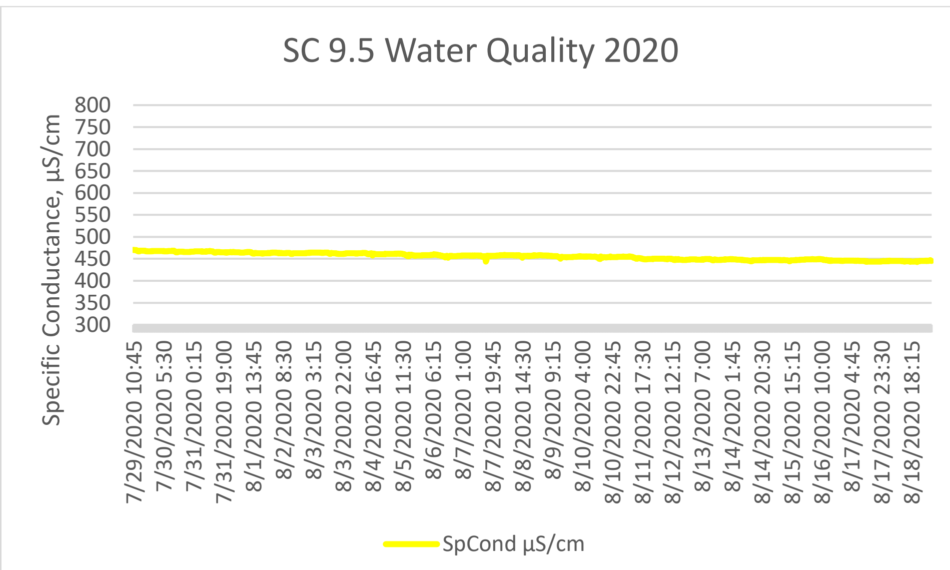


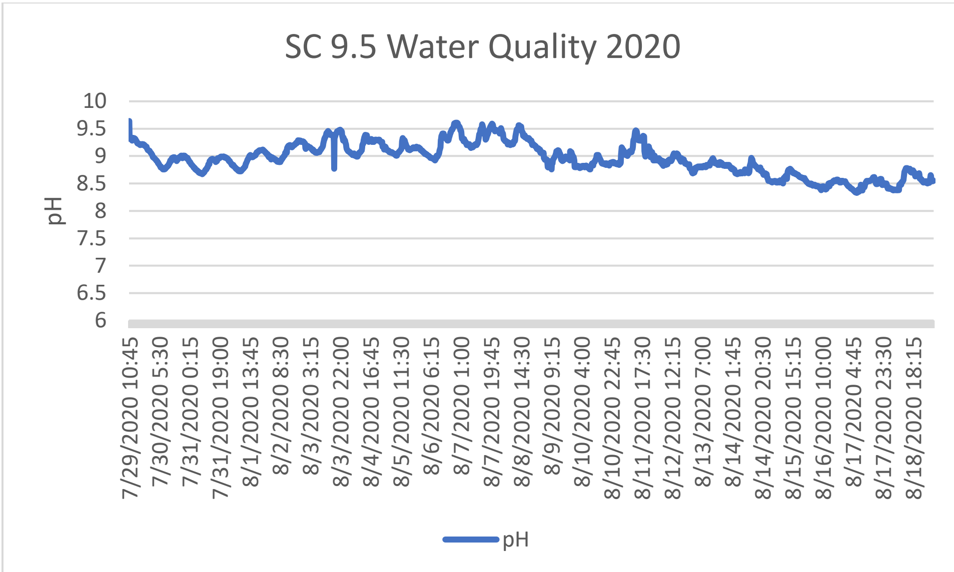
SC 7.0 Water Quality 2019
pH
10
9.5
9
8.5
8
7.5
7
6.5
6
7/18/1910:45:00
7/18/1915:00:00
7/18/1919:15:00
7/18/1923:30:00
7/19/1903:45:00
7/19/1908:00:00
7/19/1912:15:00
7/19/1916:30:00
7/19/1920:45:00
7/19/1901:00:00
7/20/1905:15:00
7/20/1909:30:00
7/20/1913:45:00
7/20/1918:00:00
7/20/1922:15:00
7/21/1902:30:00
7/21/1906:45:00
7/21/1911:00:00
7/21/1915:15:00
7/21/1919:30:00
7/21/1923:45:00
7/22/1904:00:00
7/22/1908:15:00
7/22/1912:30:00
7/22/1916:45:00
7/22/1921:00:00
7/22/1901:15:00
pH

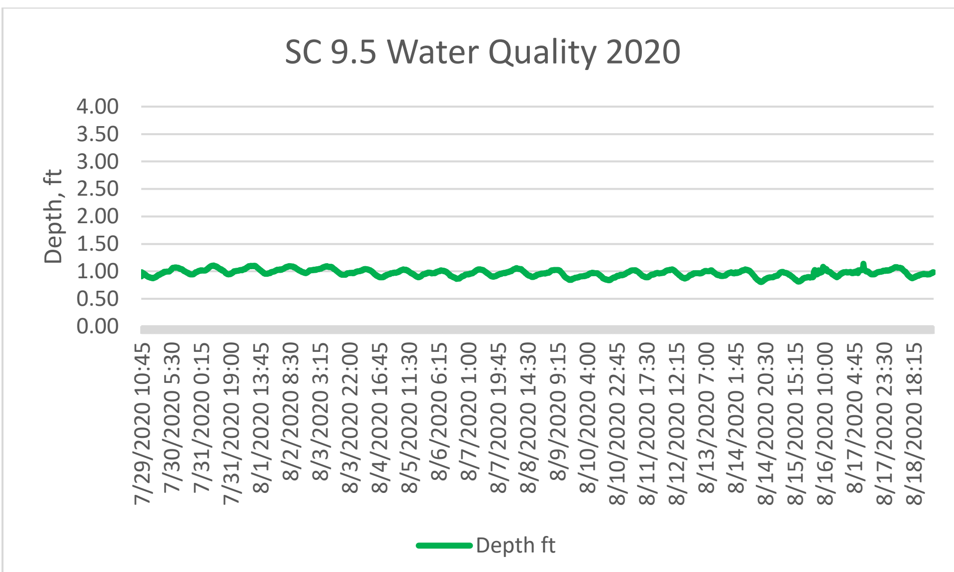


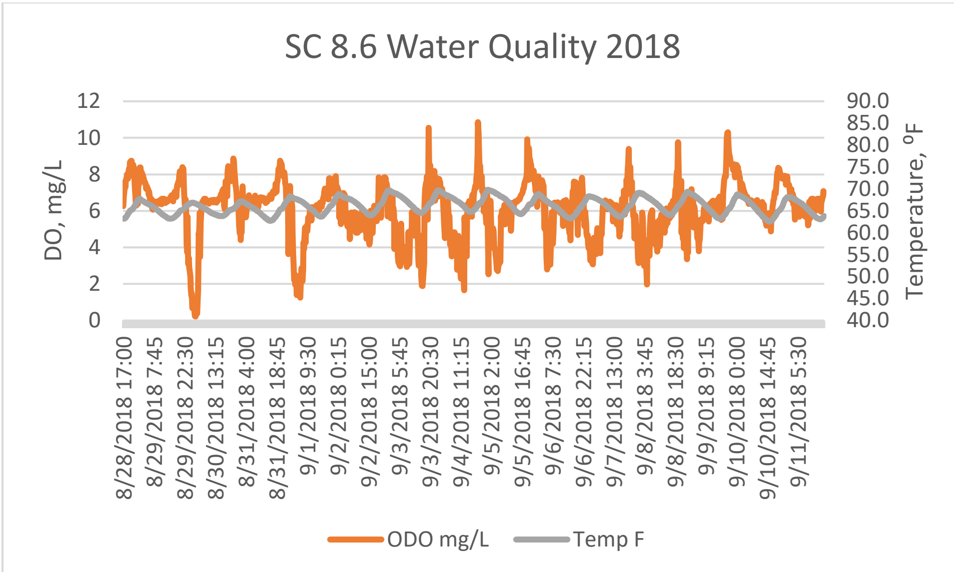
SC 7.0 Water Quality 2019
depth, ft
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
7/18/1910:45:00
7/18/1915:00:00
7/18/1919:15:00
7/18/1923:30:00
7/19/1903:45:00
7/19/1908:00:00
7/19/1912:15:00
7/19/1916:30:00
7/19/1920:45:00
7/19/1901:00:00
7/20/1905:15:00
7/20/1909:30:00
7/20/1913:45:00
7/20/1918:00:00
7/20/1922:15:00
7/21/1902:30:00
7/21/1906:45:00
7/21/1911:00:00
7/21/1915:15:00
7/21/1919:30:00
7/21/1923:45:00
7/22/1904:00:00
7/22/1908:15:00
7/22/1912:30:00
7/22/1916:45:00
7/22/1921:00:00
7/22/1901:15:00
Depth ft


SC 9.5 Water Quality 2020
DO, mg/L
12
10
8
6
4
2
0
Temperature, oF
90.0
85.0
80.0
75.0
70.0
65.0
60.0
55.0
50.0
45.0
40.0
7/29/2020 10:45
7/30/2020 8:45
7/31/2020 6:45
8/1/2020 4:45
8/2/2020 2:45
8/3/2020 0:45
8/3/2020 22:45
8/4/2020 20:45
8/5/2020 18:45
8/6/2020 16:45
8/7/2020 14:45
8/8/2020 12:45
8/9/2020 10:45
8/10/2020 8:45
8/11/2020 6:45
8/12/2020 4:45
8/13/2020 2:45
8/14/2020 0:45
8/14/2020 22:45
8/15/2020 20:45
8/16/2020 18:45
8/17/2020 16:45
8/18/2020 14:45
ODO mg/L
Temp F

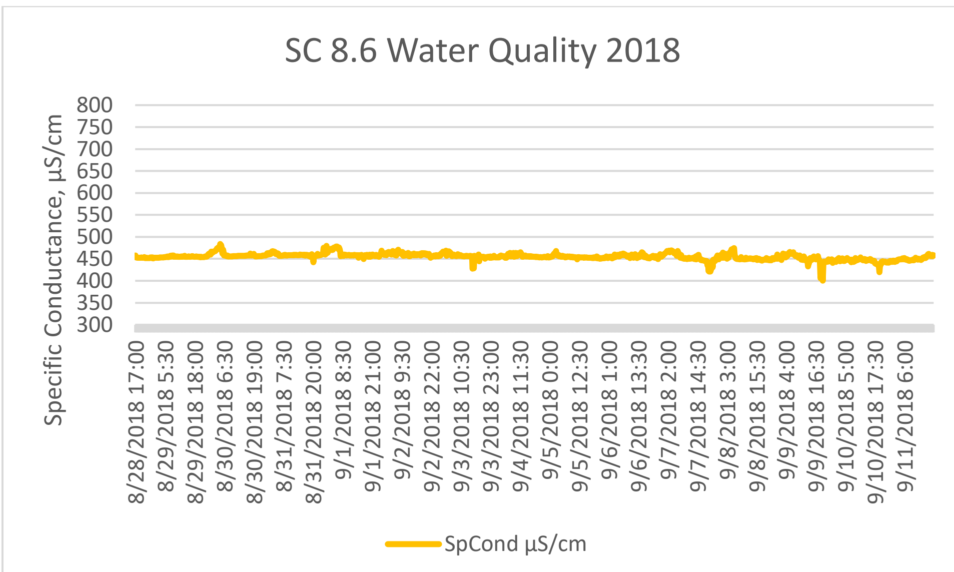

SC 9.5 Water Quality 2020
Specific Conductance, µS/cm
800
750
700
650
600
550
500
450
400
350
300
7/29/2020 10:45
7/30/2020 5:30
7/31/2020 0:15
7/31/2020 19:00
8/1/2020 13:45
8/2/2020 8:30
8/3/2020 3:15
8/3/2020 22:00
8/4/2020 16:45
8/5/2020 11:30
8/6/2020 6:15
8/7/2020 1:00
8/7/2020 19:45
8/8/2020 14:30
8/9/2020 9:15
8/10/2020 4:00
8/10/2020 22:45
8/11/2020 17:30
8/12/2020 12:15
8/13/2020 7:00
8/14/2020 1:45
8/14/2020 20:30
8/15/2020 15:15
8/16/2020 10:00
8/17/2020 4:45
8/17/2020 23:30
8/18/2020 18:15
SpCond µS/cm


SC 9.5 Water Quality 2020
pH
10
9.5
9
8.5
8
7.5
7
6.5
6
7/29/2020 10:45
7/30/2020 5:30
7/31/2020 0:15
7/31/2020 19:00
8/1/2020 13:45
8/2/2020 8:30
8/3/2020 3:15
8/3/2020 22:00
8/4/2020 16:45
8/5/2020 11:30
8/6/2020 6:15
8/7/2020 1:00
8/7/2020 19:45
8/8/2020 14:30
8/9/2020 9:15
8/10/2020 4:00
8/10/2020 22:45
8/11/2020 17:30
8/12/2020 12:15
8/13/2020 7:00
8/14/2020 1:45
8/14/2020 20:30
8/15/2020 15:15
8/16/2020 10:00
8/17/2020 4:45
8/17/2020 23:30
8/18/2020 18:15
pH

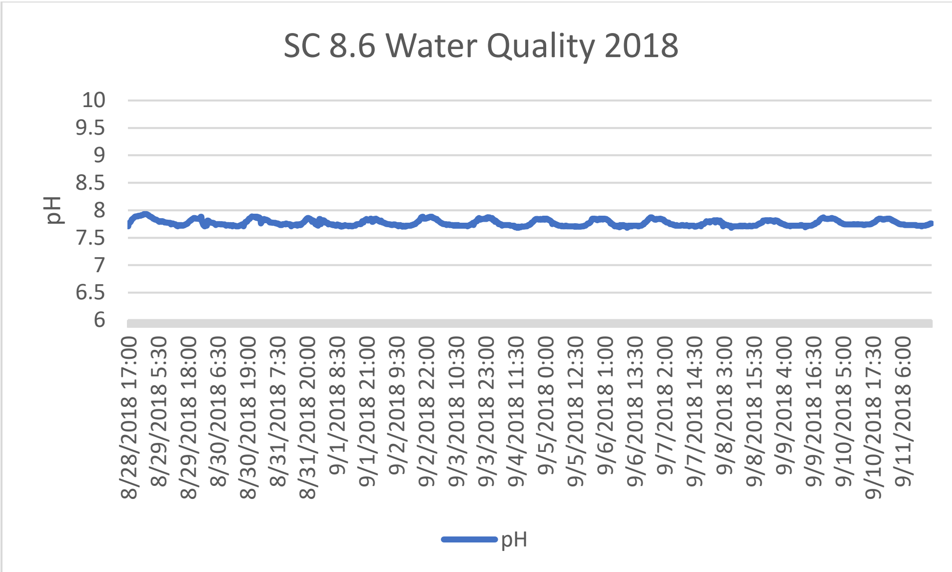

SC 9.5 Water Quality 2020
Depth, ft
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
7/29/2020 10:45
7/30/2020 5:30
7/31/2020 0:15
7/31/2020 19:00
8/1/2020 13:45
8/2/2020 8:30
8/3/2020 3:15
8/3/2020 22:00
8/4/2020 16:45
8/5/2020 11:30
8/6/2020 6:15
8/7/2020 1:00
8/7/2020 19:45
8/8/2020 14:30
8/9/2020 9:15
8/10/2020 4:00
8/10/2020 22:45
8/11/2020 17:30
8/12/2020 12:15
8/13/2020 7:00
8/14/2020 1:45
8/14/2020 20:30
8/15/2020 15:15
8/16/2020 10:00
8/17/2020 4:45
8/17/2020 23:30
8/18/2020 18:15
Depth ft



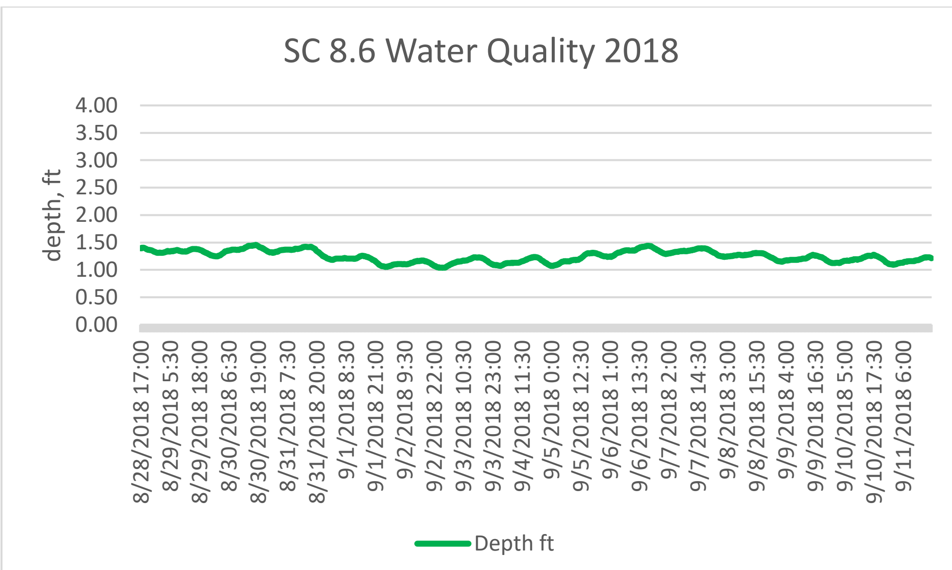
SC 8.6 Water Quality 2018
DO, mg/L
12
10
8
6
4
2
0
Temperature, °F
90.0
85.0
80.0
75.0
70.0
65.0
60.0
55.0
50.0
45.0
40.0
8/28/2018 17:00
8/29/2018 7:45
8/29/2018 22:30
8/30/2018 13:15
8/31/2018 4:00
8/31/2018 18:45
9/1/2018 9:30
9/2/2018 0:15
9/2/2018 15:00
9/3/2018 5:45
9/3/2018 20:30
9/4/2018 11:15
9/5/2018 2:00
9/5/2018 16:45
9/6/2018 7:30
9/6/2018 22:15
9/7/2018 13:00
9/8/2018 3:45
9/8/2018 18:30
9/9/2018 9:15
9/10/2018 0:00
9/10/2018 14:45
9/11/2018 5:30
ODO mg/L
Temp F



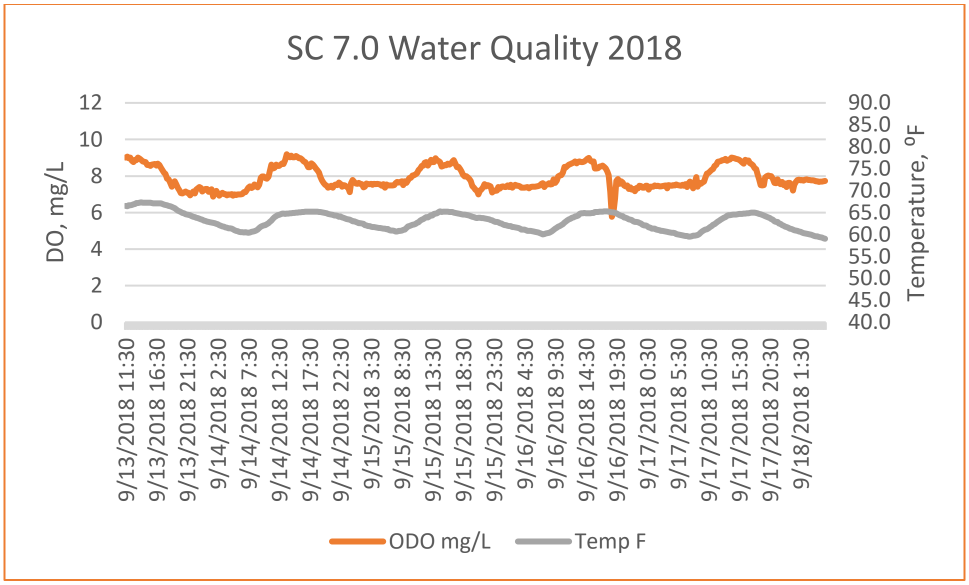
SC 8.6 Water Quality 2018
Specific Conductance, µS/cm
800
750
700
650
600
550
500
450
400
350
300
8/28/2018 17:00
8/29/2018 5:30
8/29/2018 18:00
8/30/2018 6:30
8/30/2018 19:00
8/31/2018 7:30
8/31/2018 20:00
9/1/2018 8:30
9/1/2018 21:00
9/2/2018 9:30
9/2/2018 22:00
9/3/2018 10:30
9/3/2018 23:00
9/4/2018 11:30
9/5/2018 0:00
9/5/2018 12:30
9/6/2018 1:00
9/6/2018 13:30
9/7/2018 2:00
9/7/2018 14:30
9/8/2018 3:00
9/8/2018 15:30
9/9/2018 4:00
9/9/2018 16:30
9/10/2018 5:00
9/10/2018 17:30
9/11/2018 6:00
SpCond µS/cm

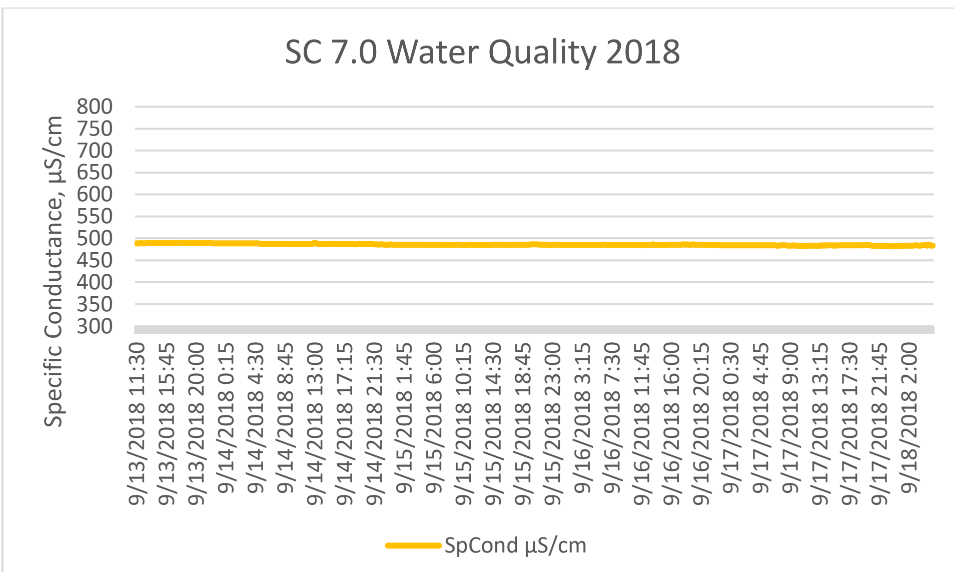


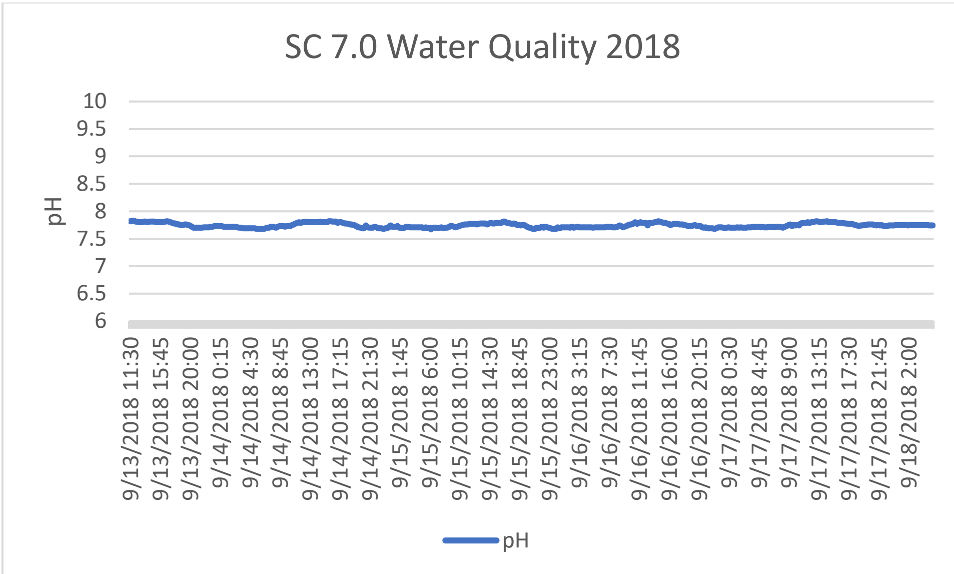
SC 8.6 Water Quality 2018
pH
10
9.5
9
8.5
8
7.5
7
6.5
6
8/28/2018 17:00
8/29/2018 5:30
8/29/2018 18:00
8/30/2018 6:30
8/30/2018 19:00
8/31/2018 7:30
8/31/2018 20:00
9/1/2018 8:30
9/1/2018 21:00
9/2/2018 9:30
9/2/2018 22:00
9/3/2018 10:30
9/3/2018 23:00
9/4/2018 11:30
9/5/2018 0:00
9/5/2018 12:30
9/6/2018 1:00
9/6/2018 13:30
9/7/2018 2:00
9/7/2018 14:30
9/8/2018 3:00
9/8/2018 15:30
9/9/2018 4:00
9/9/2018 16:30
9/10/2018 5:00
9/10/2018 17:30
9/11/2018 6:00
pH



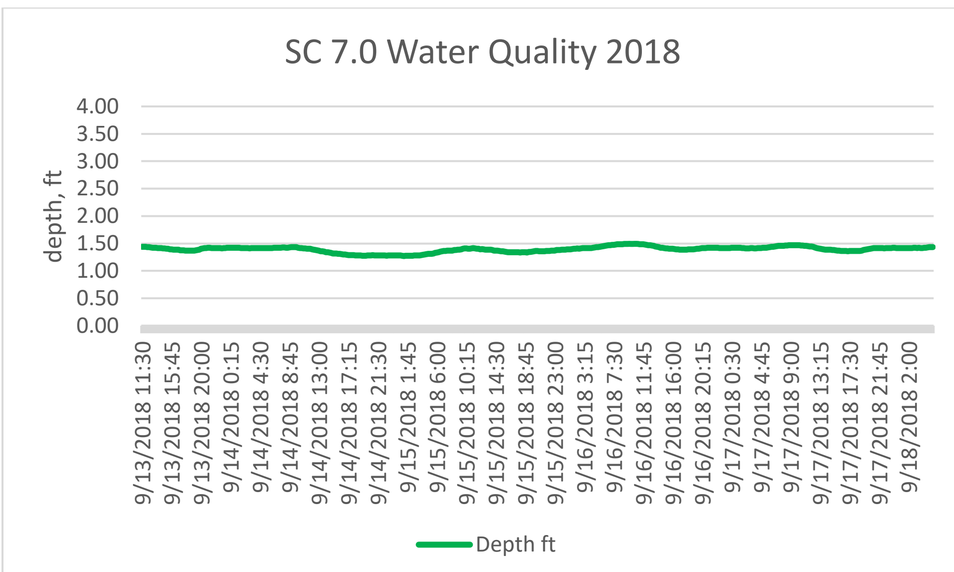
SC 8.6 Water Quality 2018
depth, ft
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
8/28/2018 17:00
8/29/2018 5:30
8/29/2018 18:00
8/30/2018 6:30
8/30/2018 19:00
8/31/2018 7:30
8/31/2018 20:00
9/1/2018 8:30
9/1/2018 21:00
9/2/2018 9:30
9/2/2018 22:00
9/3/2018 10:30
9/3/2018 23:00
9/4/2018 11:30
9/5/2018 0:00
9/5/2018 12:30
9/6/2018 1:00
9/6/2018 13:30
9/7/2018 2:00
9/7/2018 14:30
9/8/2018 3:00
9/8/2018 15:30
9/9/2018 4:00
9/9/2018 16:30
9/10/2018 5:00
9/10/2018 17:30
9/11/2018 6:00
Depth ft


SC 7.0 Water Quality 2018
DO, mg/L
Temperature, °F
ODO mg/L
Temp F

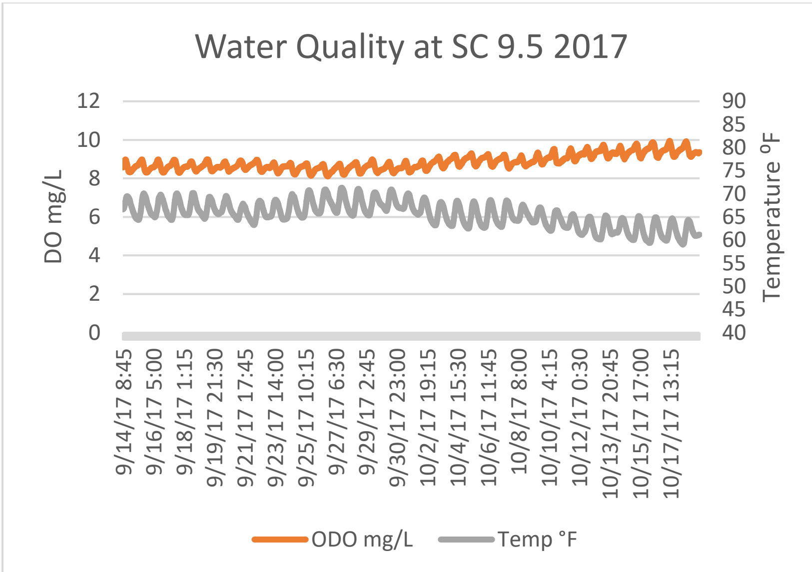

SC 7.0 Water Quality 2018
Specific Conductance, µS/cm
SpCond µS/cm

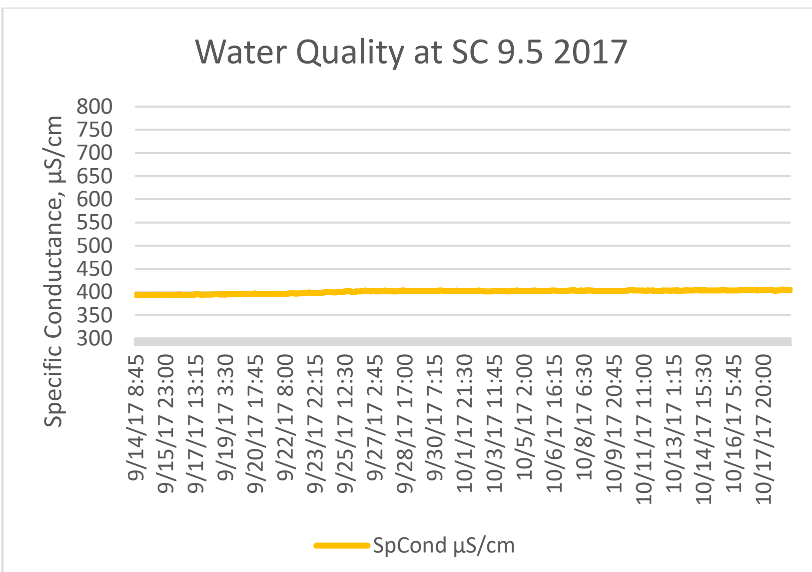


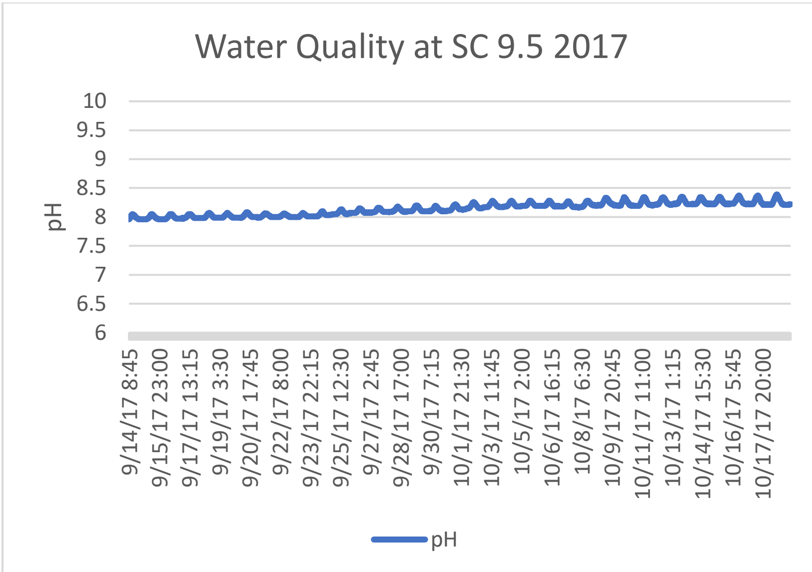
SC 7.0 Water Quality 2018
pH
10
9.5
9
8.5
8
7.5
7
6.5
6
9/13/2018 11:30
9/13/2018 15:45
9/13/2018 20:00
9/14/2018 0:15
9/14/2018 4:30
9/14/2018 8:45
9/14/2018 13:00
9/14/2018 17:15
9/14/2018 21:30
9/15/2018 1:45
9/15/2018 6:00
9/15/2018 10:15
9/15/2018 14:30
9/15/2018 18:45
9/15/2018 23:00
9/16/2018 3:15
9/16/2018 7:30
9/16/2018 11:45
9/16/2018 16:00
9/16/2018 20:15
9/17/2018 0:30
9/17/2018 4:45
9/17/2018 9:00
9/17/2018 13:15
9/17/2018 17:30
9/17/2018 21:45
9/18/2018 2:00
pH



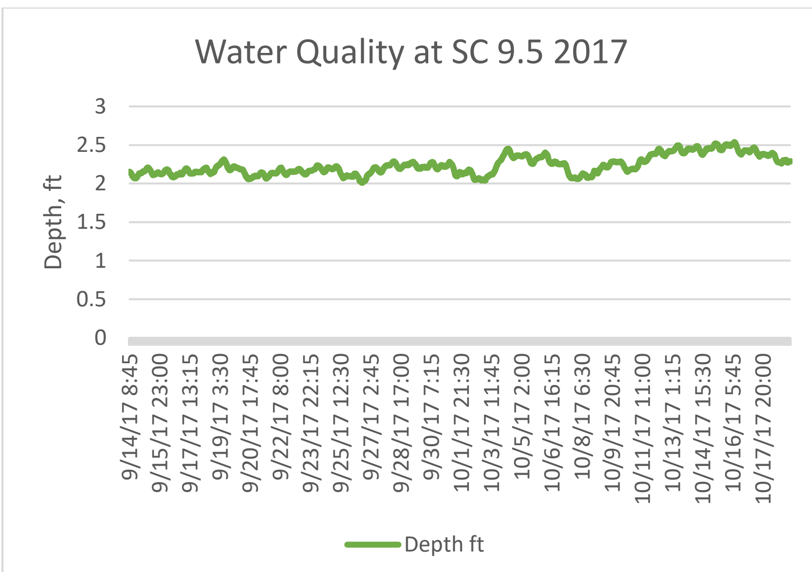
SC 7.0 Water Quality 2018
depth, ft
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
9/13/2018 11:30
9/13/2018 15:45
9/13/2018 20:00
9/14/2018 0:15
9/14/2018 4:30
9/14/2018 8:45
9/14/2018 13:00
9/14/2018 17:15
9/14/2018 21:30
9/15/2018 1:45
9/15/2018 6:00
9/15/2018 10:15
9/15/2018 14:30
9/15/2018 18:45
9/15/2018 23:00
9/16/2018 3:15
9/16/2018 7:30
9/16/2018 11:45
9/16/2018 16:00
9/16/2018 20:15
9/17/2018 0:30
9/17/2018 4:45
9/17/2018 9:00
9/17/2018 13:15
9/17/2018 17:30
9/17/2018 21:45
9/18/2018 2:00
Depth ft


Water Quality at SC 9.5 2017
DO mg/L
Temperature °F
12
10
8
6
4
2
0
90
85
80
75
70
65
60
55
50
45
40
9/14/17 8:45
9/16/17 5:00
9/18/17 1:15
9/19/17 21:30
9/21/17 17:45
9/23/17 14:00
9/25/17 10:15
9/27/17 6:30
9/29/17 2:45
9/30/17 23:00
10/2/17 19:15
10/4/17 15:30
10/6/17 11:45
10/8/17 8:00
10/10/17 4:15
10/12/17 0:30
10/13/17 20:45
10/15/17 17:00
10/17/17 13:15
ODO mg/L
Temp °F


Water Quality at SC 9.5 2017
Specific Conductance, µS/cm
800
750
700
650
600
550
500
450
400
350
300
9/14/17 8:45
9/15/17 23:00
9/17/17 13:15
9/19/17 3:30
9/20/17 17:45
9/22/17 8:00
9/23/17 22:15
9/25/17 12:30
9/27/17 2:45
9/28/17 17:00
9/30/17 7:15
10/1/17 21:30
10/3/17 11:45
10/5/17 2:00
10/6/17 16:15
10/8/17 6:30
10/9/17 20:45
10/11/17 11:00
10/13/17 1:15
10/14/17 15:30
10/16/17 5:45
10/17/17 20:00
SpCond µS/cm



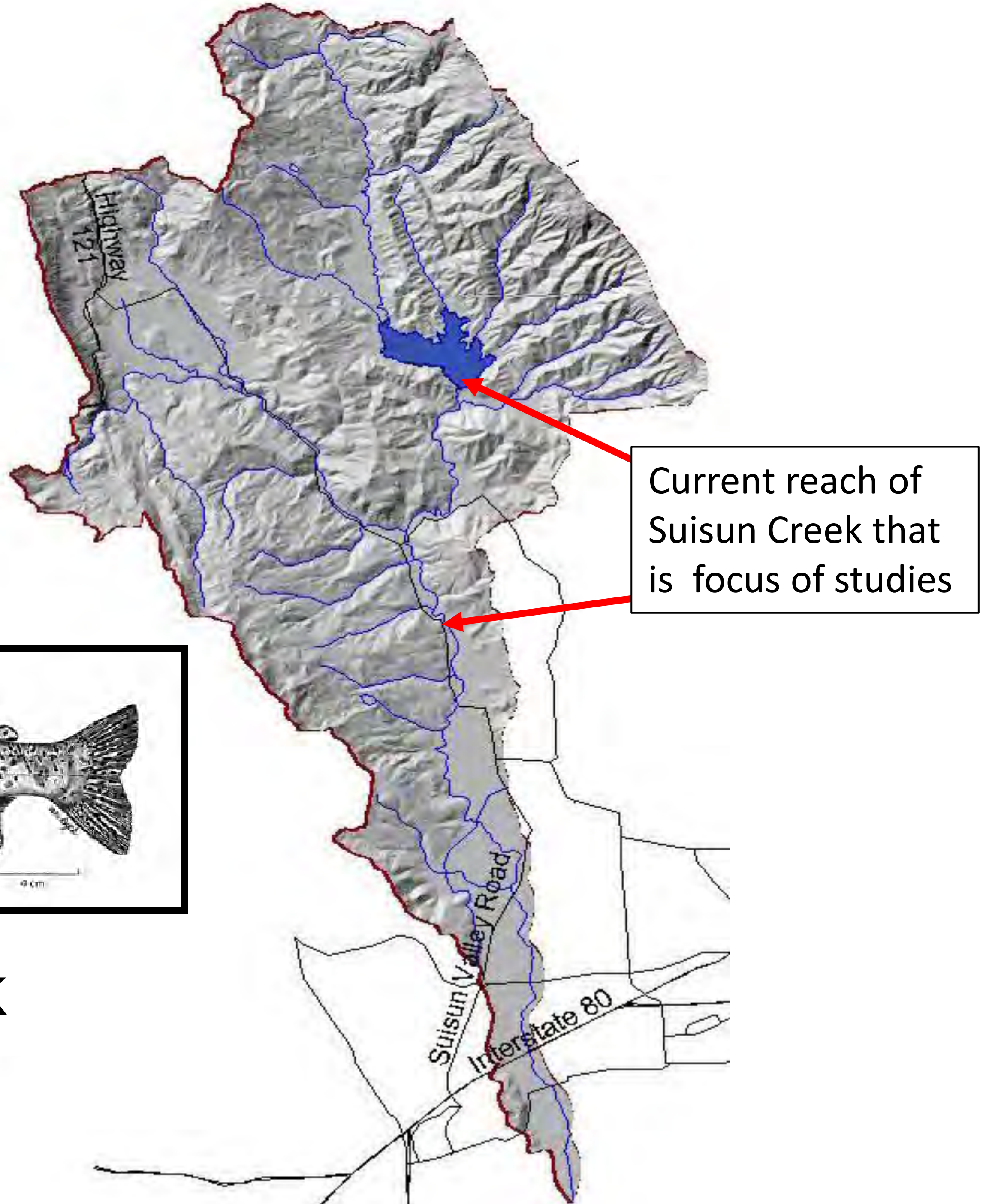
Water Quality at SC 9.5 2017
pH
10
9.5
9
8.5
8
7.5
7
6.5
6
9/14/17 8:45
9/15/17 23:00
9/17/17 13:15
9/19/17 3:30
9/20/17 17:45
9/22/17 8:00
9/23/17 22:15
9/25/17 12:30
9/27/17 2:45
9/28/17 17:00
9/30/17 7:15
10/1/17 21:30
10/3/17 11:45
10/5/17 2:00
10/6/17 16:15
10/8/17 6:30
10/9/17 20:45
10/11/17 11:00
10/13/17 1:15
10/14/17 15:30
10/16/17 5:45
10/17/17 20:00
pH

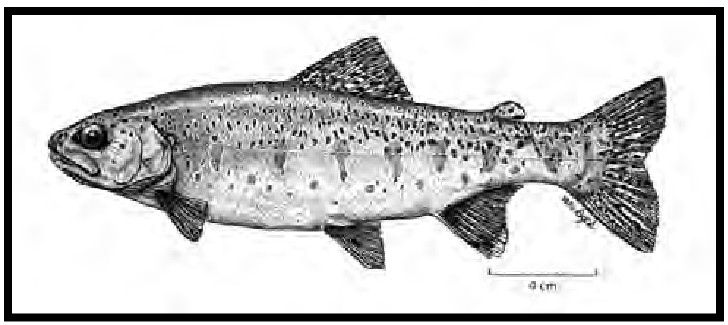


Water Quality at SC 9.5 2017
Depth, ft
3
2.5
2
1.5
1
0.5
0
9/14/17 8:45
9/15/17 23:00
9/17/17 13:15
9/19/17 3:30
9/20/17 17:45
9/22/17 8:00
9/23/17 22:15
9/25/17 12:30
9/27/17 2:45
9/28/17 17:00
9/30/17 7:15
10/1/17 21:30
10/3/17 11:45
10/5/17 2:00
10/6/17 16:15
10/8/17 6:30
10/9/17 20:45
10/11/17 11:00
10/13/17 1:15
10/14/17 15:30
10/16/17 5:45
10/17/17 20:00
Depth ft

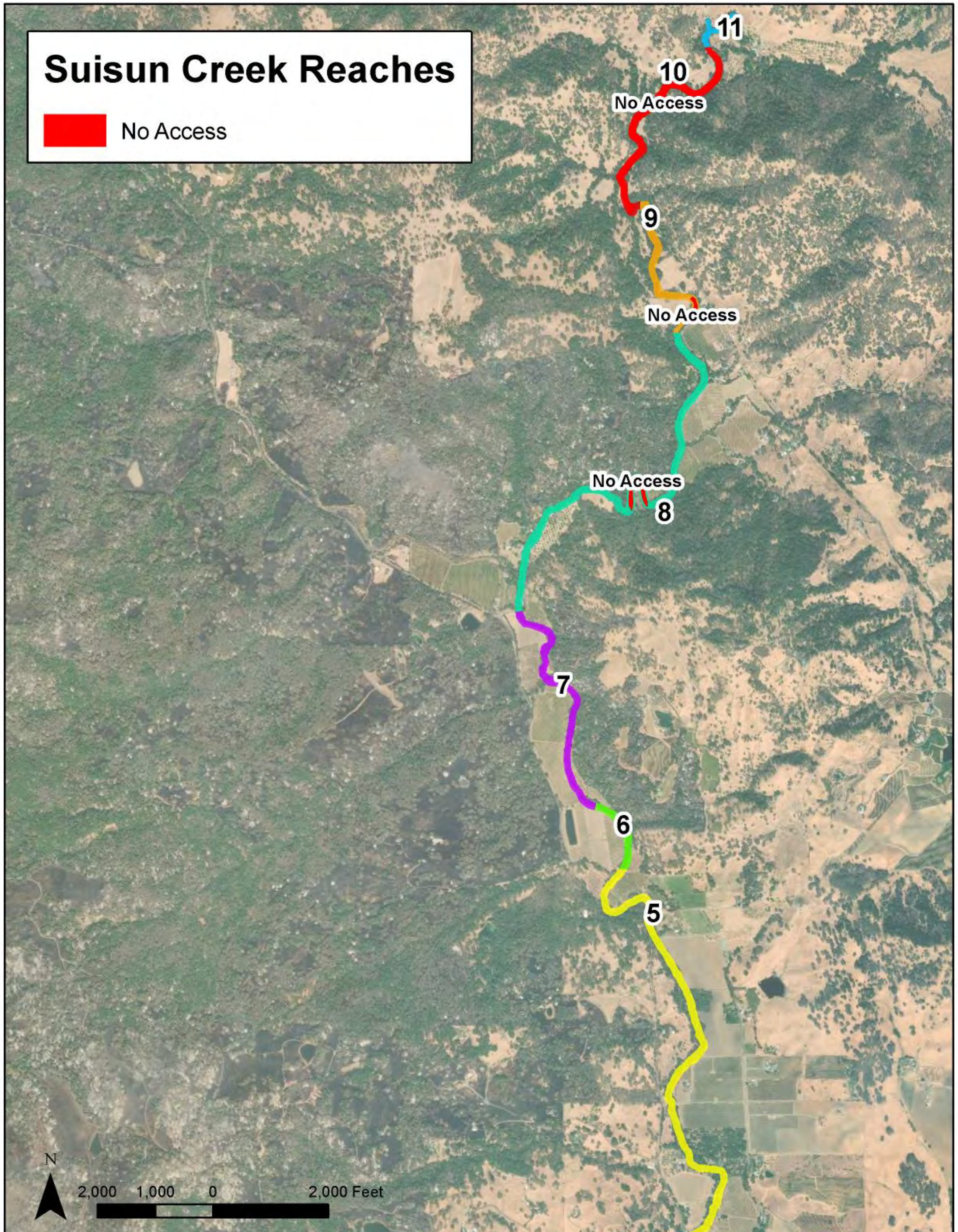
Appendix E

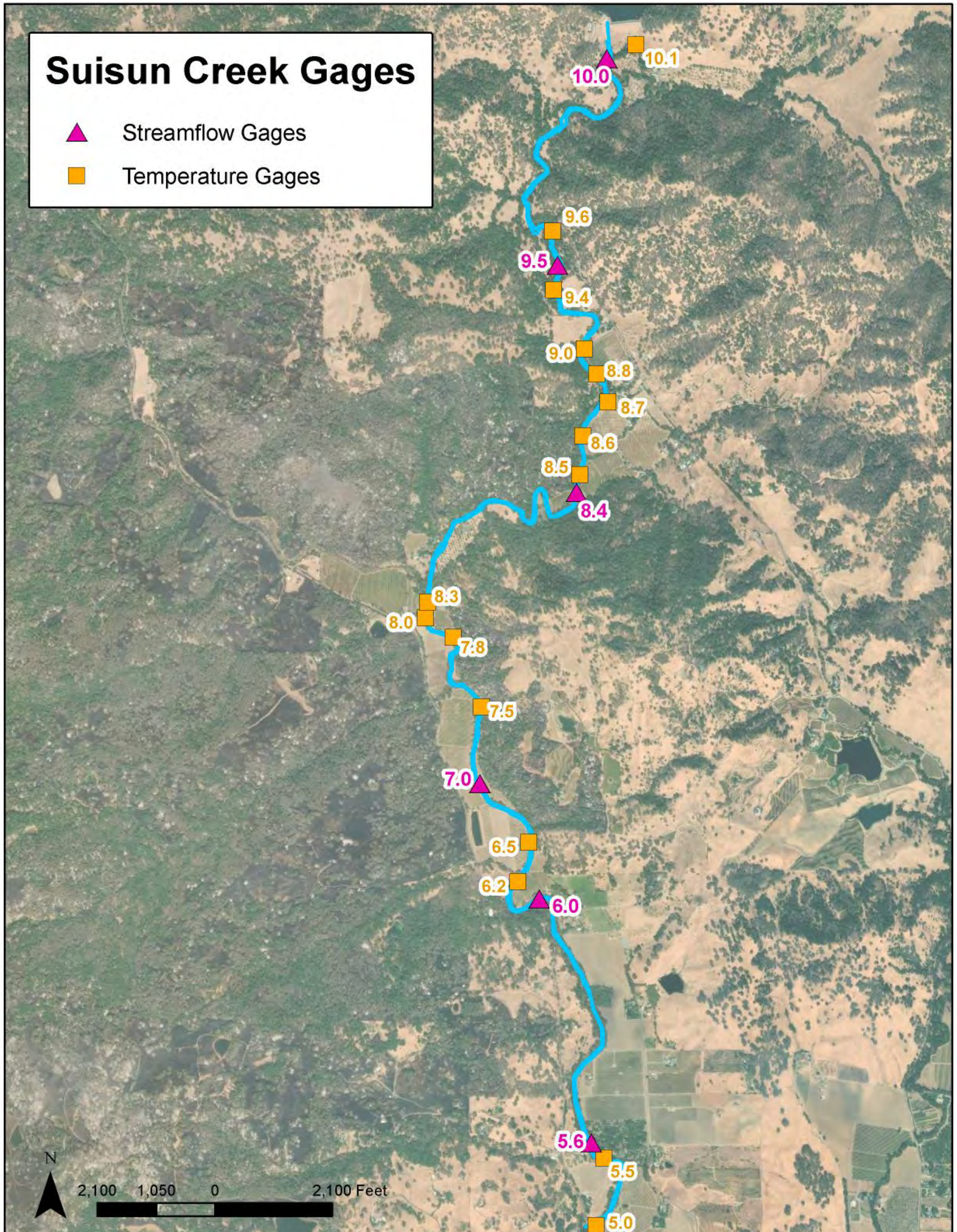
Riparian Corridor Survey of Suisun Creek



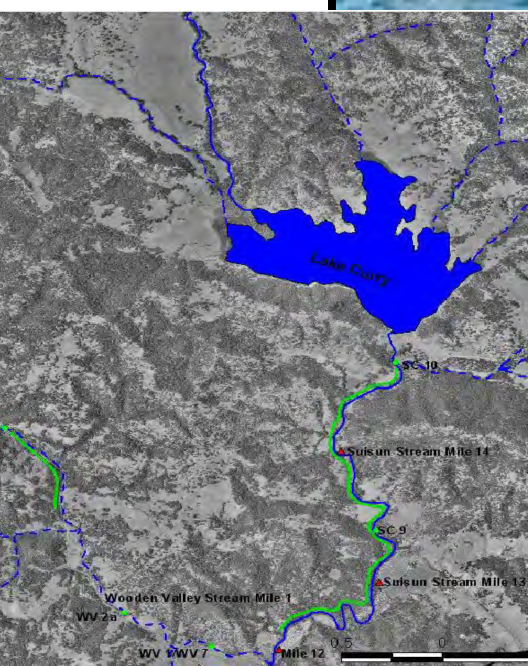


SUISUN CREEK WATERSHED


Suisun Creek Reaches
No Access
11
10
No Access
9
No Access
No Access
8
7
6
5
N
2,000 1,000 0 2,000 Feet



Suisun Creek Gages
Streamflow Gages
Temperature Gages
10.1
10.0
9.6
9.5
9.4
9.0
8.8
8.7
8.6
8.5
8.4
8.3
8.0
7.8
7.5
7.0
6.5
6.2
6.0
5.6
5.5
5.0
N
2,100 1,050 0 2,100 Feet



Lake Curry
SC 10
Suisun Stream Mile 14
SC 9
Suisun Stream Mile 13
Wooden Valley Stream Mile 1
WV 2a
WV 1/WV 7
Mile 12
0.5
0

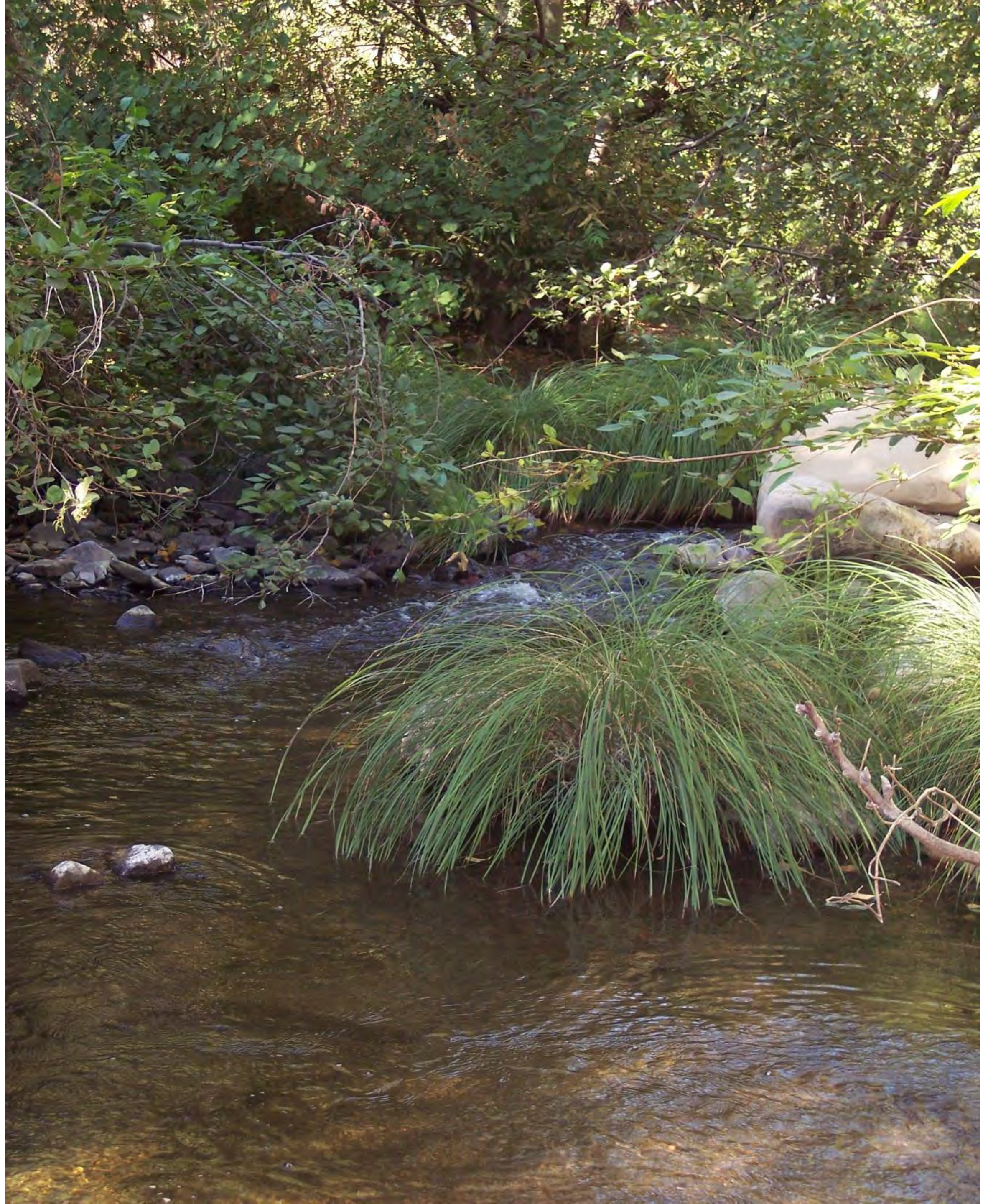

SC-10


SC-9.5


SC-8.6

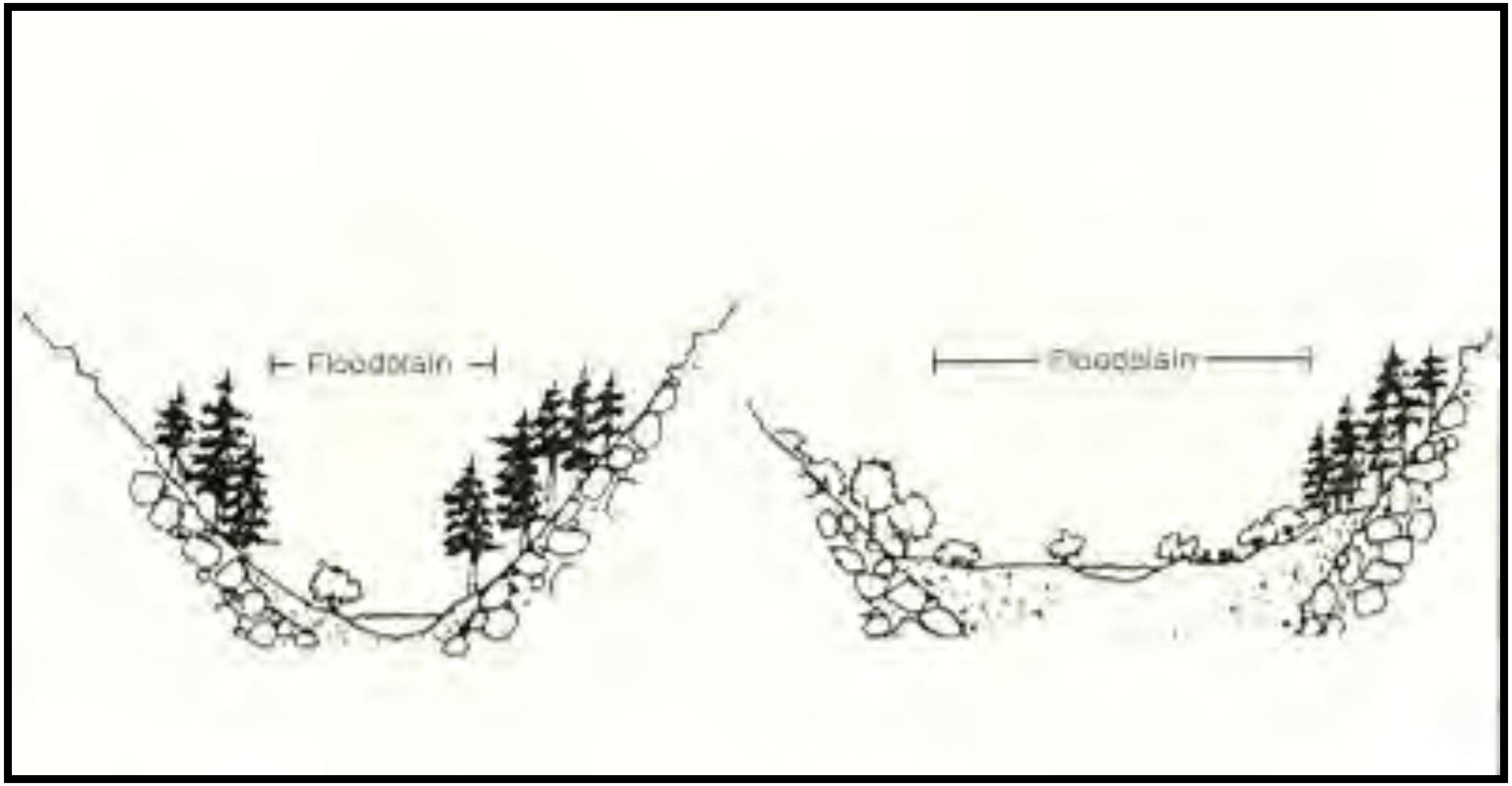
SC-8 Wooden Valley Crossroad bridge

SC-7




SC-6

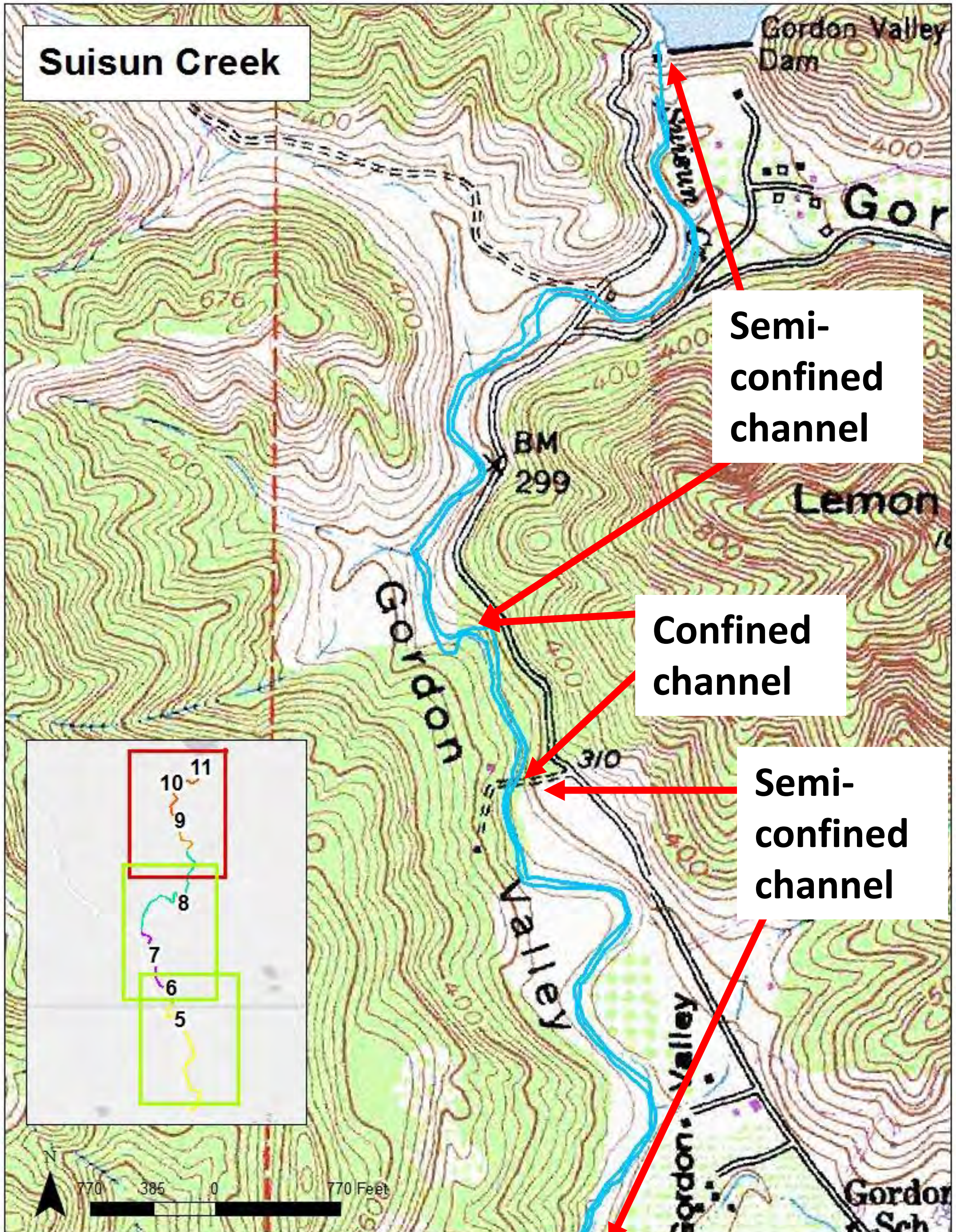

SC 5.5



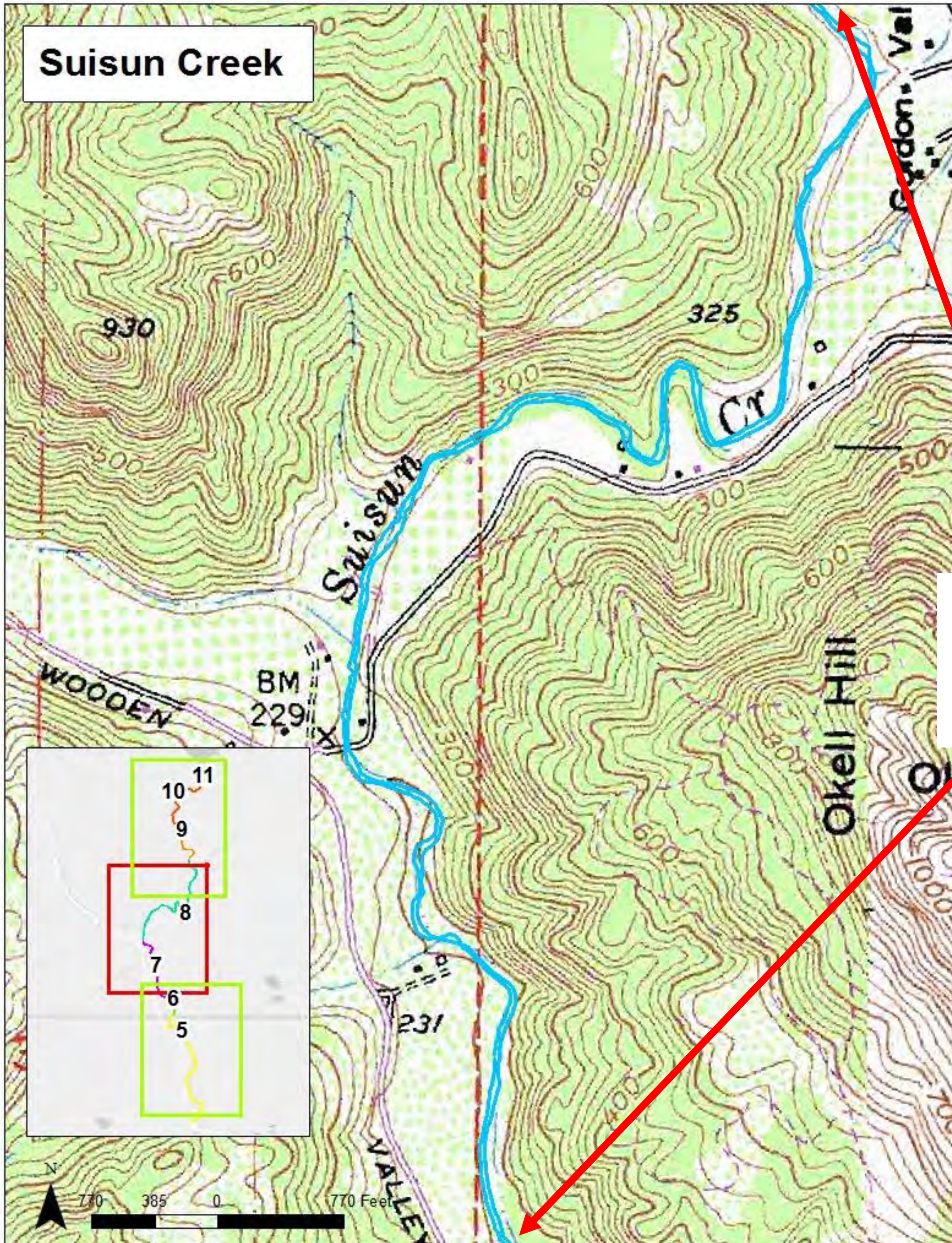
CONFINED CHANNEL

UNCONFINED CHANNEL

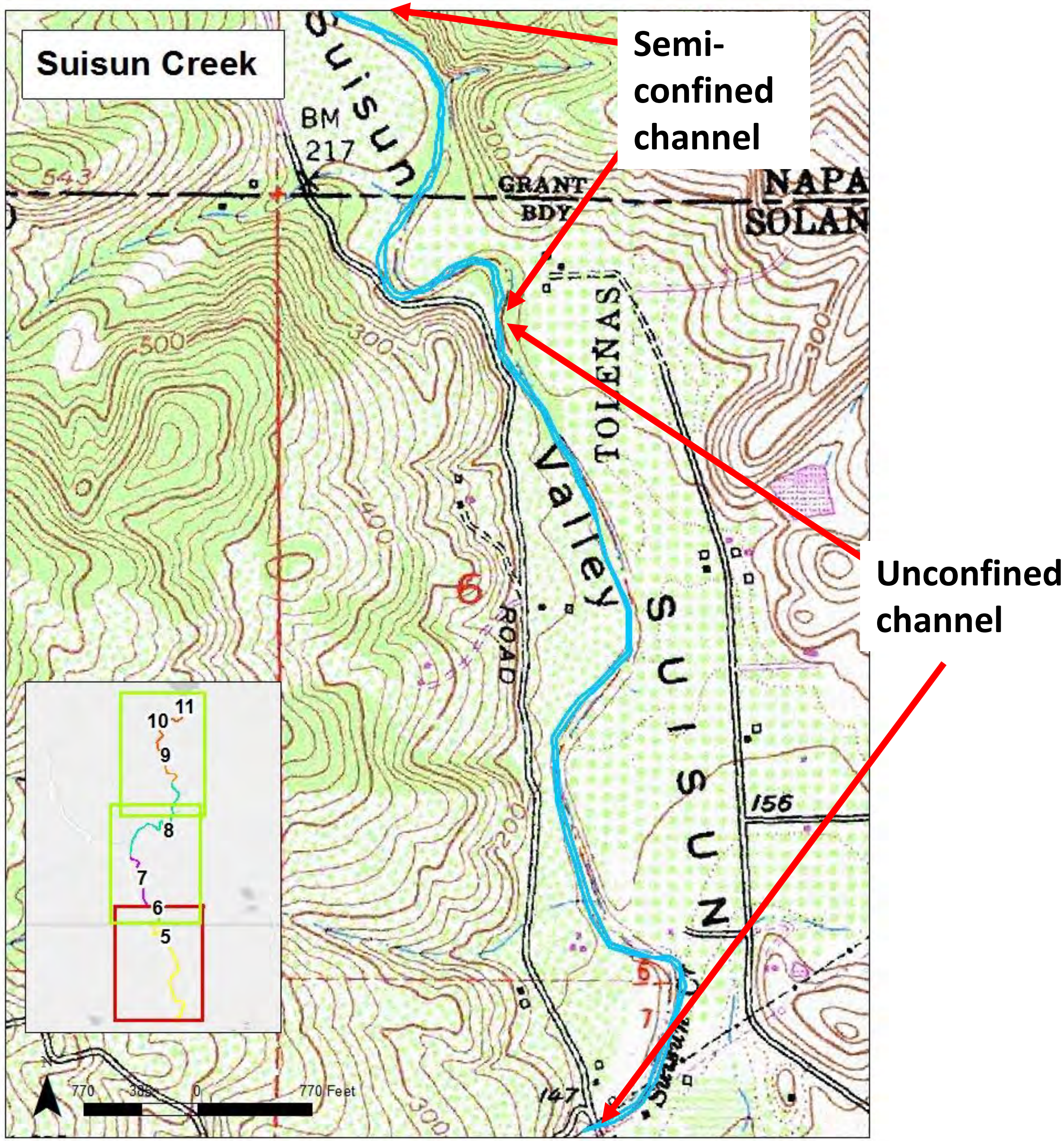
Semi-confined channel



Suisun Creek
Gordon Valley Dam
Gor
Semi-confined channel
BM 299
Lemon
Confined channel
Gordon
Valley
Semi-confined channel
Gordon Valley
Gordon Sch
11
10
9
8
7
6
5
770 385 0 770 Feet
N



Semi-confined channel

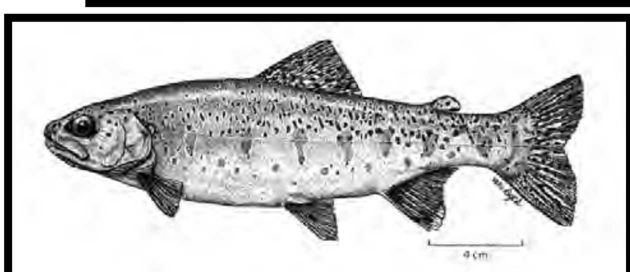


Suisun Creek
Semi-confined channel
Unconfined channel
BM 217
GRANT BDY
NAPA
SOLAN
TOLENAS
Suisun Valley
ROAD
SUISUN
543
500
300
400
200
156
147
11
10
9
8
7
6
5
770 385 0 770 Feet

8/18 Field Data Collection: Riparian Habitat

RIPARIAN WILDLIFE

Riparian trees provide bank protection against erosion



Riparian trees shade the creek and help to keep water temperatures cool for steelhead trout

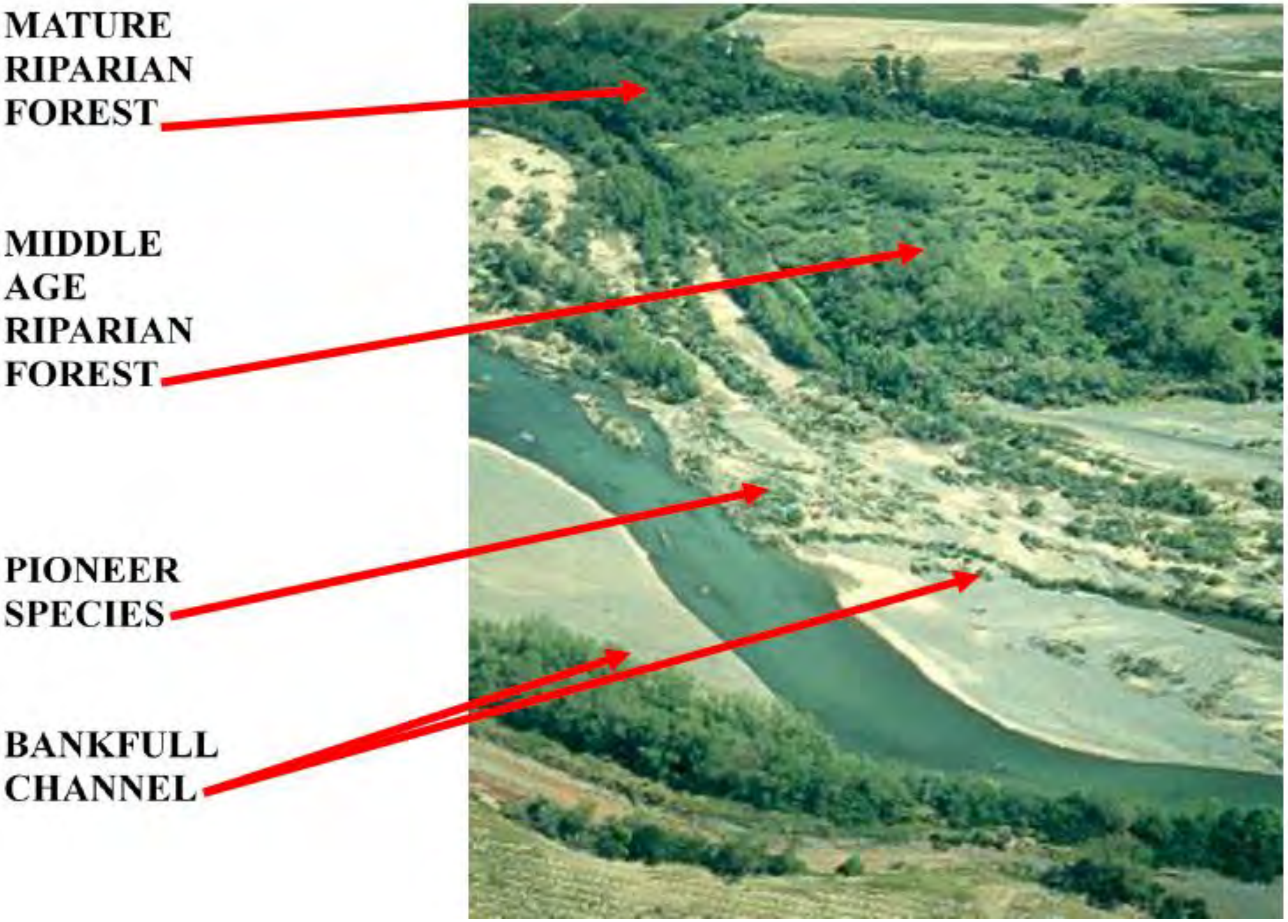
Polygons were delineated along the Suisun Creek channel. Within each polygon we recorded the condition of the channel and banks, presence of erosion, number and location of bank revetments and invasive species, dead tree impact zones, the number and size class of each tree species, understory species and density and any other conditions of note

Willow

White Alder

Fremont Cottonwood

Pioneer Species




Ca. Walnut

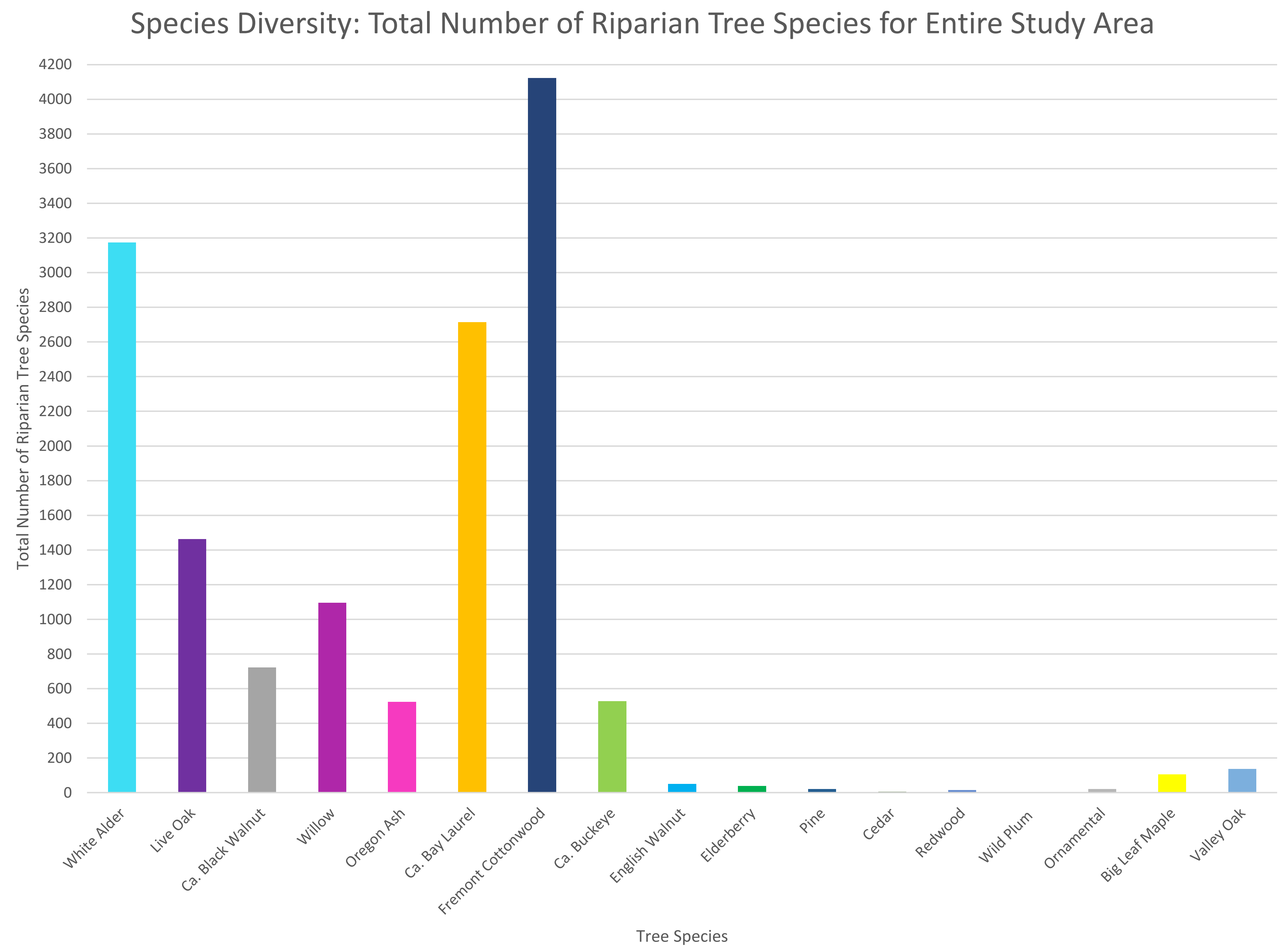

Oregon Ash


Valley Oak

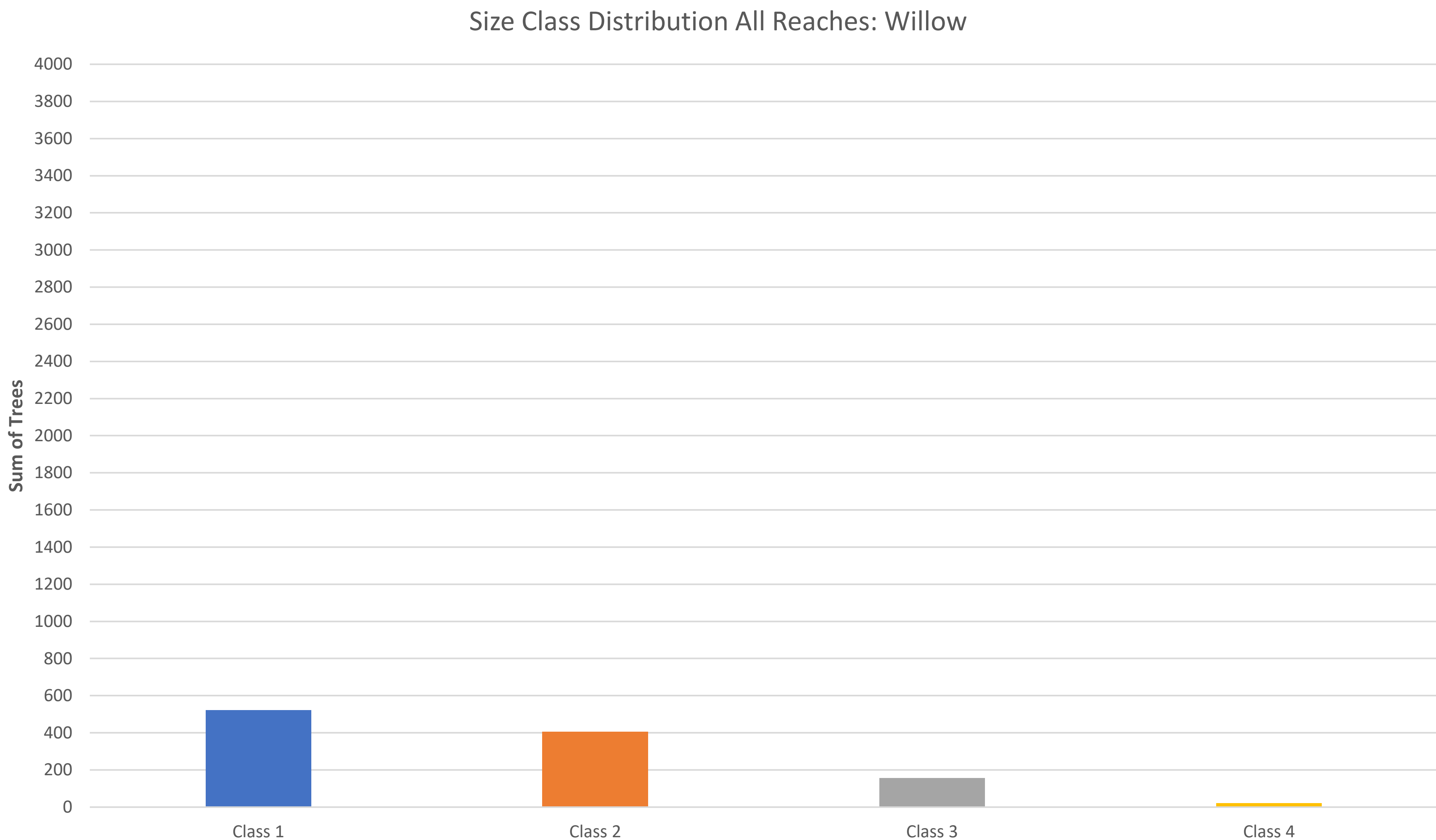

Ca. Bay Laurel


Big-leaf Maple

RESULTS OF 2018 RIPARIAN MAPPING

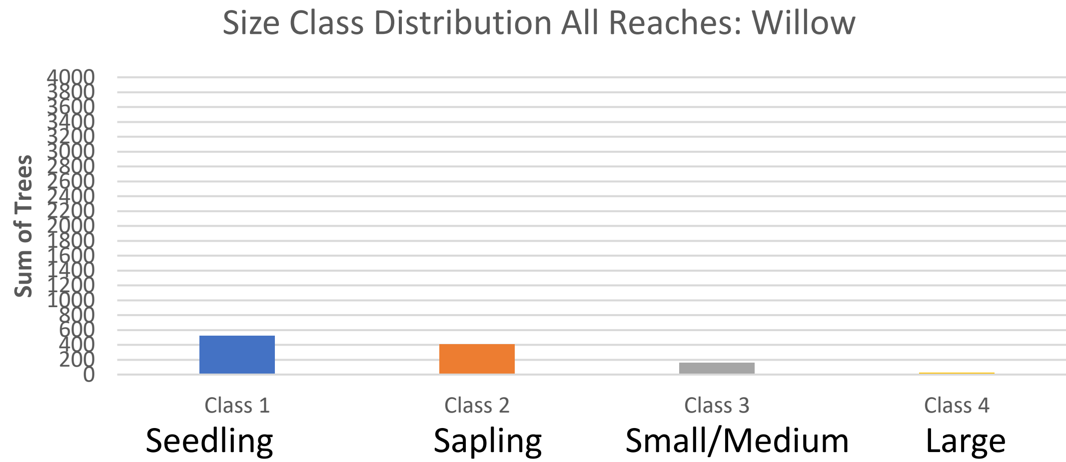


Species Diversity: Total Number of Riparian Tree Species for Entire Study Area
4200
4000
3800
3600
3400
3200
3000
2800
2600
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
Total Number of Riparian Tree Species
White Alder
Live Oak
Ca. Black Walnut
Willow
Oregon Ash
Ca. Bay Laurel
Fremont Cottonwood
Ca. Buckeye
English Walnut
Elderberry
Pine
Cedar
Redwood
Wild Plum
Ornamental
Big Leaf Maple
Valley Oak
Tree Species

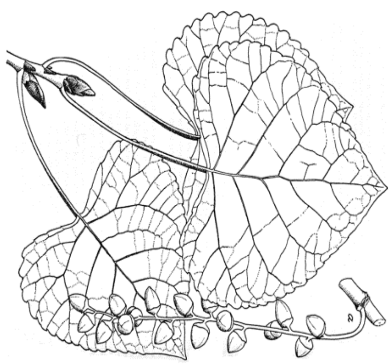


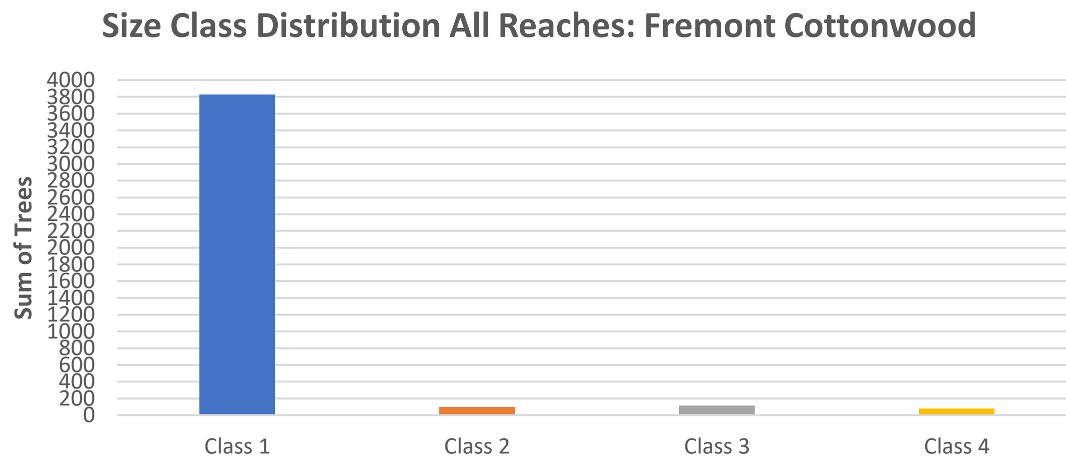
Diameter at Breast Height (DBH)	Successional Status	Tree Size Class
<1"	Seedling	C1
1"-7"	Sapling	C2
7"-24"	Small/Medium Tree	C3
>24"	Large Tree	C4

Willow (Salix sp.)

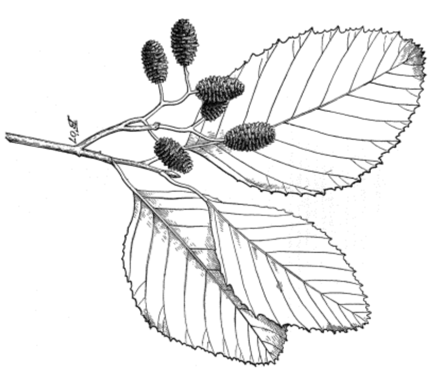


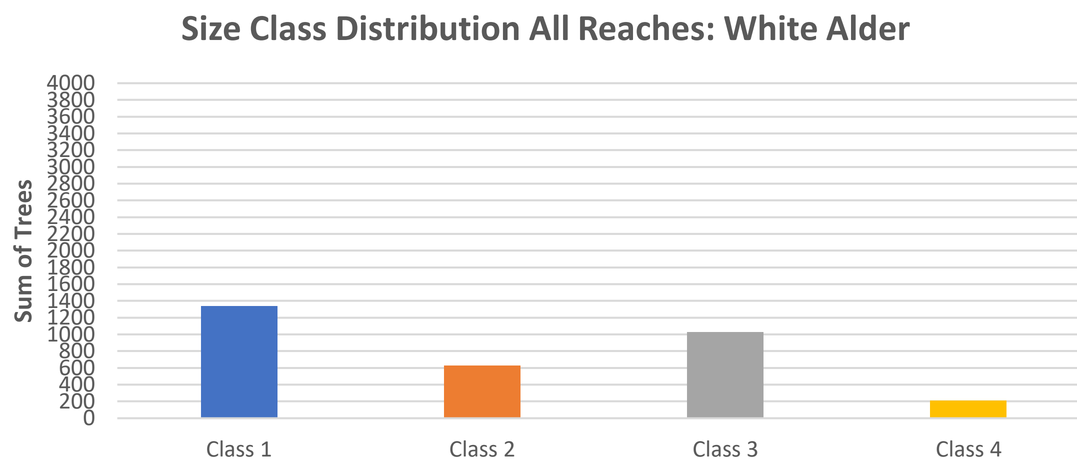
Fremont Cottonwood (Populus fremontii)



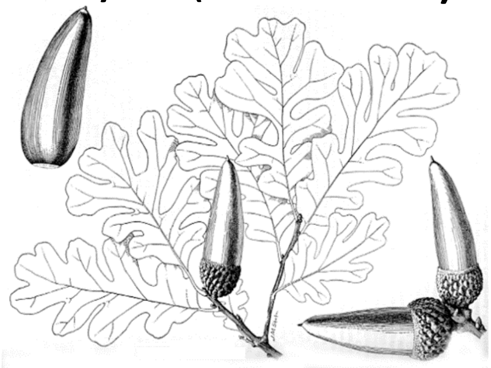


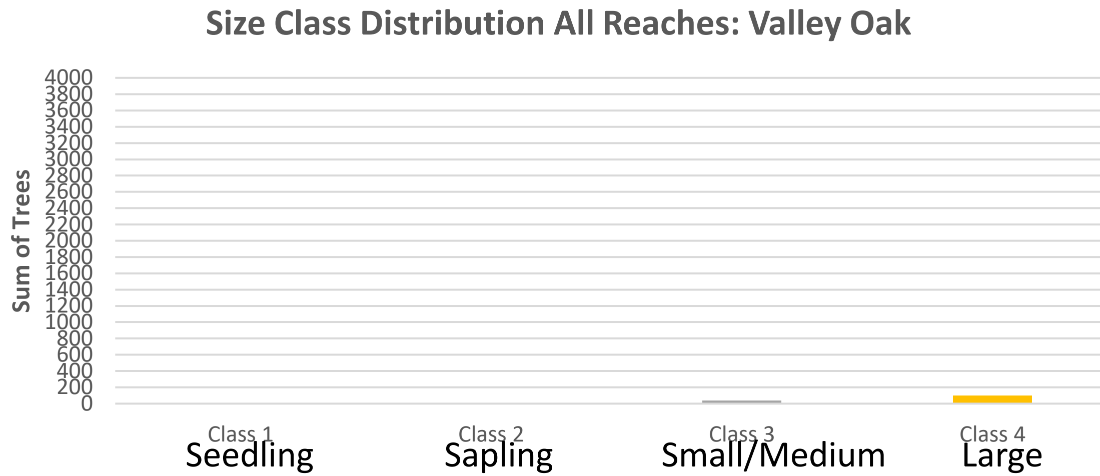
White Alder (Alnus rhombifolia)



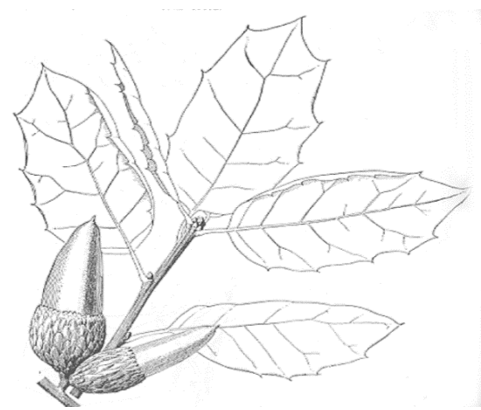


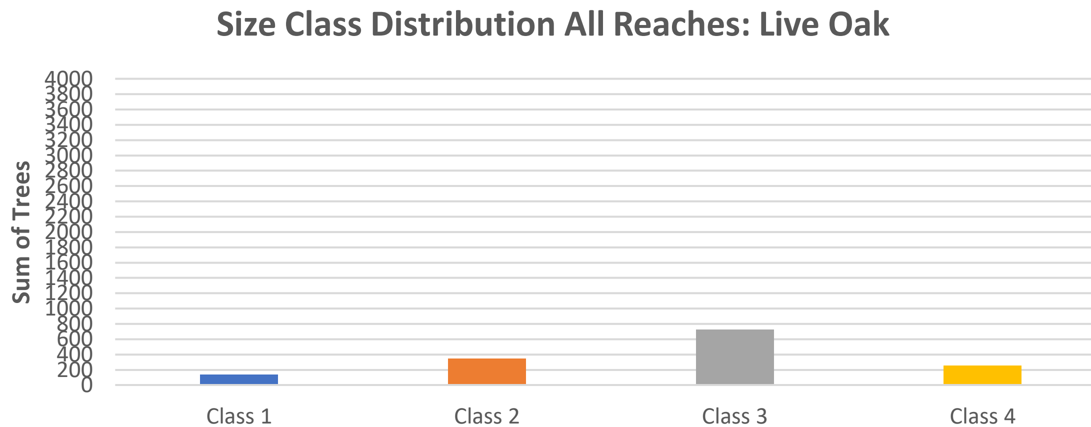
Valley Oak (Quercus lobata)



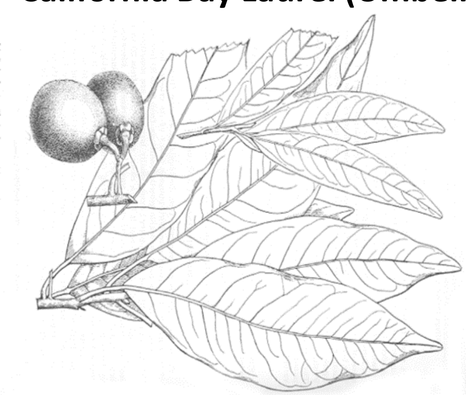


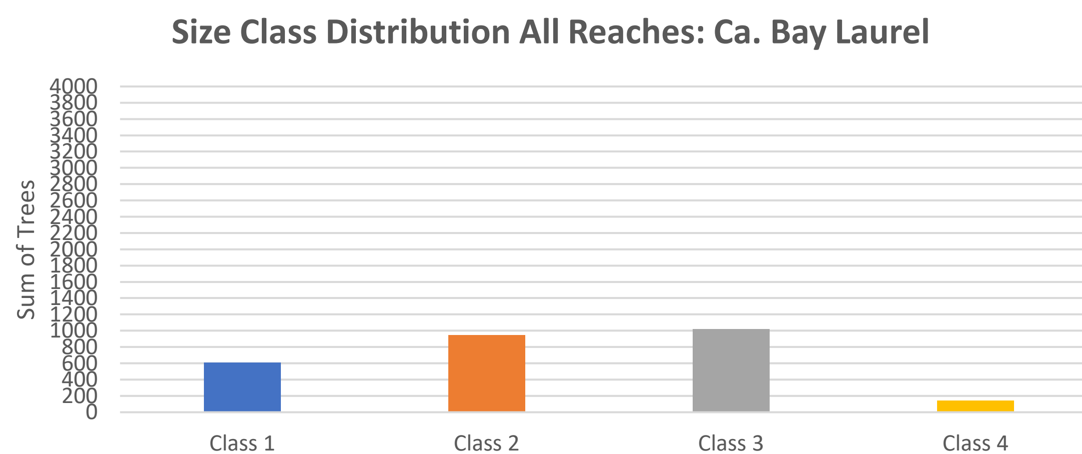
Live Oak (Quercus agrifolia)



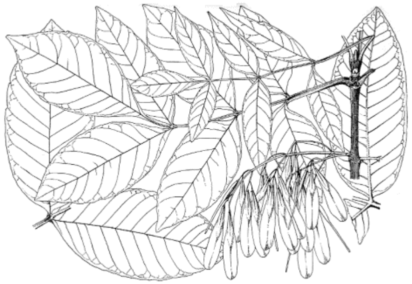


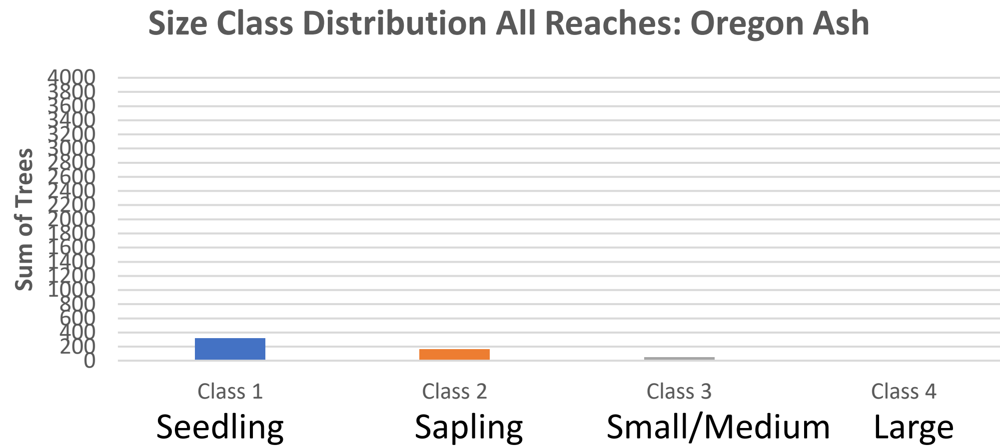
California Bay Laurel (Umbellularia californica)



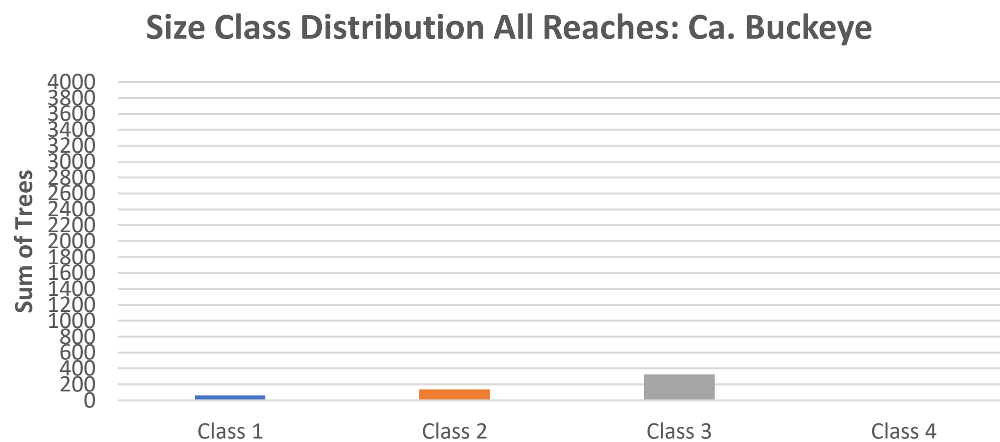


Oregon Ash (Fraxinus latifolia)

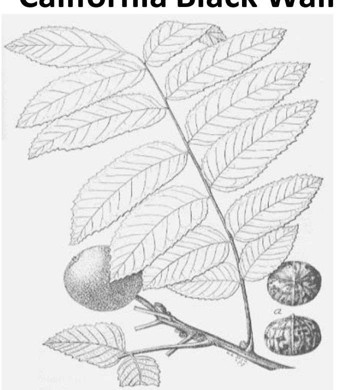


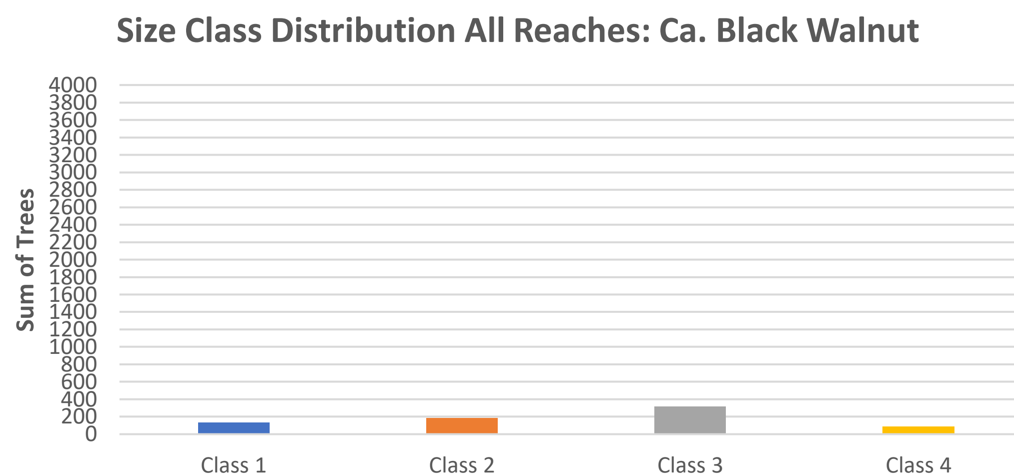


California Buckeye (Aesculus californica)

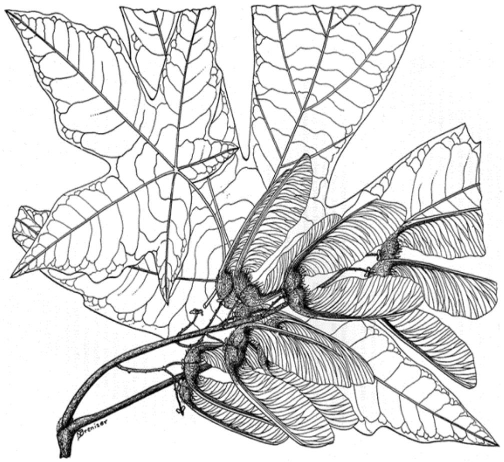


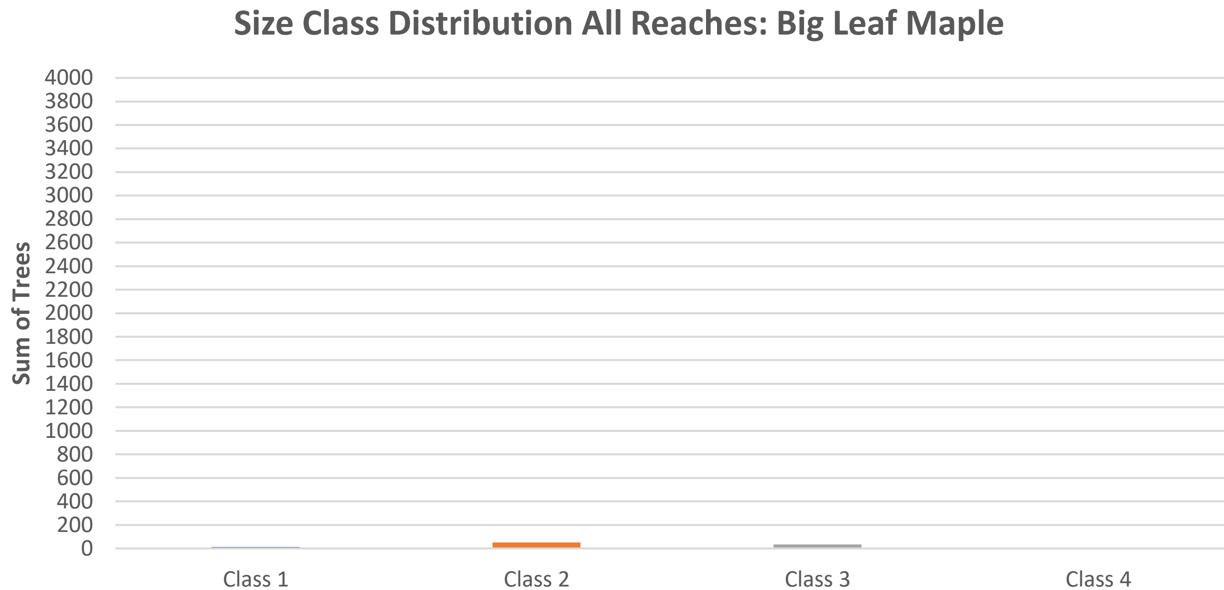
California Black Walnut (Juglans californica)





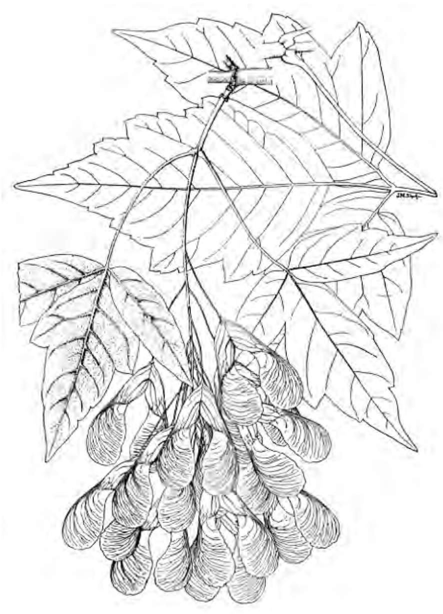
Big Leaf Maple (Acer macrophyllum)

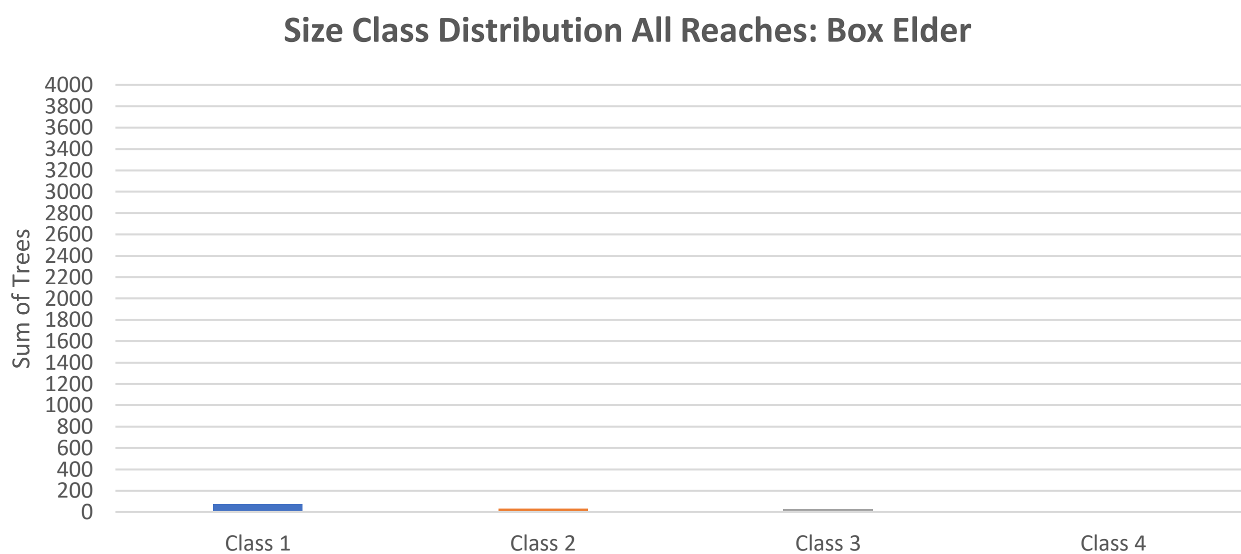




Seedling Sapling Small/Medium Large

Box Elder (Acer negundo)





Summary

11 native tree species were found providing a good level of biodiversity

Most common pioneer species – cottonwood and white alder, willow much less common

Most common mid and upper bank species – Ca bay laurel, live oak

White alder and willow have an even distribution of seedlings, saplings, small and large trees (C1-C4)

Fremont cottonwood has a high number of seedlings compared to other size classes

Live oak, Ca. bay laurel, Ca. black walnut and Oregon ash had the highest number of seedlings for the mid and upper bank species

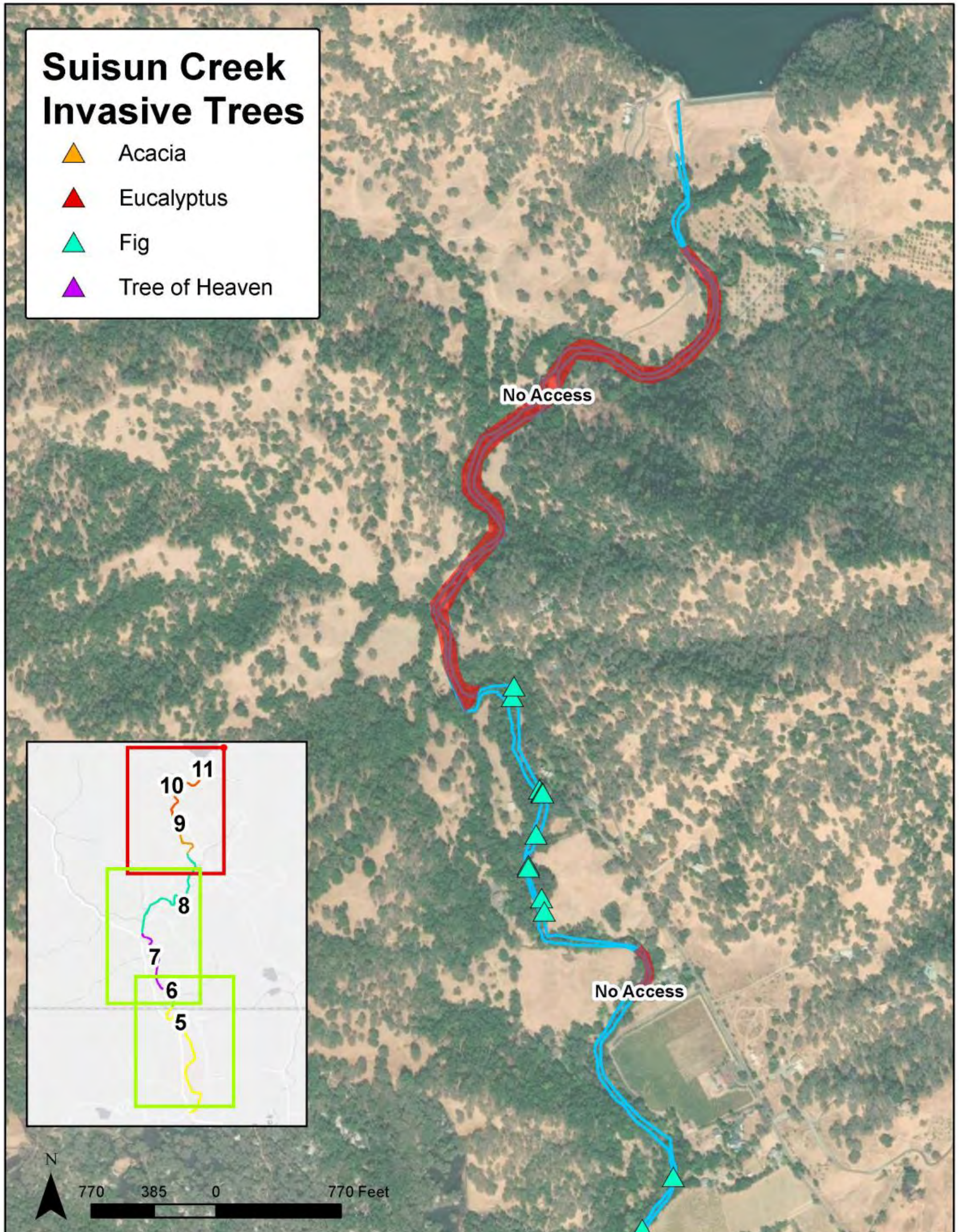
INVASIVE NON-NATIVE TREES

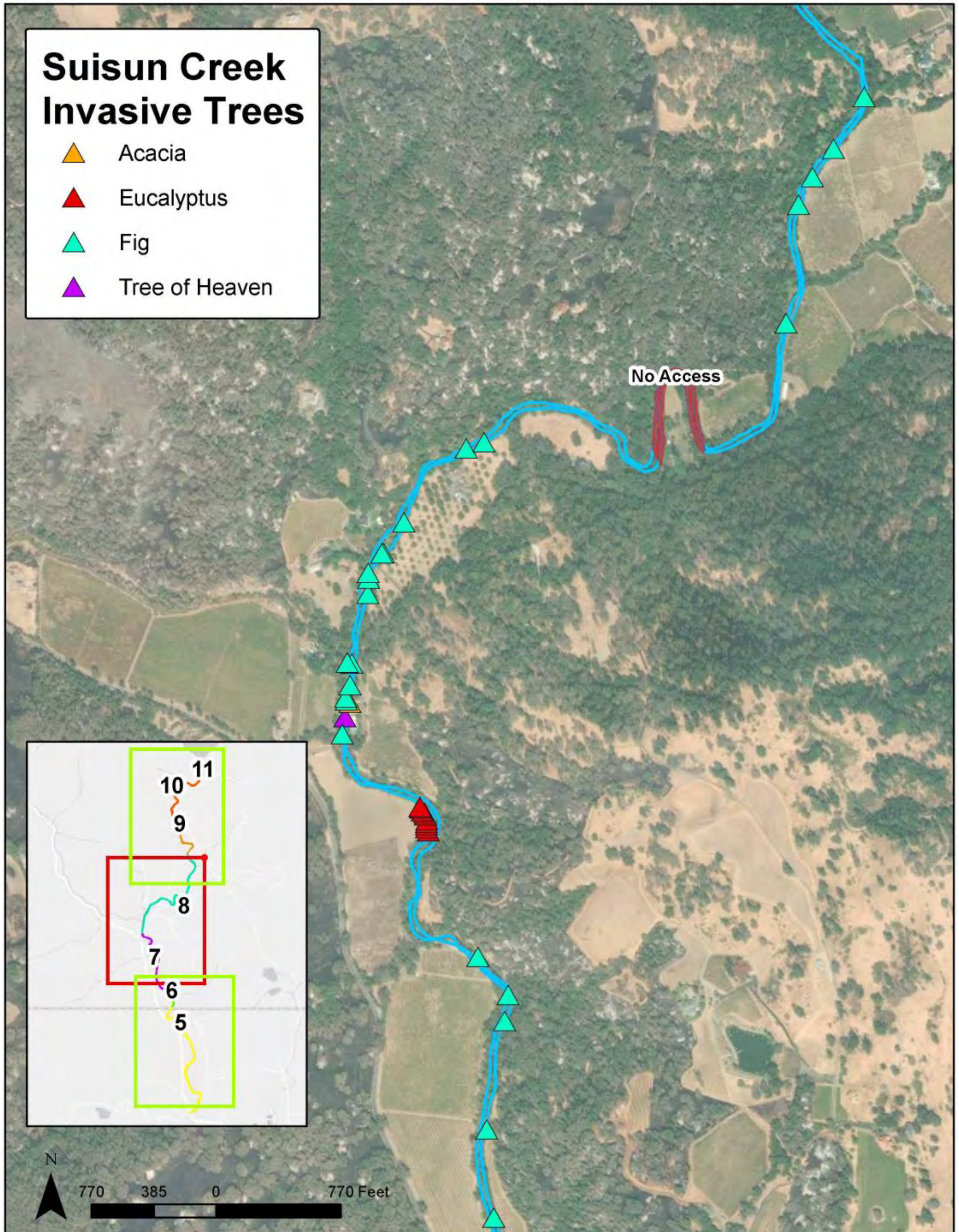

Tree of Heaven


Fig

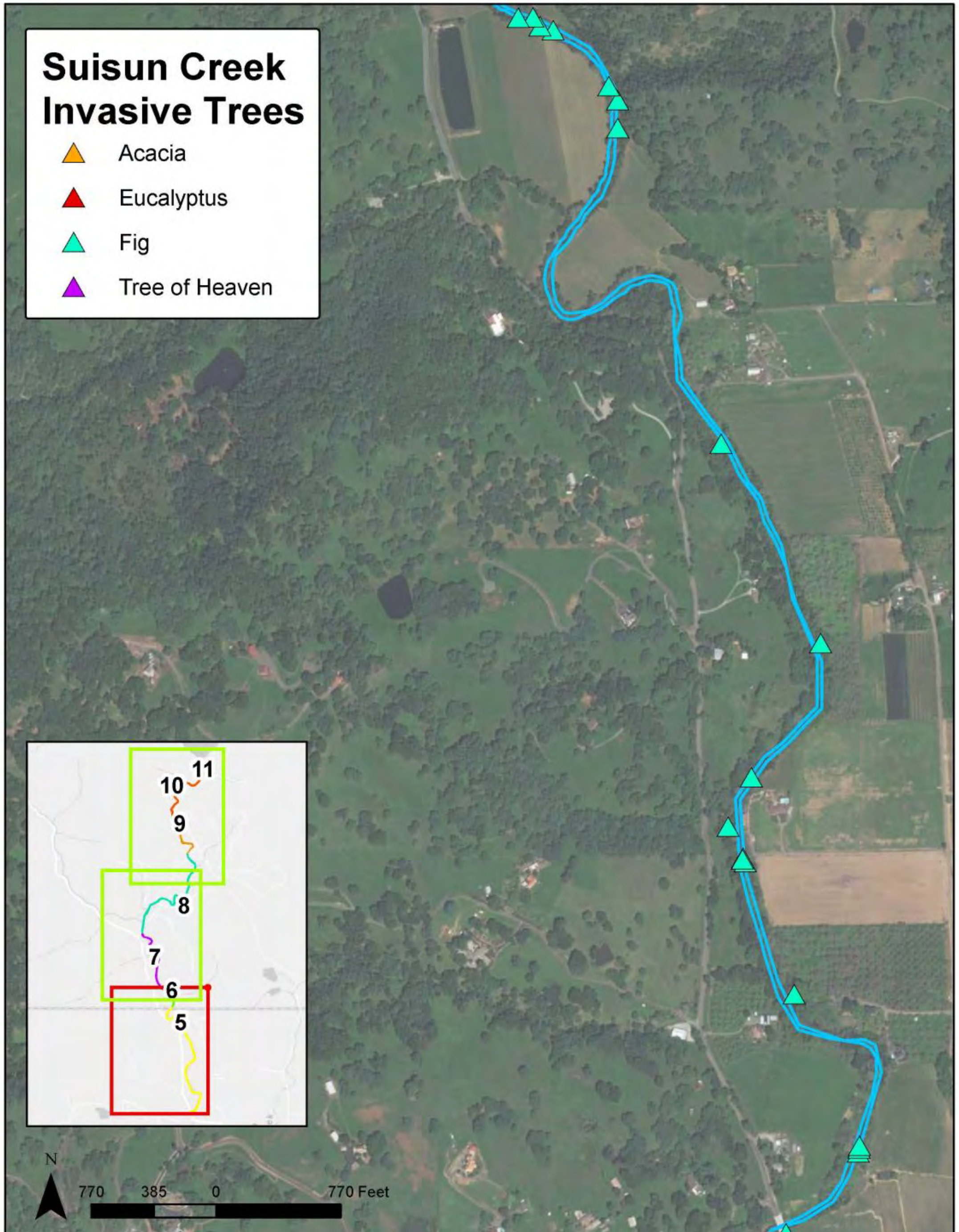

Acacia


Eucalyptus


Suisun Creek
Invasive Trees
Acacia
Eucalyptus
Fig
Tree of Heaven
No Access
No Access
11
10
9
8
7
6
5
N
770
385
0
770 Feet

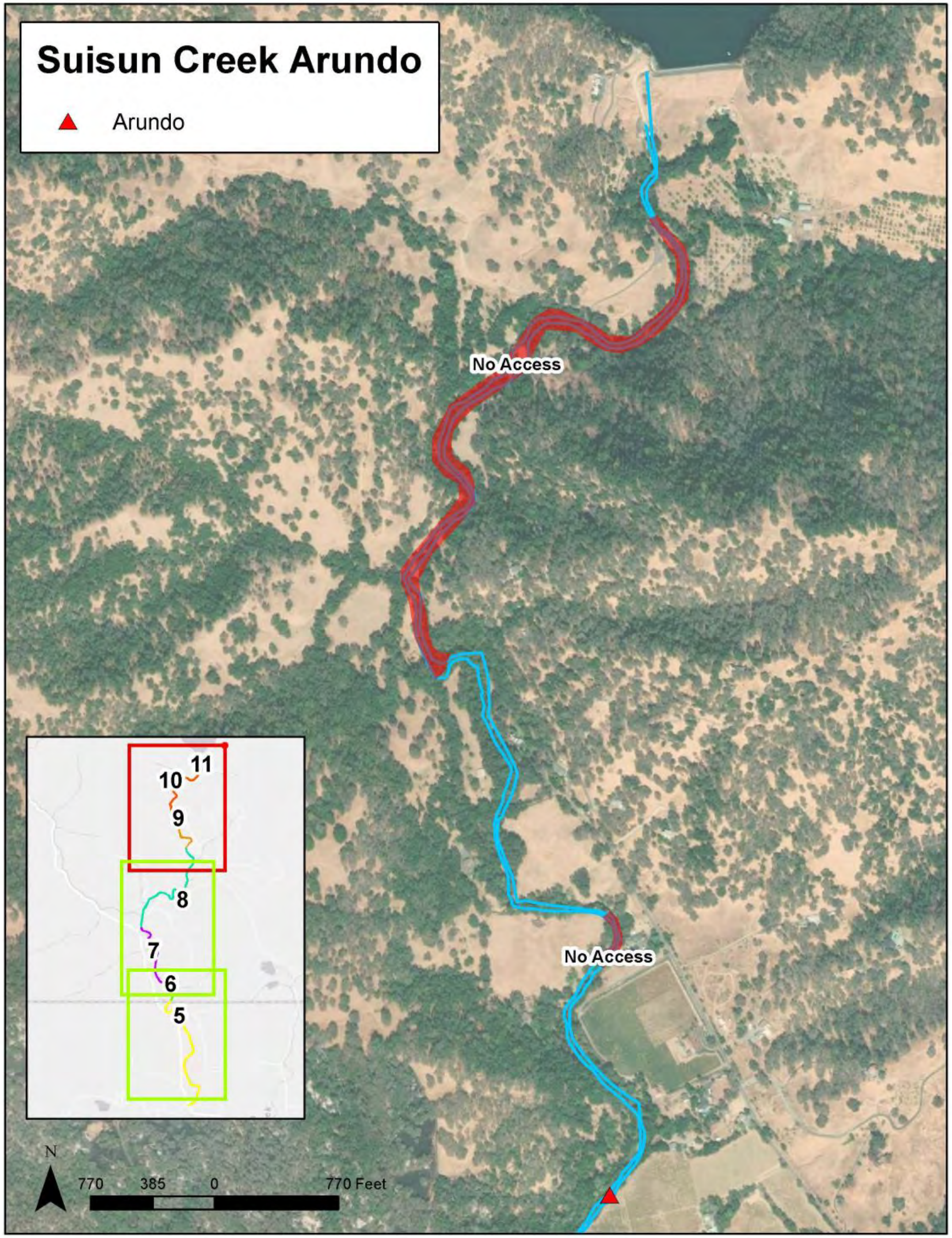


Suisun Creek Invasive Trees
Acacia
Eucalyptus
Fig
Tree of Heaven
No Access
11
10
9
8
7
6
5
N
770 385 0 770 Feet

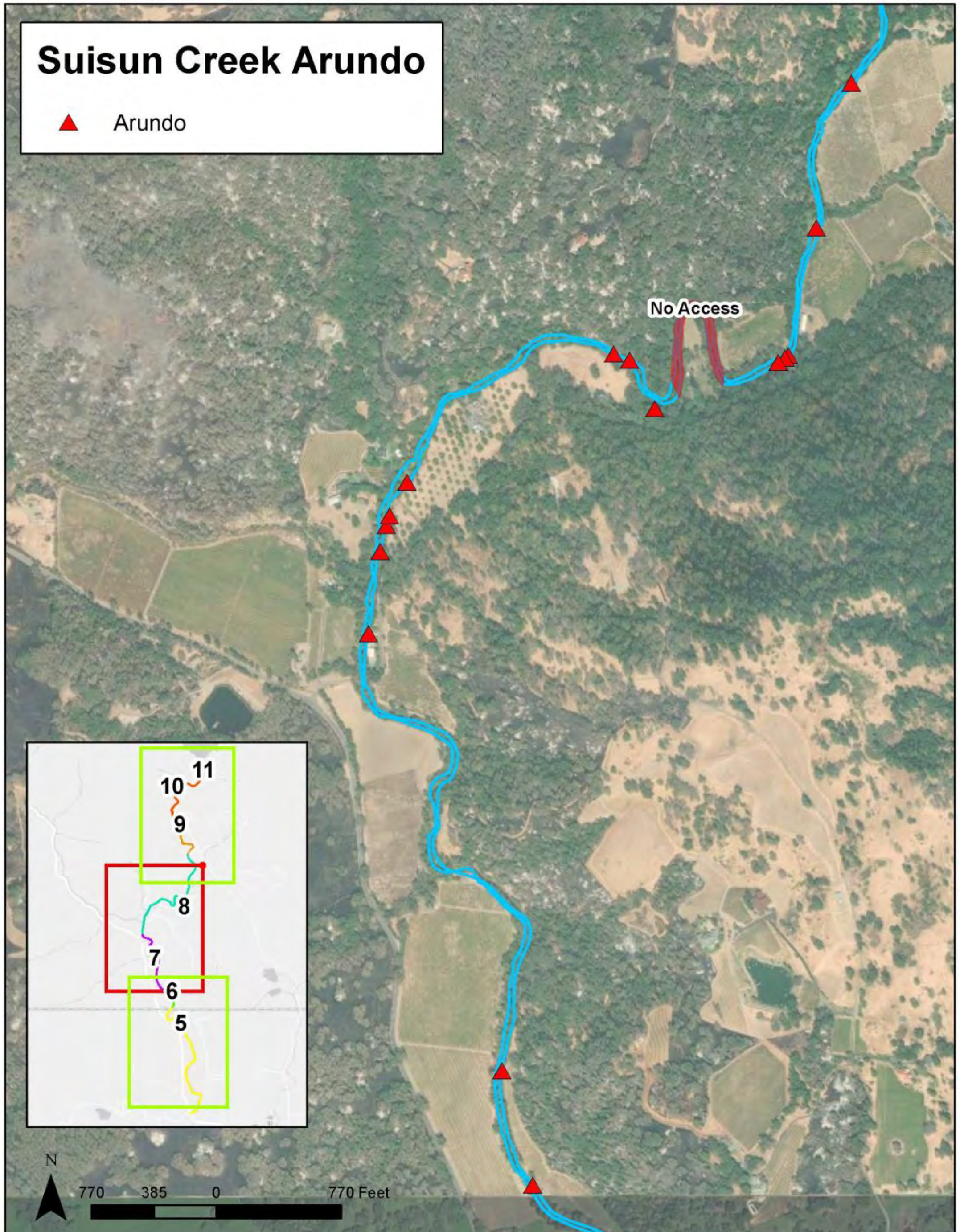


Suisun Creek Invasive Trees
Acacia
Eucalyptus
Fig
Tree of Heaven
11
10
9
8
7
6
5
N
770
385
0
770 Feet

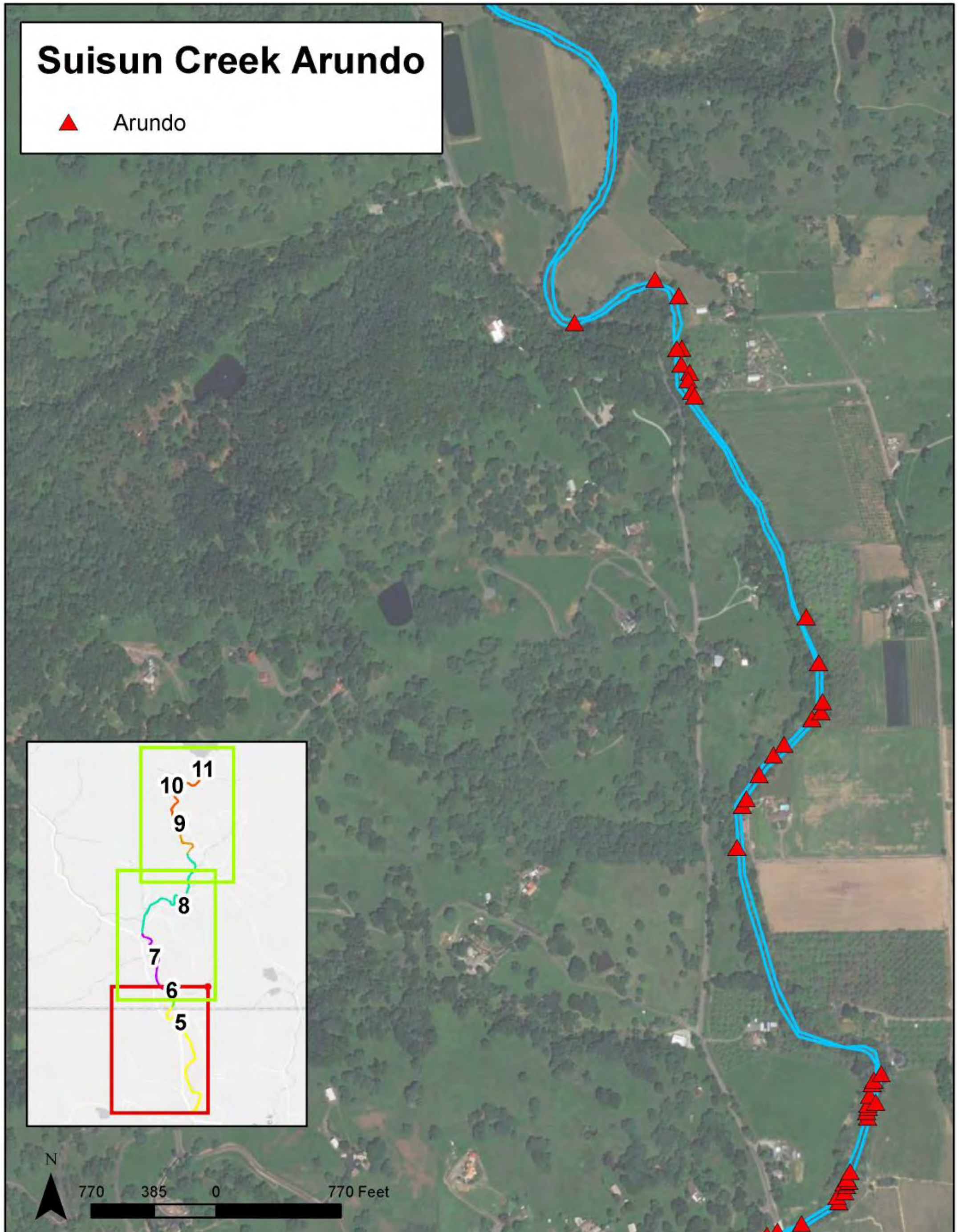
Giant Reed or Arundo donax



Suisun Creek Arundo
Arundo
No Access
No Access
11
10
9
8
7
6
5
N
770
385
0
770 Feet



Suisun Creek Arundo
Arundo
No Access
11
10
9
8
7
6
5
N
770
385
0
770 Feet



Suisun Creek Arundo
Arundo
11
10
9
8
7
6
5
N
770
385
0
770 Feet

Understory Invasive Non-native Plants

Blue Periwinkle

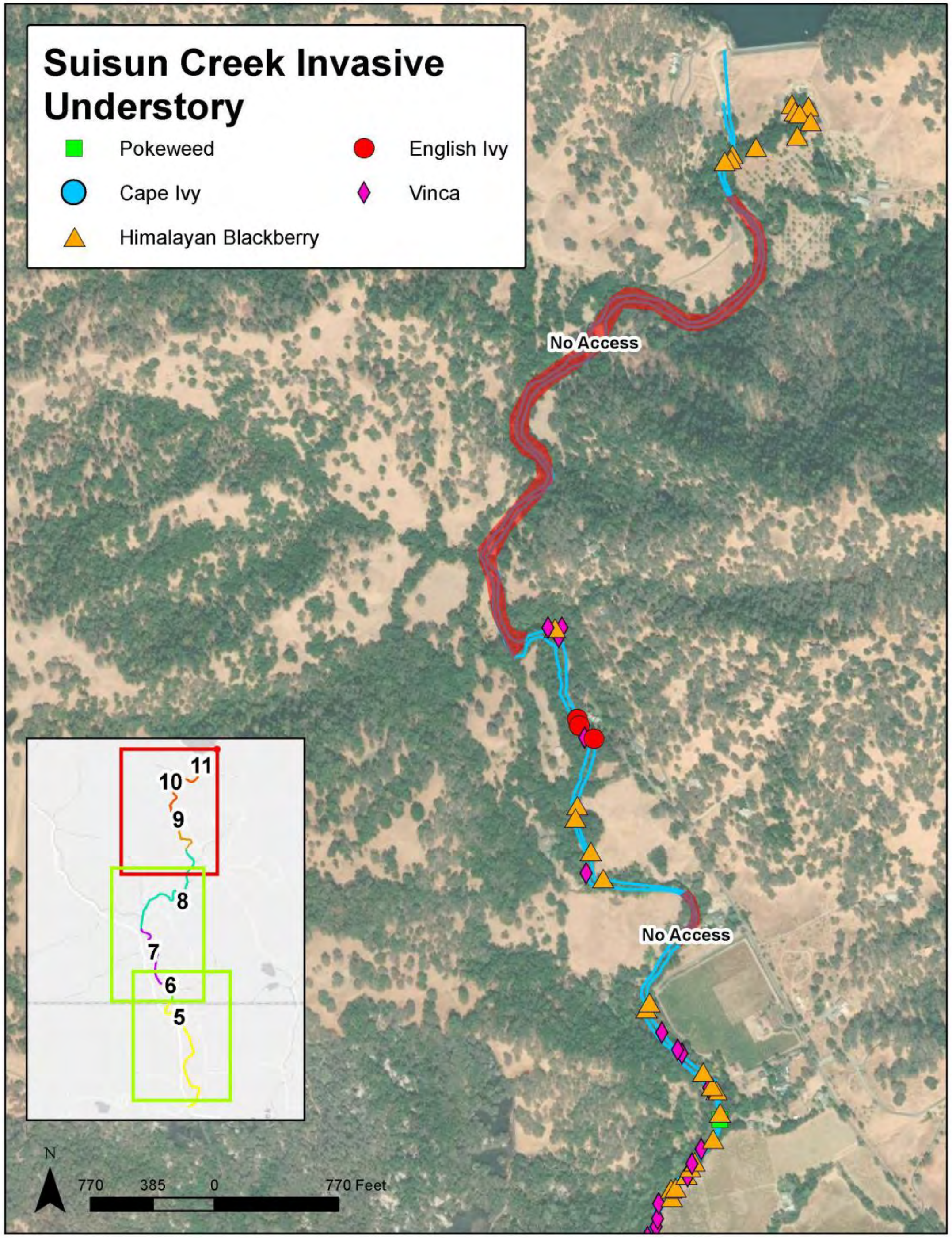
Himalayan Blackberry

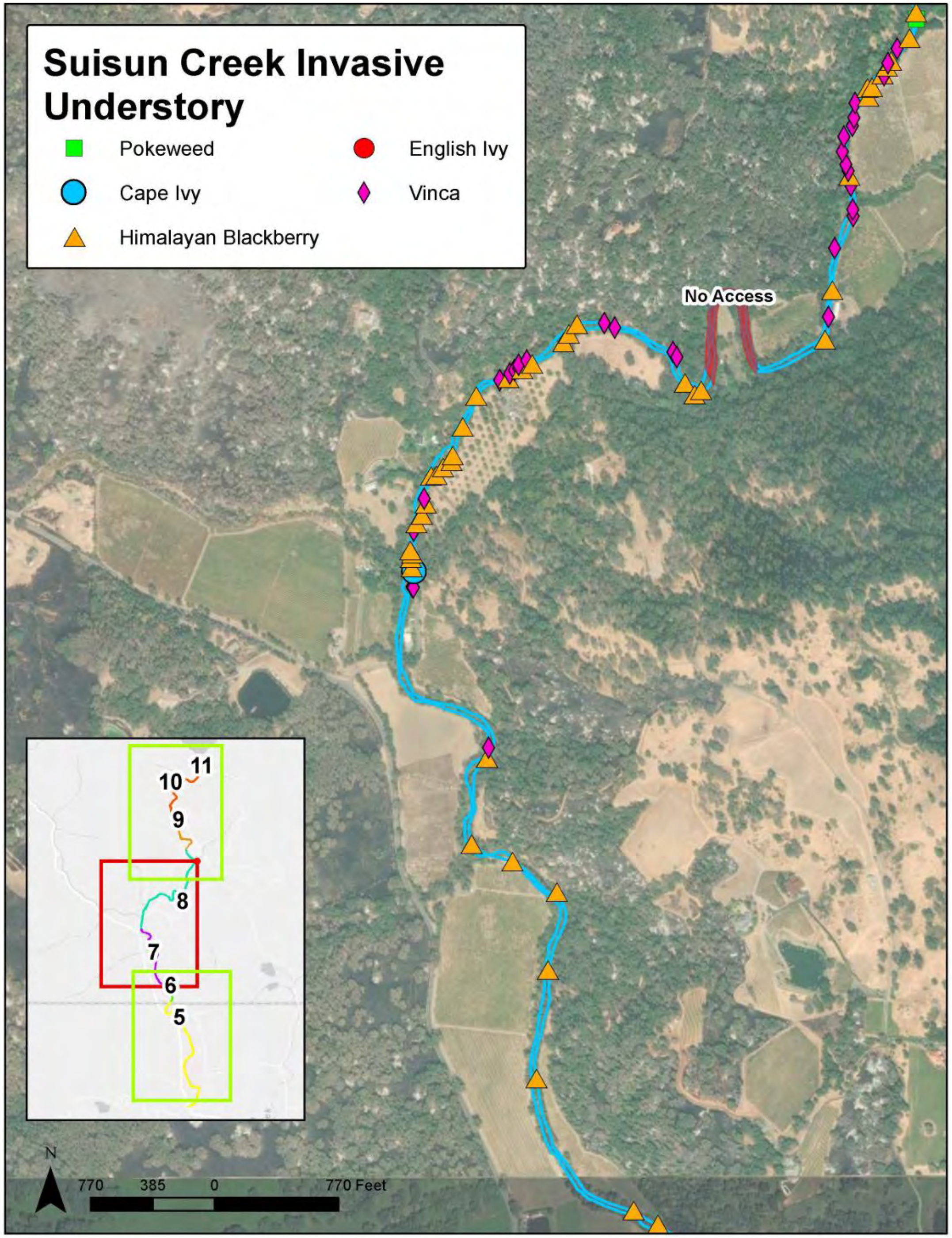

English Ivy


Cape Ivy

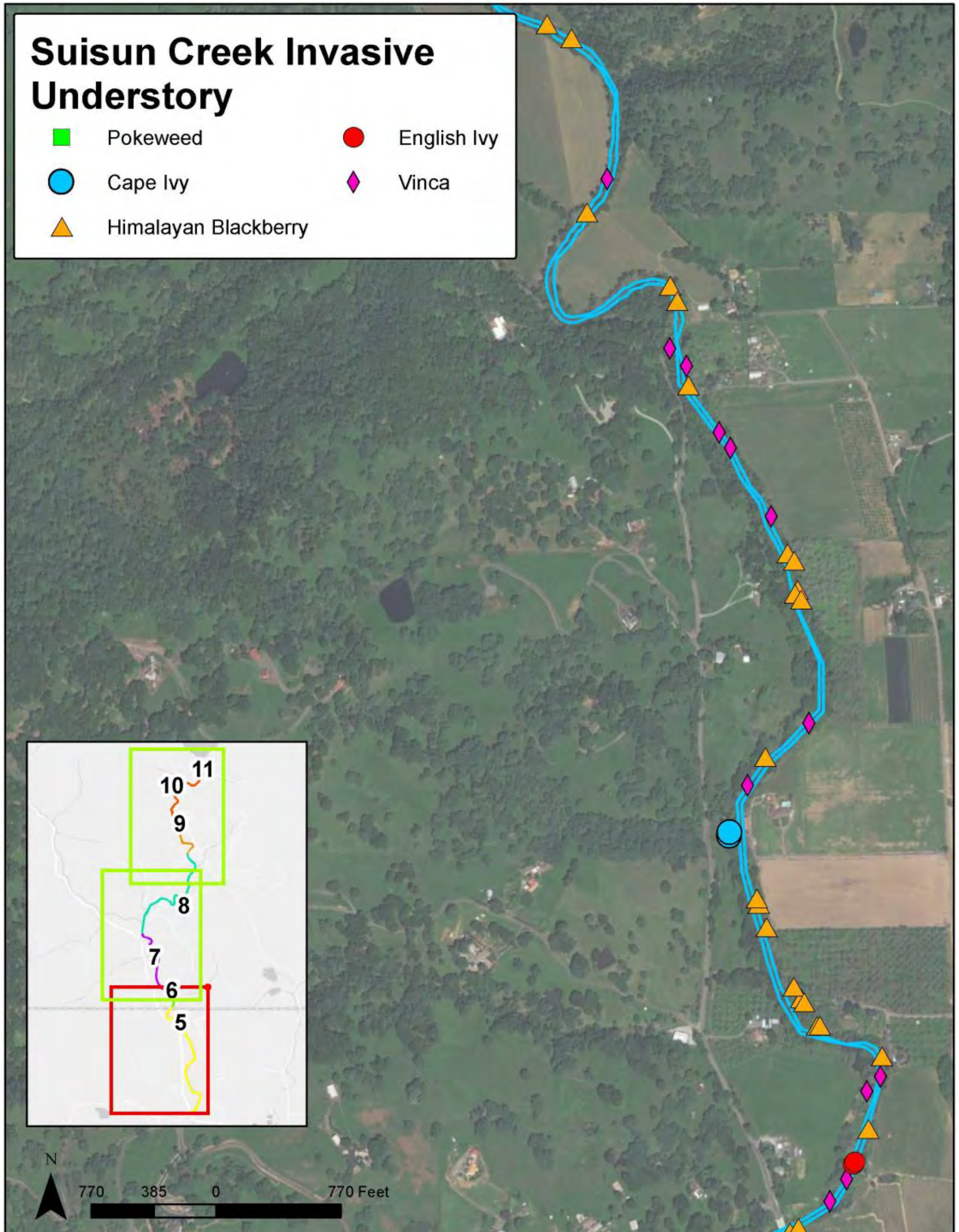

Poke Weed

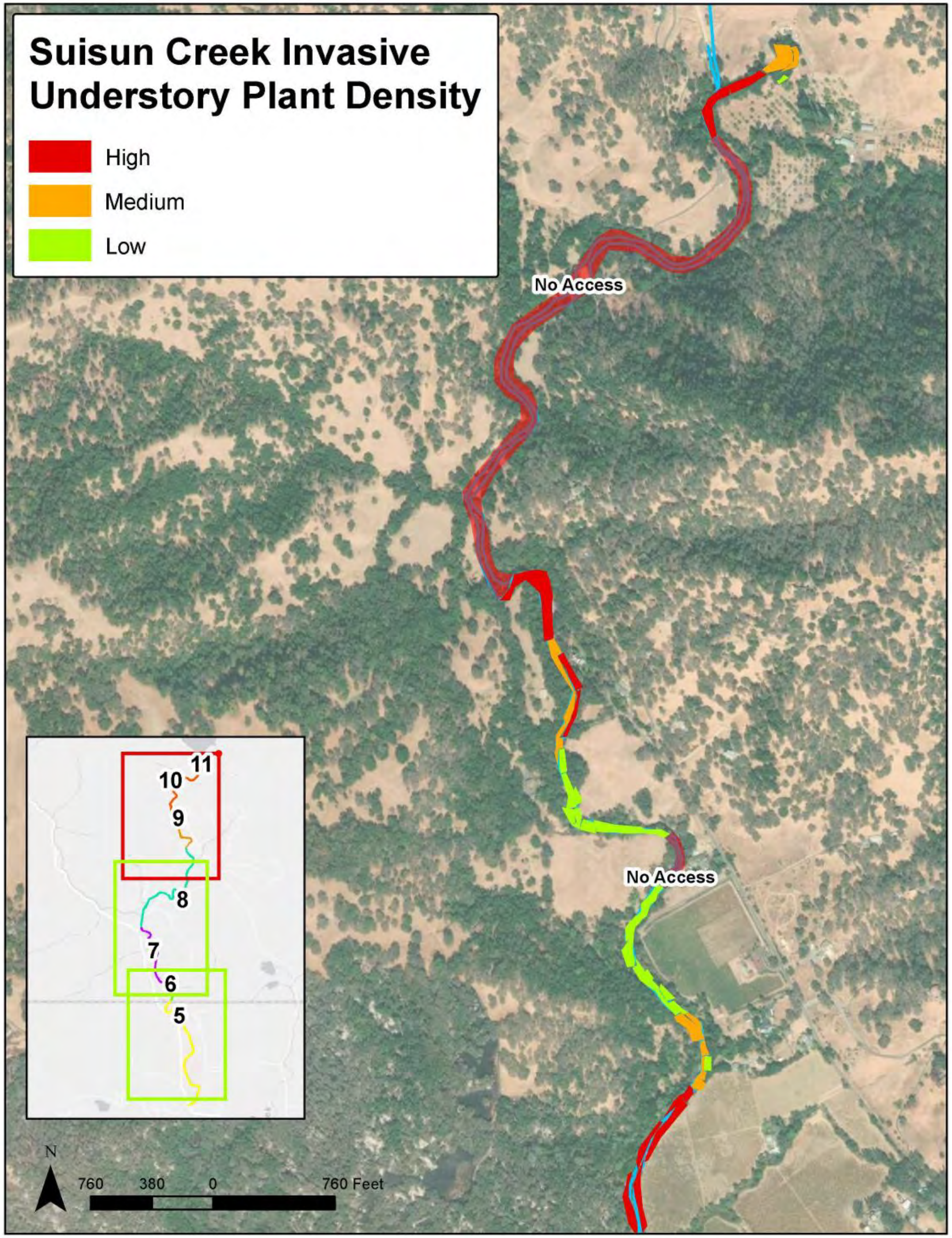
Symbols indicate large patches of the invasive non-native plant



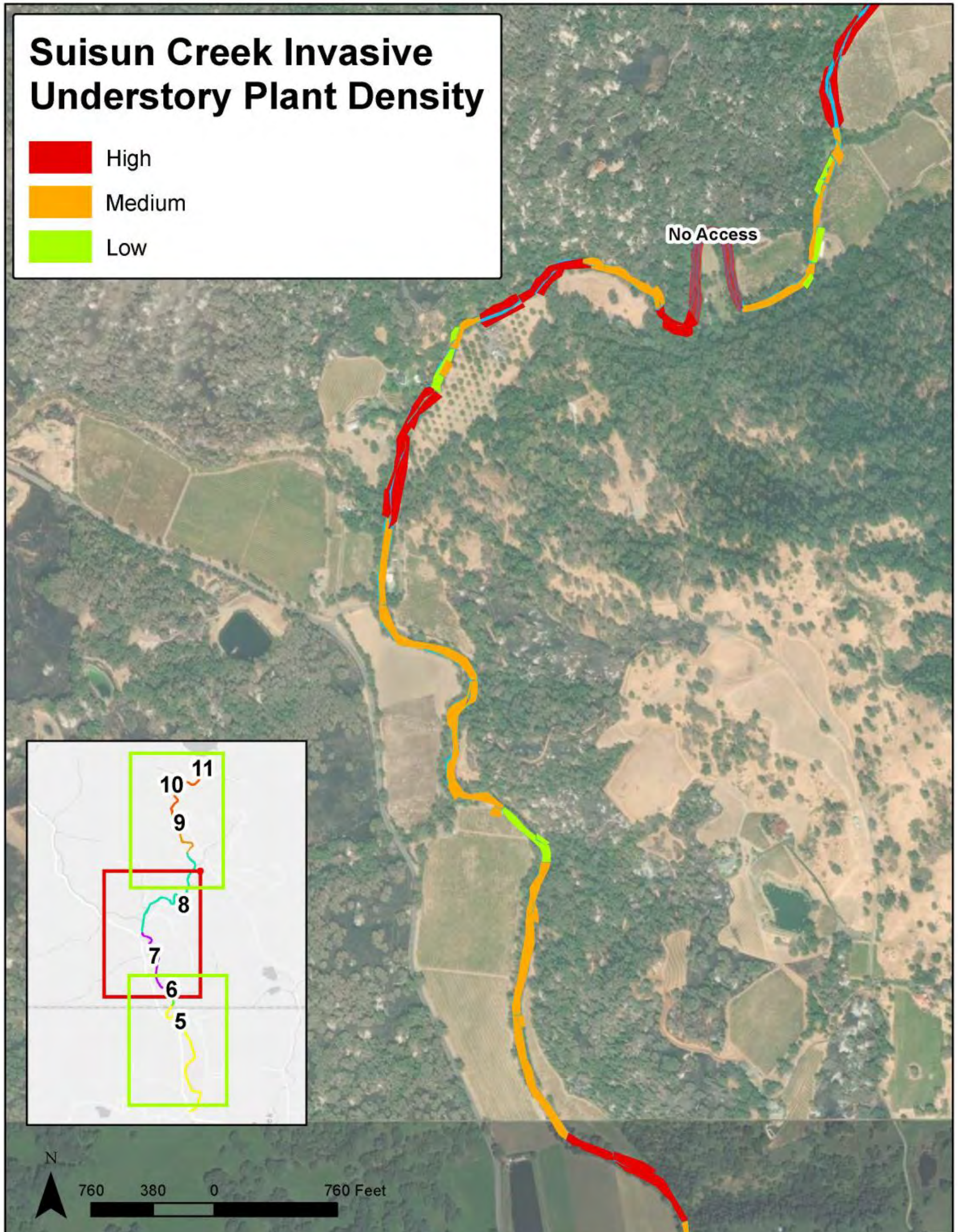


Suisun Creek Invasive Understory
Pokeweed
English Ivy
Cape Ivy
Vinca
Himalayan Blackberry
No Access
11
10
9
8
7
6
5
N
770
385
0
770 Feet


Suisun Creek Invasive Understory
Pokeweed
English Ivy
Cape Ivy
Vinca
Himalayan Blackberry
11
10
9
8
7
6
5
N
770
385
0
770 Feet



Suisun Creek Invasive Understory Plant Density
High
Medium
Low
No Access
No Access
11
10
9
8
7
6
5
N
760
380
0
760 Feet



Suisun Creek Invasive Understory Plant Density
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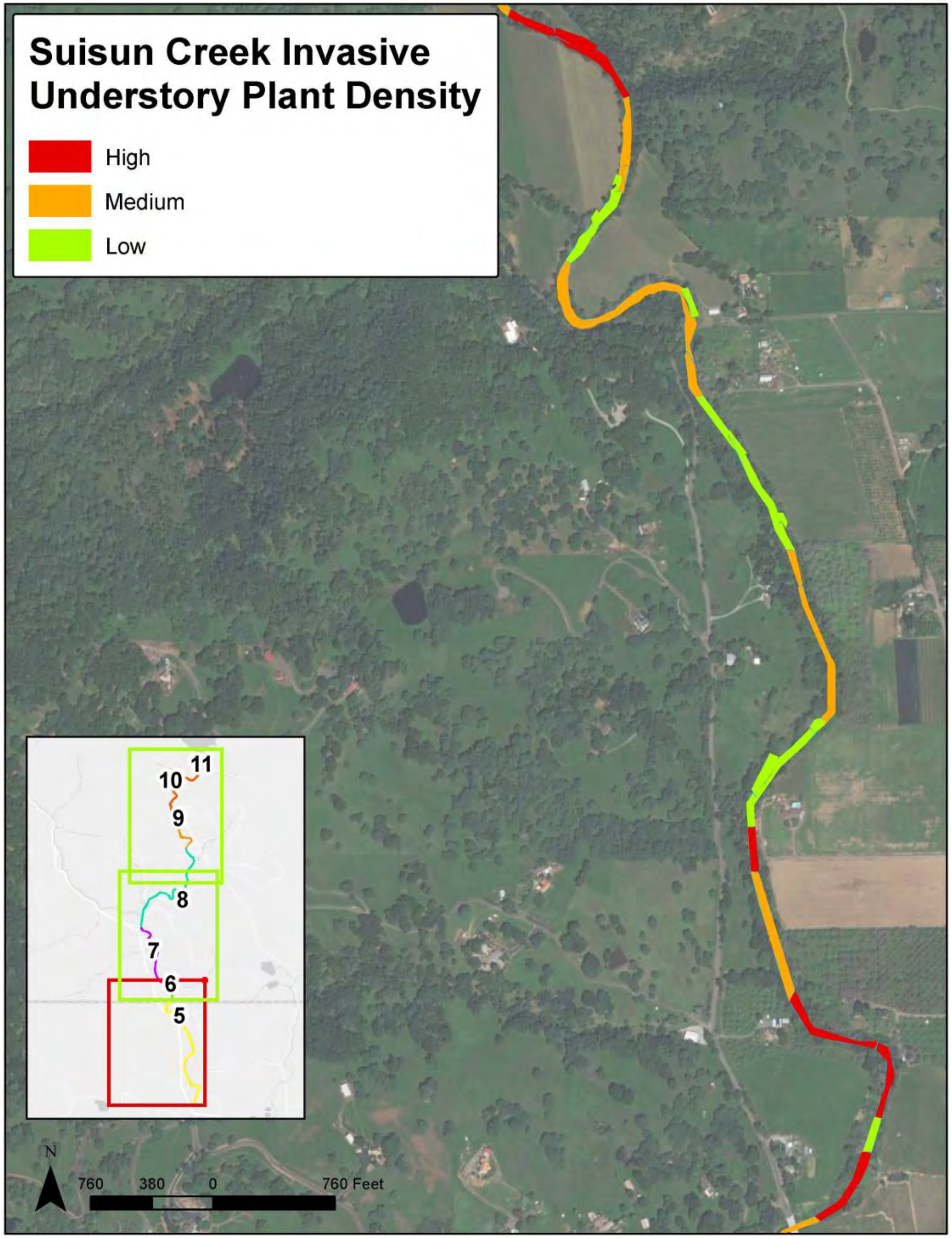

Suisun Creek Invasive Understory Plant Density
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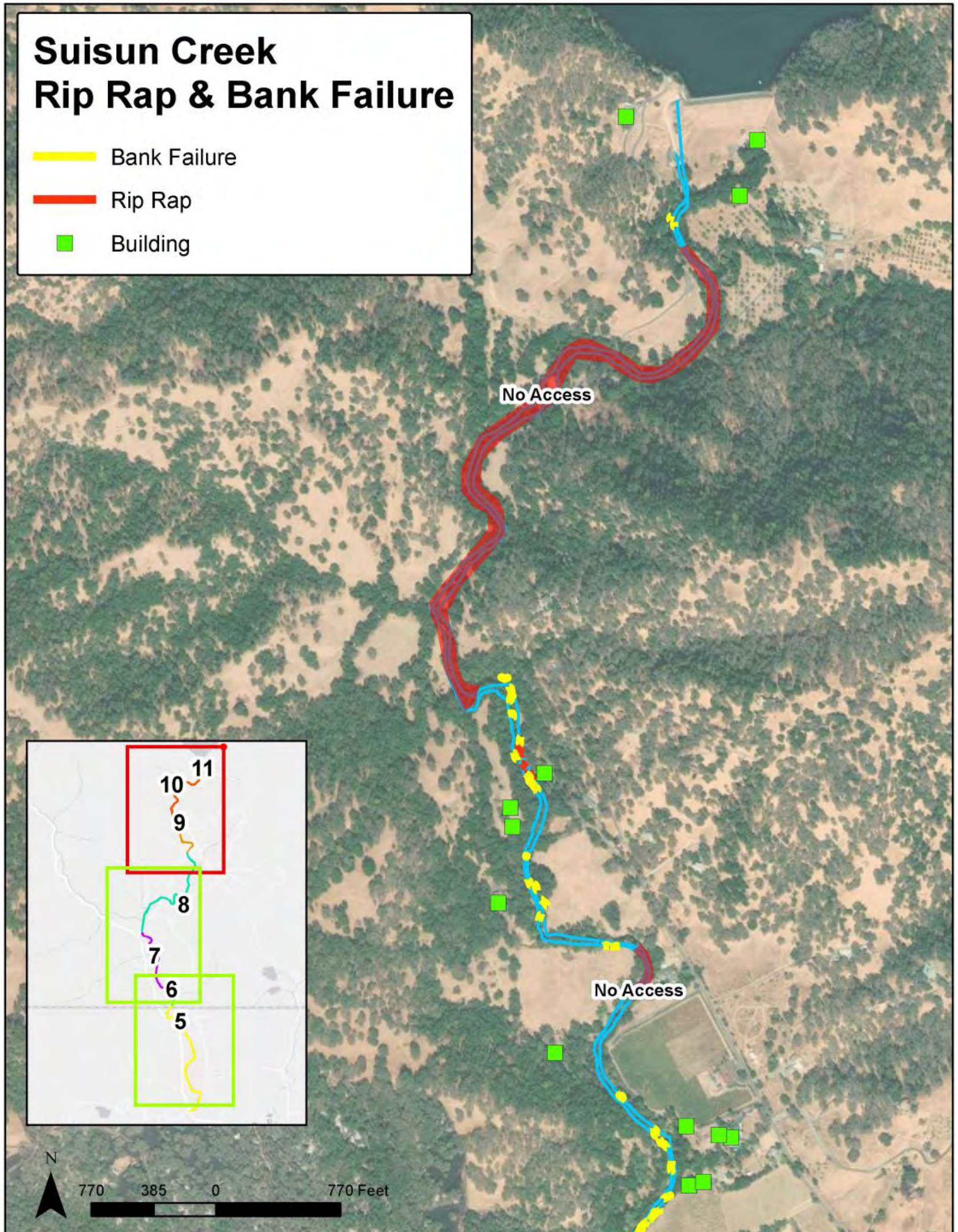
Eroding Banks and Rock Riprap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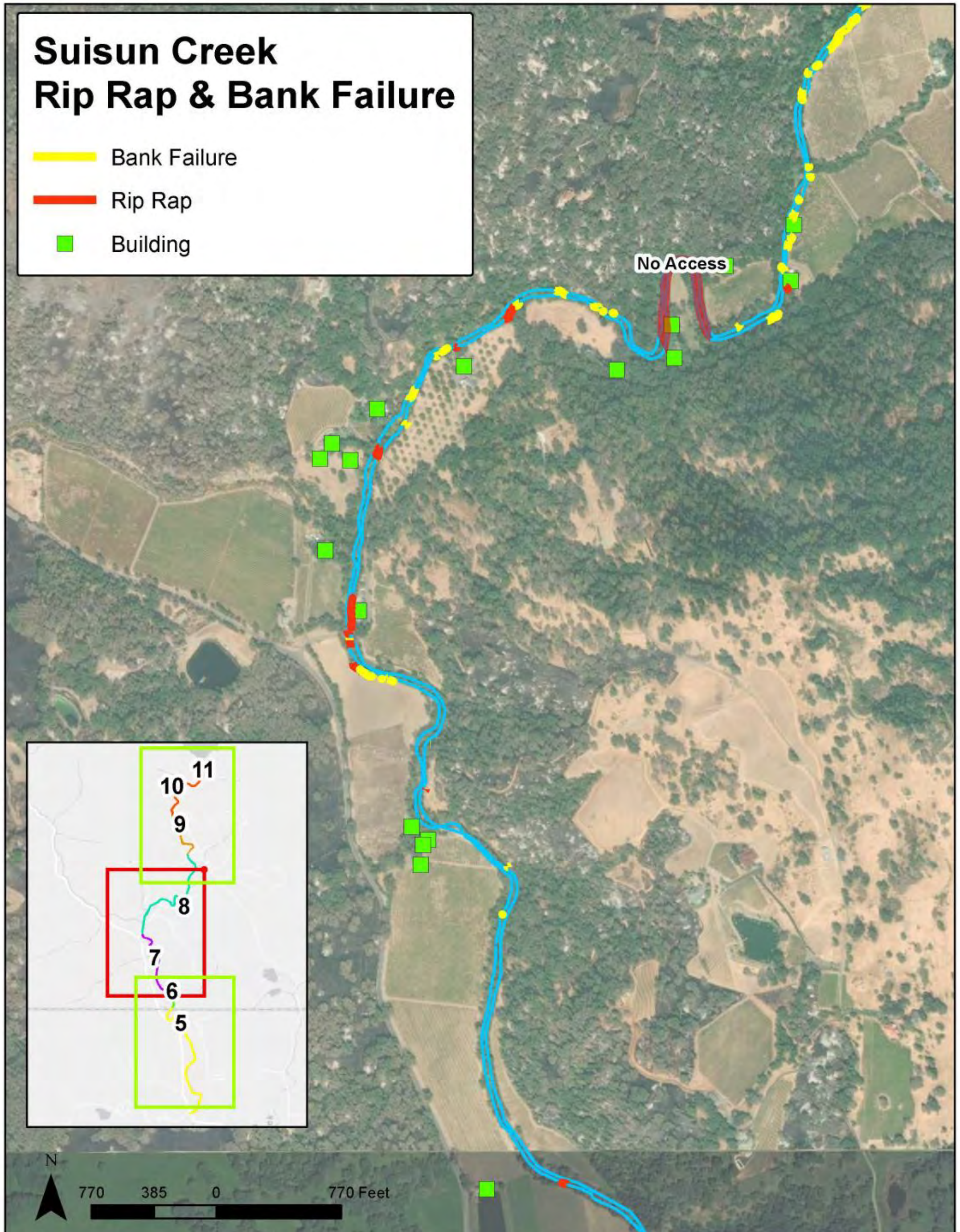
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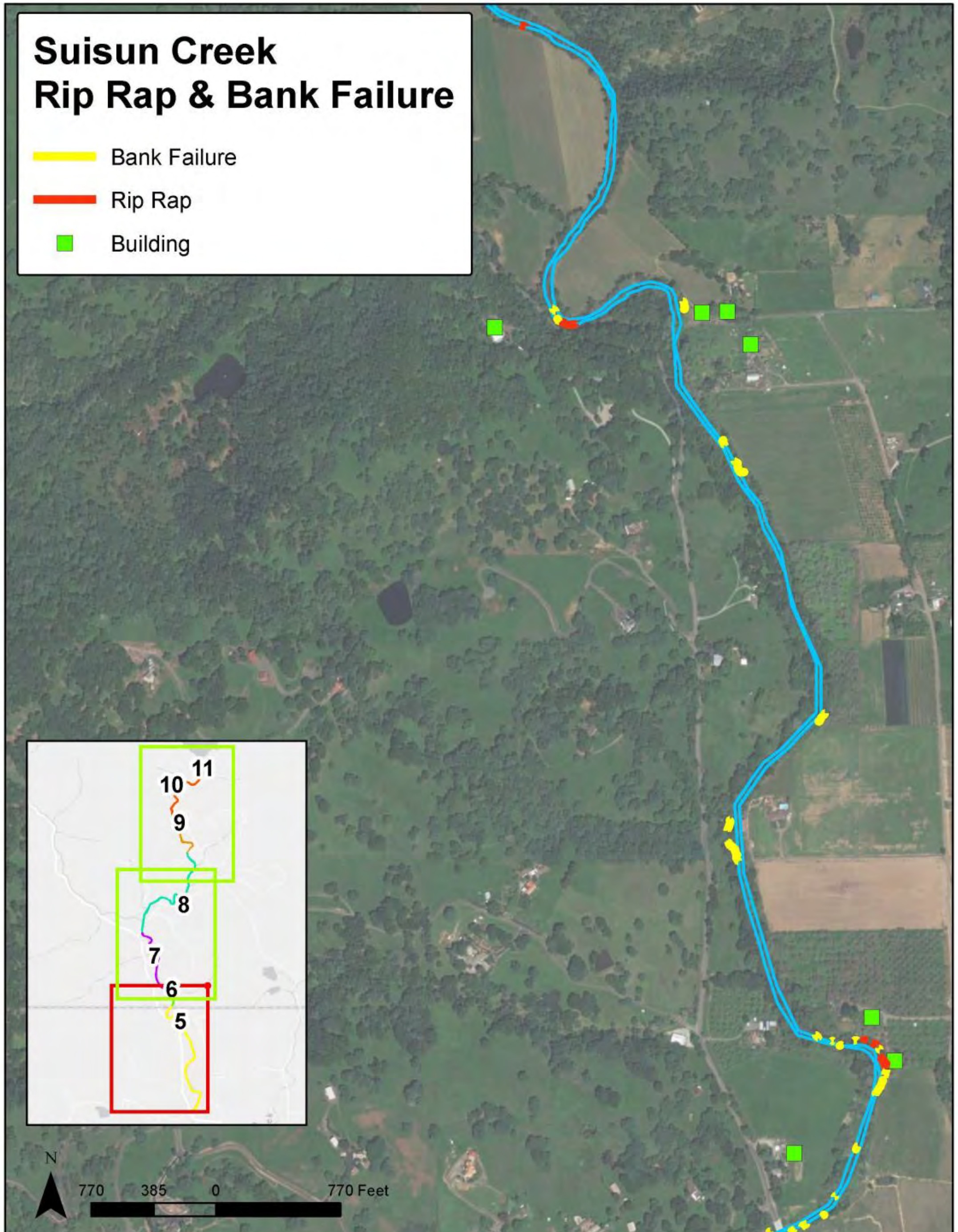

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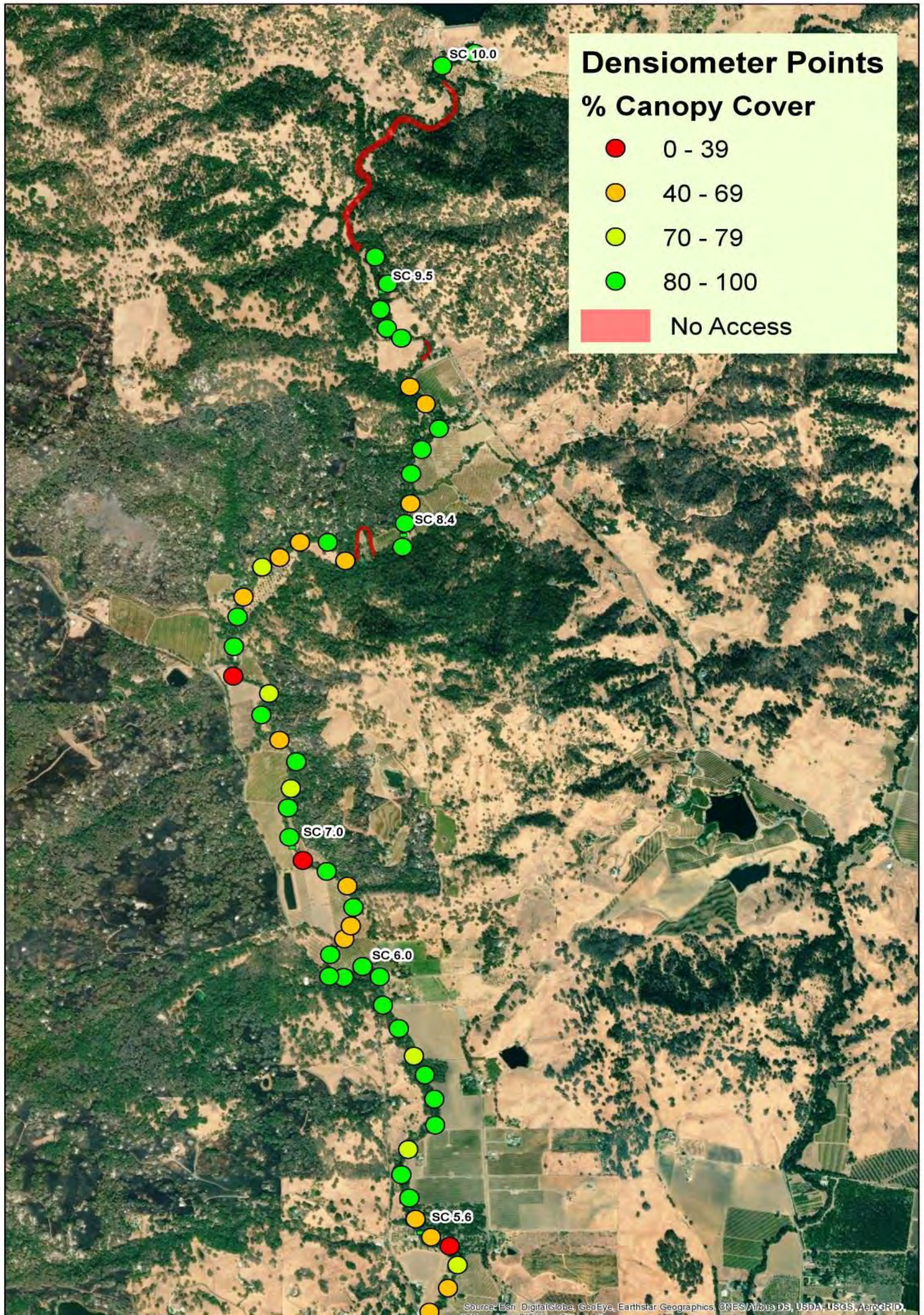


Measuring canopy cover with spherical densiometer

Riparian Ecosystem

Fairly good level of biodiversity with regeneration in both pioneer and mid and upper bank species. The most recent drought killed many white alder but both alder and cottonwood seedlings are abundant to replace these dead trees.

Thin riparian corridor along the top of the bank is being undercut by bank failures in many locations. The base of hillslopes in the semi-confined areas of the channel also has many erosion sites.

Invasive non native trees (fig is most common) and invasive understory species interfere with native tree seedling germination and growth. An invasive species eradication program in collaboration with landowners is needed.

Approximately half of the canopy cover readings along the creek are in the 80-100% range indicating a need for additional revegetation and large trees on top of bank completed in collaboration with landowners.

Revegetation Plans along Suisun Creek

<u>Site name: Twin Creeks Suisun Creek Revegetation of Riparian Corridor</u>

Location: Project is located along 1.4 miles of Suisun Creek, a steelhead stream.

Description of Problem: Many mature riparian trees are dead along Suisun Creek and do not provide adequate riparian shade canopy. Monitoring of water temperatures shows a need for greater canopy cover to support steelhead habitats. Stream banks are also eroding due to the lack of trees.

Description of Project: There are a few locations where invasive species – Himalayan blackberry (*Rubus armeniacus)* and *Arundo donax* need to be treated. Riparian trees such as live oak (*Quercus agrifolia*), valley oak (*Quercus lobata*), Oregon ash (*Fraxinus latifolia*), Ca. buckeye (*Aesculus californica*), big leaf maple (*Acer macrophyllum*), and Ca. bay laurel (*Umbellularia californica*), white alder (*Alnus rhombifolia*), Fremont cottonwood (*Populus fremontii*), and big leaf maple (*Acer macrophyllum*) will be planted at top of bank and midbank in areas where there are breaks in the canopy and non-regenerating burned trees. Bank erosion sites will be sprigged with willow or planted with cottonwood or alder at the base of the bank extending up the bank 2-5 ft. All plantings will be installed during the wet season with weed mat and protective tubes for seedlings. An ecologist will flag exact locations for each seedling. From 417 to 650 seedlings will be planted and will be irrigated from the vineyard drip system.

Budget: Seedlings $18,765- 29,250; willows $7275; Invasive control $20,000

Permits: A 1600 permit will be needed.

Table 1. Replanting plan for Suisun Creek on Twin Creeks site

Zone	Area (sq.-ft)	Acres	Percent of zone needing trees	Planting area in acres	Total riparian trees planted on 20 ft. centers @ 109 trees/acre	Total riparian trees planted on 25 ft. centers @ 70 trees/acre	Willow sprigs	Notes
1	50,815	1.17	0.2	0.23	25	16	35	Dead alders
2	58,047	1.33	0.3	0.40	44	28		Little canopy
3	24,672	0.57	0.3	0.17	19	12	35	Erosion site right bank
4	28,064	0.64	0.3	0.19	21	14	35	Dead alders and hardwoods
5	17,270	0.40	0.3	0.12	13	8	20	Canopy limited
6	29,219	0.67	0.4	0.27	29	19		Canopy limited
7	52,115	1.20	0.2	0.24	26	17		Fairly good canopy
8	7,392	0.17	0.5	0.08	9	6	20	Canopy limited
9	24,201	0.56	0.5	0.28	30	19		Canopy limited, invasives
10	5,351	0.12	0.5	0.06	7	4		Canopy limited
11	33,897	0.78	0.5	0.39	42	27		Canopy limited

Zone	Area (sq.-ft)	Acres	Percent of zone needing trees	Planting area in acres	Total riparian trees planted on 20 ft. centers @ 109 trees/acre	Total riparian trees planted on 25 ft. centers @ 70 trees/acre	Willow sprigs	Notes
12	31,452	0.72	0.5	0.36	39	25		Canopy limited
13	32,761	0.75	0.5	0.38	41	26		Canopy limited, invasives
14	26,193	0.60	0.5	0.30	33	21		Canopy limited
15	19,957	0.46	0.5	0.23	25	16	25	Dead alders, limited canopy
16	18,257	0.42	0.5	0.21	23	15	25	Dead alders, limited canopy
17	45,179	1.04	0.5	0.52	57	36		Canopy limited
18	49,354	1.13	0.5	0.57	62	40	30	Dead alders, limited canopy
19	21,254	0.49	0.5	0.24	27	17	35	Dead alders, limited canopy
20	37,772	0.87	0.5	0.43	47	30	35	Dead alders, limited canopy
21	24,390	0.56	0.5	0.28	31	20		Canopy limited, invasives
Totals				5.95	649	417	295	

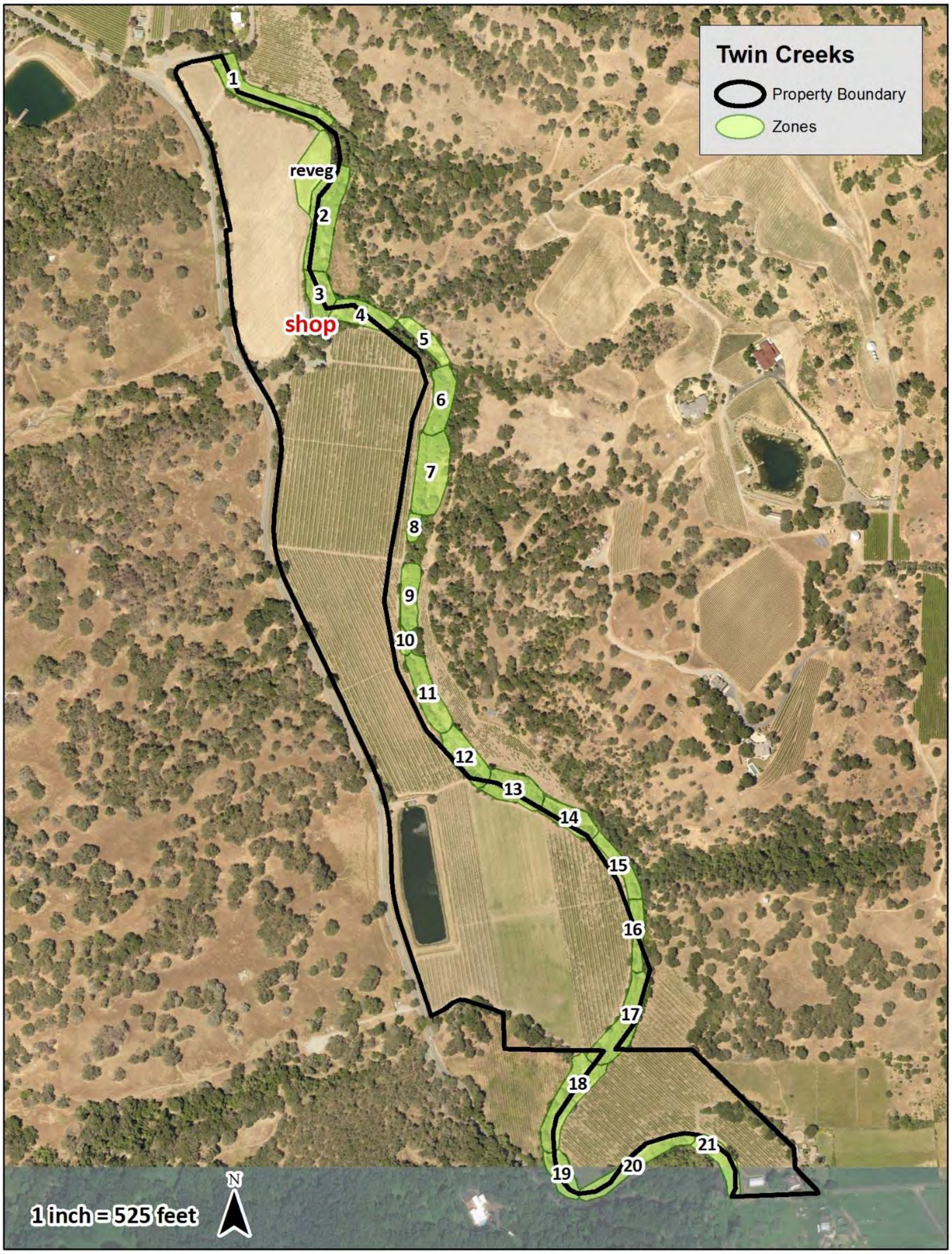


Figure 1. Planting zones and features of Twin Creeks project site.

PARKER RANCH STREAMBANK PROTECTION PLAN

Prepared by California Land Stewardship Institute

September 14, 2020

Property Address: 1100 Wooden Valley Cross Road, Napa, CA

APN: 033-330-001

Napa County

Background

California Land Stewardship Institute (CLSI) was contacted in December 2019 by Mr. Eldon Parker, resident farmer at the subject property. Mr. Parker expressed concerns about recent bank erosion that appeared to be related to fallen riparian trees and woody debris in the stream. CLSI staff conducted a field visit in December 2019. This plan is based on observations made during that site visit as well as subsequently obtained information.

Existing Conditions

The subject property is located on upper Suisun Creek downstream of the Gordon Valley Dam (Lake Curry) and upstream of the confluence with Wooden Valley Creek. Most of the parcel is on an alluvial terrace and is used for farming walnuts. A house and barn are also located on the terrace.

The stream flows along the north side of the property and is incised 15 to 20 feet below the terrace surface. Banks are very steep and show evidence of recent bank erosion. We observed several trees that have fallen into the channel in recent years, and a comparison of aerial photographs taken from 1993 to 2018 indicates a substantial loss of riparian canopy in some reaches. According to Mr. Parker, the channel has not incised noticeably since he moved to the property in 1978. The stream varies from roughly 80 to 100 feet wide. At the midpoint of the property, the Hidden Springs tributary flows into Suisun Creek from the north. Suisun Creek above this confluence has a drainage area of 22.5 square miles (including the area draining to Lake Curry), and a mean annual rainfall of 30.3 inches (USGS Streamstats). The Hidden Springs tributary has a drainage area of 0.3 square miles and a mean annual rainfall of 26.5 inches (USGS Streamstats). A small gully has developed from runoff from the western portion of the orchard flowing over the steep streambank. Most of the Suisun Creek watershed upstream of this site was burned in the 2020 LNU Complex wildfire.

Recurrence Interval, Years	Suisun Creek Peak Flows (CFS)	Hidden Springs Peak Flows (CFS)
2	868	15.4
5	1,790	35.0
10	2,460	50.2
25	3,370	71.1
50	4,060	87.8
100	4,790	106

Table 1: Peak flows for selected recurrence intervals on Suisun Creek and Hidden Springs tributary (USGS Streamstats program)

Soils along the creek include the Bressa-Dibble Complex and the Bale clay loam. Relevant soil properties are listed in Table 2.

Soil unit	Slope	Erosion Hazard Rating	Drainage	Suitability for Hand Planting
Bressa-Dibble Complex	30 to 50%	Very severe	Well drained	Moderately suited
Bale Clay Loam	2 to 5%	Slight	Somewhat poorly drained	Well suited

Table 2: Soils within the project area along Suisun Creek (USDA Web Soil Survey)

Most of the area affected by bank erosion is within the Bressa-Dibble Complex, which is rated as "very severe" for erosion hazard. The small gully originates near the contact between the Bressa-Dibble Complex and the Bale Clay Loam, and the lower infiltration rates on the Bale Clay Loam may contribute to runoff to the gully.

<u>Recommended Actions</u>

CLSI recommends actions to address both the bank erosion along Suisun Creek and the gully development in the walnut orchard.

Bank Protection (0.5 acres)

CLSI recommends following the guidelines for managed bank retreat (see attachment) to address the bank erosion along Suisun Creek. Placement of rock or other armoring is not recommended. Bank shaving, although potentially useful, is not recommended due to expense. Instead, we recommend planting of native trees to protect and strengthen banks. Recommended plantings are listed in Table 3 below for two zones. Zone 1 includes north and south streambanks where plantings are likely to be within 0 to 2 feet of the water table during dry summers. Zone 2 includes the relatively flat alluvial terrace on the south side of the stream.

Scientific name	Common name	Zone 1, streambank, 16,460 sq. ft.—number of trees	Zone 2, terrace, 16,530 sq. ft.—number of trees	Total, 32,990 sq. ft.—number of trees	Plant type
Salix spp.	Willow	35	0	35	Dormant cutting
Fraxinus latifolia	Oregon ash	12	0	12	Dee pot or tree band container
Aeschulus californica	California buckeye	15	0	15	Dee pot or tree band container
Acer macrophyllum	California bigleaf maple	0	15	15	Dee pot or tree band container

Quercus lobata	Valley oak	0	20	20	Dee pot or tree band container
Quercus agrifolia	Coast live oak	0	12	12	Dee pot or tree band container

Table 3: Trees recommended for bank protection planting at Parker Ranch

Willows, buckeyes, and ash are recommended for the streambanks, as these trees are relatively small and flexible, and have a good chance of surviving flooding while providing bank protection. They can tolerate high water tables and should grow well during summers without irrigation.

Maples and oaks are recommend for the terrace surface to provide deep roots to stabilize alluvium. These trees can extend roots from 30 to 80 feet below the land surface, and when mature they can tap groundwater below the terrace surface. However, seedlings and saplings should be drip irrigated for several hours once or twice a week for the first two to three summers.

Planting Notes

1. Zone 1 contains invasive nonnative plants that should be removed from the planting area prior to installing native plants. The invasive species include Himalayan blackberry. A Lake and Streambed Alteration Permit (Section 1600 permit) will be needed from the California Department of Fish and Wildlife to remove plants from the riparian area below the normal high-water line. CLSI will assist with the permit application.

2. The Revegetation Plan is designed to enhance and expand the riparian zone on the property. Selected plants are intended to create a riparian corridor of ecologically appropriate native plants along the top of bank and floodplain to provide canopy cover, wildlife habitat, and to aid in bank stabilization. Willow cuttings are installed at the base of the bank. It should be noted that high flows may cause bank erosion no matter how well vegetated stream and riverbanks are.

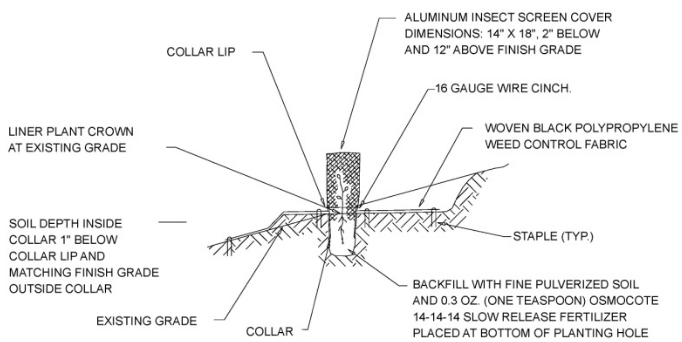
3. Planting shall be installed in the winter months, once rainfall has moistened the soil to a depth of ten inches or greater. Planting shall be completed by March.

4. Planting technique shall be predominantly liner-sized seedlings (see Planting Details) propagated from seeds and cuttings collected as close as possible to the revegetation site. Plants will be installed with protective hardware and weed mats that are appropriate to the site conditions.

5. A restoration ecologist will determine planting locations. Each planting spot shall be marked in the field with a color coded (to species) surveyor flag. Flags shall remain at each planting spot after plant installation.

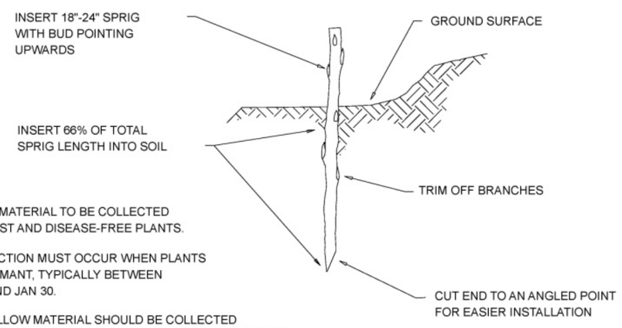
6. The property owner will be responsible for maintaining the plants. To ensure survival, plants will require frequent irrigation during the first dry season after planting. Irrigation should begin in April and continue into October. Approximately one to two gallons of water shall be applied directly to the plant during each irrigation visit. Watering interval shall be seven to ten days depending on weather conditions. Irrigation should continue during the April to October period

for the second and third summers following the planting. Weeds shall be removed around each plant for a period of three years – twice in the spring and once in the fall.



LINER PLANTING DETAIL

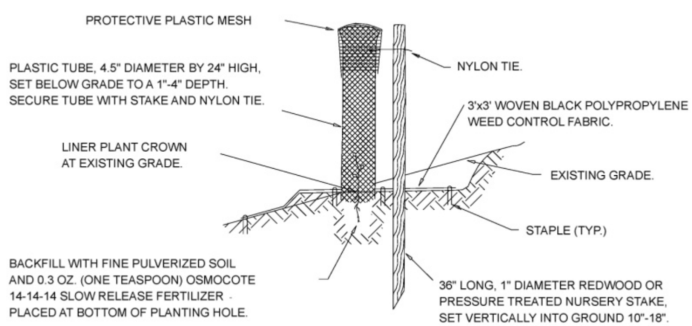
NOT TO SCALE



1. SPRIG MATERIAL TO BE COLLECTED FROM PEST AND DISEASE-FREE PLANTS.
2. COLLECTION MUST OCCUR WHEN PLANTS ARE DORMANT, TYPICALLY BETWEEN DEC. 1 AND JAN 30.
3. ALL WILLOW MATERIAL SHOULD BE COLLECTED WITHIN THE WATERSHED AS CLOSE TO THE PROJECT SITE AS POSSIBLE, AND KEPT MOIST DURING COLLECTION AND TRANSPORT.

DORMANT WILLOW SPRIG INSTALLATION

NOT TO SCALE



TREE SHELTER PLANTING DETAIL

NOT TO SCALE

Gully Repair (0.1 acres)

The small gully in the western portion of the orchard is the result of runoff from low-permeability soils (Bale Clay Loam) flowing over the steep streambank on the north side of the orchard. Runoff can be redirected around the head of the gully with straw wattles. The wattles should overlap by roughly 2 feet at any location where two wattles are joined. Wattles should be installed in shallow (2 to 3 inch) trenches and staked securely to prevent underflows. Banks can be shaved back to reduce slopes. We recommend a filter cloth and rock armor headcut treatment with two downstream loose rock check dams to stabilize the gully. Rock armoring will be used to protect the terrace surface and streambank from further erosion. The area between the straw wattles and the headcut can be planted with perennial ryegrass to stabilize the area. See the attached map. Straw wattles should be replaced at least yearly and maintained for 2-3 years after the gully stabilization is installed.

Appendix F

Fish Surveys of Suisun Creek and

Suisun Creek Quantitative Life Cycle Model

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MEMORANDUM

Date: May 25, 2018

To: Laurel Marcus, California Land Stewardship Institute

From: Mike Beakes, PhD; Rocko Brown, PhD; Joseph Merz, PhD

Subject: Water Quality Impacts on Steelhead & Black Bass

This technical memorandum provides an overview of fish communities observed in Suisun Creek and Lake Curry during 2017 surveys, information on water temperature and dissolved oxygen limits of steelhead (*Oncorhynchus mykiss*) and black bass (*Micropterus* sp.), and briefly discusses the tradeoff in creek and lake water quality for both species via Lake Curry water releases.

FISH COMMUNITIES IN SUISUN CREEK AND LAKE CURRY

Snorkel surveys were conducted from Lake Curry dam downstream approximately six miles. A total of nine species were observed including Central California Coast DPS steelhead listed as threatened under the Endangered Species Act 1973 (Table 1). Survey followed guidelines described in an American Fisheries Society publication of best practices in fisheries science (Johnson et al. 2007). Steelhead were observed in Suisun Creek as recently as September 2017.

Table 1: Summary of total abundance of each species identified during Suisun Creek snorkel surveys.

Common & Scientific Names	Total Abundance
Bluegill Sunfish (*Lepomis macrochirus*)	1
California Roach (*Hesperoleucus symmetricus*)	8179
Inland Silverside (*Menidia beryllina*)	1
Prickly Sculpin (*Cottus asper*)	1
Sacramento Pikeminnow (*Ptychocheilus grandis*)	1736
Sacramento Sucker (*Catostomus occidentalis*)	2005
Steelhead (*Oncorhynchus mykiss*)	46

Snorkel surveys of Lake Curry were also conducted in October 2017 to characterize the abundance, diversity, and distribution of fishes residing in the lake. These snorkel surveys followed methodologies reported in Mueller et al. (2001). The fish community in Lake Curry was dominated by two species (Table 2).

Table 2: Summary of total abundance of each species identified during Lake Curry snorkel surveys.

Common & Scientific Names	Total Abundance
Sunfish (*Lepomis* sp.)	2,872
Black bass (*Micropterus* sp.)	153

WATER QUALITY TOLERANCES FOR STEELHEAD AND BASS

We report water quality tolerances for bass and steelhead to highlight differences between native and invasive species requirements. This can support decision making for reservoir operations. For example, in dry years water releases for steelhead may be seen as a detriment to lake species such Largemouth Bass (*Micropterus salmoides*). In general, steelhead are far less tolerant of high water temperatures and low dissolved oxygen than black bass (e.g., Largemouth). The information provided below was compiled from peer-reviewed documents based on field studies and controlled lab experiments.

Table 3: Lethal water temperatures for steelhead/Rainbow Trout and black bass are summarized in the table below.

Common & Scientific Names	Temperature (°C)	References
Steelhead (*O. mykiss*)	> 25.0 – 27.5	1, 2, 3, 4
Black bass (*Micropterus* sp.)	> 30.0 – 36.0	5, 6, 7, 8, 9, 10, 11

Table 4: Lethal dissolved oxygen for steelhead/Rainbow Trout and black bass are summarized in the table below.

Common & Scientific Names	Dissolved Oxygen (mg/L)	References
Steelhead (*O. mykiss*)	< 3.0	12, 13, 14
Black bass (*Micropterus* sp.)	< 1.0	15, 16, 17

References: [1]Sloat and Osterback 2013; [2]Cherry et al. 1977; [3]Hokanson et al. 1977; [4]Myrick and Cech 2005; [5]Stuber et al. 1982; [6]Carlander 1977; [7]Strawn 1961; [8]Kelley 1968; [9]Badenhuizen 1969; [10]McCormick and Wegner 1981; [11]Matthews et al. 1997; [12]Gutsell 1929; [13]Doudoroff & Shumway 1970; [14]Raleigh et al., 1984; [15]Stuber et al. 1982; [16]Moss and Scott 1961; [17]Mohler 1966; Petit 1973

It is important to note that water temperatures below lethal levels but greater than or equal to 18°C will still have significant negative impacts on steelhead. These impacts can range from increased bioenergetic demands (Hanson et al. 1997), to suppressed gamete production (Pankhurst et al. 1996), and substantially reduced feeding activity (Railsback and Rose 1999). Collectively these factors present a significant threat to the viability and survival likelihood of steelhead residing in thermally stressful habitats.

AIR TEMPERATURE DRIVES WATER TEMPERATUTRE

Air temperature is considered one of the primary controls of water temperature (Stefan and Preud'homme 1993, Caissie 2006, Webb et al. 2008). It has been well documented in past research that increasing water volume and discharge makes rivers and streams less sensitive to changes in air temperatures (Smith and Lavis 1975, Ozaki et al. 2003, Webb et al. 2003, 2008). As such, decreasing the volume of water released from Lake Curry to Suisun Creek will make Suisun Creek more sensitive to increases in air temperature. Releasing water from Lake Curry to Suisun Creek will increase the creek's capacity to resist thermal change during heat waves, but these releases will also drawdown Lake Curry potentially increasing the lake's sensitivity to increased air temperatures.

BALANCING LAKE CURRY OPERATIONS AND SPECIES NEEDS

Water releases from Lake Curry will likely lead to improved habitat and water quality conditions for steelhead downstream; assuming water released from the lake isn't at or above stressful thermal levels for steelhead. Improving downstream water quality via water releases may require a tradeoff with water quality in Lake Curry for bass. The drawdown of Lake Curry may result in increased water temperatures and decreased dissolved oxygen in the lake. That said, fish species observed in the Lake Curry (e.g., Largemouth Bass, Sunfish) are robust to high water temperatures and low dissolved oxygen. As such, the tradeoff in water quality via Lake Curry water releases is not likely equal for all species affected because steelhead are much more sensitive to poor water quality conditions compared to bass. Failing to release water from Lake Curry will almost certainly have negative, and potentially lethal, consequences for ESA-listed steelhead downstream of the lake.

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MEMORANDUM

Date: January 30, 2018

To: Laurel Marcus, California Land Stewardship Institute

From: Rocko Brown, PhD; Jesse Wiesenfeld, MS

Subject: Suisun Creek Snorkel Surveys

This memorandum is to provide a summary of observations made during the fish surveys of Suisun. This project is focused on examining if water releases from Lake Curry can be used to cool over-summer water temperatures and improve *Oncorhynchus mykiss* habitat in Suisun Creek. The primary aims of these surveys were to estimate the abundance and distribution of *O. mykiss* within Suisun Creek at the time of the survey.

SUISUN CREEK SURVEYS

Snorkel surveys of Suisun Creek were conducted on June 7 & 8, 2018. Surveys were planned to cover reaches 1,2 and 3 (approximately river mile 6.5-9.0 and 9.4-9.6; Figure 1). Upon reaching the creek our crew noted that the stream was dry and did not have open channel flow (Figure 2). Our crew proceeded to walk the creek to determine if there were isolated pools with fish.

No *O. mykiss* were observed during the surveys. Two known locations within reach 2 that we had previously seen *O. mykiss* were dry (38.33521° N 122.12786° W and 38.33866° N 122.12643° W). Access to locations in river mile 9.4-9.6 where we had previously observed O. mykiss was not obtained. We did observe intermittent isolated pools upstream of river mile 8.0. Threespine stickle back (*Gasterosteus aculeatus*), Sacramento pikeminnow (*Ptychocheilus grandis),* Sacramento sucker (*Catostomus occidentalis*) and California roach (*Hesperoleucus symmetricus*) were observed, but they appeared to be in poor health, with significant fungus covering their scales.

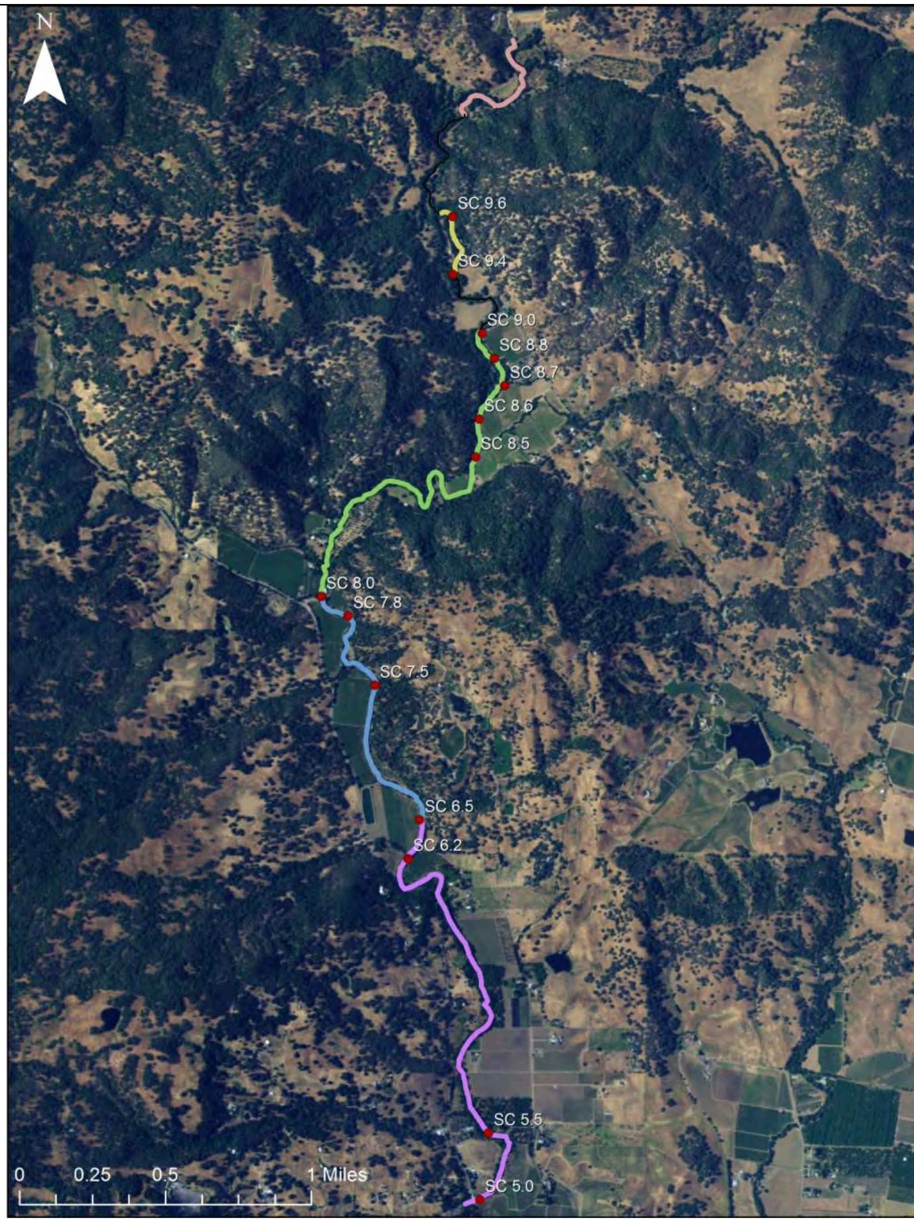

Figure 1: Map of 2017 snorkel survey extent within Suisun Creek. Colored reaches correspond to discrete survey reaches evaluated in an NMDS fish community analysis. Red points identify temperature monitoring locations and station numbers.


Figure 2. Photographs illustrating conditions upstream of river mile 8 (38.3336° N 122.13448° W).

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MEMORANDUM

Date: August 4, 2020

To: Laurel Marcus, California Land Stewardship Institute

From: Jesse Wiesenfeld, MS; Rocko Brown, PhD; Joseph Merz, PhD

Subject: Suisun Creek Fish Surveys

This technical memorandum provides a summary of fish observations made during snorkel surveys of Suisun Creek in June 2020. This project is focused on examining if water releases from Lake Curry can be used to cool over-summer water temperatures and improve *Oncorhynchus mykiss* habitat in Suisun Creek. The primary goal of the surveys was to estimate the abundance, distribution and habitat use of *O. mykiss* within Suisun Creek. Additional goals included estimating non-target fish abundance and distribution as well as describing and quantifying habitat within Suisun Creek.

SUISUN CREEK SURVEYS

Snorkel surveys of Suisun Creek were conducted 9 – 11 June 2020. Previously, snorkel surveys were performed in Suisun Creek in June, July, and September 2017 and were attempted in June 2018; however, water levels were too low to survey. The study area (SC temperature stations 6.2-9.0 and 9.2-9.4) was divided into four reaches and surveys were completed in three days: day one SC 6.2-8.0; day two SC 8.0-8.4; and day three SC 8.4-9.0 and SC 9.2-9.4 (Figure 1). Reaches were based on access and *O. mykiss* observations from previous snorkel surveys. In 2020, creek access was not available directly below the dam.

In both years, surveys generally followed the habitat inventory classifications of the California Salmonid Stream Habitat Restoration Manual (Flosi et al. 1998) and snorkel survey protocol of Johnson et al. (2007). We classified habitat using the level II hierarchy of riffle, flatwater, and pool. Additionally, we measured habitat length and wetted widths at 1/3 and 2/3 of each habitat. Single pass, no calibration, snorkel surveys were considered sufficient for evaluating fish distributions and average density (Johnson et al. 2007, Pinnex et al. 2016). However, the snorkeling sampling scheme was altered in 2020 to account for low water. In 2017, snorkelers subsampled reaches by alternating surveying or skipping each habitat type to increase coverage while staying within budget constraints. In 2020, riffles, the most commonly occupied *O. mykiss* habitat, were too shallow to snorkel or presumably to contain *O. mykiss*. Thus, snorkelers surveyed every flatwater and pool within a reach and riffles were surveyed visually from the bank for fish presence, identification, and enumeration.

Across the June 2020 snorkel surveys:

- A total of 150 habitat units were surveyed including pools, riffles, and flatwater (Table 1).
- A total of 41,951 fish were observed and identified to species and additional 1,000 fish that could not be confidently identified to species were identified to family Cyprinidae.
- A total of 8 species were observed (Table 1).

Table 1. Summary of the habitat units by type, included the number surveyed, mean length (sd), total length, mean width (sd) and estimated area (total length × mean width) during Suisun Creek snorkel surveys, June 2020.

Habitat	Surveyed	Mean length (m)	Total length (m)	Mean width (m)	Estimated Area (m^2)
Flatwater	58	38.8 (22.6)	2,253	5.59 (2.14)	12,594
Pool	43	29.2 (23.3)	1,369	6.53 (2.32)	8,940
Riffle	49	18.2 (11.9)	889	3.11 (1.54)	2,764

Table 2. Summary of total abundance of each species identified during Suisun Creek snorkel surveys, June 2020.

Common & Scientific Names	Total Abundance
Bluegill Sunfish (*Lepomis macrochirus*)	565
California Roach (*Hesperoleucus symmetricus*)	23,943
Prickly Sculpin (*Cottus asper*)	21
Sacramento Pikeminnow (*Ptychocheilus grandis*)	2,247
Sacramento Sucker (*Catostomus occidentalis*)	4,419
Tule Perch (*Hysterocarpus traskii)*	255
O. mykiss (*Oncorhynchus mykiss*)	51
Threespine Stickleback *(Gasterosteus aculeatus)*	10,450

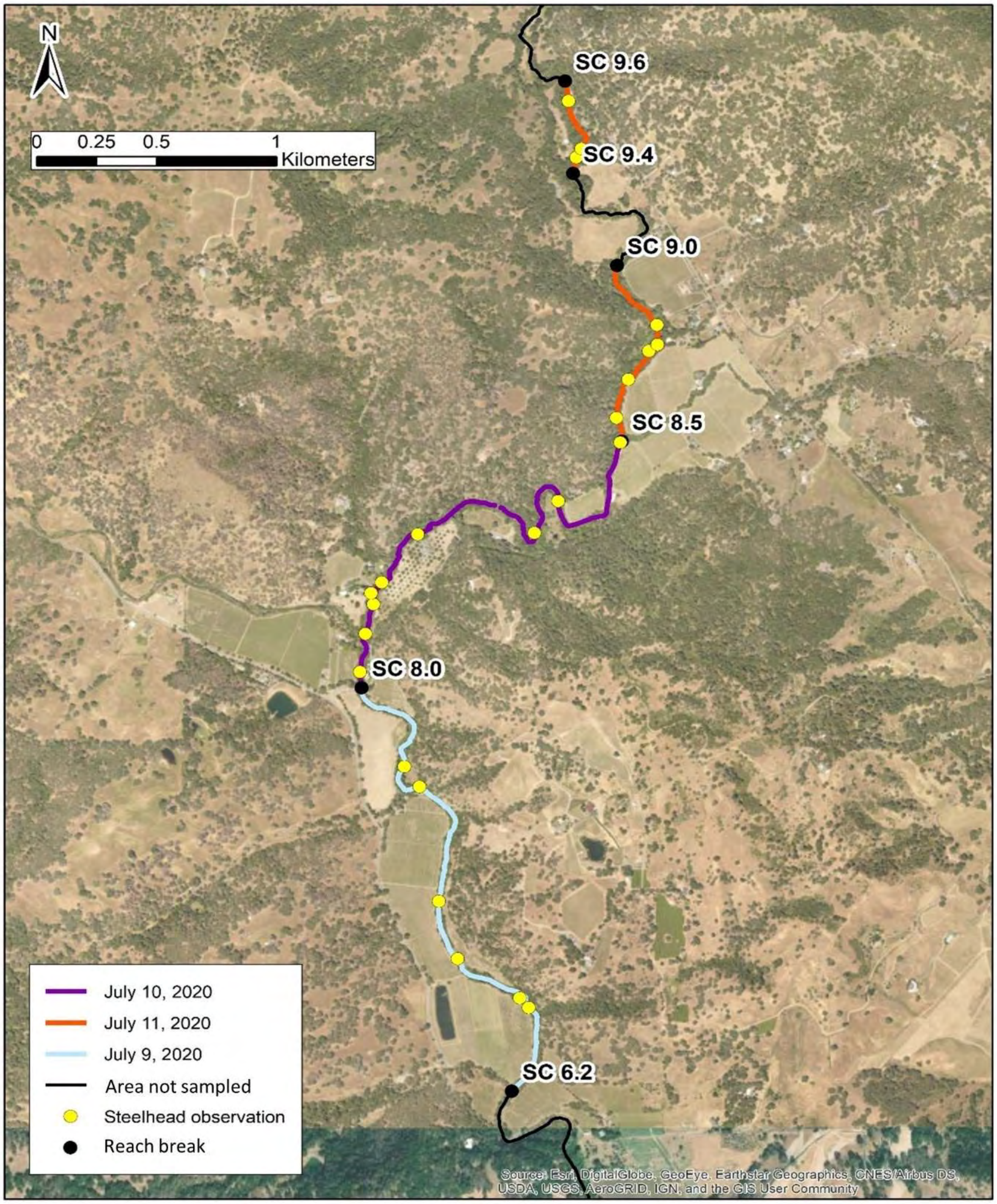

Figure 1. Map of 2020 Suisun Creek snorkel survey extent. Colored reaches correspond to the day the survey was performed. Yellow dots indicate *O. mykiss* observations and black dots are Suisun Creek (SC) temperature monitoring stations indicating the start and end of snorkel reaches. Numbers indicate stream distance from the mouth (in miles). Note, some *O. mykiss* observations dots in close proximity overlap.

Overall, *O. mykiss* abundance was relatively low across all reaches. Only 51 *O. mykiss* were observed through 4.5 km of stream (Figure 1). Of the 58 flatwater and 43 pool habitats snorkeled, 23 habitats were occupied by *O. mykiss* (23%). Riffles surveyed from the bank appeared to not contain *O. mykiss* but were excluded from analysis because species identification could not always be confirmed. There was no significant difference in observed abundance between pool (mean=1.14; sd=0.38) and flatwater (mean=1.79; sd=1.06) habitats types (two-sample Wilcoxon test: P=0.092). The proportion of *O. mykiss* observed in pool habitat (*O. mykiss* = 43, estimated pool area = 8,940 m^2) was statistically greater than the proportion of *O. mykiss* observed in flatwater habitat (*O. mykiss* = 8, Flatwater = 12,594 m^2, z-test: $P < 0.001$).

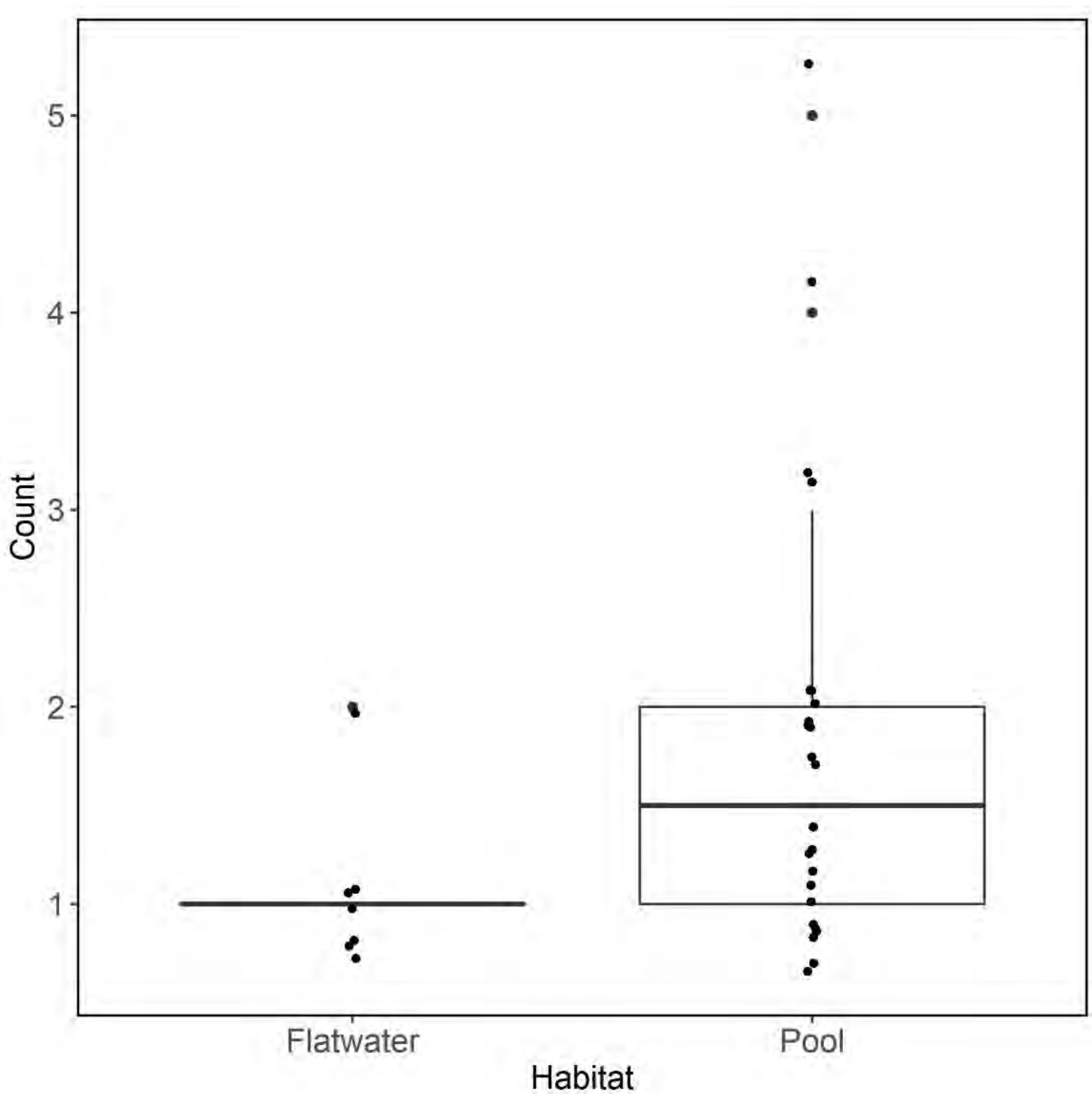

Figure 2. Box and scatter plots displaying *O. mykiss* abundance observed in occupied pool and flatwater habitats during Suisun Creek snorkel surveys, June 2020 (riffles too shallow to snorkel). Note points are "jittered" for visualization.

Snorkelers estimated *O. mykiss* sizes into distinct size classes ranging from < 50 mm to 301-400 mm. Nearly all observed *O. mykiss* were larger than 100 mm (94%) and no *O. mykiss* was smaller than 51 mm (Figure 3). The most commonly observed *O. mykiss* size classes were 151-200 mm and 201-300 mm, with 49% and 33% of respective observations.

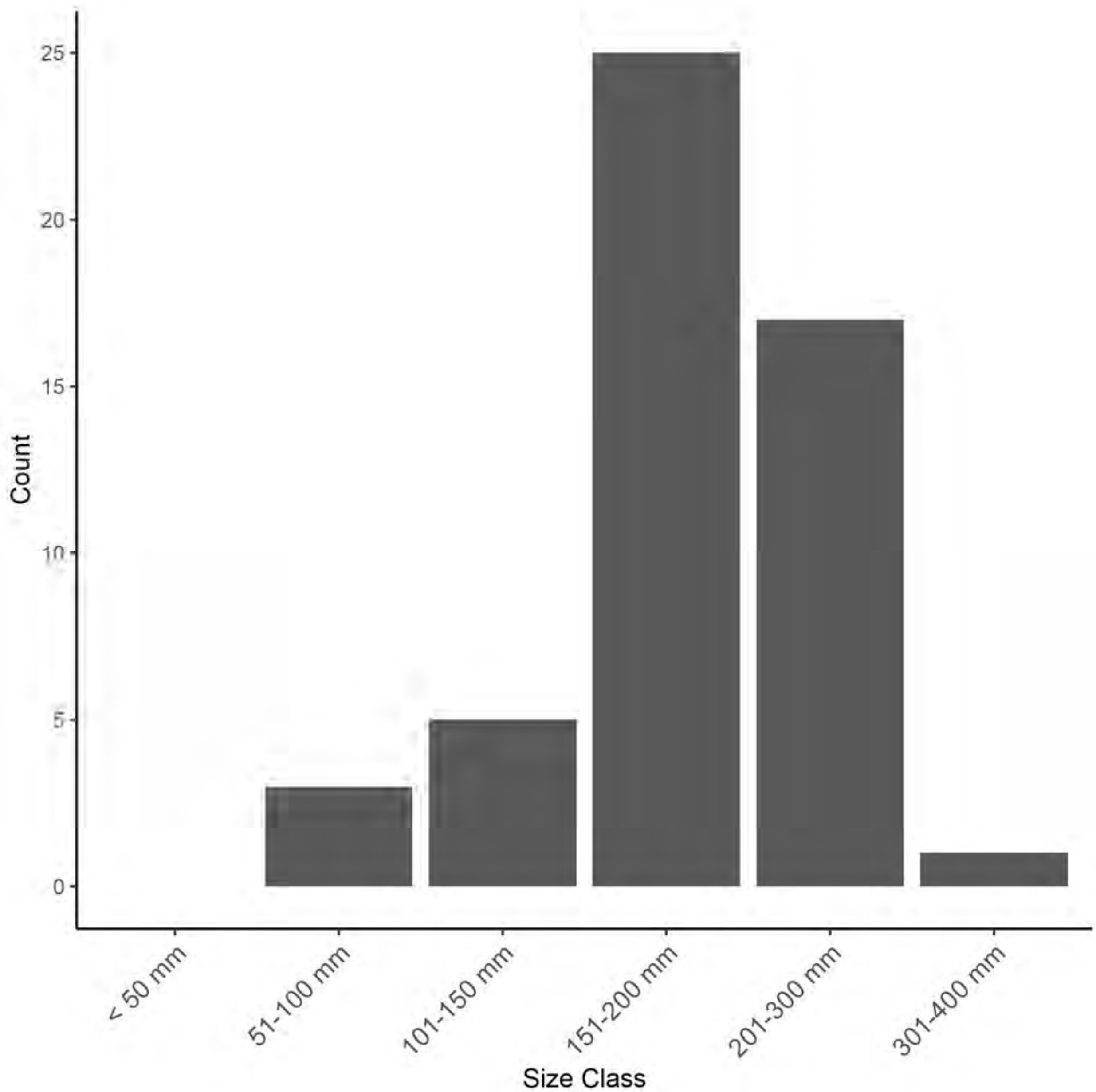

Figure 3. Size classes of observed *O. mykiss* during Suisun Creek snorkel surveys, June 2020. Note different bin size at 201-300 mm and 301-400 mm.

Fish Community

Fish communities in 2020 were relatively similar between reaches; however, we observed small shifts in fish communities from downstream to upstream (Figures 1 and 4). The largest difference was in the most downstream reach, 6.2-8.0, where we observed a higher relative abundance of

Threespine Stickleback (*Gasterosteus aculeatus*) and a lower relative abundance of California Roach (*Hesperoleucus symmetricus*) and Sacramento Sucker (*Catostomus occidentalis*) compared to upper reaches. Additionally, as sampling progressed upstream, the relative abundance of Sacramento Pikeminnow (*Ptychocheilus grandis*) decreased, while Bluegill Sunfish (*Lepomis macrochirus*) increased. *O. mykiss* density increased from downstream to upstream, with the highest *O. mykiss* density observed in 9.2-9.4 (Table 3). The higher density in 9.2-9.4 was primarily driven by two observations, containing four and five *O. mykiss* in large pools. We suspect the patterns observed in fish communities to be largely driven by stream temperature, distance from the dam, and differences in habitat (i.e. gradient).

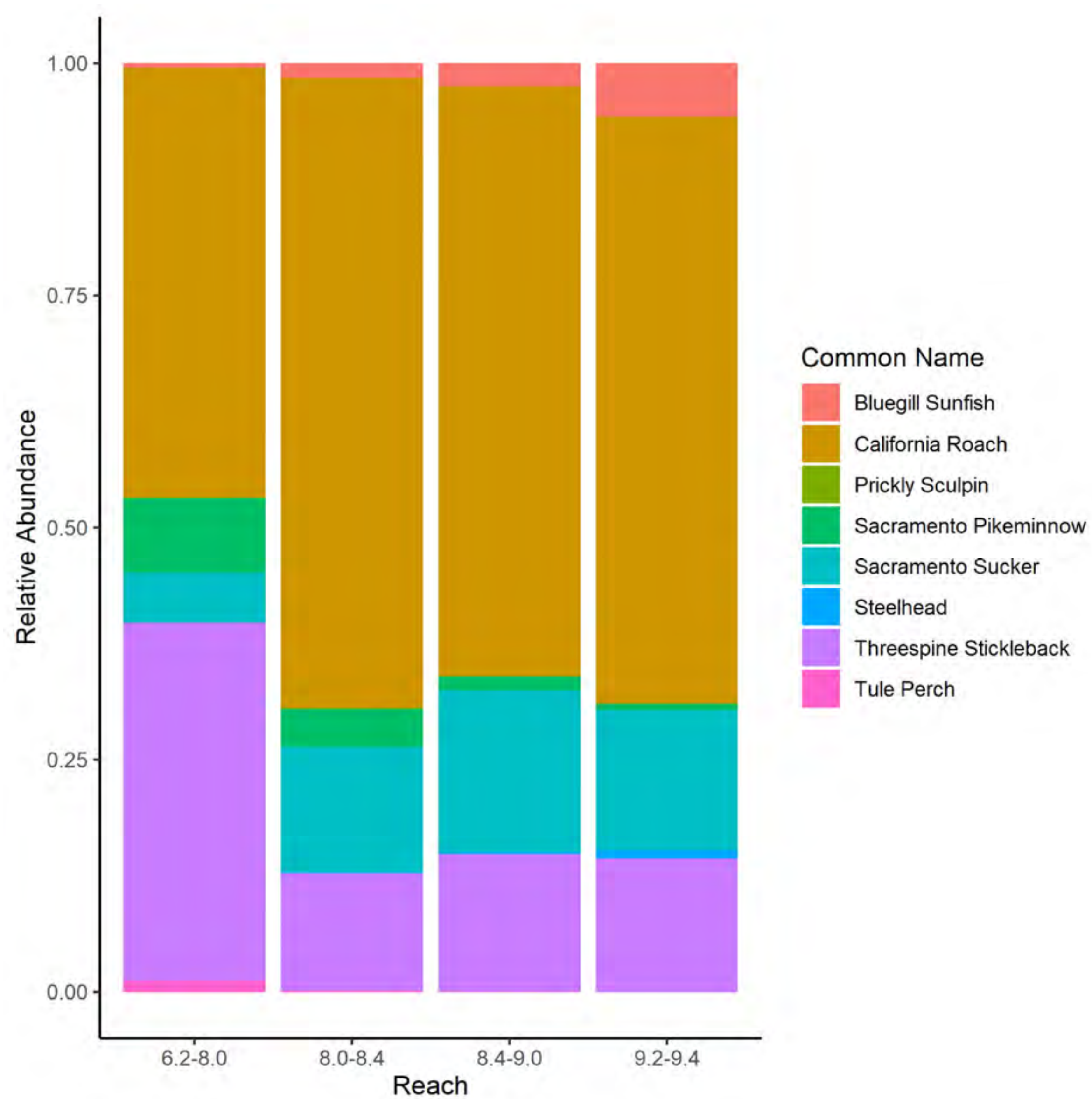

Figure 4. Relative abundance of observed fish species by reach during Suisun Creek snorkel surveys, June 2020.

Table 3. Summary of the number of *O. mykiss* observed in each reach, the length of each reach (m) and density (*O. mykiss* per m) in each reach during Suisun Creek snorkel surveys, June 2020.

Reach	*O. mykiss*	Reach length (m)	Density
6.2-8.0	9	1,363	0.006
8.0-8.4	18	1,886	0.009
8.4-9.0	11	907	0.012
9.2-9.4	13	356	0.037

Comparison with 2017 Snorkel Surveys

Snorkel surveys conducted in Suisun Creek in 2020 yielded overall similar results to 2017 surveys. However, relatively low *O. mykiss* abundance and only two monitoring seasons do not support rigorous comparisons of annual trends. Even so, general comparisons of the raw data provide potentially useful insights. In both 2017 and 2020 surveys, we observed a number of similarities: (1) *O. mykiss* were more abundant in upper reaches; (2) observed non-target fish species were similar; and (3) abundance of non-target species was relatively high throughout all reaches. Although overall low in both years, *O. mykiss* abundance appears to be higher in 2020 (n = 51) compared to a similar sampling event in July 2017 (n = 17, Figure 5). Additionally, there appears to be a shift in *O. mykiss* size classes from 2017 to 2020. In 2017 surveys, the majority of *O. mykiss* were smaller than 100 mm (53%) and no observations were larger than 150 mm. In 2020 surveys, the majority of observed *O. mykiss* were larger than 150 mm (82%) and the largest observed size class was 301-400 mm.

We observed a shift in *O. mykiss* habitat use from 2017 to 2020 (Figure 5). In 2017, *O. mykiss* were primarily observed in riffle habitat (n=15) and to a lesser extent in pools (n=2), and none were observed in flatwater. However, in 2020, with riffles almost dry and a shift in size classes, the majority of *O. mykiss* were presumably excluded from riffles and were observed in pools (n= 43) as well as in some flatwater (n=8).

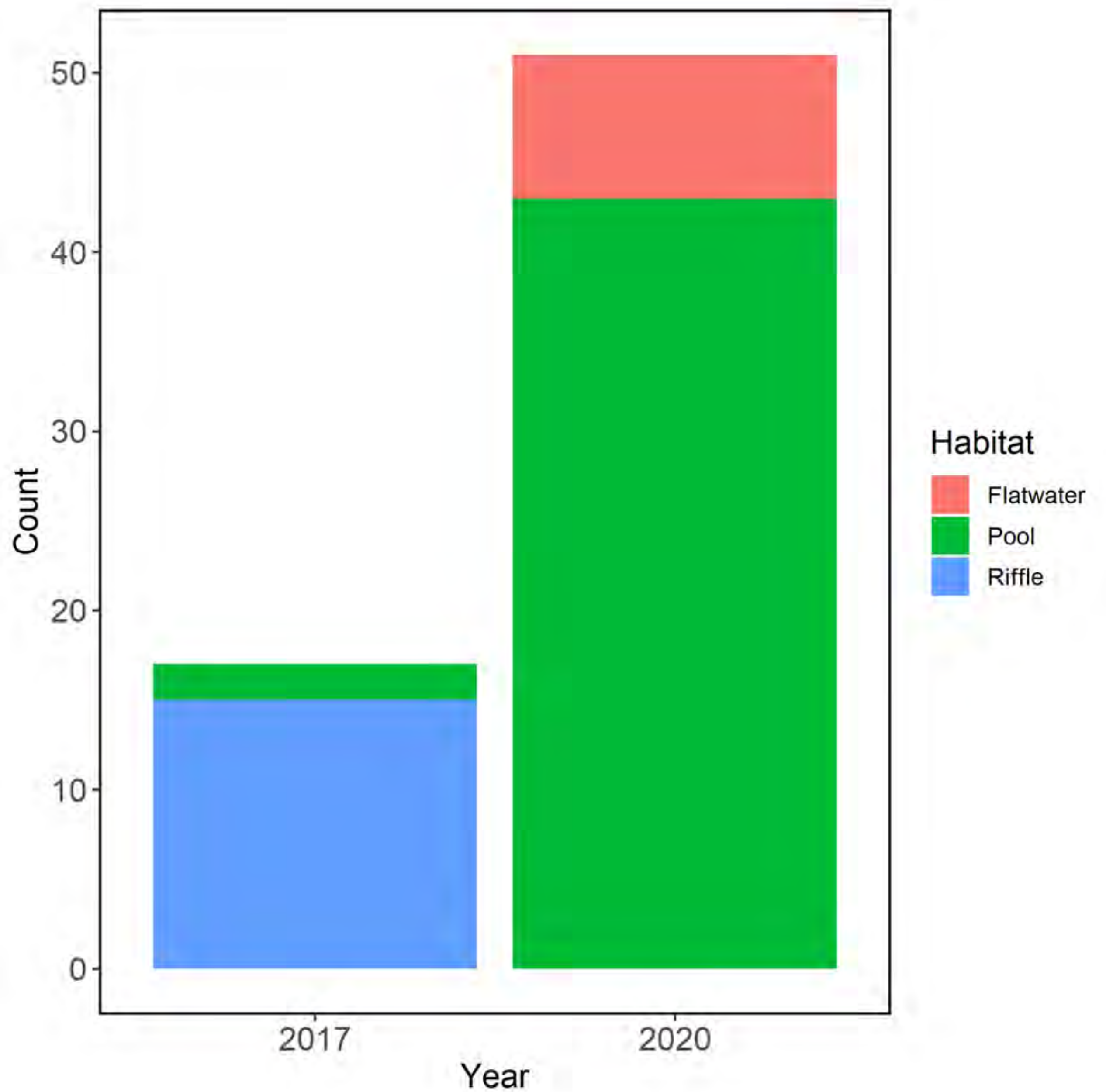

Figure 5. Abundance of *O. mykiss* observed in pool and flatwater habitats during Suisun Creek snorkel surveys in July 2017 and June 2020. Low flow prohibited snorkel surveys of riffle habitat in 2020.

Conclusions and Next Steps

- Overall, snorkel surveys revealed a relatively low number of *O. mykiss* in 2020 but were greater than in 2017.
    - Similar to 2017 surveys, *O. mykiss* density was skewed towards the upper reaches of Suisun Creek where stream temperatures were cooler.
    - *O. mykiss* populations may be trending upwards from 2017 after years of extreme drought in California, which likely adversely impacted Suisun and may explain the relatively low abundances we observed in 2017.
    - Based on the differences in *O. mykiss* size classes in 2017 and 2020, we estimate that age classes have shifted from consisting of entirely age 0 and 1 in 2017 to consisting of predominantly age 2+ and age 3+ *O. mykiss*.
    - Without additional *O. mykiss* recruitments, populations will not recover to sustainable levels and are susceptible to stochastic events.

- Suisun Creek contains a relatively greater proportion of native fishes.
    - Greater relative abundances of Bluegill Sunfish in upstream reaches may indicate fish are spilling over the dam into the creek and colonizing downstream.
    - Lake Curry contains a high abundance of black bass (*Micropterus spp*.). If bass spill into Suisun Creek and become established, the native fish community could be negatively impacted by predation.

- Recovery of Suisun Creek *O. mykiss* populations may be stalled by low stream flows.
    - Low stream flows cause a reduction in spawning and rearing habitat, which may explain the shift in age classes from 2017 to 2020.
    - Low stream flows reduce macroinvertebrate production and drift, limiting food availability for juvenile *O. mykiss.*
    - Low stream flows limit migration out of Suisun creek and movement within the system.
    - Low flows increase over summer stream temperatures above optimal limits.

- Information from these surveys will be incorporated into a quantitative life cycle model which will inform:
    - a population recovery target, quantifying a minimum viable *O. mykiss* population;
    - basic life history information, including identification of different life stages and their habitat associations (general demographics);
    - spawning habitat needs;
    - incubation and emergence requirements;
    - rearing habitat needs;
    - migration needs (both immigration and emigration);
    - and general water quality needs.

- We recommend additional monitoring to answer questions about food availability, growth, and habitat availability for Suisun Creek *O. mykiss*.

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Mueller, K. W., D. P. Rothaus, and K. L. Fresh. 2001. Underwater methods for sampling the distribution and abundance of smallmouth bass in Lake Washington and Lake Union. Washington Department of Fish and Wildlife, Fish Management Program, Technical Report # FPTO1-17, Olympia

Pinnix, W. D., K. De Juilio, Paul Petros, and N. A. Som. 2016. Feasibility of snorkel surveys for determining relative abundance and habitat associations of juvenile Chinook salmon on the mainstem Trinity River, California. Yurok Tribal Fisheries Program, Hoopa Valley Tribal Fisheries Department, U. S. Fish and Wildlife Service, Arcata Fish and Wildlife Office, Arcata Fisheries Technical Series Report Number TR 2016-24, Arcata, California.

2017 Memorandum

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MEMORANDUM

Date: January 30, 2018

To: Laurel Marcus, California Land Stewardship Institute

From: Mike Beakes, PhD; Rocko Brown, PhD; Joseph Merz, PhD

Subject: Suisun Creek and Lake Curry Fish Surveys

This technical memorandum is to provide a summary of observations made during the fish surveys of Suisun Creek and Lake Curry. This project is focused on examining if water releases from Lake Curry can be used to cool over-summer water temperatures and improve *O. mykiss* habitat in Suisun Creek. The primary aims of these surveys were to estimate the abundance and distribution of *O. mykiss* within Suisun Creek and evaluate the Lake Curry fish community.

SUISUN CREEK SURVEYS

Snorkel surveys of Suisun Creek were conducted on June 26 & 27, July 14 & 28, and September 26, 27, and 28. Surveys were stratified in space and time from Lake Curry dam downstream to stations 5.0 (Figure 1). We generally followed snorkel survey guidelines described in an American Fisheries Society publication of best practices in fisheries science (Johnson et al. 2007). Here, single pass, no calibration, snorkel surveys are considered sufficient for evaluating fish distributions and average density (Johnson et al. 2007, Pinnex et al. 2016). Across all 2017 surveys:

- Approximately 570 habitat units were surveyed including pools, riffles, and flatwater.
- A total of 14,682 fish were observed and identified to species. A total of nine species were observed (Table 1).

Table 4: Summary of total abundance of each species identified during snorkel surveys.

Common & Scientific Names	Total Abundance
Bluegill Sunfish (*Lepomis macrochirus*)	1
California Roach (*Hesperoleucus symmetricus*)	8179
Inland Silverside (*Menidia beryllina*)	1

Prickly Sculpin (*Cottus asper*)	1
Sacramento Pikeminnow (*Ptychocheilus grandis*)	1736
Sacramento Sucker (*Catostomus occidentalis*)	2005
Steelhead (*Oncorhynchus mykiss*)	46

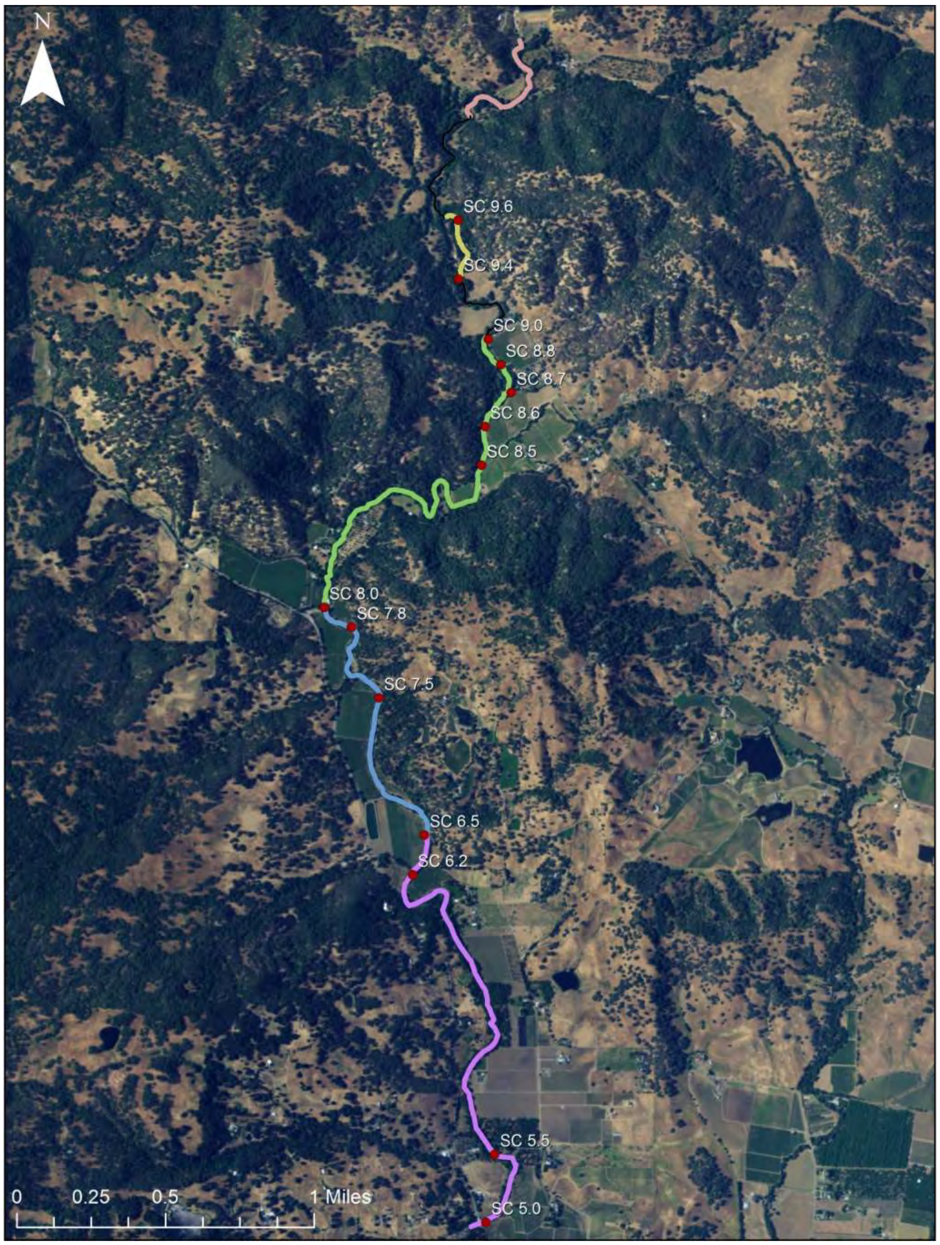

Figure 6: Map of 2017 snorkel survey extent within Suisun Creek. Colored reaches correspond to discrete survey reaches evaluated in an NMDS fish community analysis. Red points identify temperature monitoring locations and station numbers.

In total we observed 46 steelhead between June, July, and September. The majority of steelhead observed were located in habitats upstream of station 8.0 (Figure 1, 2). Overall, steelhead abundance was relatively low across habitats surveyed, where most occupied habitats had 1-2 fish (Figure 2). All steelhead were located in either riffle or pool habitats but there was no significant difference in observed abundance between these habitat types (Two-sample T-test, $P > 0.05$).

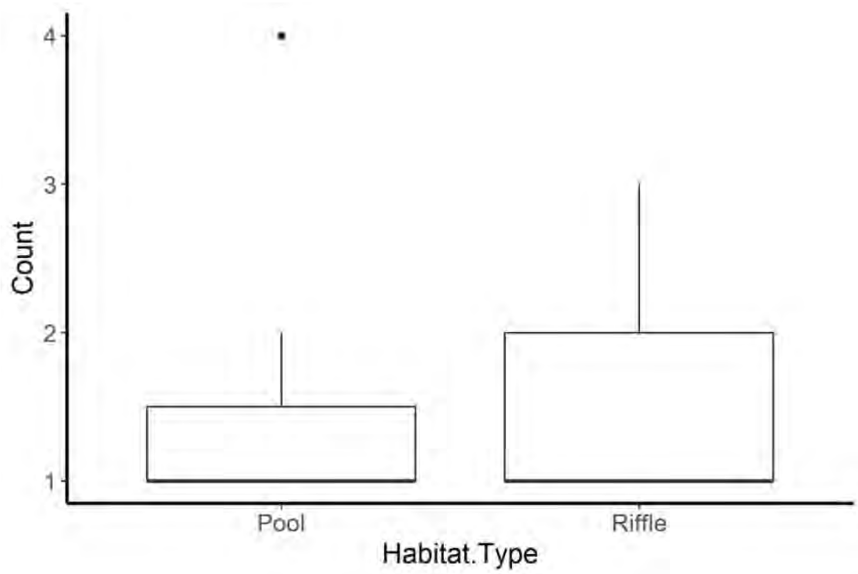

Figure 7: Box and whisker plot illustrating the distribution of steelhead abundance observed in pool and riffle habitats within Suisun Creek.

We observed no significant chance in the mean abundance of steelhead observed within any habitat type across the months surveyed (Figure 3; GLM, $P > 0.05$). On average, we observed 1.3-1.8 steelhead in occupied habitats across the surveyed months with the highest average abundance in June (Figure 3).

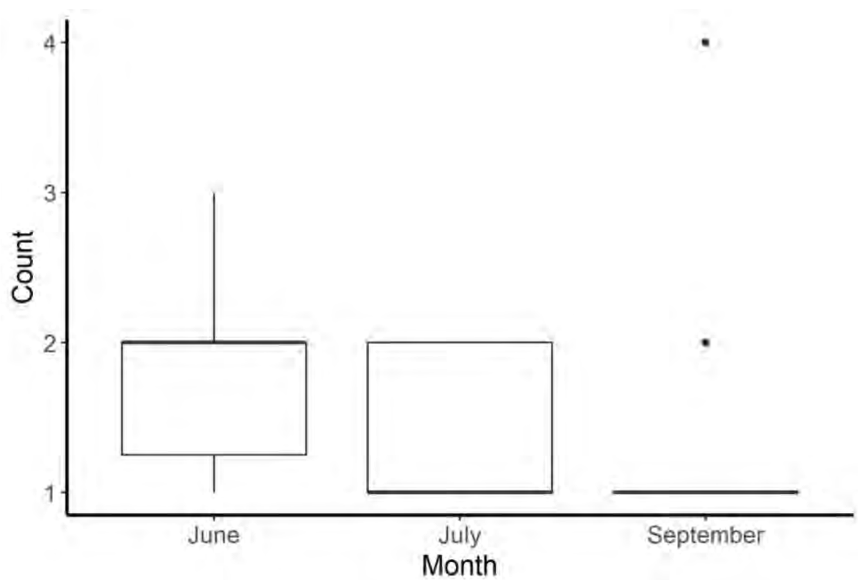

Figure 8: Box and whisker plot illustrating the distribution of steelhead abundance observed in June, July, and September within Suisun Creek

Low abundance and high variability will make detecting changes in abundance through space and time challenging. A power analysis of similar sampling designs indicates that sampling effort would have to increase substantially in order to detect changes in abundance either between months or habitats (Figure 4). For example, in order to have a 90% probability of detecting a 10% and significant change (i.e., $P < 0.05$) in abundance between riffles and pools we would have to survey over 2000 of both riffles and pools.

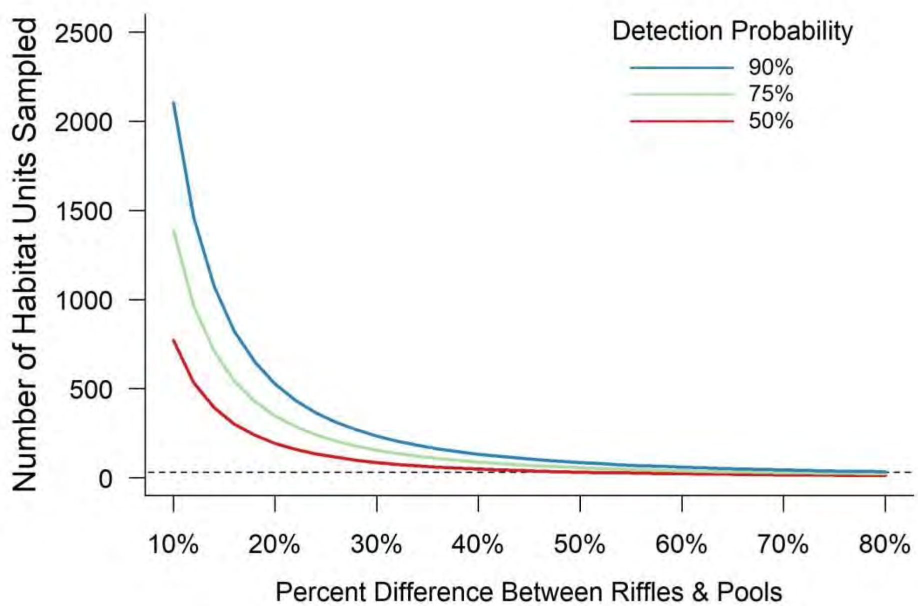

Figure 9: Power analysis depicts the sampling frequency needed to have a 90%, 75%, and 50% chance of detecting 10-80% differences in steelhead abundance between riffles and pools.

The fish communities observed in Suisun Creek changed predictably moving from upstream down. Generally, the community was dominated by more warm-water fishes further down the creek (Figure 5). Whereas, cooler-water fishes such as steelhead were found higher in the watershed. We suspect the patterns we observed in fish communities are being largely driven by stream temperatures.

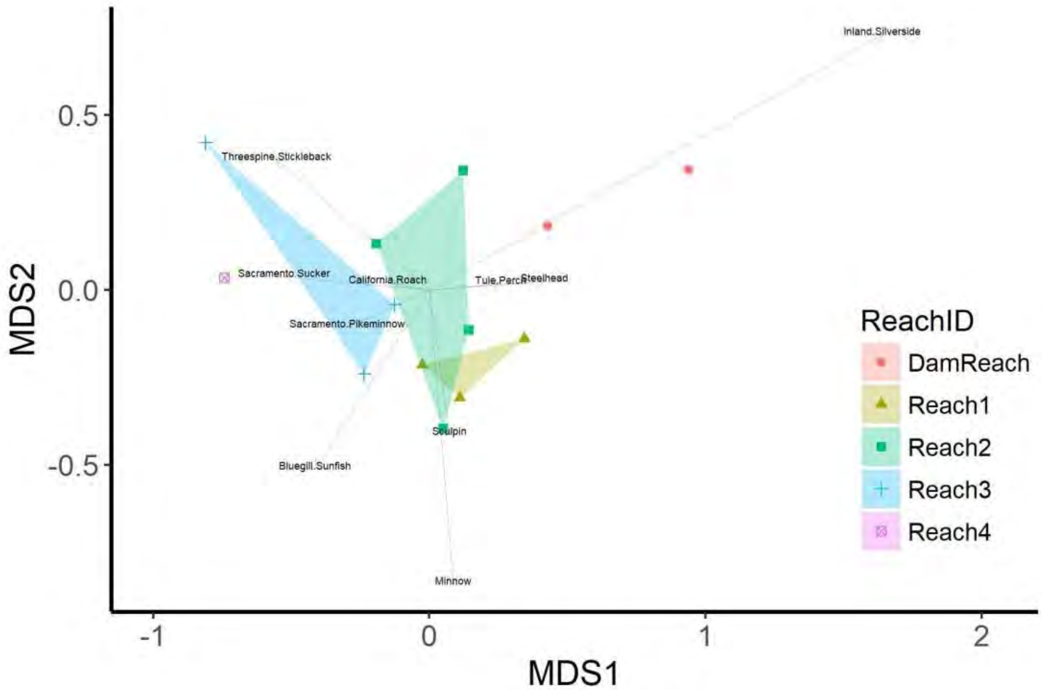

Figure 10: MDS plot of fish communities summarized by survey reaches. Reach locations and colors coincide with the colored polyline in Figure 1. Note that the length of each species vector plotted in the MDS ordination scales with the strength of impact that species had on the overall community structure.

We found that the likelihood of observing steelhead in either riffle or pool habitats changed predictably as surveys moved from downstream up. We found the distance from the dam was significantly and negatively correlated with the probability steelhead would be occupying creek habitats (Figure 6; GLM, $P < 0.01$). On average we found the probability of observing a steelhead in either a pool or riffle was ~20% at the Lake Curry dam outlet. By contrast, the probability of observing a steelhead in any habitat dropped to less than 2% within 4 miles from the dam outlet.

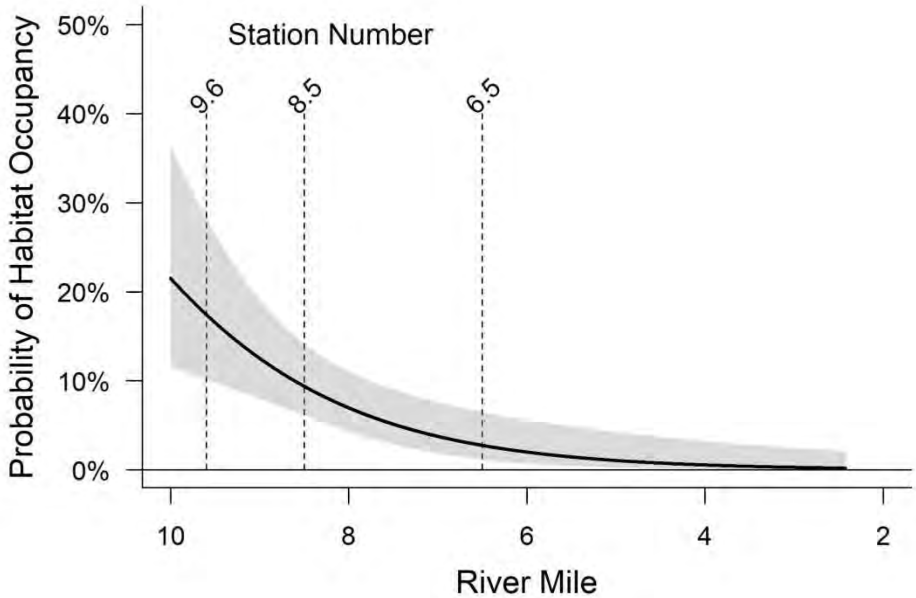

Figure 11: Binomial GLM estimating the probability of detecting steelhead in any habitat type as a function of River Mile. River Mile 10 is at the Lake Curry dam outlet. The mean model fit (solid line) is encompassed by 95% confidence intervals (grey polygon).

LAKE CURRY FISH SURVEY

We conducted snorkel surveys of Lake Curry to characterize the abundance, diversity, and distribution of fishes residing in the lake. These snorkel surveys followed methodologies reported in Mueller et al. (2001). This information is needed to determine potential effects of drawdown of the lake level for releases. In total, we observed 3,030 fish in surveys stratified around the lake. The fish community within Lake Curry was dominated by Black Bass (*Micropterus* sp., n = 153) and sunfish (*Lepomis* sp., n = 2,872). Bass were predominantly Largemouth Bass (*Micropterus salmoides*) and Bluegill sunfish (*Lepomis macrochirus*). However, we note the majority of sunfish could not be identified to species level and five fish could not be identified to genus due to relatively poor water clarity in the lake.

CONCLUSIONS AND NEXT STEPS

- Overall, snorkel surveys revealed a relatively low number of steelhead.
    - The distribution of steelhead was skewed towards the upper reaches of Suisun Creek and the likelihood of observing steelhead declined significantly and precipitously as surveys moved further from the dam.
    - The previous years of extreme drought in California likely adversely impacted Suisun Creek's steelhead population and may partly explain the relatively low abundances observed.
- Sensitivity analyses indicated that it will be difficult to capture changes among habitat types (e.g., riffles and pools) or over time using classic frequentist statistics (e.g., t-test, ANOVA). The population is currently too small and much of the available habitat is currently unoccupied.

- We recommend revising our sampling approach and follow a binary mode of data collection, where we identify if steelhead are present or absent across habitat types along the creek gradient.
    - These data can be used to improve the model fit shown in figure 6.
    - Additional covariates can be used to explain additional variance in the likelihood of habitat occupancy (e.g., stream temperature).
    - We can use this modelling platform to test hypotheses related to flow and water temperature as it relates to upstream and downstream shifts in steelhead distribution.
    - Collecting these binary data in a spatially explicit way (i.e., record x, y coordinates of surveyed locations) will allow us to use these data in advanced statistical applications tailored for analysis of streams and rivers (e.g., SSN models).

- The fish community observed in Lake Curry was dominated by non-native bass and sunfish.
    - These species are notoriously robust to warm water and relatively low water quality conditions.
    - We suspect that the impacts of lake drawdown on these species would be minimal. However, we note that both species construct nest or spawning beds in relatively soft-bottom shallow water.
    - Spawning typically occurs during the spring (Black bass) and late spring to summer (Bluegill).
    - As a consequence, there is a possibility that lake drawdown during the spring and summer will strand and desiccate Black Bass and/or Bluegill nests.

CITATIONS

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MEMORANDUM

Date: 12 July 2021

To: Laurel Marcus, California Land Stewardship Institute

From: Jason Hall, MS; Joseph Merz, PhD; Rocko Brown, PhD

Subject: Suisun Creek Quantitative Life Cycle Model

The Suisun Creek Watershed Instream Flow Enhancement Project (Project) focuses on examining if Lake Curry releases can be used to cool over-summer water temperatures and improve steelhead (anadromous form of Rainbow Trout; *Oncorhynchus mykiss*) habitat in Suisun Creek. To help inform this effort, Cramer Fish Sciences (CFS) developed a life cycle model to estimate spawning and rearing habitat needed to support steelhead in Suisun Creek in collaboration with the California Land Stewardship Institute. This technical memorandum provides the following:

- an overview of the modeling approach to estimate spawning and rearing habitat needs
- demographics and parameters used to parameterize the model
- summary of estimated spawning and rearing habitat needs
- conclusions and next steps
- an appendix that includes a list of the rules and sources used to parameterize the model (**Appendix A**); and
- an overview of the workbook and a Shiny Graphical User Interface that was developed as a frontend to an R package containing a coded version of the workbook (**Appendix B**).

The primary objective of this effort is to provide tools and information to support planning and assessment of steelhead habitat management goals that will allow stakeholders to:

- identify measurable goals that relate to federal and state laws and helps determine when "enough is enough"
- identify gaps in understanding and provide an iterative and transparent process whereby new information can fill knowledge gaps; and
- "game" habitat quantity and available water to wisely and adaptively manage flow and non-flow actions that support steelhead population targets.

The overall process to determine watershed ability to support a target steelhead population assumes that a viable population goal and habitat needs can be quantified, and general relationships between potential habitat and flow can be developed (Figure 1). This work addresses the first steps in this process, which are to determine the minimum spawning and rearing habitat requirements needed to support a viable steelhead population in Suisun Creek using a life cycle model approach. This was an iterative process with stakeholders to develop and refine the objectives, approach, and demographic information to estimate spawning and rearing habitat area requirements.

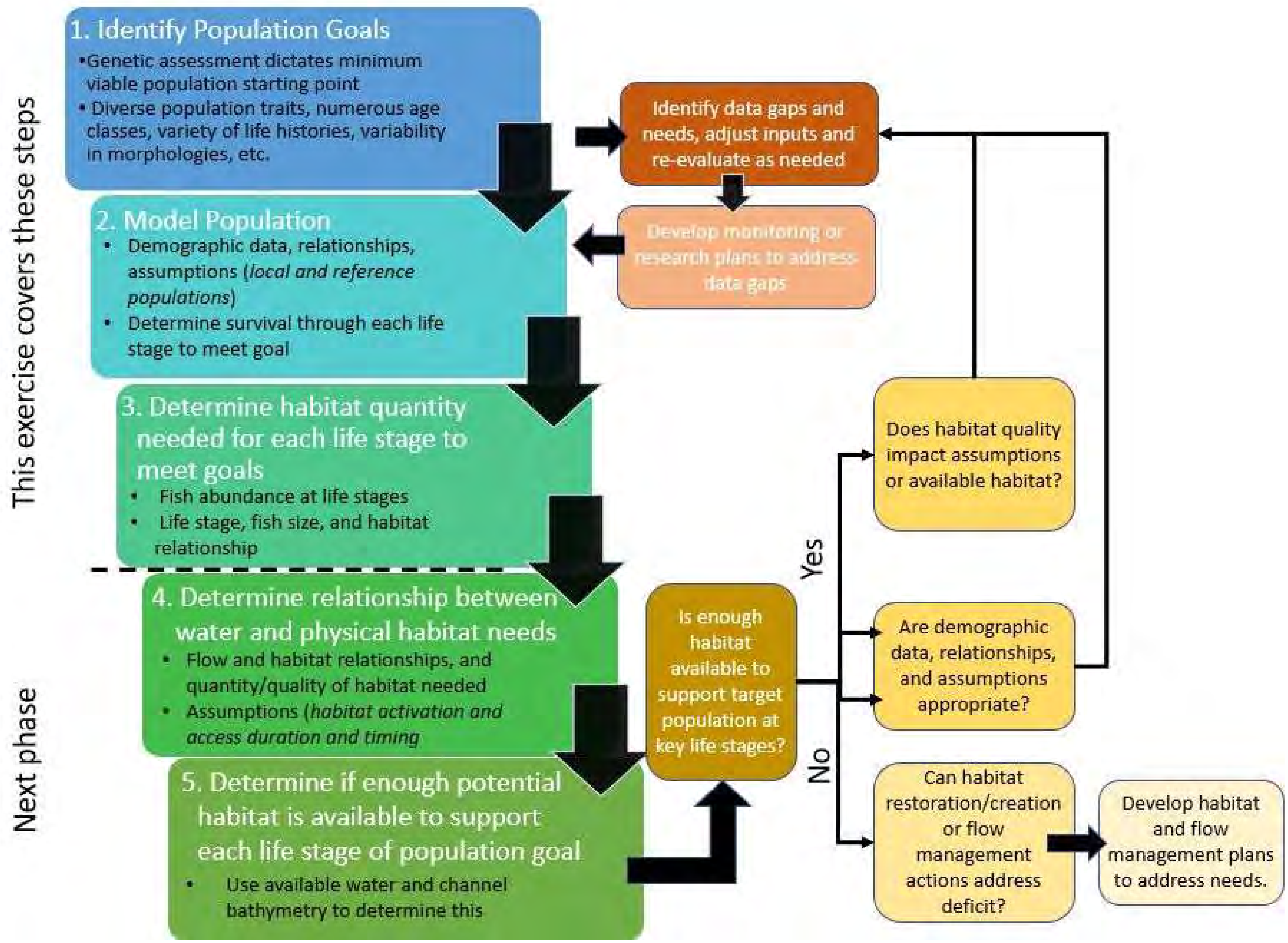

Figure 1. General process to determine watershed ability to support target steelhead population assuming a viable population goal is identified, habitat needs are quantified and general relationship between potential habitat and flow can be developed. For this exercise, Steps 1-3 were performed.

APPROACH

We used a combination of stakeholder input and information from other studies to parameterize a life cycle model to estimate habitat requirements to support an identified population target. In collaboration with stakeholders, we identified parameters that described targets, demographics, and habitat requirements at key life stages to estimate the minimum spawning and rearing habitat (area) needed to support the population abundance target (Figure 2). This approach does not consider current habitat quantity or quality, or current population status, but provides a necessary starting point for evaluating limiting factors and management actions by estimating the habitat needed to support population targets that can then be compared to current habitat conditions and management strategies (Figure 1). Information needed to parameterize the life cycle model used for this analysis include the following parameters which are described in more detail later:

1. Population targets
2. Adult age, size, and sex structure
3. Adult immigration and spawning timing
4. Redd size, territory requirements, and fecundity
5. Incubation timing, duration, and emergence timing and survival
6. Freshwater growth, size structure, and mortality
7. Juvenile emigration timing, duration, and production
8. Juvenile rearing territory requirements

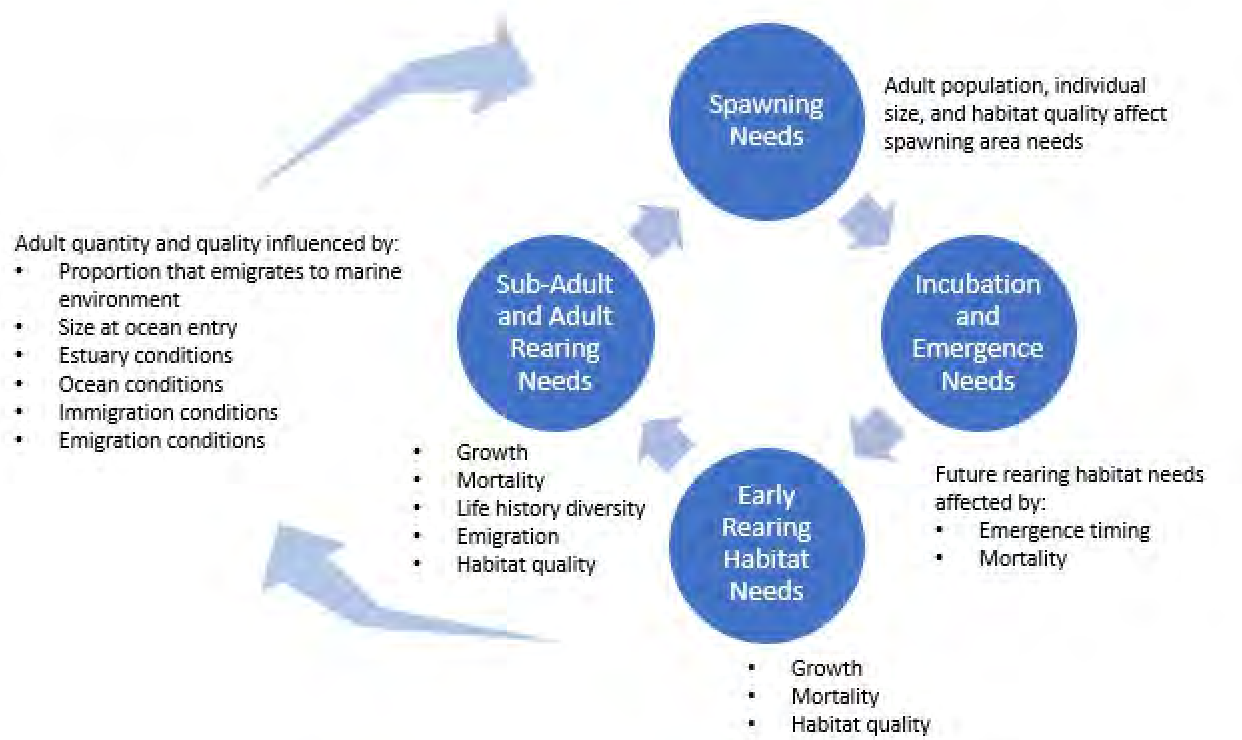

Figure 2. Conceptual diagram of the life cycle model approach used to estimate spawning and rearing habitat requirements for a target population using demographic information and relationships for key life stages.

Ideally, we would only use demographic information and relationships for these parameters that were developed from a healthy Suisun Creek steelhead population. However, limited data are available for this population and we must rely on reference data from other systems or assumptions to inform the model. Where reference data are used, we use data available to us from systems within the same geographic region and with similar hydrographic regimes (e.g., rain vs snow-dominated) that can influence demographic patterns and population dynamics. Examples of Central California and coastal systems considered for reference data are shown in Figure 3. The demographic data, relationships, and assumptions used to parameterize the model are described in the following section, including information on the reference systems used. This also helps identify data gaps and sources of uncertainty that can be addressed through future monitoring and research.

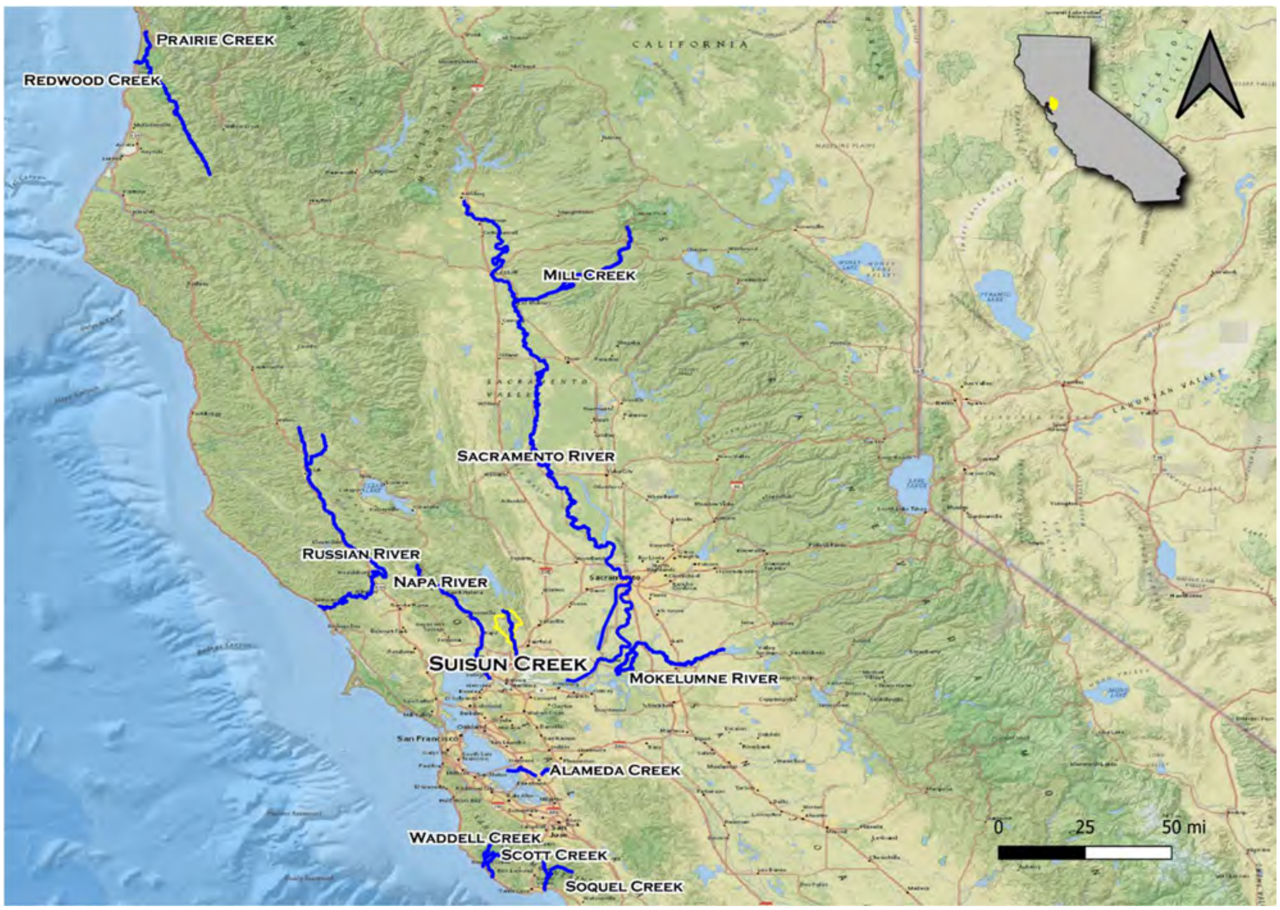

Figure 3. Suisun Creek watershed (Yellow) and example reference systems considered for demographic information to inform the life cycle model.

DEMOGRAPHICS AND PARAMETERS

The following section provides a narrative of the demographics, assumptions, and relationships used to parameterize the life cycle model used to estimate spawning and rearing habitat area requirements for Suisun Creek steelhead. The list of metrics and values discussed in this section and used in the model can be found in **Appendix A**.

Population targets

We used 833 spawning adult steelhead as the Suisun Creek population target with no harvest or harvest goals, which represents a minimum viable population abundance of spawning adults with low extinction risk. Spence et al. (2008), establish extinction risk criteria based on effective population size.[1] These criteria are intended to address risks associated with inbreeding and loss of genetic diversity within a population. The criteria, for salmonid populations in general, is 2500 for low extinction risk and 250 for high extinction risk. Effective population is assumed to be 20% of the total population size; and, since both effective and total population are generational, to relate it to annual run size, one would divide the total population size by the average age at reproduction (Brian Spence pers. comm.). In doing this for federal recovery planning purposes, Spence et al. (2008) assumed average age of 3 years for steelhead. The resulting population estimate for Suisun Creek watershed, expressed as annual run size, would be 83 (50/0.2/3) for high extinction risk, and 833 for low extinction risk. This minimum viable population target was selected by stakeholders for estimating spawning and rearing habitat requirements for Suisun Creek steelhead.

Adult age, size, and sex structure

We assumed a ratio of 1:1 female to male spawners (Shapovalov and Taft 1954; Waddell Creek), from which we are able to estimate that approximately 417 adult female spawners are needed to reach population targets (833/2). We also assumed a minimum age at maturity of age 2 for adult spawners and a maximum age of age 5 for spawning adults with no difference in sex structure among adult age classes (Kendall et al. 2014). From this, we used age structure from Waddell Creek (Satterthwaite et al. 2009) filtered to age 2 to age 5 adults only (excludes older age classes with relatively low proportional returns) to estimate the number of adult females of each age class that are needed to meet the population target (Table 1). Size structure was used to estimate fecundity as described later, which was based on mean female size by age class derived from Shapovalov and Taft (1954) for Waddell Creek steelhead (Table 1).

Table 1. Proportion of spawners by age class (Satterthwaite et al. 2009), size structure (Shapovalov and Taft 1954), and estimated abundance of female spawners of each age classes needed to meet population targets.

Age	Size (FL, mm)	Proportion	Female abundance
2	391	0.035	15
3	467	0.337	140
4	666	0.537	224
5	725	0.092	38

Adult migration and spawning timing

The timing and duration of adult immigration and spawning influences the timing and duration of egg deposition and incubation in the system, as well as the timing and duration of spawning habitat needed to support the population target. We used timing and duration information from Mokelumne River (East Bay Municipal Utility District, Lodi CA, unpublished data), with adult migration occurring from October to April and spawning occurring from December to April. The proportion of spawners for each month (Figure 4) was used to determine the monthly spawning

[1] NMFS' extinction risk criteria are available at https://swfsc.noaa.gov/publications/TM/SWFSC/NOAA-TM-NMFS-SWFSC-423.pdf.

habitat needed based on the number of female spawners for each month as well as allocating female spawners by age class to each month to estimate total monthly egg deposition.

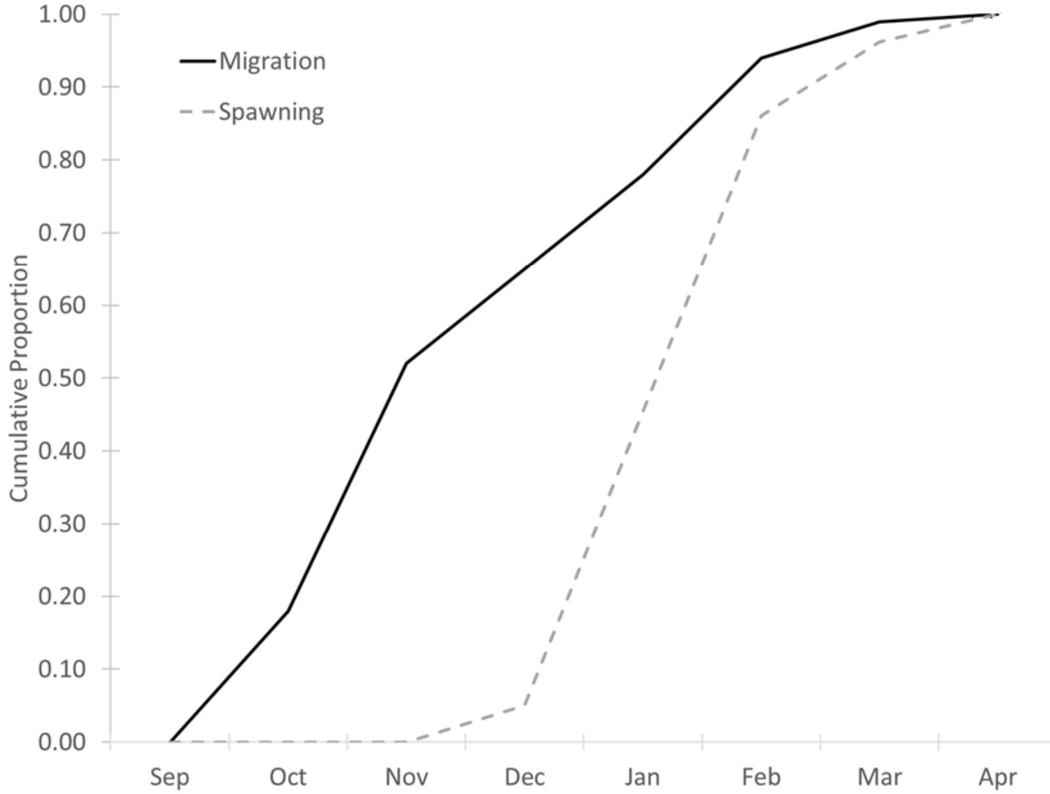

Figure 4. Cumulative proportion of adults migrating and spawning per month based on information from Mokelumne River (East Bay Municipal Utility District, Lodi CA, unpublished data).

Redd size, territory requirements, and fecundity

For redds, we assumed one redd per female with a mean redd size of 1.78 m^2 (0.14 SE, standard error) based on Gallagher and Gallagher (2005) for coastal California systems. No differences in redd sizes by age class or adult size were used based on the findings of Gallagher and Gallagher (2005) but reported redd sizes can range up to 11 m^2 and the assumed redd sizes directly influence estimated spawning habitat requirements. Because more area than that which is occupied by a completed redd is needed for construction, including redd defense by the female spawner, we assumed a territory requirement of 4x the mean redd area to estimate spawning habitat requirements (Burner 1951). This approach does not consider habitat quality, and it would be expected that reduced spawning habitat quality would increase the total habitat area needed to support the population target.

To estimate total egg deposition by month, we used mean lengths by adult age class and a relationship between length and total egg production from Shapovalov and Taft (1954) from Scott Creek in combination with total adult females by month. This represents a starting point for the incubation of cohorts by month with emergence timing and survival used as described below to estimate initial cohort rearing abundances.

Incubation timing, duration, and emergence timing and survival

To determine the incubation duration, we used monthly stream temperature averages from three stations in Suisun Creek (December – May), which ranged from 49 to 60°F, respectively (Barry Hill, California Land Stewardship Institute, personal communication). Average estimated incubation duration in days at these temperatures ranged from 38 days in December to only 18 days in May, which were estimated for each month based on relationships from Leitritz and Lewis (1980). Given that we use monthly time steps for abundance estimates, we assumed a one-month lag for incubation duration based on monthly spawner abundance to estimate emergence abundance per month based on monthly egg deposition from fecundity estimates. This could be adapted to a more dynamic emergence timing if finer time steps are used for spawner and redd abundances (e.g., weekly spawner estimates). Total egg deposition per month and estimated incubation duration for each month were used in combination with egg to fry survival rates from Prairie Creek (Briggs 1953) to estimate initial emergent fry cohort abundance for each month. This resulted in five cohorts of emergent fry that emerge from January to May, with peak emergence occurring in February and March.

Freshwater growth, size structure, and mortality

We assumed an initial emergent size of 23 mm for all cohorts from the Mokelumne River (Merz et al. 2016). Within each cohort, we used daily growth rates from Scott and Soquel creeks (Sogard et al. 2012) to estimate mean cohort fish sizes per month after emergence for winter/spring and summer/fall periods. We used age 0+ growth rates of 0.2 mm/day and 0.007 cm/day for winter/spring and summer/fall months, respectively for all young of the year, and age1+ growth rates of 0.3 mm/day and 0.05 mm/day, respectively, for all juveniles ages 1-3. This assumes growth rates remain constant after age1+ (see Kuzishschin et al. 2021) given that age-specific seasonal growth rates were not available for older age classes from Central California populations .

Suisun Creek snorkel surveys indicated that *O. mykiss* (instream rearing may include resident Rainbow Trout and anadromous steelhead life histories) size classes ranged from 50-400 mm in the month of June (Figure 5), which is consistent with the presence of multiple age classes rearing in Suisun Creek. Based on initial emergence size and timing, we estimated that juveniles rearing in Suisun Creek in June will include fish that range in size from 31 – 244 mm, which captured the majority of size classes observed in Suisun Creek in the month of June (Figure 5).

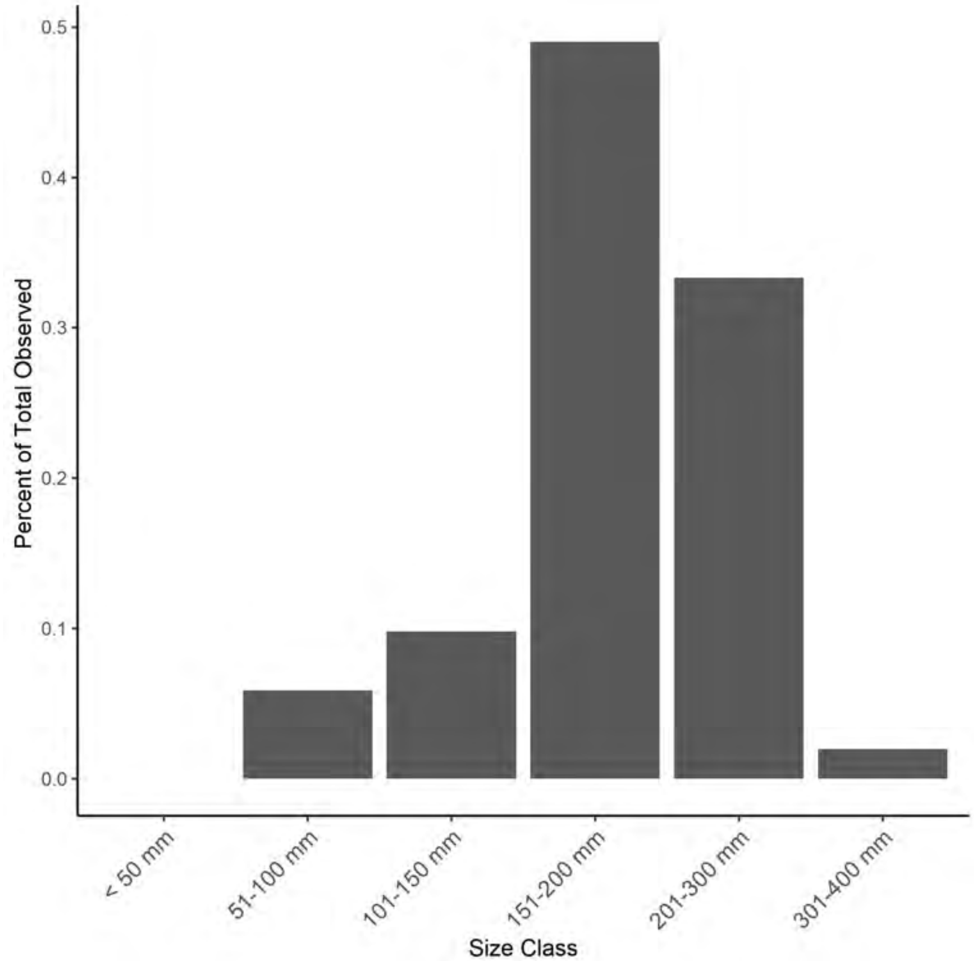

Figure 5. Size classes of observed *O. mykiss* during Suisun Creek snorkel surveys, June 2020 (Wiesenfeld et al. 2020). Note different bin size at 201-300 mm and 301-400 mm.

The initial cohort abundance of emergent fry was also adjusted monthly using daily mortality rates from Hokanson et al. (1977) of 0.0035 for winter/spring, and an estimated daily mortality rate of 0.0044 for summer/fall (25% higher than winter/spring) using the assumption that mortality increases during summer months when temperatures are higher and available habitat is reduced. Total juvenile abundance for each month was adjusted with these daily mortality rates such that the total abundance of rearing juveniles from each cohort is reduced monthly from the month of emergence through December of their third year. This assumes a maximum age of three years for rearing juveniles, which accounts for the majority (98%) of steelhead migrants observed in a well-studied coastal California stream (Shapovalov and Taft 1954; Wadell Creek). In addition, this approach also assumes mortality is not influenced by size at age or month.

Juvenile emigration timing, duration, and production

The total abundance of rearing juveniles was also adjusted based on emigration timing, which we assumed occurs from February to June with peak outmigration occurring in April based on a compilation of studies from multiple systems (Barnhart 1986; Fukushima and Lesh 1998; Merz 2002; Merz et al. 2016; Kelson and Carlson 2019). We used the adult spawner abundance target (833), age-specific smolt to adult return rates (Ward 1989), outmigrant age structure (Merz 2002; Hodge et al. 2016; Merz et al. 2016), and marine survival rates (Ward 1989; Welch et al. 2000) to estimate the total number of outmigrants of each age class that are needed to produce the target adult spawner abundance. These outmigrants were apportioned to each cohort based on initial emergent abundance from each month and removed from the rearing population monthly from February to June for each year. This approach assumes no outmigration occurs outside of this period, most migrants produced are age 0 to age 3, size at age or month does not influence the probability of emigration among cohorts, and that marine survival is dependent on size at ocean entry.

Juvenile rearing territory requirements

With monthly abundance estimates for each cohort adjusted for daily mortality and emigration (migrant production), we used estimated mean monthly cohort sizes to estimate territory requirements for rearing juveniles based using a log linear relationship between an individual's body size at its territory requirements (Grant and Kramer 1990) to estimate total monthly rearing habitat requirements. Given that brood year cohorts will overlap across years, we summed rearing requirements by months across years for cohorts to estimate total rearing habitat requirements for a composite population. This approach allows us to consider the rearing habitat requirements for a population needed to support the target adult population, which includes fish that will be lost to mortality during both freshwater and marine life stages.

RESULTS AND DISCUSSION

Spawning habitat requirements

For a target population of 833 adult steelhead spawners with no harvest goal, we estimate that between 0.04 acres to 0.73 acres of spawning habitat area is needed with a maximum of 0.73 acres needed in April (Figure 6). Given that embryos require incubation prior to emergence, total spawning habitat area needed to support incubation should extend through May (Figure 6) based on estimated emergence timing given Suisun Creek temperature patterns. These estimates are based on timing and duration of Mokelumne River immigration and spawning (East Bay Municipal Utility District, Lodi CA, unpublished data). If the periodicity of spawning in Suisun Creek differs substantially from these reference systems, it would shift the monthly spawning habitat requirements but would not affect the total cumulative habitat area requirement estimated. Also, these estimates do not consider habitat quality which could directly influence the required amount of habitat needed given the assumption that required habitat increases as habitat quality decreases.

Estimated spawning and incubation habitat area requirements are also derived from the assumptions of mean redd size, female to redd and female to male ratios are even, and that spawners require 4x the redd area for spawning. Changing territory requirements per redd, redds per female, sex structure, and mean redd areas will all directly influence the estimated spawning habitat area requirement. For example, increasing the redd area by 2x would increase the habitat area requirements by 2x, while using the upper range of 11 m^2 per redd from Gallagher and Gallagher (2005) would increase habitat area requirements to 4.5 acres.

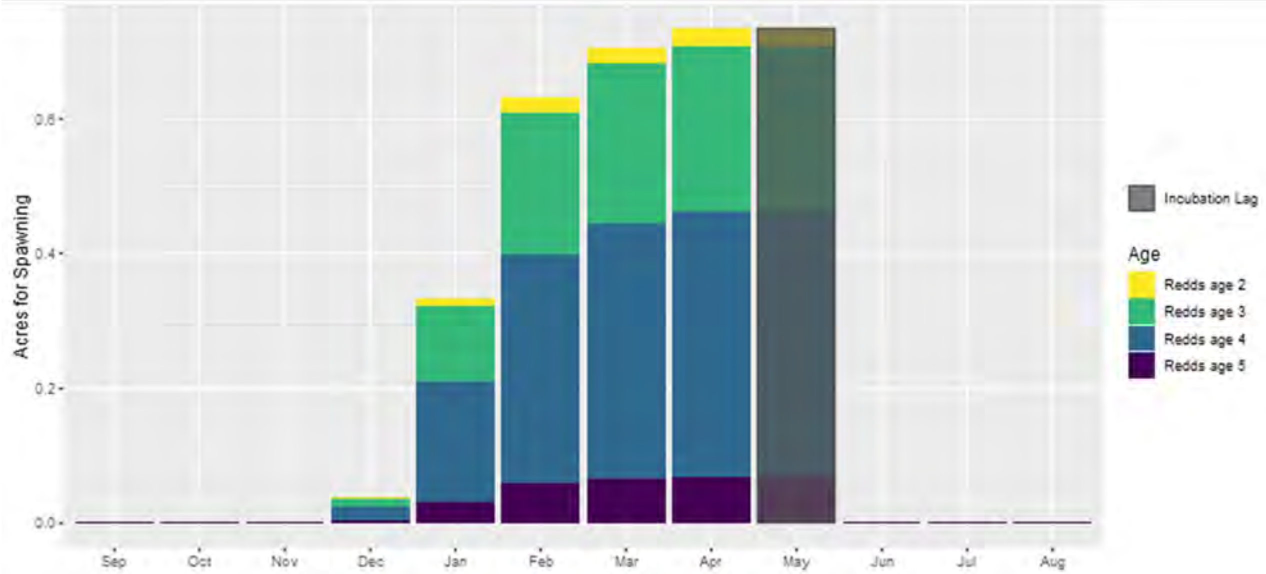

Figure 6. Cumulative habitat area for spawning and incubation needed to support a population of 833 adult steelhead spawners by month using selected demographic parameters and relationships. Incubation habitat area is based on a one-month lag to account for incubation and emergence timing to represent habitat area that needs to be maintained to account for incubating eggs.

The estimated spawning habitat requirements are based on demographic information and relationships from other reference systems and populations, and it is important to consider that demographic data for Suisun Creek steelhead represents a significant data gap that, if addressed, could improve the parameterization of the life cycle model. However, the estimated spawning habitat area requirements from the model using reference demographic data fall well within rough estimates of total potential habitat area within Suisun Creek and its tributaries – assuming potential distribution within Suisun Creek downstream of the reservoir (≈11.5 miles) and in Wooden Valley Creek and White Creek tributaries (≈7 and 4 miles, respectively). This suggests that estimated spawning habitat area requirements allow for potential spatial heterogeneity of suitable habitat, variance in habitat quality, and error associated with using reference demographic data. Therefore, the Suisun Creek LCM provides a good starting point to evaluate minimum habitat area requirements relative to currently available habitat area and quality within the context of management actions and strategies, and potential variance in habitat area requirements related to a variety of demographic parameters.

Rearing habitat requirements

We estimate that rearing habitat needs, for a minimum viable steelhead population, range between 75 to 118 acres throughout the year, with a peak of 118 acres required in April (Figure 7). As with spawning habitat (see above), these estimates do not consider habitat quality and it is assumed that reduced habitat quality would increase the required rearing habitat area. Conversely, increased habitat quality would also decrease habitat area needed or increase the total number of rearing steelhead Suisun Creek can support. In addition, nearly all demographic information and relationships used to inform estimates of rearing habitat requirements are based on data from reference systems or populations, except for Suisun Creek water temperature data we use to estimate incubation duration and emergence timing. Therefore, demographic information specific to Suisun Creek steelhead represents a significant data gap that could improve our ability to estimate rearing habitat requirements to meet steelhead population targets. It is also worth noting that the estimated rearing habitat area requirements rely on more assumptions and demographic information than we used to estimate spawning habitat requirements.

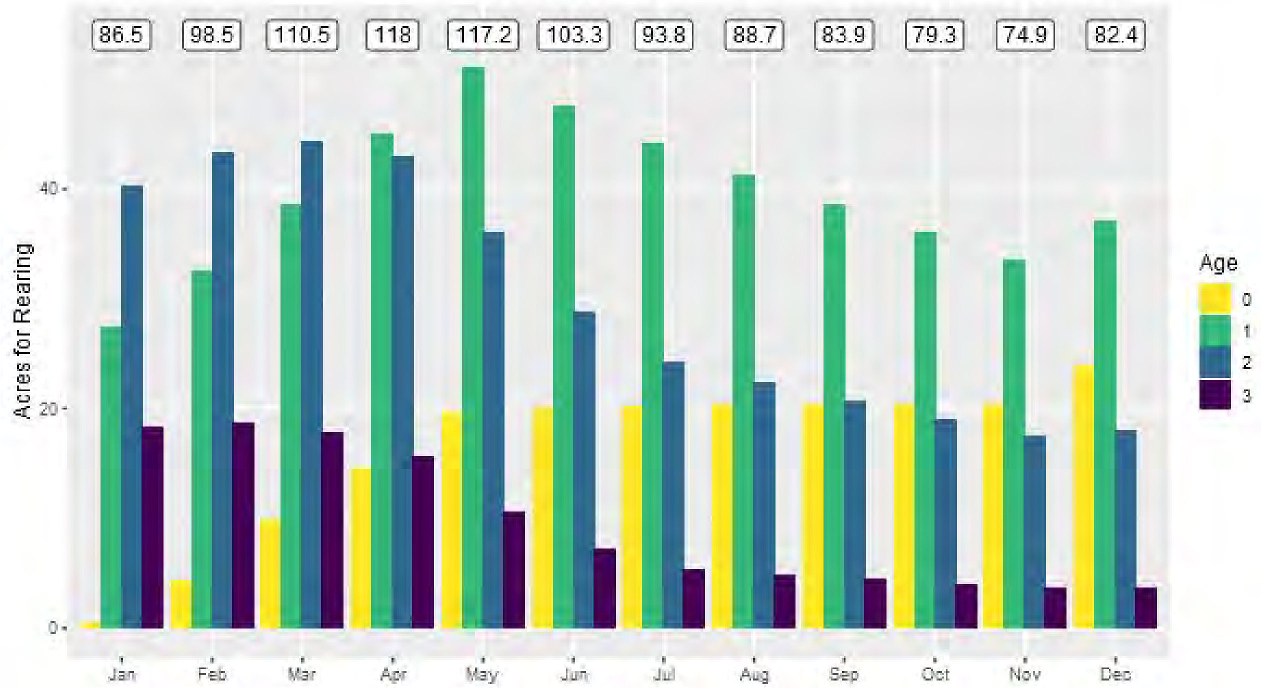

Figure 7. Estimate monthly rearing habitat area requirements by age class that accounts for size and timing of emergence, daily growth rates, daily mortality, emigration from the system, and territory size requirements based on fish length.

To support an adult population target of 833 spawners, we first estimated the total abundance and timing of emergent fry based on the target spawning population, spawning timing, fecundity, egg to fry survival, and stream temperatures. As with adult spawning habitat area requirements, shifting the timing and duration of spawning will directly influence incubation timing and duration that is used to estimate emergent fry abundance and timing. Fecundity is based on body length to egg production relationships, which is an exponential function that results in larger or older females producing disproportionately more eggs than smaller or younger females (Shapovalov and Taft 1954). Therefore, appropriate size and age structure estimates, that are currently based on reference data, are important in estimating total egg deposition that is used to estimate emergent fry abundance and rearing habitat requirements.

We used monthly mean water temperatures in Suisun Creek to estimate incubation duration based on the month of deposition, and assuming a uniform initial emergent size for each cohort then we apply daily growth rates to estimate the size of each cohort over time. Territory size requirements are estimated from log linear regressions based on fish length, therefore adjusting territory requirements (e.g., due to habitat quality) or cohort fish sizes (e.g., through growth, emergence timing, or emergent size) will significantly impact estimated rearing habitat requirements. For example, if we increase winter/spring growth rates by 1.8x we see that estimated rearing habitat requirements increase to between 148 acres to 263 acres, which is 2.8x the habitat area requirements estimated from growth rates reported in Sogard et al. (2012). This 1.8x growth rate was chosen for an example as it translates to fish lengths in June that more closely match those observed during recent snorkel surveys (Figure 5), with estimated fork lengths ranging from 36 – 395 mm.

Estimated rearing habitat requirements are also sensitive to emigration rates, outmigrant age structure, and daily mortality rates, which remove fish from the rearing population over time. Emigration rates and the total emigrant numbers of each age class (age 0 to age 3) were estimated based on the number of outmigrants needed to produce a returning adult population of 833 adults. This was based on the relationship between marine survival and size at ocean entry, and outmigrant age and size structure from reference data. This is a key assumption and aspect to estimating rearing habitat requirements to produce the adult population target. Increasing size at ocean entry (e.g., through growth rates or shifting the outmigrant age structure older) will increase marine survival which will reduce the number of smolts needed to support the minimum target population, but could also increase rearing habitat requirements due to increased rearing fish sizes.

We assume a maximum of age 3 juveniles for rearing and emigration, but production of older smolt age classes and resident life histories can similarly impact rearing habitat area estimates given that this would increase the size range of rearing juveniles. that could be refined with data for Suisun Creek populations. However, age 4 and older fish likely contribute little to migrant production (Shapovalov and Taft 1954) and we therefore assume that these older fish would not greatly impact the estimated number of migrants needed to produce the target returning adult population. The current demographic reference data and assumptions (e.g. emergent timing, initial size, growth rates) produce juveniles with sizes ranging from 31 to 244 mm in June with mixed cohorts. This is comparable to size classes observed in June during recent snorkel surveys, but with larger size classes being observed in low frequency within Suisun Creek (Figure 5; Wiesenfeld et al. 2020). The presence of larger size classes could suggest either higher growth rates, presence of older age classes, and/or resident life history expression within the Suisun Creek population, which could indicate that rearing habitat area estimates are biased towards lower numbers.

Similarly, the model is sensitive to daily mortality rates given that mortality compounds daily and directly determines the number of rearing fish in the river over time. We use reference data from Hokanson et al. (1977) for winter/spring and assume higher mortality (25%) for summer/fall, however we know that mortality is influenced by fish size and small changes in daily mortality rates will significantly impact the estimated rearing requirements for the target population given that mortality is compounded daily. For example, increasing daily mortality rates by 5% reduces maximum rearing habitat requirements by 12% while also shifting the abundance to younger age classes. In addition, the current life cycle model does not link daily mortality to temperature, which could be done with additional reference data.

Depending on the spawner distribution in the system, spatial variation in spawning location could influence the duration and timing of fry emergence, growth rates, and mortality rates given that temperatures generally decrease with increasing distance upstream in Suisun Creek (Jackson et al. 2010; Wiesenfeld et al. 2020). The current life cycle model does not incorporate spatial distribution of spawning or incubation, which could be used to refine incubation duration, emergence timing, growth, and daily mortality rates. For example, if spawners favor upper reaches or tributaries with cooler temperatures, incubation duration and emergence timing could be shifted later in the year while also potentially reducing growth opportunity in the year of emergence.

We compared estimated rearing habitat requirements to rough estimates of potential habitat in Suisun Creek to determine if the estimated results make sense given the demographic inputs, relationships, and assumptions used to parameterize the life cycle model. Assuming steelhead use approximately 22.5 miles of stream below Lake Curry (Suisun Creek) and within Wooden Valley and White creek tributaries combined (Marcus et al. 2004), and an average stream width of 22 ft based on recent surveys (Wiesenfeld et al. 2020), there is an approximate 61 acres of potential habitat available to steelhead. This estimate of total available stream habitat area is very rough and does not consider seasonal flow variation, but it is within the same order of magnitude as estimated rearing habitat requirements provided by the model given the current reference demographics and relationships (75 - 118 acres) (Figure 7). Furthermore, variance in demographic parameters and relationships from reference systems (e.g., growth and mortality rates) further allows for variation in estimated rearing habitat area requirements that overlap with rough estimates of total potential habitat area in Suisun Creek. Therefore, the Suisun Creek LCM provides a useful tool for estimating juvenile rearing habitat area requirements using reference demographic data that can be used to evaluate habitat area requirements to support a minimum viable population target relative to current habitat area and quality within the context of management actions and strategies, and potential variance in habitat area requirements related to a variety of demographic parameters.

SUMMARY OF CONCLUSIONS AND NEXT STEPS

- Between 0.04 and 0.73 acres of spawning habitat is required between December and May to support spawning and incubation for a minimum viable population of adult steelhead (Figure 6).
    - Information on the timing and duration of adult spawning and redd sizes in Suisun Creek would improve estimated monthly habitat area requirements.
    - The target population used in this life cycle model was based on a minimum viable population estimate and could be adjusted by stakeholders depending on recovery goals.
    - Use of other population targets defined by stakeholders would directly influence the estimated habitat area requirements.
    - A recovery plan should consider habitat requirements based on good and poor ocean conditions that can directly influence the number of out migrants needed to support the target population, as well as the range of precipitation conditions that occur in the Mediterranean climate of California.
- Between 75 and 118 acres of rearing habitat is required throughout the year, with the peak occurring in April (Figure 7).
    - Information on seasonal mortality and growth rates, especially during summer months, in Suisun Creek would improve estimates of rearing habitat area requirements for the population target.
    - Estimates of migrant production, age structure, and size structure for Suisun Creek would also improve model parameterization.
- Estimates of spawning and rearing habitat area requirements appear to fall within rough estimates of total potential habitat area in Suisun Creek assuming steelhead use of Suisun Creek below Lake Curry and within Wooden Valley and White Creek tributaries.
    - This provides support for the validity of the estimated habitat requirements, but development of more quantitative estimates are needed to further evaluate and calibrate model assumptions and parameters.
    - Flow, season, and habitat quality should be considered when comparing estimates of habitat quantity to spawning and rearing habitat requirements, not only for Lake

Curry releases into lower Suisun Creek, but Wooden Valley and White Creek as well.

- The estimated spawning and rearing habitat requirements developed here relies on data from reference populations/systems for many of the demographic parameters and relationships considered in the life cycle model.
  - This analysis identified significant data gaps for Suisun Creek that could impact estimates of spawning and rearing habitat requirements to support a target population of steelhead.
  - Water temperatures were the only parameter we were able to develop from Suisun Creek to parameterize the life cycle model, with all other parameters being developed from reference systems or populations (we were able to validate rearing length reference data from recent Suisun Creek snorkel surveys).
  - Development of monitoring data for key demographic parameters (e.g., periodicity and age structure) for Suisun Creek steelhead populations could improve estimates of spawning and rearing habitat requirements for this population.
  - Development of monitoring data or refined estimates of demographic parameters for Suisun Creek to address data gaps could prioritize parameters that have the greatest impact on estimated habitat requirements (e.g., growth and mortality; emigration age structure, timing, and duration).
  - Identification of reference data from watersheds more closely related to Suisun Creek, may be a stopgap until Suisun Creek-specific data are available.
- This model covered the first key steps in the process to determine Suisun Creek's ability to support a target steelhead population in quantifiable habitat terms (Figure 1). The next phase will build on the results of this exercise to develop the tools and information needed to evaluate flow and non-flow management strategies by:
  - Determining relationships between water and physical habitat quantity and quality needs in Suisun Creek
  - Improving/informing information on effects of demographics, including fish size at age on mortality rates
  - Determining if enough potential habitat is available to support each life stage of the population goal using available water, channel bathymetry, and habitat information
  - Using hydrographic and habitat information to evaluate water release strategy effects on available habitat during key months, especially if flows limit available habitat, habitat connectivity, and water quality in the system
  - Evaluating data gaps and model assumptions and adjust inputs as needed; and
  - Identifying strategies to address habitat deficits, or habitat quality deficits, through flow management and habitat restoration strategies to support a viable steelhead population into the foreseeable future.

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APPENDIX A

Table 2. List of demographic parameters, assumptions, and relationships used to parameterize the life cycle model to estimate spawning and rearing habitat area requirements for Suisun Creek steelhead. See references for sources cited in table.

Parameter Class	Parameter	Value	Units	Source(s)	Notes
Population Targets	Minimum viable population	833	Adults	Hines email 26 April, 2017; Spence et al. 2008	Minimum viable population for adult salmon for low extinction risk
Population Targets	Harvest goal	0	Adults	None	Assumed goal
Sex Structure	Proportion female spawners	0.5	Proportion	Shapovalov and Taft 1954	Waddell Creek, Pacific Ocean (Santa Cruz Co., CA)
Sex Structure	Min female age at maturation	2	Age	None	Assumed minimum age of mature female
Sex Structure	Proportion smolts female	0.7	Proportion	Williams 2006	Not currently used, but could be used to adjust smolts needed to meet adult return targets. Sacramento River, CA
Age Structure	Proportion age 2 female spawners	0.035	Proportion	Satterthwaite et al. 2009	Waddell Creek, Coastal CA; Filtered to ages 2-5
Age Structure	Proportion age 3 female spawners	0.337	Proportion	Satterthwaite et al. 2009	Waddell Creek, Coastal CA; Filtered to ages 2-5
Age Structure	Proportion age 4 female spawners	0.537	Proportion	Satterthwaite et al. 2009	Waddell Creek, Coastal CA; Filtered to ages 2-5
Age Structure	Proportion age 5 female spawners	0.092	Proportion	Satterthwaite et al. 2009	Waddell Creek, Coastal CA; Filtered to ages 2-5
Age Structure	Proportion age 0+ migrant adults	0.002	Proportion	Shapovalov and Taft 1954	Wadell Creek

Parameter Class	Parameter	Value	Units	Source(s)	Notes
Age Structure	Proportion age 1+ migrant adults	0.1	Proportion	Shapovalov and Taft 1954	Wadell Creek
Age Structure	Proportion age 2+ migrant adults	0.69	Proportion	Shapovalov and Taft 1954	Wadell Creek
Age Structure	Proportion age 3+ migrant adults	0.19	Proportion	Shapovalov and Taft 1954	Wadell Creek
Periodicity	Adult migration - Sep	0.00	Cumulative Proportion	Williams 2006	Mill Creek at Clough Dam
Periodicity	Adult migration - Oct	0.18	Cumulative Proportion	Williams 2006	Mill Creek at Clough Dam
Periodicity	Adult migration - Nov	0.52	Cumulative Proportion	Williams 2006	Mill Creek at Clough Dam
Periodicity	Adult migration - Dec	0.65	Cumulative Proportion	Williams 2006	Mill Creek at Clough Dam
Periodicity	Adult migration - Jan	0.78	Cumulative Proportion	Williams 2006	Mill Creek at Clough Dam
Periodicity	Adult migration - Feb	0.94	Cumulative Proportion	Williams 2006	Mill Creek at Clough Dam
Periodicity	Adult migration - Mar	0.99	Cumulative Proportion	Williams 2006	Mill Creek at Clough Dam
Periodicity	Adult migration - Apr	1.00	Cumulative Proportion	Williams 2006	Mill Creek at Clough Dam
Periodicity	Adult spawning - Sep	0.00	Cumulative Proportion	M. Saldate, East Bay Municipal Utility District, unpublished data	Cumulative redds completed assuming Mokelumne River spawn timing
Periodicity	Adult spawning - Oct	0.00	Cumulative Proportion	M. Saldate, East Bay Municipal Utility District, unpublished data	Cumulative redds completed assuming Mokelumne River spawn timing

Parameter Class	Parameter	Value	Units	Source(s)	Notes
Periodicity	Adult spawning - Nov	0.00	Cumulative Proportion	M. Saldate, East Bay Municipal Utility District, unpublished data	Cumulative redds completed assuming Mokelumne River spawn timing
Periodicity	Adult spawning - Dec	0.05	Cumulative Proportion	M. Saldate, East Bay Municipal Utility District, unpublished data	Cumulative redds completed assuming Mokelumne River spawn timing
Periodicity	Adult spawning - Jan	0.46	Cumulative Proportion	M. Saldate, East Bay Municipal Utility District, unpublished data	Cumulative redds completed assuming Mokelumne River spawn timing
Periodicity	Adult spawning - Feb	0.86	Cumulative Proportion	M. Saldate, East Bay Municipal Utility District, unpublished data	Cumulative redds completed assuming Mokelumne River spawn timing
Periodicity	Adult spawning - Mar	0.96	Cumulative Proportion	M. Saldate, East Bay Municipal Utility District, unpublished data	Cumulative redds completed assuming Mokelumne River spawn timing
Periodicity	Adult spawning - Apr	1.00	Cumulative Proportion	M. Saldate, East Bay Municipal Utility District, unpublished data	Cumulative redds completed assuming Mokelumne River spawn timing
Size Structure	Age 2 female spawners	39.1	Mean FL, cm	Shapovalov and Taft 1954	Based on most common FW/SW ages, means from Waddell Creek
Size Structure	Age 3 female spawners	46.7	Mean FL, cm	Shapovalov and Taft 1954	Based on most common FW/SW ages, means from Waddell Creek
Size Structure	Age 4 female spawners	66.6	Mean FL, cm	Shapovalov and Taft 1954	Based on most common FW/SW ages, means from Waddell Creek
Size Structure	Age 5 female spawners	72.5	Mean FL, cm	Shapovalov and Taft 1954	Based on most common FW/SW ages, means from Waddell Creek

Parameter Class	Parameter	Value	Units	Source(s)	Notes
Size Structure	Emergence size	2.3	FL, cm	Merz et al. 2016	Mokelumne River
Size Structure	Age 0+ migrant	6	FL, cm	Merz et al. 2016 and Merz 2002	Assuming daily growth rate and starting size as above
Size Structure	Age 1+ migrant	20	FL, cm	Hodge et al. 2016; generalized from multiple systems	Size at ocean entry
Size Structure	Age 2+ migrant	24	FL, cm	Hodge et al. 2016; generalized from multiple systems	Size at ocean entry
Size Structure	Age 3+ migrant	26.5	FL, cm	Hodge et al. 2016; generalized from multiple systems	Size at ocean entry
Territory Size	Redds per female	1	Adults	None	Assumed
Territory Size	Mean redd size	1.78	m^2	Gallagher and Gallagher 2005	SE = 0.14, n = 102; Coastal Rivers of CA
Territory Size	Mean redd size SE	0.14	m^2	Gallagher and Gallagher 2005	SE = 0.14, n = 102; Coastal Rivers of CA
Territory Size	Ratio of spawning habitat needed per redd	4	Ratio per redd	Burner 1951	Columbia River, but not based on steelhead
Territory Size	Juvenile territory size	log10(territory size, m2) = 2.61*(log10 length in cm) – 2.83	Relationship	Grant and Kramer 1990	Includes 5 species, not just *O. mykiss*, from 10 studies to create regression. Also includes a table of measured territory area from each study.
Fecundity	Length to ova ratio, y=ab^x (FL in cm)	0.95	a	Shapovalov and Taft 1954	Scott and Wadell Creek, CA
Fecundity	Length to ova ratio, y=ab^x (FL in cm)	2.12	x	Shapovalov and Taft 1954	Scott and Wadell Creek, CA

Parameter Class	Parameter	Value	Units	Source(s)	Notes
Periodicity	Water temp mean, December	49	F	Barry H <barryh@fishfriendlyfarming.org> (August 11, 2020	SC 8.4, 9.5, and 10.0 Stations 2017-2020.
Periodicity	Water temp mean, January	49	F	Barry H <barryh@fishfriendlyfarming.org> (August 11, 2020)	SC 8.4, 9.5, and 10.0 Stations 2017-2020.
Periodicity	Water temp mean, February	48	F	Barry H <barryh@fishfriendlyfarming.org> (August 11, 2020)	SC 8.4, 9.5, and 10.0 Stations 2017-2020.
Periodicity	Water temp mean, March	52	F	Barry H <barryh@fishfriendlyfarming.org> (August 11, 2020)	SC 8.4, 9.5, and 10.0 Stations 2017-2020.
Periodicity	Water temp mean, April	57	F	Barry H <barryh@fishfriendlyfarming.org> (August 11, 2020)	SC 8.4, 9.5, and 10.0 Stations 2017-2020.
Periodicity	Water temp mean, May	60	F	Barry H <barryh@fishfriendlyfarming.org> (August 11, 2020)	SC 8.4, 9.5, and 10.0 Stations 2017-2020.
Periodicity	Incubation, Dec	38	days	Leitritz and Lewis 1980 based on mean water temps	Based on incubation time ranges from Leitritz and Lewis 1980
Periodicity	Incubation, Jan	38	days	Leitritz and Lewis 1980 based on mean water temps	Based on incubation time ranges from Leitritz and Lewis 1980
Periodicity	Incubation, Feb	39	days	Leitritz and Lewis 1980 based on mean water temps	Based on incubation time ranges from Leitritz and Lewis 1980
Periodicity	Incubation, Mar	29	days	Leitritz and Lewis 1980 based on mean water temps	Based on incubation time ranges from Leitritz and Lewis 1980

Parameter Class	Parameter	Value	Units	Source(s)	Notes
Periodicity	Incubation, Apr	21	days	Leitritz and Lewis 1980 based on mean water temps	Based on incubation time ranges from Leitritz and Lewis 1980
Periodicity	Incubation, May	18	days	Leitritz and Lewis 1980 based on mean water temps	Based on incubation time ranges from Leitritz and Lewis 1980
Periodicity	Incubation time	19	days at 60°F	Leitritz and Lewis 1980	
Periodicity	Incubation time	24	days at 55°F	Leitritz and Lewis 1980	
Periodicity	Incubation time	31	days at 50°F	Leitritz and Lewis 1980	
Periodicity	Incubation time	48	days at 45°F	Leitritz and Lewis 1980	
Periodicity	Incubation time	80	days at 40°F	Leitritz and Lewis 1980	
Survival	Egg to fry	0.65	Proportion	Briggs 1953	Prairie Creek, Redwood Creek, Pacific Ocean (Humboldt Co., CA)
Survival	Marine	0.035	Proportion	Welch et al. 2000	Keogh River, Vancouver Island, BC
Survival	Smolt to adult return rate, Age 0+ migrant	0.00051	Proportion	Ward 1989; Merz et al. 2016 and Merz 2002; Hodge et al. 2016	Total SAR adjusted by relative survival rates among age classes of migrants
Survival	Smolt to adult return rate, Age 1+ migrant	0.0095	Proportion	Ward 1989; Merz et al. 2016 and Merz 2002; Hodge et al. 2016	Total SAR adjusted by relative survival rates among age classes of migrants
Survival	Smolt to adult return rate, Age 2+ migrant	0.014	Proportion	Ward 1989; Merz et al. 2016 and Merz 2002; Hodge et al. 2016	Total SAR adjusted by relative survival rates among age classes of migrants
Survival	Smolt to adult return rate, Age 3+ migrant	0.016	Proportion	Ward 1989; Merz et al. 2016 and Merz 2002; Hodge et al. 2016	Total SAR adjusted by relative survival rates among age classes of migrants

Parameter Class	Parameter	Value	Units	Source(s)	Notes
Survival	Smolt to adult return rate, Age 0+ migrant	0.015	Proportion	Ward 1989; Merz et al. 2016 and Merz 2002; Hodge et al. 2016	Based on mean smolt size by age class and proportion survival by length
Survival	Smolt to adult return rate, Age 1+ migrant	0.27	Proportion	Ward 1989; Merz et al. 2016 and Merz 2002; Hodge et al. 2016	Based on mean smolt size by age class and proportion survival by length
Survival	Smolt to adult return rate, Age 2+ migrant	0.41	Proportion	Ward 1989; Merz et al. 2016 and Merz 2002; Hodge et al. 2016	Based on mean smolt size by age class and proportion survival by length
Survival	Smolt to adult return rate, Age 3+ migrant	0.46	Proportion	Ward 1989; Merz et al. 2016 and Merz 2002; Hodge et al. 2016	Based on mean smolt size by age class and proportion survival by length
Survival	Smolt to adult (y=mx +b); 0-14 cm FL	0.0024	m, FL cm	Ward 1989	Keogh River, Vancouver Island, BC; assumes linear interpolation between points and 0 intercept
Survival	Smolt to adult (y=mx +b); 0-14 cm FL	-3.47E-18	b, FL cm	Ward 1989	Keogh River, Vancouver Island, BC; assumes linear interpolation between points and 0 intercept
Survival	Smolt to adult (y=mx +b); 14-16 cm FL	0.028	m, FL cm	Ward 1989	Keogh River, Vancouver Island, BC; assumes linear interpolation between points and 0 intercept
Survival	Smolt to adult (y=mx +b); 14-16 cm FL	-0.36	b, FL cm	Ward 1989	Keogh River, Vancouver Island, BC; assumes linear interpolation between points and 0 intercept

Parameter Class	Parameter	Value	Units	Source(s)	Notes
Survival	Smolt to adult (y=mx +b); 16-18 cm FL	0.046	m, FL cm	Ward 1989	Keogh River, Vancouver Island, BC; assumes linear interpolation between points and 0 intercept
Survival	Smolt to adult (y=mx +b); 16-18 cm FL	-0.65	b, FL cm	Ward 1989	Keogh River, Vancouver Island, BC; assumes linear interpolation between points and 0 intercept
Survival	Smolt to adult (y=mx +b); 18-20 cm FL	0.041	m, FL cm	Ward 1989	Keogh River, Vancouver Island, BC; assumes linear interpolation between points and 0 intercept
Survival	Smolt to adult (y=mx +b); 18-20 cm FL	-0.56	b, FL cm	Ward 1989	Keogh River, Vancouver Island, BC; assumes linear interpolation between points and 0 intercept
Survival	Smolt to adult (y=mx +b); 20-22 cm FL	0.055	m, FL cm	Ward 1989	Keogh River, Vancouver Island, BC; assumes linear interpolation between points and 0 intercept
Survival	Smolt to adult (y=mx +b); 20-22 cm FL	-0.82	b, FL cm	Ward 1989	Keogh River, Vancouver Island, BC; assumes linear interpolation between points and 0 intercept
Survival	Smolt to adult (y=mx +b); 22-26 cm FL	0.018	m, FL cm	Ward 1989	Keogh River, Vancouver Island, BC; assumes linear interpolation between points and 0 intercept

Parameter Class	Parameter	Value	Units	Source(s)	Notes
Survival	Smolt to adult (y=mx +b); 22-26 cm FL	-0.025	b, FL cm	Ward 1989	Keogh River, Vancouver Island, BC; assumes linear interpolation between points and 0 intercept
Survival	Daily mortality rate, FW winter/spring	0.0035	Proportion	Hokanson et al. 1977	
Survival	Daily mortality rate, FW summer/fall	0.0044		Assumed	
Growth	Age 0+ winter/spring	0.02	FL, cm per day	Sogard et al. 2012	Scott and Soquel Creek, CA
Growth	Age 0+ summer/fall	0.007	FL, cm per day	Sogard et al. 2012	Scott and Soquel Creek, CA
Growth	Age 1+ winter/spring	0.03	FL, cm per day	Sogard et al. 2012	Scott and Soquel Creek, CA
Growth	Age 1+ summer/fall	0.005	FL, cm per day	Sogard et al. 2012	Scott and Soquel Creek, CA
Life History	Proportion anadromous	0.23	Proportion	Zimmerman et al. 2009	Not currently used, Multiple CA streams, based on proportion of progeny from steelhead or resident trout
Life History	Proportion anadromous	0.91	Proportion	Stillwater 2007	Not currently used, Napa River Watershed

Workbook LCM Overview

We developed a workbook-based LCM to estimate spawning and rearing habitat requirements using the demographic information, parameters, and relationships described in this memo. The workbook includes a **Rules** tab that contains all the demographic values, assumptions, and relationships that are referenced in the tabs used to estimate spawning and rearing habitat area requirements. The sources of these values are provided as citations with full references listed in the **Sources** tab. These values can be changed to evaluate the effects of different assumptions or reference data on the estimated habitat requirements, but these should be adjusted with care to not break the references to the values needed to complete all the calculations in dependent tabs. In addition, the values are not currently constrained by rules to enforce value ranges (e.g., proportions sum to one, fork lengths are within expected ranges etc.) and it is possible to create unrealistic outputs depending on the values entered. Furthermore, changing values can result in outputs that fail to meet entered population targets (e.g., juvenile migrants needed to produce the target adult spawner abundance).

The **Spawners** tab is used to estimate spawning habitat area requirements based on the timing and duration of spawning, sex ratios, age structure, redd abundance, redd areas, and territory requirements for redd construction. This tab is protected so that references are not easily broken, but can be edited without a password if needed. The results of these calculations are based on the values in the **Rules** tab, and are summarized in the **Chart_Spawning** tab.

The **Juvenile Production** tab uses information from the **Rules** tab and the **Spawners** tab to estimate the monthly deposition of eggs, emergence of fry, and total juvenile emigrants needed to meet adult spawner abundance targets. This tab is also protected but can be unlocked without a password if changes are needed.

The **Rearing** tab is a tabular breakdown of juvenile fish sizes and abundances that account for mortality and emigration to estimate monthly rearing habitat requirements based on territory and size relationships from the **Rules** tab. Each cohort is tracked through time for three years from emergence based on emergence timing assuming a one-month lag. This could be converted to a dynamic lag if the model were revised to include weekly spawner abundance estimates. A diagnostic flag is included that indicates whether the total abundance of juveniles at each monthly timestep are sufficient to produce the required juvenile migrants, estimated in the **Juvenile Production** tab, needed to meet target adult spawner abundances. The total rearing habitat area estimates from this tab are summarized in the **Chart_Rearing** tab.

Shiny GUI Tool Overview

We developed a Shiny Graphical User Interface based on the life cycle model workbook that was developed as a frontend to an R coded version of the workbook described above. This GUI allows the user to easily manipulate parameters and inputs to evaluate different scenarios, assumptions, or sensitivity to demographic information.

Figure 8. The Suisun LCM Graphic User Interface made in R Shiny showing inputs and outputs for spawning and rearing habitat area requirements.

The GUI is broken into two sections, an input panel on the left, and output figures on the right (Figure 8). The input panel is tabbed to organize the variety of inputs used in the model. The default tab "Parameters" contains several of the parameters most likely to be altered, while other parameters are located under thematically named tabs.

Output is reactive to input, and the graphs update whenever input values are altered. We included several forms of QA/QC and validation for inputs including:

- validation for values (correct type, and within range),
- forcing proportions to sum to one, and
- enforcing cumulative distributions rules (between zero and one, and monotonically increasing).

In addition, we also include flags or notifications to highlight potential model input and output issues like the loss of a cohort, or lack of population abundance needed to meet specified targets. This allows the user to easily see when parameters have been adjusted past the thresholds needed to meet the target population requirements.