Report

Effects Of A Riparian Forest On Water Temperatures In The Restoration Area

2014 Mid-Year Technical Report

SAN JOAQUIN RIVER
RESTORATION PROGRAM

July 2014

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Abbreviations and Acronyms

°F	degrees Fahrenheit
ACOE Park	Army Corps Park Ripon River Crossing
cfs	cubic feet per second
mph	miles per hour
SJRRP	San Joaquin River Restoration Program

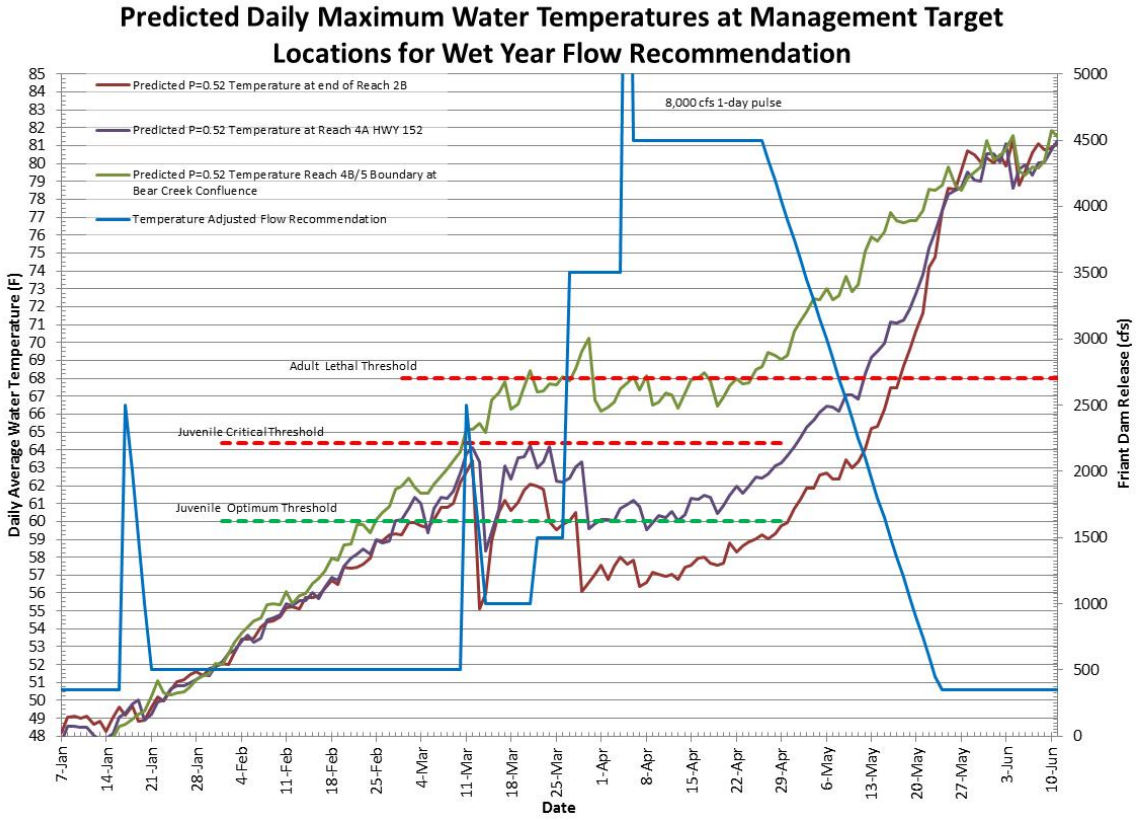
1.0 Effects of A Riparian Forest On Water Temperatures In The Restoration Area

1.1 Background

Predictions from the initial HEC-5Q water temperature model (SJRRP 2008a) suggest that the daily maximum water temperatures in reaches 4B and 5 will exceed the lethal threshold for adult spring-run Chinook salmon at a Friant release of 4,500 cubic feet per second (cfs) by April 24 during median (P = 0.52 exceedance) meteorological conditions (Figure 1). When the model was recalibrated with 2009-2010 interim flow data, the lethal threshold was exceeded by April 28 (SJRRP 2012). If the recalibrated model reflects current conditions, then only up to 30 percent of the adults may be able to migrate to Reach 1 based on migration timing data from Mill and Butte creeks (Johnson et al. 2006; Greg Blair, ICF, personal communication). During the same period, juveniles are also experiencing critical temperatures and few would be expected to survive (Figure 1). A consequence of using high volume pulse flows in April and May for adults is the inability to release prolonged pulse flows earlier in the year to benefit juvenile salmon. If no more than 30 percent of the adults can successfully migrate to Reach 1 where they could spawn and flow for juvenile passage must be limited to brief pulses, restoration actions to cool temperatures may be needed to reach the population viability target.

Previous water temperature model analyses for the San Joaquin River Restoration Program (SJRRP) Restoration Area evaluated the effects riparian shading and channel narrowing on daily maximum water temperatures primarily upstream from Mendota Pool (SJRRP 2008b). The riparian shading study (Set 4 Sensitivity Analysis) used solar radiation measurements from a Stanislaus River site that was shaded for approximately half the day and those data were used in a conceptual analysis of the median of the maximum daily temperatures in 5-foot deep pools at four sites including: Gravelly Ford, below Chowchilla Bypass, above Mendota Pool and Sack Dam. There was uncertainty in the results due to a lack of data on the effects of shade trees on wind speed and humidity, both of which would partially negate the benefits of providing shade and were not included in the sensitivity study. The results suggested that a half day of heavy riparian shade could reduce daily maximum water temperatures by about 2 degrees Fahrenheit (°F) at Gravelly Ford in late spring and summer at a flow release of 1,500 cfs, assuming there were no negative effects of reduced wind speed and increased humidity. Temperature reductions due to riparian shading would likely decline as flows increase above 1,500 cfs. The results for the Sack Dam site, which was only conducted at a flow of 350 cfs, suggest that the effects of riparian shading would be less at Sack Dam than at Gravelly Ford. There are several limitations of this study. First, it does not fully address the effect of riparian shading on both banks of the river below Sack Dam. The reaches below Sack Dam are particularly important to study, because the effects of riparian

shading would be less in channels flowing toward the North (Restoration Area below Mendota Pool) compared to channels flowing toward the West (Restoration Area above Mendota Pool). Second, the study does not consider the cumulative effect of providing shade throughout the Restoration Area. Presumably, water temperatures in reaches 4B and 5 are partially dependent on the temperature of the water flowing in from the upstream reaches.



Note: Possible Wet Year flow recommendation designed to maximize adult spring-run passage and two brief pulse flows for juvenile passage relative to the predicted daily maximum water temperatures (SJRRP 2008a) during average meteorological conditions from 1980 to 2005 (P = 0.52 exceedance) just upstream from Mendota Pool (Reach 2B), at Highway 41 (Reach 4A), and the confluence with Bear Creek (Reach 4B-5 boundary). The lethal threshold for adult salmon is a 7-day mean daily maximum temperature of 68°F and so temperatures that exceed the threshold for fewer than 7 days would not be lethal. The water temperature predictions in reaches 4B and 5 in this figure may exceed actual temperatures by about 2°F in April and by 1-2°F in May (SJRRP 2012).

Figure 1. Possible Wet Year Flow Recommendation

The channel narrowing analysis (Set 5 Sensitivity Analysis, SJRRP 2008b) evaluated the effects of three channel modifications on the median of the maximum daily water temperatures in conceptual 5-foot deep pools at Gravelly Ford, below Chowchilla Bypass, and above Mendota Pool at flow releases of 350 and 700 cfs: (1) 25 percent width reduction and no change in depth, (2) 25 percent width reduction and a 33 percent depth increase, and (3) a 50 percent reduction in width and depth. The results suggest that 50 percent reductions in channel width and depth might reduce May daily maximum temperatures by about 6°F at a flow of 700 cfs at Gravelly Ford. Flow magnitude had no effect on the temperature reduction as long as flows remained in the low flow channel (≤

700 cfs). Temperature reduction due to channel narrowing and deepening was diminished at the Below Chowchilla and Above Mendota Pool sites compared to the Gravelly Ford site, presumably because the existing channel was wider at these sites than at Gravelly Ford. No analysis was done for the reaches below Mendota Pool where shading may affect daily maximum water temperatures in the northerly flowing channel differently from those modeled at Gravelly Ford and above Mendota Pool which flow toward the West.

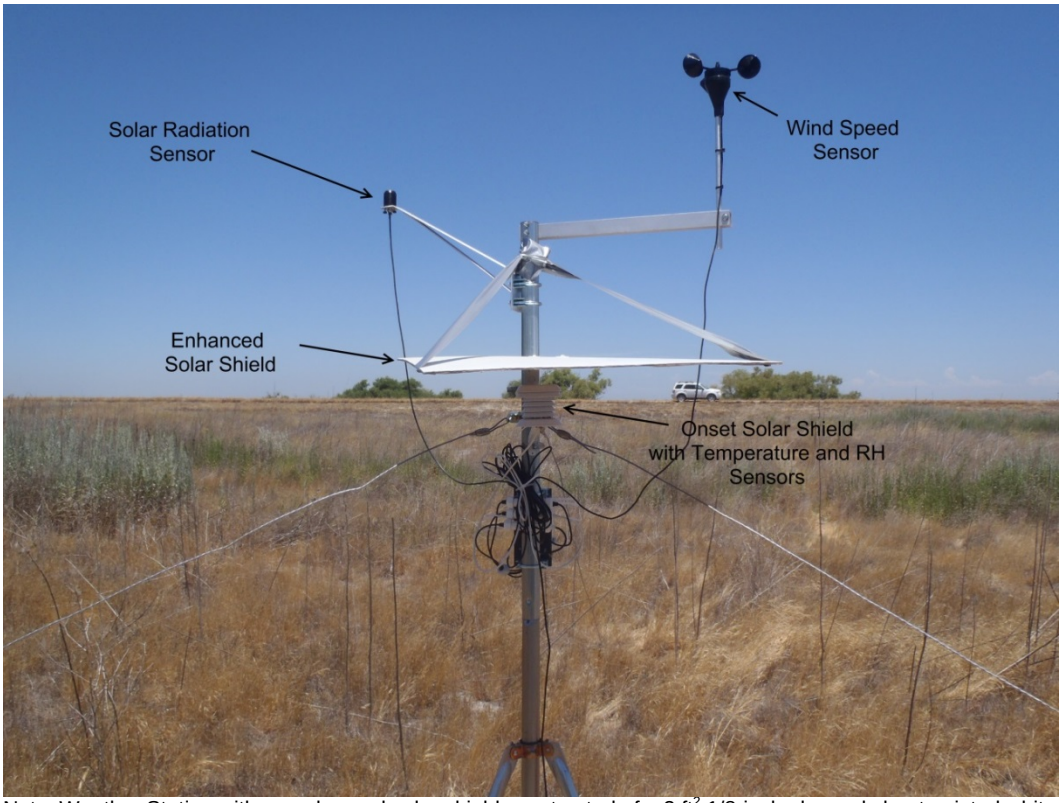
The overall objective of this study and a companion HEC-5Q modeling study is to determine the effect of restoring a riparian forest on daily maximum water temperatures in reaches 4B and 5 during the spring. Wide riparian canopies reduce air temperatures at the river and reduced air temperatures may reduce water temperatures (Moore et al. 2005). Studies in upper watersheds in northern California indicated that a 30-meter wide riparian tree canopy reduced above stream air temperatures by 8.6°F compared to sites without riparian trees (Moore et al. 2005). The rate of decline in air temperature due to riparian tree canopies is highest up to a width of 30 meters and only 0.36°F for each additional 10 meters of width. It would be possible to use estimates of air temperature reduction, increases in humidity, and reduction in wind speed in a conceptual modeling analysis based on the data provided by Moore et al. (2005). The objective of this study is to evaluate the effects of a wide riparian forest on the microclimate in the Restoration Area. The objective of the companion HEC-5Q modeling study is to use the SJRRP HEC-5Q model and the riparian forest microclimate data to predict the effects of a riparian forest on water temperatures in the Restoration Area.

1.2 Methods

Preliminary studies were conducted that deployed 20 Onset weather stations with sensors for air temperature, wind speed, relative humidity, solar radiation, and soil moisture at 10 paired sites near the riverbank of the San Joaquin River between May 16 and June 29, 2014. Each paired site included one in an area with a mature riparian tree canopy between 30 and 100 meters wide on one side of the river and the other in a nearby area with a minimal tree canopy representative of typical conditions in the SJRRP Restoration Area. Eight paired sites (Sites 1-8) were selected in Reaches 4B and 5 within the San Luis National Refuge and two paired sites were selected in Reach 1 (Sites 9 and 10).

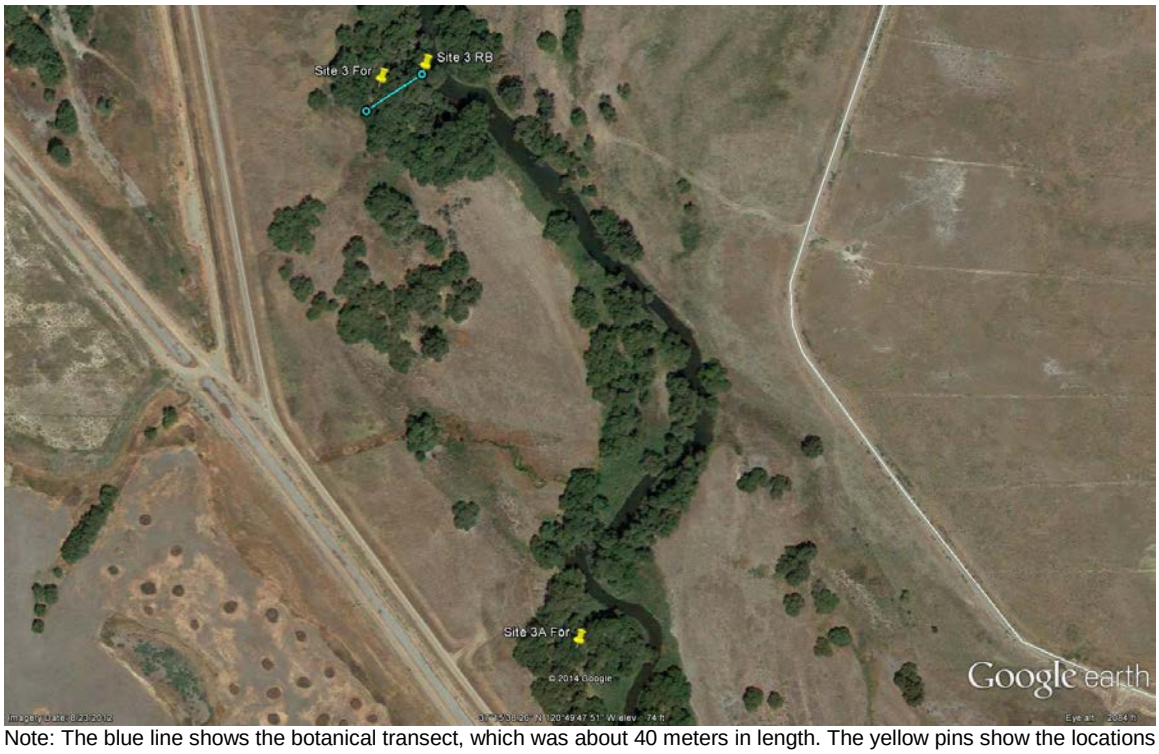
Based on the preliminary studies, enhanced solar shields were installed for Phase 2 studies that began June 30, 2014. The enhanced solar shields were 2 square feet 1/8-inch plywood sheets painted white and suspended about 3 inches above the Onset solar shield (Figure 2). The enhanced solar shields were oriented toward the South to maximize shading. The enhanced shields were observed to completely shade the Onset solar shield (model RS3) containing the air temperature and relative humidity sensor between 10 AM and 4 PM during July 2014. The enhanced shields were installed, because the Onset shields are not 100 percent effective, particularly at wind speeds less than 5 miles per hour (mph), which was common in the forested sites. For example under laboratory conditions, the temperature rise for a ventilated radiation shield was 9.4°F when the sun was directly overhead and the wind speed was 0.45 mph (Gill 1983).

For Phase 2 studies, there were a total of 15 relocated weather station sites in the San Luis National Refuge and the Stanislaus River. The relocated stations included sensors for air temperature, wind speed, relative humidity, and solar radiation, but not soil moisture. Two stations were established in the center of forested areas, one near the riverbank, and two in non-forested sites at Site 3 in the San Luis National Refuge (Figure 3). Two more stations were established in the center of forested areas, one near the riverbank, and one in a non-forested site at Site 7 in the San Luis National Refuge (Figure 4). Sites 3 and 7 in the San Luis National Refuge are among the largest forested areas in the Restoration Area. Three weather stations were also established along the Stanislaus River near the riverbank within large forests at the Caswell Memorial State Park (Caswell) and the Army Corps Park Ripon River Crossing (ACOE Park). Caswell has a dense, old growth, valley oak woodland that is about 7.4 river kilometers (4.6 miles) long (Figure 5). The ACOE Park site is also a relatively large (300 meter diameter), old growth woodland (Figure 6). Three more stations were established in non-forested areas on City of Ripon property (Figure 6).



Note: Weather Station with an enhanced solar shield constructed of a 2 ft^2 1/8-inch plywood sheet painted white, an Onset solar shield with temperature and relative humidity sensors, a solar radiation sensor, and wind speed sensor in a non-forested site on the San Luis National Refuge.

Figure 2. Weather Station with an Enhanced Solar Shield



Note: The blue line shows the botanical transect, which was about 40 meters in length. The yellow pins show the locations of the weather stations near the riverbank (RB) and middle of the forest (For). The non-forested site, which is not shown, is about 1 mile downstream.

Figure 3. Google Earth Image of Sites 3 and 3A in the San Luis National Wildlife Refuge Near River Mile 138

Permanent vegetation monitoring sites were established at all forested and open sites at the San Luis National Refuge where plant density, percent cover, canopy height, and species composition were recorded (Technical Service Center botanists, Greg Reed and Rebecca Siegle). A single hemispheric photo was taken immediately above a t-post in the middle of the botanical transect at each forested site just after dusk in May and June 2014 to quantify the tree canopy density. A white plastic pointer was used to indicate magnetic North in each photo to help evaluate changes in canopy density over time. Hemispheric photos were taken at the Stanislaus River forested sites on July 25 and 29 during the mid-morning, when there was too much sunlight for a quantitative analysis of canopy density.

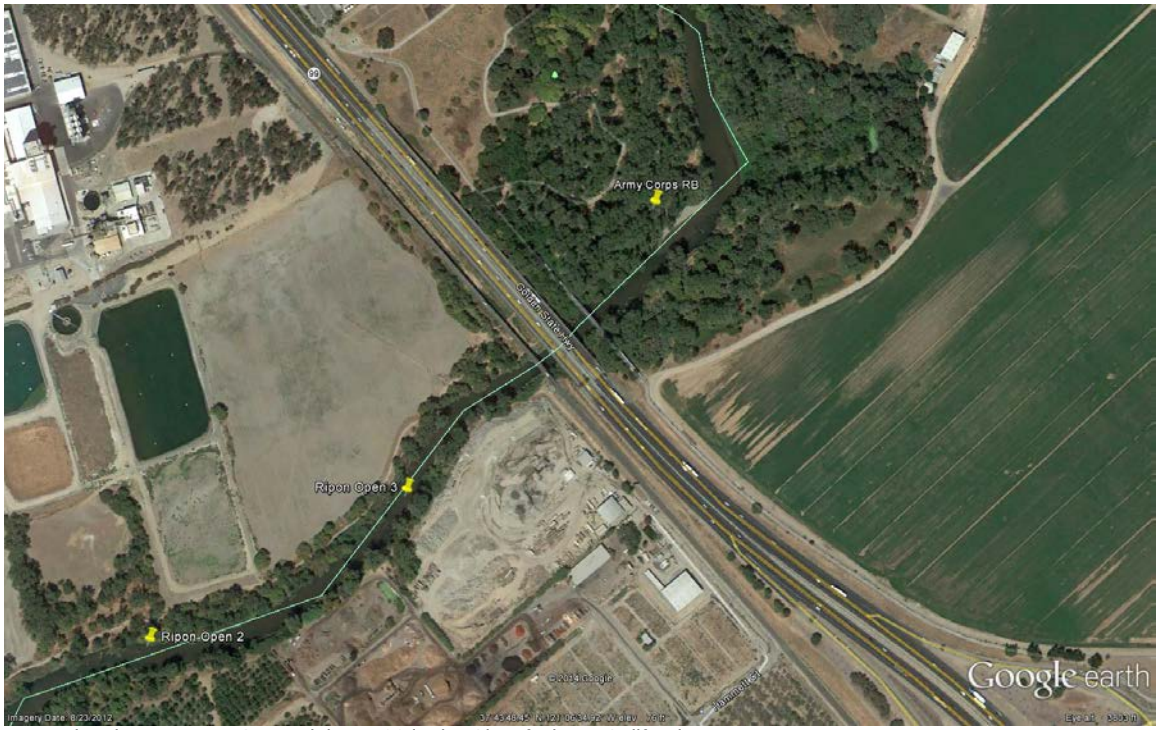
Note: The blue line shows the botanical transect, which was about 50 meters in length. The yellow pins show the locations of the weather stations near the riverbank (RB) and middle of the forest (For). The non-forested site, which is not shown, is about 2 miles downstream.

Figure 4. Google Earth Image of Site 7 in the San Luis National Wildlife Refuge Near River Mile 144

Microclimate data were collected at 15-minute intervals at each site. The pyranometers (solar radiation) and anemometers (wind speed) were set at 2 meters above the ground on a leveled tripod anchored to the ground with 3 guy wires. Wind speed was recorded as the mean and gust speed for each 15-minute interval. The relative humidity and air temperature sensor was attached to the tripod 1.5 meters above the ground within the Onset RS3 solar radiation shield and the readings were recorded in 15-minute intervals. The soil moisture sensor was buried about 0.2 meters below the ground. The mean difference in microhabitat conditions between forested and open sites was quantified relative to the canopy density, canopy radius, and wind gust speed.

Note: The yellow pins show the locations of the weather stations near the riverbank (RB).

Figure 5. Google Earth Image of Caswell Memorial State Park Sites 1 and 2 on the Stanislaus River Near River Mile 7



Note: The sites are near State Highway 99 in the City of Ripon, California.

Figure 6. Google Earth Image of the Locations of Three Weather Stations on the Stanislaus River at the Army Corp Park and Two of Three Non-forested Sites Called Ripon Open 2 and 3

1.3 Preliminary Results

The riparian tree species in the San Luis National Refuge study sites 1-8 were predominately Goodding's Willow (*Salix gooddingii*). The dominant tree and shrub species at Site 9 in Reach 1 include arroyo willow (*S. lasiolepis*), white alder (*Alnus rhombifolia*), buttonbush (*Cephalanthus occidentalis*), valley oak (*Quercus lobata*), and Oregon ash (*Fraxinus latifolia*). At Site 10 in Reach 1, the species are buttonbush, valley oak, Oregon ash, and sycamore (*Platanus racemosa*). The percentage of tree canopy cover at forested sites 1-8 ranged from 58 percent at Site 7 to 87 percent at Site 3 based on the hemispherical photos (Table 1). Botanical surveys had not been conducted at the Stanislaus River sites when this report was written. Hemispherical photos, which shows a 360-degree image from the middle of the botanical transects, are presented for Site 3 (Figure 7), Site 7 (Figure 8), Caswell Site 1 (Figure 9), Caswell Site 2 (Figure 10), and ACOE Park Site 1 (Figure 11). The hemispherical photos show that the forest canopies are much denser at the Caswell and ACOE Park sites than at Sites 3 and 7 in the San Luis National Refuge.

Table 1. Estimates of the Percent Canopy Cover for the Forested Study Sites as Measured with Hemiphotos Taken of the Middle of the Botanical Transects

Location	Photo	% Cover
Site 1	725	74.4
Site 2	730	66.7
Site 3	738	86.9
Site 4	746	74.3
Site 5	758	81.5
Site 6	795	60.1
Site 7	773	58.3
Site 8	785	63.4

Figure 7. Hemispherical photo of the forested Site 3 in the San Luis National Refuge

Figure 8. Hemispherical photo of the forested Site 7 in the San Luis National Refuge

Figure 9. Hemispherical Photo of Caswell Site 1 on the Stanislaus River

Figure 10. Hemispherical Photo of Caswell Site 2 on the Stanislaus River

Figure 11. Hemispherical Photo of ACOE Park Site 1 on the Stanislaus River

1.3.1 Microclimate Effects

Results are presented for preliminary studies conducted from May 16 to June 29, 2014 and for Phase 2 studies that began June 30, 2014, after corrections were made. The preliminary studies were affected by (1) partially effective solar radiation shields that had higher error rates for the forested sites where wind velocities were low, (2) small forested areas with highly variable microclimate conditions in the Restoration Area, (3) differences in channel morphology between some of the non-forested and forested sites, and (4) declining flow rates in the San Luis National Refuge.

1.3.2 Preliminary Studies

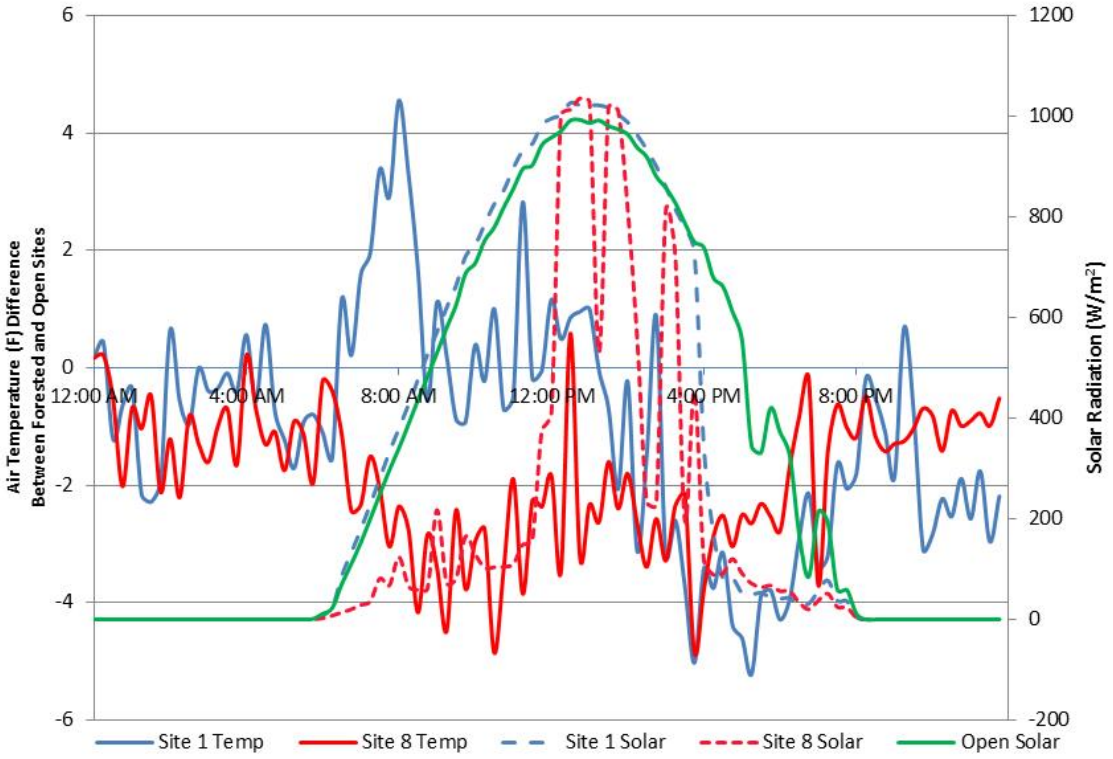
Microclimate data from weather stations deployed from May 16 to June 29, 2014 suggest that corrections were needed to evaluate the effects of a riparian forest on air temperature, wind speed, or relative humidity in the Restoration Area. The preliminary data suggested that the observed air temperature differences between the forested and non-forested sites were affected by solar radiation and wind speed at the shielded air temperature sensor. For example, the data from the Site 1 forested weather station exhibited unusually poor cooling compared to other forested sites, probably because the solar shield at Site 1 was exposed to the sun whereas the solar shields at the other sites (e.g., Site 8) were partially shaded by vegetation (Figure 12). To resolve this problem, enhanced solar shields were installed over the Onset solar shields as described in the Methods.

Another concern that arose from the preliminary studies was that most sites in the Restoration Area had forested areas that were so small (e.g., Sites 1 and 8) that the degree

of cooling was highly variable during the day (Figure 12). The high variability was presumably a result of the sensors alternately receiving warm air from open areas and cool air from the forest. To resolve this problem, some weather stations were relocated to the middle of the largest forests in the San Luis National Refuge and new sites were selected within large forests on the Stanislaus River as described in the Methods.

Another potential problem with the preliminary studies was that many of the non-forested sites were on upper terraces that were about 3.3 meters above the water surface, whereas the forested areas were typically within the low-flow channel within 1 meter of the water surface elevation. Relatively low wind speeds and high relative humidity levels at the forested sites compared to the open areas may have been partially due to the difference in channel morphology and elevation between the forested and open sites. This was resolved by selecting new non-forested sites in the San Luis National Refuge and the Stanislaus River that were within the low-flow channel and close to the water's surface.

Another factor was that flow of water through the San Luis National Wildlife Refuge (Stevinson gage) was generally less than 3 cfs during May and early June 2014 and the unusually low flows and elevated water temperatures may have affected the observed differences in relative humidity between the forested and non-forested sites. During the Phase 2 studies, streamflow in the San Luis National Refuge dropped to zero whereas there was about 300-400 cfs in the Stanislaus River.



Note: Negative values indicate that the forested areas were cooler than the open areas.

Figure 12. Difference in Air Temperatures (Temp) Between the Forested and Non-forested Areas and the Observed Solar Radiation (W/m²) at the Forested and Non-forested (Open) Areas at Sites 1 and 8 in the San Luis National Refuge on May 23, 2014

1.3.3 Phase 2 Studies

Microclimate data collected after the stations were redeployed and enhanced solar shields were installed between June 30 and July 28 suggest that large valley floor forests like those at Caswell and the ACOE Park can consistently reduce air temperatures by 5-10°F and achieve a maximum reduction of 12.0°F, which is similar to the 8.6°F reduction observed in the upper watersheds (Moore et al. 2005). In contrast, even the largest forested areas in the Restoration Area (Sites 3 and 7) were too small to reduce air temperatures by more than a mean of 2.3°F (Table 2). The largest temperature reductions occurred at ACOE Park Site 1, which had the largest forest area (Table 2), minimal herbaceous understory, a very dense tree canopy (Figure 11), and no detectable wind speed from July 25 to July 27, 2014.

The reductions in air temperatures at the forested sites at the Caswell and ACOE Park sites were relatively consistent during the afternoon (12 PM to 4 PM) compared to those at Sites 3 and 7 at the San Luis National Refuge. The following describes comparisons in microclimate data between two consecutive days that were selected to show a wide range in observed values. At the Caswell sites, the temperature reductions were usually greater at Site 2 than at Site 1 and greater on July 19 when wind gust speeds were relatively low and air temperatures were high compared to conditions on July 20 (Figure 13). Similarly, temperature reductions at Sites 3 and 3A in the San Luis National Wildlife Refuge were greater on July 7 when wind speeds were low compared to July 6 (Figure 14). There was a high degree of variability in the air temperature reductions at Site 7 in the San Luis National Wildlife Refuge on July 6 and 7 (Figure 15). On July 6, when wind gust speeds were higher than on July 7, air temperature reductions were greatest near the riverbank at Site 7 particularly when compared to the mid-forest weather station at Site 7. These data suggest that warm air from surrounding non-forested areas on the valley floor can readily overcome the cooling ability of small forested areas, particularly as wind speed increases. Additional data are required to quantify the temperature reduction in forested areas during the spring when most spring-run Chinook salmon would be expected to be migrating.

The Phase 2 studies also suggest that large valley floor forests may reduce wind speeds by 95 percent to 99 percent if the comparison is made between forested and treeless areas; whereas there may be little effect on wind speed if the comparison is made between forested and areas with a narrow band of trees along the river. Reductions in wind speed were 99 percent at Sites 3-RB and 7-RB in the San Luis National Refuge when compared to treeless open sites in the refuge (Table 2). In contrast, there was a narrow band of trees at Ripon Open Sites 1 and 2, but no trees at Ripon Open Site 3, which was on a levee (Figure 6). The mean afternoon wind speed was 4.6 mph at Ripon Open Site 3, but only 0.8 mph at Ripon Open Site 1 and 0.01 mph at Ripon Open Site 2 from July 16 to July 20. The comparisons presented in Table 2 were between Caswell Site 1-RB and Ripon Open Site 1, Caswell Site 2-RB and Ripon Open Site 2, and ACOE Park Site 1 and Ripon Open Site 2. Both sets of results may be applicable to the Restoration Area, because some reaches have a narrow band of trees (e.g., Reach 1 and Reach 3), whereas other reaches, such as Reach 4, have few trees.

The Phase 2 studies also suggest that the large valley floor forests along flowing rivers, such as those at Caswell and the ACOE Park, may increase relative humidity levels by 20 to 54 percent (Table 2). This is higher than the 10-15 percent increase in relative humidity that was observed in the upper watersheds (Moore et al. 2005). In contrast, the mean increase in relative humidity levels at Sites 1-6 and 8 at the San Luis National Refuge was 8 percent (-2 to 25 percent) during the Preliminary Studies when the river had less than 3 cfs of flow. After June 30 when there was ponded water but no flow at the San Luis National Refuge, the mean increase in relative humidity was 14 percent for Sites 3-RB and 7-RB (Table 2). Additional data will be needed to assess the effect of wide forests on relative humidity levels after Restoration Flows have been restored below Sack Dam. It is anticipated that approximately 70 cfs will be released below Sack Dam in 2015.

1.4 Recommendations

The Phase 2 studies suggest that the microclimate data from the upper watersheds (Moore et al. 2005) may not reflect changes in wind speed or relative humidity in the Restoration Area. If this is confirmed with data collected in 2015, then the HEC-5Q model (SJRRP 2014) should be recalibrated to reflect valley floor microclimate data. It is also possible that data collected in June and July do not reflect conditions that would occur in March through May, when spring-run Chinook salmon would be expected to migrate in the Restoration Area. Therefore, microclimate data should be continued to be collected in the San Luis National Wildlife Refuge, Stanislaus River, and possibly other valley floor sites through spring 2015.

1.5 References

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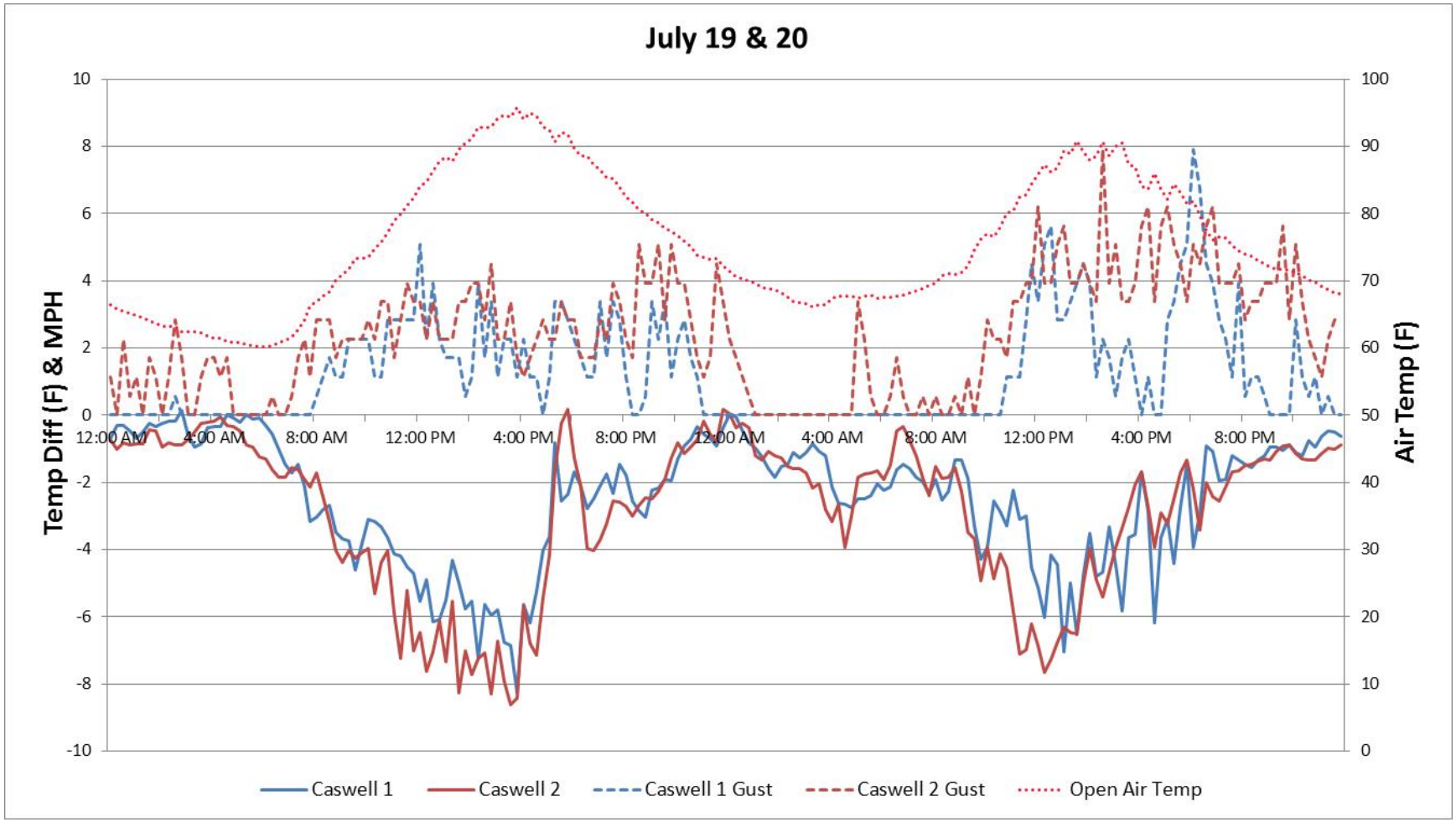
Table 2. Sampling Dates, Site Location, Minimum Continuous Canopy Radius from Each Weather Station

Site	Dates Sampled	Latitude	Longitude	Minimum Canopy Radius (m)	Mean Temp (°F)	Mean Wind Gust Speed (mph)	Mean Daily Max Temp Reduction (°F)	Mean Temp Reduction (°F)	Mean Wind Speed Reduction	Mean Relative Humidity Increase
3-RB	7/01 to 7/25	37°15'44.0"N	120°49'51.4"W	40	88.8	1.83	3.09	1.58	99.4%	15.8%
3-FOR	6/30 to 7/25	37°15'43.8"N	120°49'52.5"W	22	88.5	1.88	3.89	2.08	97.3%	11.5%
3A-FOR	6/30 to 7/25	37°15'32.7"N	120°49'47.6"W	22	91.9	1.21	3.06	1.56	99.9%	6.3%
7-RB	7/03 to 7/25	37°13'00.9"N	120°46'57.9"W	12	94.1	3.25	4.61	2.31	98.8%	12.1%
7-FOR	7/01 to 7/25	37°13'00.7"N	120°46'58.7"W	31	97.0	2.19	1.47	0.32	99.8%	1.0%
7A-FOR	7/01 to 7/25	37°12'56.0"N	120°46'59.2"W	30	95.1	4.00	3.44	1.59	85.8%	6.1%
CAS 1-RB	7/16 to 7/25	37°41'30.6"N	121°11'30.6"W	74	82.6	2.89	7.25	5.40	94.5%	24.3%
CAS 2-RB	7/18 to 7/25	37°41'21.4"N	121°10'58.1"W	143	82.3	3.85	8.01	6.24	No Wind	20.8%
ACOE 1-RB	7/25 to 7/27	37°43'37.5"N	121°06'54.6"W	146	88.4	0.10	12.44	9.66	No Wind	54.3%

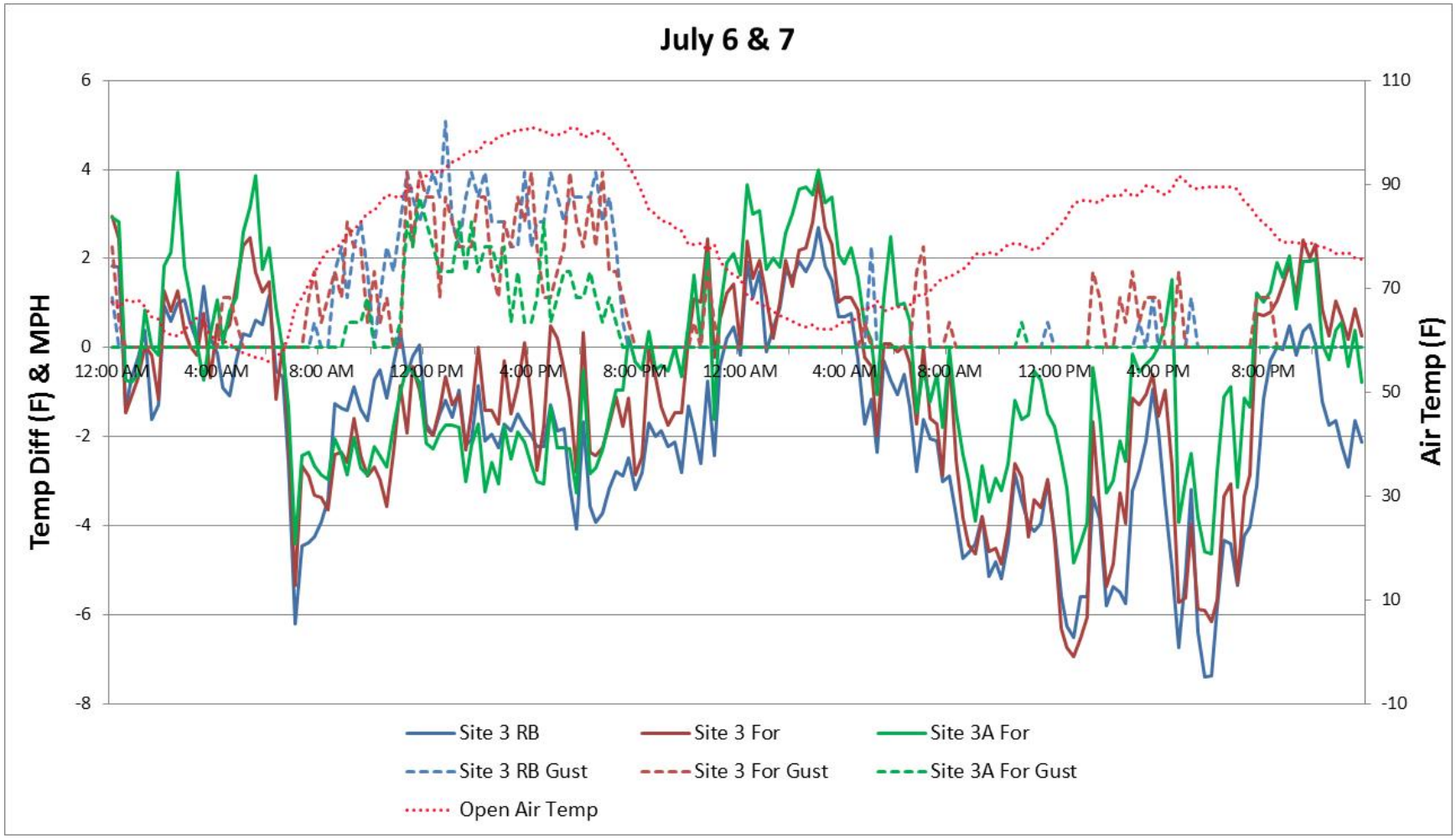
Note: Sampling dates, site location, minimum continuous canopy radius from each weather station, mean air temperature, mean maximum temperature reduction, mean temperature reduction, mean wind speed percent reduction, and mean percent increase in relative humidity between 12 PM and 4 PM at Sites 3 and 7 in the San Luis National Refuge and the Caswell (CAS) and Army Corp Park (ACOE) on the Stanislaus River. Some weather stations were located near the riverbank (RB) whereas some were located near the middle of the forested areas (FOR).

Key:
°F = degrees Fahrenheit
m = meter
mph = miles per hour



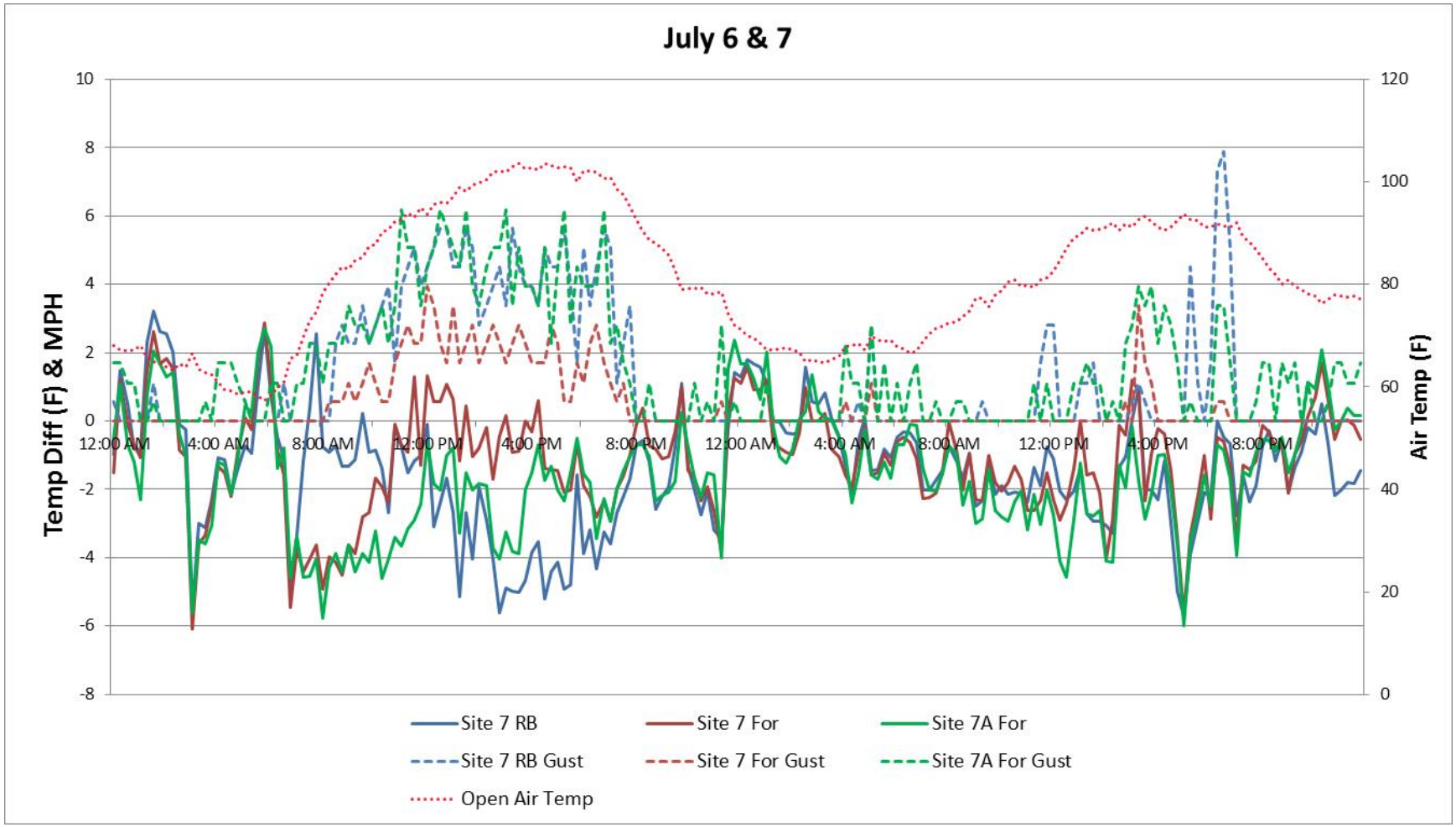
Note: Air temperature at the non-forested Ripon Open Site 1, wind gust speeds (mph) at forested sites Caswell 1 and Caswell 2, and the difference in air temperatures between forested site Caswell 1 and the non-forested Ripon Open Site 1 and forested site Caswell 2 and the non-forested Ripon Open Site 2 in 15-minute intervals on July 19 and July 20, 2014.

Figure 13. Air Temperature at the Non-forested Ripon Open Site 1



Note: Air temperature at the non-forested open site, wind gust speeds (mph) at the riverbank (RB) and mid-forest (For) weather stations, and the difference in air temperatures between forested sites and the non-forested open site in 15-minute intervals at Site 3 in the San Luis National Wildlife Refuge on July 6 and July 7, 2014.

Figure 14. Air Temperature at the Non-forested Open Site



Note: Air temperature at the non-forested open site, wind gust speeds (mph) at the riverbank (RB) and mid-forest (For) weather stations, and the difference in air temperatures between forested sites and the non-forested open site in 15-minute intervals at Site 7 in the San Luis National Wildlife Refuge on July 6 and July 7, 2014.

Figure 15. Air Temperature at the Non-forested Open Site

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