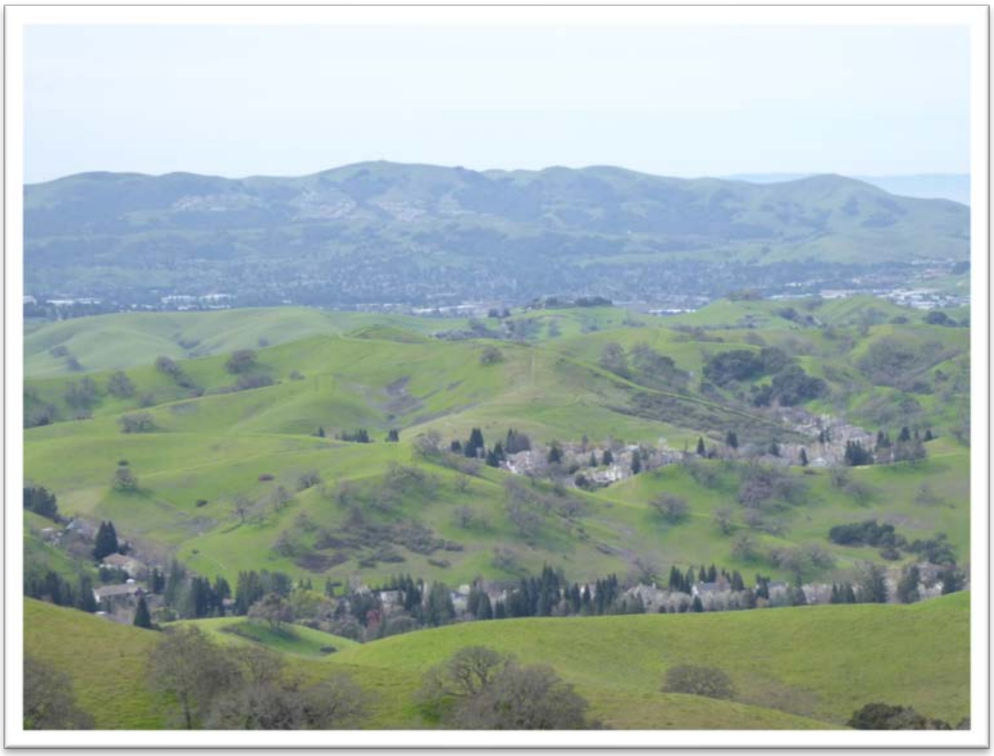
Mesoclimate Patterns of the Livermore Valley AVA



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Summary

The Livermore Valley American Viticultural Area (AVA) is generally suspected to have a climate that warms and becomes dryer moving inland from west to east. Along with a field review, data from a total of 41 weather stations in and around the Livermore Valley AVA were assessed. Also assessed were data sets from the PRISM Climate Group climate model. Results suggest the Livermore Valley AVA is influenced by a series of wind gaps, allowing marine airflow into the AVA. The funneling of airflow within the AVA, the topography, and warming from an urban heat island all work together to make the AVA more diverse than simple generalizations would suggest. Based on current available data, the AVA could be broken up into seven mesoclimates.

Background

The Livermore Valley AVA (27 CFR Part 9 §9.46) was created in 1982 and amended in 2006 to recognize the unique viticulture of the inland East Bay area of the San Francisco Bay Area. The AVA occupies sections of the Diablo Range in southern Contra Costa and eastern Alameda counties, including the Amador, Livermore, and San Ramon valleys (often referred to as the Tri-Valley area). The Diablo Range is a subset of the greater Coastal Ranges.

Despite its inland location, the Livermore Valley AVA experiences the cooling effects of coastal air flow, moderating temperatures compared to the hotter inland locations of the San Joaquin Valley to the east. In general, the Livermore Valley AVA is positioned farther from the Pacific Coast than many Central Coast or North Coast viticutlural areas and is not adjacent to inland bays. Nevertheless, a series of wind gaps allow cooler air to penetrate the Livermore Valley AVA, an influence that wanes in certain sections of the AVA. In general, the Livermore Valley AVA has been described as a transitional area between cooler climate regions to the west and warmer locations further inland, with temperatures warmer and drier as one moves from west to east through the AVA. Local growers, however, suggest that climatic shifts are much more complex than this generalization would suggest, perpetuated by a combination of varied topography, airflow, and urban influences.

This report takes an objective look at the climatic variations within the Livermore Valley AVA, analyzing data from existing weather stations. This study is part of a larger effort to better define districts within the AVA. This study is funded by a California Department of Food and Agriculture grant to the Livermore Valley Winegrowers Association.

Methodology

In researching climatic variations within the Livermore Valley AVA, weather data from existing weather stations both inside and approximate to the AVA were analyzed. An effort was made to first locate meteorological data from government institutions, especially research institutions, as the placement of weather stations and the management of the equipment typically ensures more reliable data. Sources included the Lawrence Livermore Laboratory, the East Bay Municipal Utility District, the Western Region Climate Center, and the California Data Exchange Center. Data from private weather stations managed by Wente Vineyards were also analyzed, as was limited data provided by Cedar Mountain Winery. Finally, weather stations with sufficient and reasonably complete data were located at the Weather Underground website to fill in coverage gaps within and adjacent to the AVA. As sources of data provided to Weather Underground are not immediately known, this source was utilized only when other data could not be found.

For every source, data were inspected for completeness and any obvious errors. Data from any station with more than seven days of consecutive data missing within one year were excluded from the analysis, as were any data with more than fourteen days of total missing dates during the traditional April 1 to October 31 growing season. In the case of seven or fewer missing dates of data, temperatures were interpolated using an average of an equal number of days prior to and following the missing dates. For precipitation, missing dates were assumed to have zero precipitation, unless it was reasonably suspected that precipitation occurred on the missing date(s). For average wind speed, missing dates were not calculated into the overall average.

The following data were collected from weather stations determined to be reasonably reliable: maximum daily temperature, minimum daily temperature, daily precipitation, and average wind speed. In some cases, average wind speeds were calculated. Not all data were available from every source utilized.

All temperatures data were collected in Fahrenheit for three reasons. First, the Winkler Scale of Growing Degree Day accumulations, which was established in Fahrenheit, remains a highly-referenced method for comparing temperatures in California's wine growing regions. Second, it was anticipated that more data would be available in Fahrenheit, but that some data might need to be converted if Celsius had been chosen. Finally, Fahrenheit has higher resolution than Celsius, and as such, conversions to Celsius, when needed, offer greater accuracy than conversions to Fahrenheit. As temperature is generally considered the most important climate control in viticulture, the collection of temperatures data was given greatest consideration. Precipitation data was collected in millimeters. Wind speeds were collected in English units and the International System of Units (SI units – either m/s or kph) and converted to knots.

Comparative heat summations used the Winkler Scale, sometimes referred to as the Amerine/Winkler Scale, as a basic guide. The Winkler Scale references heat summations during the growing season, which was defined as April 1 through October 31. The methodology deployed, however, utilized daily accumulations, rather than monthly accumulations. Hence, heat summations were calculated using daily accumulations of average daily temperatures, specifically heat summations equal to the sum of daily growing season GDD, where GDD=$\sum (T_{max}-T_{min})/2-50°F$, unless $T_{max}-T_{min}$ was less than zero for any given day, in which case GDD equaled zero for that given day.

Comparisons of average heat summations were done in ten-year (2007-2016), three-year (2014-2016), and two-year (2015-2016) data sets. When data were available for fewer than ten years, averages were calculated only if eight or more years of data were available and the missing years did not include the two years with the highest (2014) and lowest (2010) average temperatures. No exceptions were made for the three-year and two-year data sets; all years during the studied time period had to be reasonably complete.

Other methodologies exist for comparative temperature analysis. For a limited number of stations, specifically the weather stations with the most complete ten-year data sets, the Heliothermal Index (also known as the Huglin Index or the Huglin Heliothermal Index) was used to note differences in ripening potential. Heliothermal Index (HI) values are calculated as follows: HI= $\sum [(((T_{max}-T_{min})/2-10°C)+(T_{max}-10°C))/2]k$. In this case, T_{max} and T_{min} are in Celsius, the conversion for which was calculated using °C=(°F-32)5/9. The value for k is based on latitude, in this case 1.00 for all locations analyzed. HI calculations are based on April 1 to September 30 totals. Standard deviations of both the Heliothermal Index and Growing Degree Days were calculated to determine if one offered a better methodology for determining mesoclimatic variation within the study area.

Average wind speed, like temperature, was considered during the April 1 to October 31 growing season. Precipitation, on the other hand, was looked at using annual totals. These totals correlated with the calendar year, rather than the winter rainy season.

Not every meteorological attribute was studied at every weather station for which data were collected. GDD was given priority in the analysis for distinguishing trends across the AVA, and getting a relatively complete picture of GDD patterns dictated where Weather Underground data were collected. Other data were assessed based on availability or in response to preliminary analysis.

The author of this report conducted a field review of the Livermore Valley AVA in March 2017. For the study, the field review was meant to provide the following:

1. Any changes in vegetation, topography, soil, or drainage that might suggest subtle shifts in characteristics.
2. Insight from local growers.

The field review was meant to both support any findings of this report and to provide guidance to any additional methodologies that might help establish a more accurate picture of the climatic shifts within the Livermore Valley AVA.

Kelly Bobbitt of Mike Bobbitt and Associates was retained to develop maps of the area using geographic information systems (GIS). Maps included an aerial demonstration of the weather stations in the study and a visual presentation of calculated results. These maps were then reviewed to establish areal distinctions. For this report, computer-generated interpolations were added to demonstrate shifts in data, but no attempt was made to alter these interpolations to account for topography or urban influences.

Finally, Vestra Resources, Inc. was retained to map weather data publically available on the PRISM Climate Group website. These data were created based on a computer model, utilizing elevation and existing weather stations data. Cumulative temperature and precipitation totals from 2011 to 2016 and the most recent 30 year (1981 to 2010) normal temperatures and precipitation data were assessed. Temperatures data included average maximum, average minimum, and average mean temperatures. Data for 2011 to 2016 were available and portrayed spatially in 4000m by 4000m rasters, while normals were available and portrayed in 800m by 800m rasters. Data were portrayed in a GIS tool that allowed for monthly, multiple month, and annual numbers. April through October growing season totals and annual precipitation were assessed for this study. Further, GDD totals were calculated for both 2011 to 2016 and temperature normals, using monthly mean temperatures and the $GDD=\sum ((monthlyT_{mean})-50°F) \times 30)$ formula. This methodology varies from the above-noted GDD methodology in that it is a monthly accumulation, rather than daily accumulation. The same methodology was applied to data from previously-assessed weather stations where data were reasonably complete for both 2011 to 2016 and/or 1981-2010. These totals were then compared to the PRISM model results.

Results

A total of 41 weather stations were deemed to have reasonably reliable data in and around the Livermore Valley AVA. More weather stations likely exist with reasonable data, but the quantity and time required to review data from each weather station made further review impractical. The total number of reviewed stations included eighteen stations within the Livermore Valley AVA and a 19^{th} nearly on the AVA boundary and, for the purposes of this study, considered a Livermore Valley AVA weather station. Of the weather stations within the Livermore Valley AVA, all but two were within Alameda County.

Temperatures

Ten year data was limited to eighteen weather stations, five of which are within the Livermore Valley AVA. As noted above, one station is within a half a kilometer of the boundary, and, for the purposes of this study, will be considered a Livermore Valley AVA weather station. Ten-year GDD averages within the Livermore Valley AVA range from 3128°F at the Lawrence Livermore National Laboratory meteorological tower to 3766°F in central Livermore (LivCoop). Growing Degree Day totals west of the Livermore Valley AVA range from 2432°F in Moraga (CIMS178) to 3051°F in Fremont. North of the Livermore Valley AVA, the GDD averages range from 3211°F at the

Lafayette Reservoir (LafRes) to 3903°F in Pacheco (ConWWTP). East of the AVA, GDD averages ranged from 3615°F at Mallory Ridge (MLR) to 4592°F at the Tracy Pumping Station (TracyPmP). Only one station with ten years of reliable data was located south of the Livermore Valley AVA, which showed an average GDD of 3144°F (Rose Peak, RSP).

Table 1 – 2016-2007 average Growing Degree Day heat summations

Station	Elevation (ft) asl	GDD °F
	Livermore Valley AVA	
MtDiabJct*	2170	3147
CIMS191	355	3317
LVK	393	3746
LivCoop	480	3766
LNL*	572	3128
Sandia*	647	3134
	West	
CIMS178	510	2432
HywrdAir*	43	2912
Fremont**	38	3051
	North	
LafRes	452	3211
ConWWTP	40	3903
CCR	18	3794
BKD	1600	3464
	East	
MLR*	2040	3615
CIMS047**	45	3757
TracyPmp	61	4592
Site300	1270	4278
	South	
RSP*	3060	3144

*Average of nine years of data.
**Average of eight years of data.

Table 2 – 2016-2007 average GDD for all assessed weather stations

Year	Average GDD °F
2016	3657
2015	3718
2014	3845
2013	3611
2012	3464
2011	3144
2010	3059
2009	3438
2008	3545
2007	3320
Average 2016-2007	**3480**

Three-year data and two-year data had more complete data sets, but also covered a period for which temperatures were generally warmer than average. Table 2 shows the average temperatures for 2016-2007, for all weather stations at which ten-year temperatures data were calculated.

For both the three-year GDD average and the two-year GDD average, the Livermore Municipal Airport (LVK) had the highest average heat summations (4150°F and 4106°F, respectively), with the lowest of the assessed stations coming from Foothill High School (FoothilHi) over three years (3315°F average) and Calaveras Road (CAD) over two years (3283°F average). West of the AVA, the three-year GDD averages ranged from 2669°F in Moraga to 3205°F at the Hayward Airport (HywrdAir), and the two-year averages ranged from 2691°F in Moraga to 3493°F in Castro Valley (CVUpprRdwd).[1] North of the Livermore Valley AVA, Lafayette Reservoir (LafRes) experienced the coolest average temperatures at 3340°F over three years and 3215°F over the last two years, and the highest average heat summations were found at Pacheco (ConWWTP), with 4193°F degree days over three years and 4207°F degree days over two years. Pacheco was the only station to have a higher two-year average than three-year average. East of the Livermore Valley AVA, three-year and two-year GDD averages were highest at the Tracy Pumping Station (4881°F and 4806°F, respectively) and lowest at Mallory Ridge (3896°F and 3804°F, respectively). Finally, of the two stations south of the AVA, a weather station in the Sunol highlands had the highest three-year and two-year average (3499°F and 3456°F, respectively, compared to 3297°F and 3216°F, respectively, at Rose Peak).

Average Heliothermal Index calculations were made for weather stations with a full ten years of data available. These stations showed a range of values from 1843 at the Moraga CIMIS station to 2948 at the Tracy Pumping Station, which corresponded with the coolest and warmest stations under the GDD methodology. Standard deviations were

[1] 2014 data were not available for this station, so it was not included in the two-year averages.

calculated for both GDD and HI to measure variance. The standard deviation for HI was 280 (11% of the mean), while it was 566 for GDD (16% of mean).

Table 3 – 2016-2014 average Growing Degree Day heat summations

Station	Elevation (ft) asl	GDD °F
	Livermore Valley AVA	
EchoPrk	331	3369
FoothilHi	367	3315
CIMS191	355	3654
OrlffPrk	352	3710
CAD	1140	3336
WenteRub	424	3702
LVK	393	4150
WenteKal	627	3822
LivCoop	480	3997
WenteAry	606	3756
WenteErn	574	3884
LFERCFld	521	3697
WenteKar	637	3770
LNL	572	3383
Sandia	647	3341
WenteGhi	843	3694
	West	
EastmntHls	423	3153
CIMS178	510	2669
HywrdAir	43	3205
Fremont	38	3051
Sundale	46	3288
	North	
LafRes	452	3340
ConWWTP	40	4193
CCR	18	4125
WAlamo	269	3916
BKD	1600	3673
	East	
MLR	2040	3896
TracyPmp	61	4881
Site300	1270	4514
	South	
Sunol	2188	3499
RSP	3060	3297

Table 4 – 2016-2015 average Growing Degree Day heat summations

Station	Elevation (ft) asl	GDD °F
	Livermore Valley AVA	
EchoPrk	331	3371
FoothilHi	367	3307
SunolRR	256	3813
Lysander	698	3646
CIMS191	355	3586
OrlffPrk	352	3712
CAD	1140	3283
WenteRub	424	3586
LVK	393	4106
WenteKal	627	3756
LivCoop	480	3893
WenteAry	606	3664
WenteErn	574	3862
LFERCFld	521	3632
WenteKar	637	3710
LNL	572	3253
Sandia	647	3193
WenteGhi	843	3383
	West	
EastmntHls	423	3325
CIMS178	510	2691
HywrdAir	43	3194
CVUpprRdwd	305	3493
Sundale	46	3329
	North	
LafRes	452	3215
BrtnVlly	610	3434
ConWWTP	40	4207
CCR	18	4156
WAlamo	269	3986
MyrtlDr	348	3834
BKD	1600	3638
	East	
MLR	2040	3804
TracyPmp	61	4806
Questa	52	4698
Site300	1270	4453
	South	
Sunol	2188	3456
RSP	3060	3216

Table 5 – Heliothermal Index (HI) and Growing Degree Days (GDD) for weather stations with most complete data sets

Station	HI	GDD°F
	Livermore Valley AVA	
CIMS191	2367	3317
LVK	2551	3746
LivCoop	2623	3766
	West	
CIMS178	1843	2432
	North	
LafRes	2223	3211
ConWWTP	2600	3903
CCR	2560	3794
BKD	2439	3464
	East	
TracyPmp	2948	4592
Site300	2664	4278

Table 6 – Standard deviation of Heliothermal Index and Growing Degree Days for weather stations with most complete data sets

	HI	GDD°F
Mean	2481	3650
Standard Deviation	280	566
Standard Deviation as % of Mean	11%	16%

A review of the Vestra GIS tool showed relatively consistent growing season normal low temperatures throughout the AVA, but higher growing season normal temperatures in the western sections of the Livermore Valley and southern San Ramon Valley compared to the rest of the AVA. Normal average growing season low temperatures are consistently 50-54°F, except along the opposing slopes of the San Ramon Valley in the northern part of the AVA, where normal temperatures are slightly lower (46-50°F). A very small section of Mallory Ridge shows average normal low temperatures slightly warmer, in the 57-61°F range. Data sets for 2011-2016 show the same trend, but with slightly warmer temperatures in the northwestern and far eastern sections of the AVA, with two areas showing average low temperatures in the 57-61°F range. Average growing season normal high temperatures range between 68-82°F, with the coolest locations at Mt. Diablo and a small pocket in the higher elevations southeast of Livermore. The warmest locations in the western Livermore Valley and San Ramon Valley experience average normal temperatures in the 79-82°F range. Generally cooler locations are located in the western ridges (e.g., Dublin Grade), foothills of Mt. Diablo, and the southern-most section of the AVA (72-75°F). The same temperature range is found for the 2011-2016 average maximum temperature, with the highest temperatures found throughout most of the Livermore Valley and southern San Ramon Valley and only the lowest temperatures found on Mt. Diablo. Average growing season normal mean temperatures are warmest in the Livermore Valley, southern San Ramon Valley, Sunol and the Amador Valley, and in very limited pockets in the eastern highlands (mean temperatures in the 64-68°F range). Outside of these areas, average growing season normal mean temperatures are in the 64-68°F range, except at Mt. Diablo, which has average growing season mean temperatures in the 57-61°F range. Average 2011-2016 growing season mean temperatures are in the 64-68°F range in the southern San Ramon Valley and Sunol and the Amador Valley, throughout the Livermore Valley, and in the eastern ridgelines, except south of the Altamont Pass. Otherwise, average growing season mean temperatures are in the 61-64°F range. Maps 5-12 demonstrate screen shots of temperatures data from the Vestra-developed PRISM tool. Month-to-month review of average normal high temperatures shows the western Livermore Valley experiencing warmer temperatures than other sections of the AVA in July and August, with average temperatures in the 86-90°F range. This pattern is consistent with 2011-2016 average maximum temperatures, which saw the eastern Livermore Valley experiencing the warmest temperatures (in the 86-90°F range) in July and consistency throughout the Livermore Valley AVA in August. Month-to-month review also shows temperatures throughout the majority of the AVA cooling to 46-50°F in October when viewing normal average temperatures, but such cooling was only experienced in the San Ramon Valley and around Pleasanton in the 2011-2016 data sets.

In terms of calculated GDD using the PRISM data sets, GDD totals using normal mean temperatures are highest in the western Livermore Valley (3484-3652°F) and lowest at Mt. Diablo (2409-2754°F). In general, GDD is highest in the Livermore Valley, San Ramon Valley, and Sunol and the Amador Valley and near Mallory Ridge (ranging from approximately 3345-3483°F), and coolest in the west, south, and north (ranging between 2409-3344°F). A thin band of lower GDD is also found to the east of the Livermore Valley, showing GDD in the 3066-3344°F range. GDD in the 2011-2016 data sets shows higher totals for most of the AVA, with some of the Livermore Valley in the 3653-3810 range and with other areas in the 3484-3652°F range. Only the extreme southern and western sections of the AVA, along with Mt. Diablo, demonstrate GDD at 2920°F or lower.

Table 7 – Normal and 2011-2016 Average GDD in and adjacent to the Livermore Valley AVA.

Station	2011-2016 Ave. GDD	Normal GDD
CIMIS191	3420	*
LVK	3833	3395
LivCoop	3765	3595
LNL	3141	2959
Sandia	*	2988
MtDiabloJct	*	3201
MLR	3669	*

**Data unavailable or incomplete.*

A total of five weather stations in and adjacent to the Livermore Valley AVA were found to have 1981-2010 normal temperatures data. Further, a total of five stations had data covering 2011-2016, with three stations having both normal temperatures and 2011-2016 data. Note that Sandia, LNL, and LVK had years of incomplete or missing data, but sufficient data for the respective sources to list normal temperatures. Totals are presented in Table 7.

Precipitation

As the majority of the precipitation in coastal California occurs during the winter, annual precipitation, rather than growing season precipitation, was assessed. Of the climatic attributes assessed, precipitation has the greatest variability, and therefore only stations with ten years of data were used in the analysis, which included three weather stations with only precipitation data. Table 8 outlines the results. The highest average annual precipitation within the Livermore Valley AVA was found at Mt. Diablo Junction, with 596 mm of average annual precipitation, while the Sandia station east of Livermore was the driest, at 258 mm of average annual precipitation. Two general patterns are observed. First, higher elevations generally received the greater amount of precipitation. Second, the eastern Livermore Valley and stations east of the AVA were generally drier. In every case, 2013 was the driest year, with 2010 and 2016 being the wettest.

A review of the PRISM climate model data showed precipitation normals highest in the northwestern section of the AVA and at Mt. Diablo (Map 13), with precipitation ranging between 22.61 inches and 33.00 inches (574 mm-838mm). In terms of the western areas of the AVA, normal annual precipitation is lower to the south, with 18.63 inches to 20.39 inches more common in the Sunol area (473mm-518mm). In the Livermore Valley, the western part of the valley experiences a steep gradient from the area west of Pleasanton to the eastern Livermore Valley. The hills east of Livermore demonstrate the driest area of the AVA, with annual precipitation values of 13.83 inches to 14.65 inches (351mm-372mm).

A review of 2011-2016 PRISM data show a similar pattern, although overall conditions are drier throughout most of the region. During this time period, the wettest area (22.61 inches to 33.00 inches) represents a much smaller part of the AVA, limited to a few blocks of the western part of the AVA. Meanwhile, the drier eastern hills experience 11.70 inches to 12.40 inches (297mm-315mm). Much of the western and norther sections of the AVA are shown as receiving between 16.66 inches to 33.00 inches (423mm-838mm), while the Sunol area is shown as receiving approximately 14.66 inches to 15.39 inches (372mm-391mm).

A review of monthly precipitation values shows conditions relatively wetter in the western part of the AVA and in and around Mt. Diablo for every month except June through September, when all areas receive little-to-no precipitation. This pattern was true for both temperature normals and 2011-2016 data. The 2011-2016 data did show some minimal amounts of precipitation in the western highlands during the month of June, with quantities in the 0.47in-0.91in range (12mm-23mm), which is not consistent with normal precipitation.

Table 8 – 2016-2007 average annual precipitation in millimeters

Station	Elevation	Precipitation (mm)
	Livermore Valley AVA	
MtDiabJct	2170	596
CIMS191	355	395
LVK	393	312
LivCoop	480	306
LNL	572	281
Sandia**	647	258
	West	
ChabRes	279	516
CIMS178**	510	773
ChabRes	279	516
USLRes	479	629
HywrdAir	43	325
Fremont	38	309
	North	
LafRes*	452	554
WTWTP	380	479
ConWWTP	40	404
CCR	18	357
BKD***	1600	371
	East	
MLR**	2040	549
CMIS047*	45	290
TracyPmp	61	261
Site300	1270	242
	South	
RSP***	3060	498

*Average of nine years of data. **Average of eight years of data. ***Average of seven years of data.

Wind

Interviews with local growers point to wind patterns that bring cooling coastal air over and through the western foothills, mostly via the Dublin Grade, Sunol Grade, Crow Canyon, and the Highway 24 corridor and from the Walnut Creek area via the Ygnacio Valley. The most direct air flow onto the Livermore Valley, based on a review of topography, would be over the Dublin Grade, while air flowing over the Sunol Grade would move either into the Amador Valley and then into the Livermore Valley or into the Vallecitos Valley and then into southern Livermore. The San Ramon Valley would pick up cooling airflow from the Dublin Grade, Bollinger Canyon, and Highway 24 corridor, as well as via the Ygnacio Valley. Most airflow is funneled around Mt. Diablo into the Altamont Pass east and north of Livermore. Topography also adds to the variety in wind patterns, and a number of sheltered locations exist throughout the region.

The following table identifies average growing season wind speeds, but wind direction was not calculated as part of this study. As wind speeds are generally more consistent year-to-year, two-year averages rather than ten-year averages were calculated to get greater distribution. Wind speeds within in the study area ranged from still (below 0.5 knots) in the Burton Valley in Lafayette (west of the northern part of the AVA) to 13 knots at Site 300 east of the AVA. Within the Livermore Valley AVA, Orloff Park shows the lowest two-year average at 1 knot, while a station on Calaveras Road showed the highest average wind speed at 8 knots.

Table 9 – 2016-2015 average growing season wind speed in knots

Station	Ave. Speed (kn)
Livermore Valley AVA	
EchoPrk	3
FoothilHi	3
SunolRR	2
CIMS191	3
OrlffPrk	1
CAD	8
WenteRub	3
WenteKal	5
WenteAry	4
WenteErn	4
LFERCFld	4
WenteKar	3
LNL	5
Sandia	5
WenteGhi	4
West	
EastmntHls	3
CIMS178	4
CVUpprRdwd	2
Sundale	3
North	
BrtnVlly	0
WAlamo	3
MyrtlDr	1
BKD	10
East	
MLR	8
CMIS047	5
Questa	3
Site300	13
South	
Sunol	2
RSP	6

Vegetation

Field review and aerial imagery revealed a clear change in vegetation moving from the western hills, which were more-heavily vegetated in forest and woodland, to the eastern hills, which are better described as grasses and shrubland. So too does vegetation increase at the higher elevations of Mt. Diablo in the northern section of the AVA. Vegetation is greatly influenced by exposure between south-facing slopes (dryer, with less vegetation) and north-facing slopes (not as dry, with more vegetation). This characteristic is especially true of the foothills of Mt. Diablo, as well as the mountainous terrain south of Livermore.

Photo 1 – Looking east at the Altamont Pass (taken from Vasco Road, north of Interstate 680); very little vegetation, other than grasses, is evident in the western slopes of the AVA.

Photo 2 – Much denser vegetation is observed west of the AVA (photo taken along Redwood Road, looking east towards the San Ramon Valley).

Photo 3 – Vegetation is also heavily influenced by northern/southern exposure, especially east of the Dublin Grade and west of the Altamont Pass. Here trees and shrubs are more predominant on slopes facing north (photo taken from Morgan Territory Road looking south, towards the Livermore Valley AVA and the hills south of the valley).

Viticulture

By far, the greatest location of viticulture within the Livermore Valley AVA is south of Livermore and southeast of Pleasanton. The bulk of the viticulture is planted to Chardonnay and Cabernet Sauvignon. Smaller pockets of viticulture are found north of Interstate 680 and west of Pleasanton, along Palomares Road. The northern part of the AVA is limited in viticulture, with mostly small vineyards located in larger suburban lots. A trend of using landscape viticulture in some of the newer neighborhoods also was observed. It is not immediately known if this viticulture will be used for commercial production.

Photo 4 – Viticulture in the San Ramon valley tends to be small suburban/semi-rural lots, like this vineyard along South Gate Road north of the community of Diablo.

Photo 6 – The largest and most common viticulture operations are found on the valley floors or in the rolling foothills south of Livermore.

Discussion

The cooling impact of the flow of air cooled by the Pacific Ocean inland through pressure differentials created by conventional uplift at much warmer inland locations is well-documented. This airflow plays an important role in coastal California viticulture, including the Livermore Valley AVA. A series of wind gaps, starting with the Golden Gate, allow air movement that eventually invades the Livermore Valley AVA, moderating temperatures, but also creating a transitional zone between cooler coastal regions and warmer inland locations.

Greater emphasis in this analysis is placed on weather station data than on the PRISM climate model. Although the climate model takes into account variables such as topography, which are not taken into account when interpolating climate station observations, actual climatic data are preferred to computer-generated data when assessing actual conditions. Unfortunately, observational data are limited in both coverage and duration. Hence, the PRISM data offer context to the weather station observations. Note, however, that the PRISM data sets only demonstrated accuracy for GDD calculations in one of the five stations where temperature normals are available (LVK) and in only two of the five weather stations where 2011-2016 data are available (CIMS178 and LivCoop).

Both PRISM data sets and temperature observations suggest that more recent temperatures are warmer than historical data sets. PRISM data sets show warmer temperatures in the 2011-2016 data than in the thirty year normal temperatures. Temperature observations show two- and three-year averages as warmer than ten-year averages. As this is a comparative analysis, not a long-term analysis assessment of climatic warming trends, this trend is not explored further. Nevertheless, future revisions to thirty normal temperatures will likely show overall warmer temperatures. Shifting patterns are considered, however, especially in terms of heat island impact. Definitive conclusions, however, are hard to draw, until more data become available.

Observed weather station data demonstrate a clear transitional trend from cooler locations closer to San Francisco Bay to warmer San Joaquin Valley locations inland, but to suggest that there is a straight correlation between distance from the coast and temperature is not supported. Variations in temperature are influenced by wind patterns, elevation, and urban heat islands. Map 1 demonstrates a geographic distribution of weather stations and their respective Growing Degree Day heat summations. Interpolations are used to give a rough estimation of isotherms. These isotherms should be considered with some caution, as they neither can be used to identify heat summations at any given geographic location, other than the respective weather station, nor do they take into account the topographic or aeolian characteristics largely responsible for climatic variations. For example, the cooler temperatures found at LNL and Sandia are likely a result of air flow over the Sunol Grade and through the Valecitos Valley, into southern/eastern Livermore. The location of Sandia, south of LNL with warmer stations to the west, suggests the cooling influences come from the south, rather than the west.

LVK and LivCoop very likely demonstrate warmer temperatures associated with urban heat islands (again, note that the interpolated isotherm does not match the urban community). The Environmental Protection Agency estimates a 1.8-5.4°F average increase of temperature associated with areas of one million people or more.[2] That said, a number of studies suggest that heat islands occur in significantly smaller populations. For example, annual temperature increases in Fairbanks, Alaska, a city smaller than Livermore, were estimated at 0.4°C (0.7°F) in 1999.[3] The characteristics of heat island effects are complicated by insolation, albedo, seasonality, and air movement, so a simple equation cannot be applied to establish the net effect of this heat island. Regardless of the net effect, an interesting point should be made: Livermore Valley viticulture is unique in that the majority of the commercial viticulture destined for fine wines is in close proximity to an urban landscape the size of the Livermore/Pleasanton/Dublin population center. Similar distinctions could be made about viticulture on the Santa Rosa Plain, but the heart of the Livermore Valley Wine Country sits just south of Livermore. Hence, the urban heat island phenomenon likely has an effect on Livermore Valley viticulture,

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[2] U.S. Environmental Protection Agency, "Urban Heat Island Basics," *Reducing Urban Heat Islands: Compendium of Strategies*. Draft, May 2017; Oke, T.R., "Urban Climates and Global Environmental Change," *Applied Climatology: Principles & Practices*, Routledge, New York, 1997, pp. 273-287.
[3] Magee, N., Curtis, J., and Wendler, G., "The Urban Heat Island Effect at Fairbanks, Alaska," Theoretical and Applied Climatology, Vol. 64, Issue 1, October 1999, pp. 39-47.

especially in moderating early-season and late-season temperatures, as well as nocturnal temperatures.

Mapping two-year GDD averages creates even greater variation in temperatures (Map 2), to the point that interpolations no longer make complete sense, unless modifications are used to take into account other local characteristics (no such modification was made to Map 2). While longer-term averages provide a clearer picture of climate, short-term averages may be used to provide comparative analysis. The two-year average should not be used to define the climate the Livermore Valley AVA, but these data were calculated to get a sense of comparative temperature patterns within the Livermore Valley AVA. Note, while "average" can become clearer with a greater duration of time, 2014 was the warmest year over the ten-year period assessed. Further, 2015 and 2016 were both above average, which may influence overall climate patterns. As this study is looking at averages, and not extremes, three-year GDD averages are no longer considered as they included the 2014 extreme.

The complications of climatic patterns found when assessing the two-year averages may be attributed, in part, to the variety of sources, which were derived from different equipment, with no good process for assessing the accuracy of placement for each station. Assuming consistency of equipment and appropriate placement of this equipment, a number of factors can help explain the mesoclimatic and microclimatic variations noted in the two-year data. Not only are temperatures influenced by wind patterns drawing in cooler Pacific air and the influences of urban heat islands, elevation may have multiple influences. First, unless a marine inversion is present, temperatures generally decrease with elevation at an average rate of 3.6°F per 1000 feet. The cool air that invades the Livermore Valley AVA, however, creates such inversions, often meaning locations above 1000 feet in elevation experience warmer temperatures than those below 1000 feet. Further, early- and late-season air drainage of cooler air may create valley inversions, with cooler nocturnal temperatures in valley bottoms leading to overall lower average temperatures. Finally, fog (created from the release of radiant heat, air drainage, or marine layers), reduces solar insolation, causing cooler diurnal temperatures, while moderating nocturnal temperatures.

The impacts of air drainage versus marine layers are inconclusive with the available data, but the impacts of inversion layers are evident. A number of cool pockets are consistent with some of the wind patterns observed (e.g., EchoPrk and FoothilHi), while a combination of wind patterns and air drainage may moderate temperatures at other locations (e.g., WenteRub Sandia and LNL). Further, elevation may help moderate temperatures at CAD and RSP and MtDiabJct.

PRISM data sets for mean temperature support the idea the southern Livermore Valley is cooler than most of the Livermore Valley and southern San Ramon Valley, although a review of maximum temperatures suggests higher normal maximum temperatures west of Livermore, in Pleasanton and San Ramon, than in Livermore. This pattern changes when viewing 2011 to 2016 data, although the lower raster resolution complicates the overall picture. As higher maximum temperatures appear to extend from San Ramon and eastern

Pleasanton to downtown Livermore, recent data suggests that Livermore is seeing greater relative maximum temperatures in recent years, compared to thirty-year normals. This pattern may be temporary, and not indicative of long-term averages, as it constitutes an eight-year period rather than a 30-year average. If the change in pattern is sustained, it may be supported by the growing urban population. Although Pleasanton has seen greater overall growth since 1980 (35,160 in 1980 to 82,270 in 2016) compared to Livermore (according to the U.S. Census bureau and not taking into account changes in the city boundaries) combined with fast growth in San Ramon and Dublin, much of the growth has been east towards Livermore. Hence, infill population growth may have altered temperature patterns in the Livermore Valley. Further study would be needed to draw any conclusion regarding a possible change in temperature patterns and whether or not these patterns can correlate to population growth.

Some limitations exist with the utilization of Growing Degree Days as a unit for measuring temperature. First, GDD does not take into account duration of high or low temperatures. The simplification of this methodology was established at a time when temperatures data and calculations were restricted, compared to modern software. Hence, a station experiencing a short duration of high temperatures is given equal GDD weight compared to a station experiencing longer periods of high temperatures. Coastal areas of California are prone to see shorter warm periods, as the moderating effect of fog and cool air invasion in summer months typically occurs in the early afternoon, when most areas are experiencing the warmest period of the day. The net effect can be seen with slight modification to the GDD calculation. As noted in the methodology described earlier in this report, GDD is technically calculated using an average temperature, defined as the average of high and low temperatures readings, [Ave=(T_{max}-T_{min})/2]. Using the averages of temperatures readings (e.g., hourly or 15 minute readings) can produce very different results. Table 9 demonstrates differences in average 2016-2007 GDD readings for select stations (with hourly data readily available over the ten-year period). Note that for most stations, GDD based on max/min temperatures is higher than GDD based on average temperature readings, which could either be because high temperatures are not sustained or low temperatures are sustained for longer periods. The lone exception is Brentwood (CIMS047), which represents a warmer climate, possibly offering some evidence that duration in temperature can create greater variance in climatic conditions than the calculated numeric differences provided by GDD figures alone.

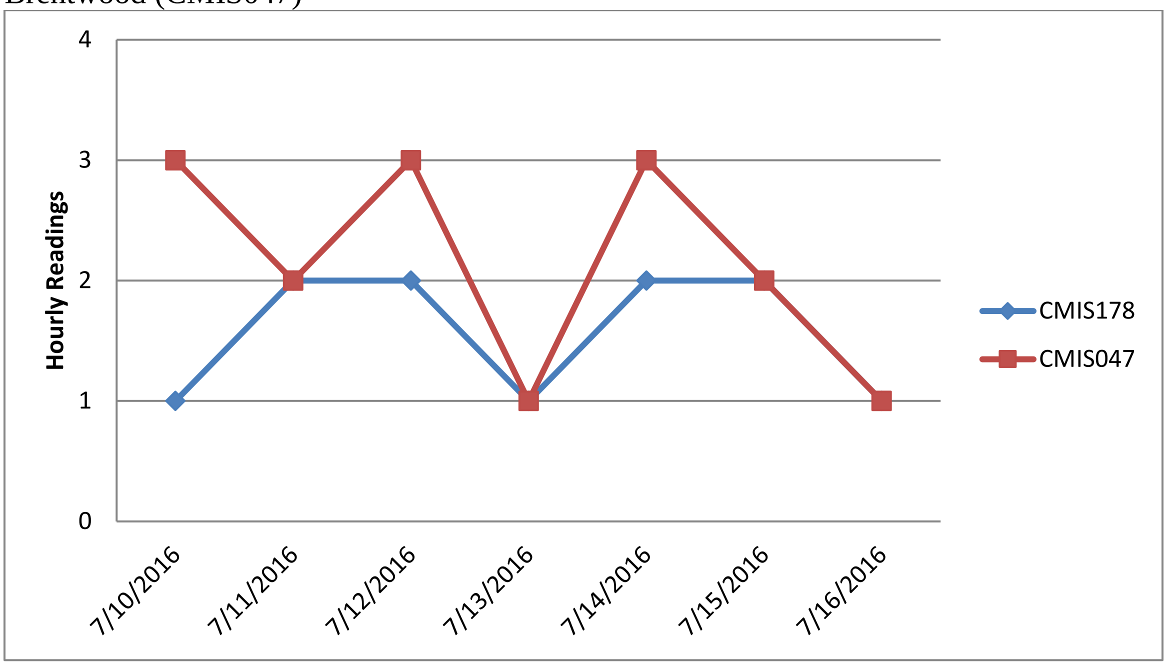
A look at the duration of high temperatures in the Livermore Valley AVA compared to inland areas shows temperatures in inland areas, where marine influences are less pronounced, remain at or near the high temperature longer than at the Pleasanton CIMIS station. In the case of the Brentwood CIMIS station versus the Pleasanton station, high temperatures readings during a one-week period in the heart of the growing season (the week of July 10, 2016) remained within 0.5°F longer (based on hourly reports) on three of the seven days. Similar patterns were found between the Santa Rosa CIMIS station, another area known to be impacted by afternoon fog intrusions, and warmer inland locations at Manteca and Modesto (Graph 2). While only one week was assessed, if such a pattern was consistent through much of June, July, and August, when fog intrusion is known to be at its highest, the cumulative effect would be more significant than the difference in GDD would suggest. Extreme coastal locations (e.g., Point San Pedro), where fog and cool Pacific air are predominant throughout the day, also would not experience the climatic variations found in a location like the Santa Rosa Valley or the Livermore Valley AVA. In the case of coastal extremes, fog is much more consistent, and as such, does not allow for high temperatures to build before being influenced by the cooling impacts of invading fog.

Table 9 –2016-2007 dual GDD methodologies for calculating average temperature (°F)

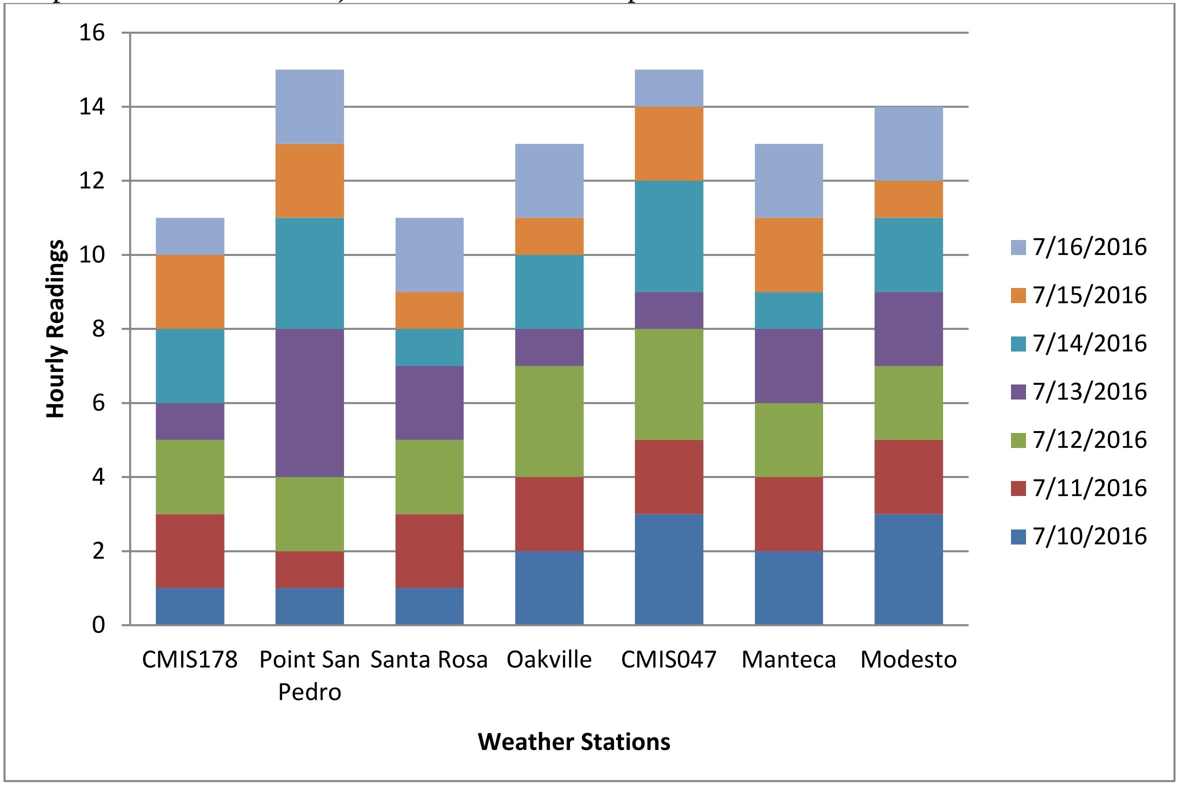
Station	GDD Based on T_{max}-T_{min}	GDD Based on Ave. Hourly	Difference
CIMS178**	2432	2282	-150
CIMS191	3317	3111	-206
RSP*	3144	3114	-30
BKD	3464	3384	-80
MLR*	3615	3542	-70
CIMS047	3757	3852	95

*Average of nine years of data.
**Average of eight years of data.

Graph 1 – Number of hourly readings at high temperature (based on temps within 0.5°F) for the week of July 10, 2016, for CIMIS stations in Pleasanton (CMIS178) and Brentwood (CMIS047)



Graph 2 – Combined number of hourly readings at high temperature (based on temperatures within 0.5°F) for Pleasanton and representative CIMIS stations



The distinction of high temperature duration between the Livermore Valley AVA and other viticultural areas is made not so much to distinguish the AVA from other AVAs, but to demonstrate that, like many cooler climate viticultural areas, invading Pacific air plays a significant role in moderating temperatures within the Livermore Valley AVA. Hence, airflow needs to be taken into consideration when assessing climatic variation. Where the impact of airflow is at its greatest, temperatures should be moderated, with diminishing impact moving away from the Golden Gate. GDD may demonstrate the relative locations of these locales (where data are available), but may not fully demonstrate the extent of the distinction from areas surrounding the AVA. Further, the possibility exists that greater variation is present than what is represented by the numbers demonstrated in the results of this study.

A number of studies have suggested that a combination of indices may better define climatic distinctions. These range from variations of GDD to entirely new indices developed in conjunction with pre-existing data sets. One such study, for example, suggested that a combination of Dryness Index (DI), Heliothermal Index (HI), and Cool Night Index (CI) offers a range of climatic characteristics important to grape maturation.[4] Such studies, however, focus on macroclimatic variations, rather than mesoclimatic variations.

[4] Tonietto, Jorge and Carbonneau, Alain, "A Multicriteria Climatic Classification System for Grape-Growing Regions Worldwide," *Agriculture and Forestry Meteorology*, Elsevier, 2004.

This study focused on Heliothermal Index as an alternative to GDD as a potential for offering greater climatic variation, as it is a common index used in the wine industry. As noted in Table 6, however, the standard deviation for HI calculations for weather stations with the most complete data sets is lower than for GDD comparisons (i.e., 280 for HI compared to 566 for GDD). As this study is assessing climatic variations, a lower deviation is not preferred. This lower variance is likely a result of HI's dependency on Celsius rather than Fahrenheit units. As Fahrenheit has as greater resolution (1.8°F per 1.0°C), the overall difference from station to station is similar if assessed in common units between the two systems. As such, this study relied on the more traditionally-used GDD calculations for comparative analysis.

As airflow is important to filtering cool air into the Livermore Valley AVA, wind was considered. Establishing exact airflow patterns, however, was beyond the scope of this study. Rather, airflow is important in regards to the cooling effect of Pacific airflow and marine inversion, and as such should be reflected in temperature patterns. Nevertheless, air speeds were calculated to see if distinct patterns could be found across the AVA. Map 3 demonstrates that average airflow appears more intense on the eastern edge of the AVA than on the western side. This pattern is likely a result of the funneling effect of air around Mt. Diablo and through the Livermore Valley. The impact may also be a result of pressure differential, which is often greater on the advancing edge of marine inversions than on areas already subject to cool (hence, heavier) marine air. As the eastern hills are simply not subject to these inversions in the same way the valleys are, they more commonly remain in a differential pressure pattern. Similar patterns have been observed in many parts of coastal California. While the observation of wind speeds is inconclusive to wind patterns, it does support, however, the idea that the Livermore Valley AVA, though not known as a cool climate location for wine grape production, is moderated by Pacific air that makes the area cooler than its inland location would suggest. Further analysis would be needed to assess the time of day when wind speeds are greatest and the duration of winds.

Conversations with local professionals suggest later harvest dates within the Livermore Valley AVA compared to other Central Coast/North Coast locations known for Cabernet Sauvignon production. If accurate, a possible explanation could be greater marine influence in the Livermore Valley AVA than is typical of other regions during growing season months when marine intrusions are most common. As this is a comparative study within the Livermore Valley AVA, and not a comparative analysis between other wine growing regions, further research would be needed to offer any support for this explanation.

Aside from the impact of wind on Pacific airflow, wind plays an important role in temperature (especially nocturnal temperatures) and vine and grape development. Air movement will moderate low temperatures by preventing the cooling of surface air caused by nocturnal heat radiation. Further, wind is known to have an impact on the skins of fruit by slowing photosynthesis rates, with sustained wind speeds of at least 7 knots believed to be needed to impact photosynthesis.[5] As most of the Livermore Valley AVA,

[5] Greenspan, Mark, "Row Direction—Which End is Up?," *Wine Business Monthly*, July 2008.

with the exception of a few pockets, has average wind speeds below 7 knots, airflow likely plays a more indirect role by impacting temperatures.

Finally, as water is commonly referred to when discussing Livermore Valley AVA viticulture with local growers, and many vineyards require some irrigation, a review of annual precipitation was conducted. Precipitation alone is not sufficient to assess soil moisture. So too would the field capacity of soils and evapotranspiration rates need to be assessed. Many of the soils in the Livermore Valley AVA are known to be well-drained, but this study focusses on climate, rather than edaphic factors. Evapotranspiration rates are impacted by temperature and vegetation. Appendix 2 shows calculated annual evapotranspiration rates across the state, and while the scale of this map is too small for any clear local analysis, the Livermore Valley AVA obviously sits within a transitional zone, occupying Zone 6, Zone 8, and Zone 14 of the AVA.

Map 4 demonstrates annual precipitation values, with values interpolated to approximate isohyets (lines connecting areas of equal precipitation). As is the case with temperature, these lines do not take into account topography. If they did, the highlands west of Pleasanton would likely demonstrate higher precipitation values than demonstrated on this map. In general, higher elevations experience greater precipitation than valleys, especially on the windward side of these topographic features. As air rises, it cools, often increasing the chance for condensation, while air slipping into valleys commonly warms, leading to drier conditions. As the elevation changes being reviewed in this study are typically only a few hundred feet, the overall impact is modest (i.e., the Livermore Valley AVA does not experience desert-like conditions because it is in a rain shadow of the coastal hills); nevertheless, a series of topographic ridges between the Livermore Valley AVA and the coast has a drying effect as air moves inland. Where this impact is perhaps best-witnessed is in vegetation. Woodlands and forest occupy the western extents of the AVA, while grassland is common in the eastern hills.

Conclusions

A simple hypothesis that temperatures warm as one moves inland would not be supported by the findings of this study. Rather, the climatic characteristics of the Livermore Valley AVA are more complex, subject to both cooling from Pacific airflow and topographic influences, as well as urban heat islands. A hypothesis that the climate becomes drier moving west-to-east seems to be better supported, with an understanding that topography may modify this overall pattern.

Despite generally being considered a warmer climate (Region III on the Winkler scale) than the coastal Region I/Region II climates on the north and central coasts of California, the Livermore Valley AVA is nevertheless impacted by Pacific airflow in much the same way that Santa Rosa or Los Caneros would be, albeit to a lesser extent. Rather than the singular access points that dominate the majority of moderating Pacific air found in locations like the Napa Valley or the Alexander Valley, The Livermore Valley AVA has multiple entry points of air flow, further complicating a general classification for the AVA.

Climatically, the Livermore Valley AVA could best be broken down into seven mesoclimatic sub-regions. Starting from the north, they would include Mt. Diablo, the Mt. Diablo foothills, the western highlands, the tri-valley junction, the urban landscape, the southern and eastern Livermore Valley, and Sunol/Vallecitos Valley/southern highlands. Following is a very brief description of each.

Mt. Diablo includes Mt. Diablo State Park, generally above 2000 ft. This mesoclimate is most impacted by topography, leading to temperatures moderated by elevation and increased precipitation from adiabatic lifting. This terrain is unlikely to house viticulture, but does occupy the northern-most extent of the Livermore Valley AVA.

The Mt. Diablo foothills include the mountainous terrain south of Mt. Diablo, east of San Ramon, and north of the Livermore Valley. Here, elevations often exceed the upper layer of intruding fog, while valleys tend to be protected from Pacific airflow. If elevation is high enough, temperatures may be moderated, while valley bottoms may be subject to air drainage. Exposure to solar insolation is important to evapotranspiration rates.

The western highlands are both, in general, the wettest and coolest segment of the AVA, with annual precipitation typically above 500 millimeters and GDD generally below 3400°F.

The tri-valley junction includes the southern San Ramon Valley, the northern Amador Valley, and much of the western Livermore Valley. Climate models suggest this area has some of the warmest temperatures, but as the area experiences inflow, cooler Pacific air. Hence, high temperatures are likely short lived. The area does not have the same orographic lifting found in the western highlands.

The urban landscape includes the areas in and around the cities of Livermore, eastern Pleasanton, and eastern Dublin and the Interstate 580 corridor. The heat island impact likely has its greatest influence in this area. Climate models of recent temperature patterns suggest that temperature patterns may have warmed to match some of the warmer locals to the west, but observations suggest temperatures may exceed those to the west. Typically, heat island impacts are especially effective at reducing low temperatures.

The southern/eastern Livermore Valley is moderated by the cooling influences of airflow funneling toward the Altamont area, but is not subject to the same degree of heat island impacts as the urban landscape noted above. Further, airflow through the southern Vallecitos Valley has a moderating impact on temperatures.

The Sunol/Vallecitos Valley/southern highlands is impacted by cooling air over the Sunol Grade, which gets funneled toward the southern Livermore Valley, but is also subject to topographic influences that allow for temperature variation based on elevation.

These seven mesoclimates offer a starting point in explaining the diversity of Livermore Valley AVA climates. Further analysis and greater availability of data may allow for greater subdividing of the Livermore Valley AVA. Recommended is an effort to increase the distribution of reliable weather stations for future analysis.

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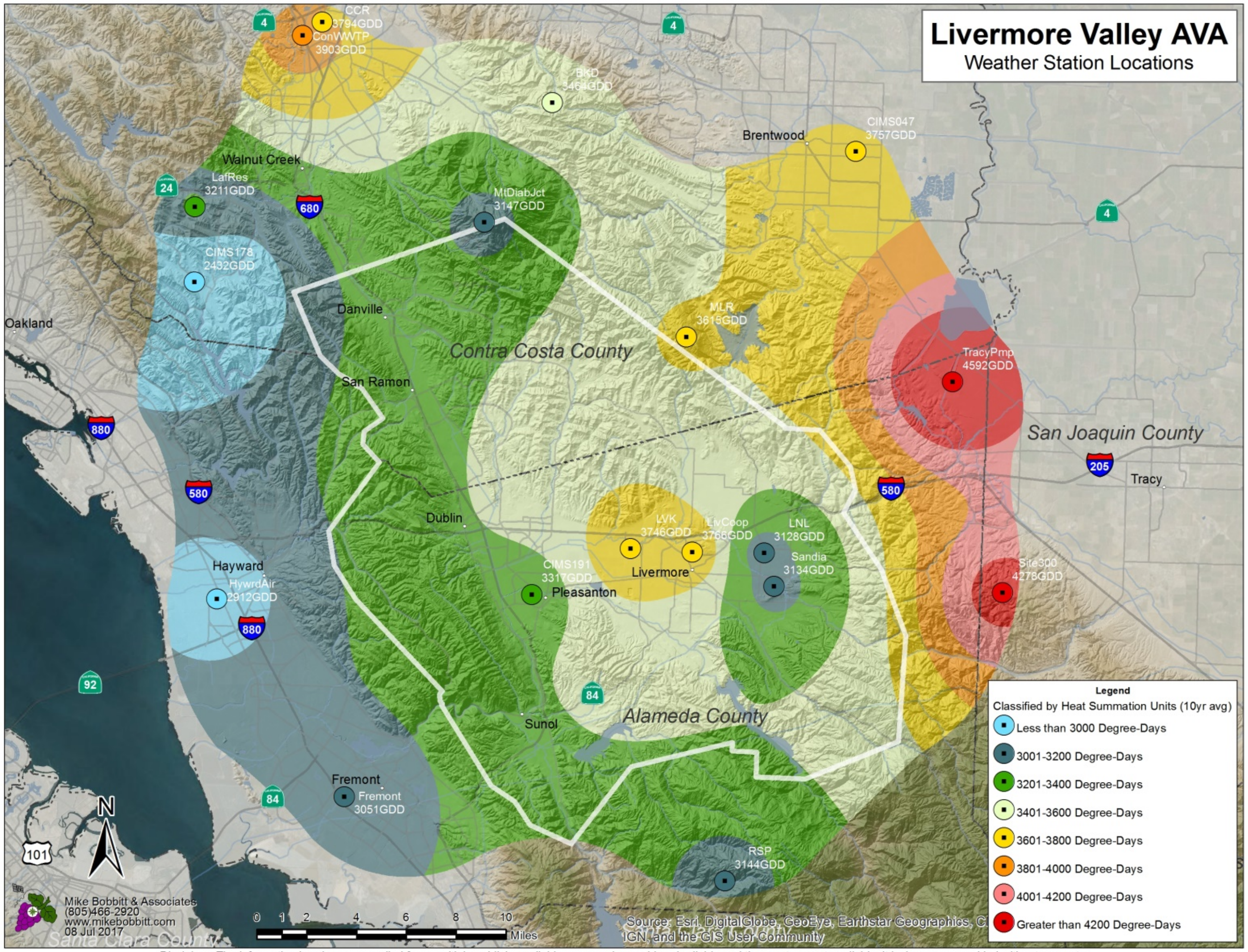
Map 1 – Ten-Year Average GDD (2007-2016) Interpolated in the Livermore Valley AVA



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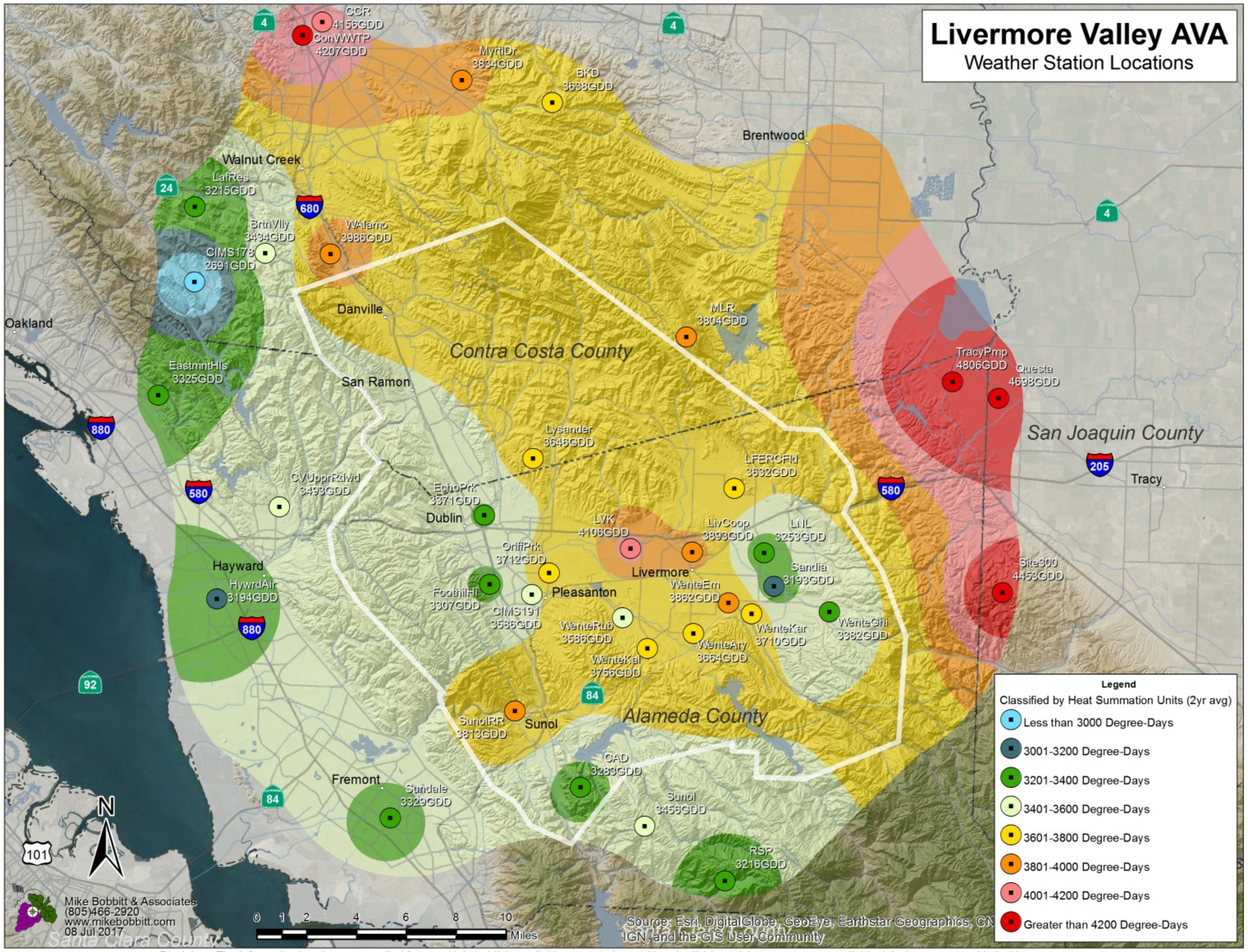
Map 2 – Two-Year Average GDD (2015-2016) Precipitation Interpolated in the Livermore Valley AVA



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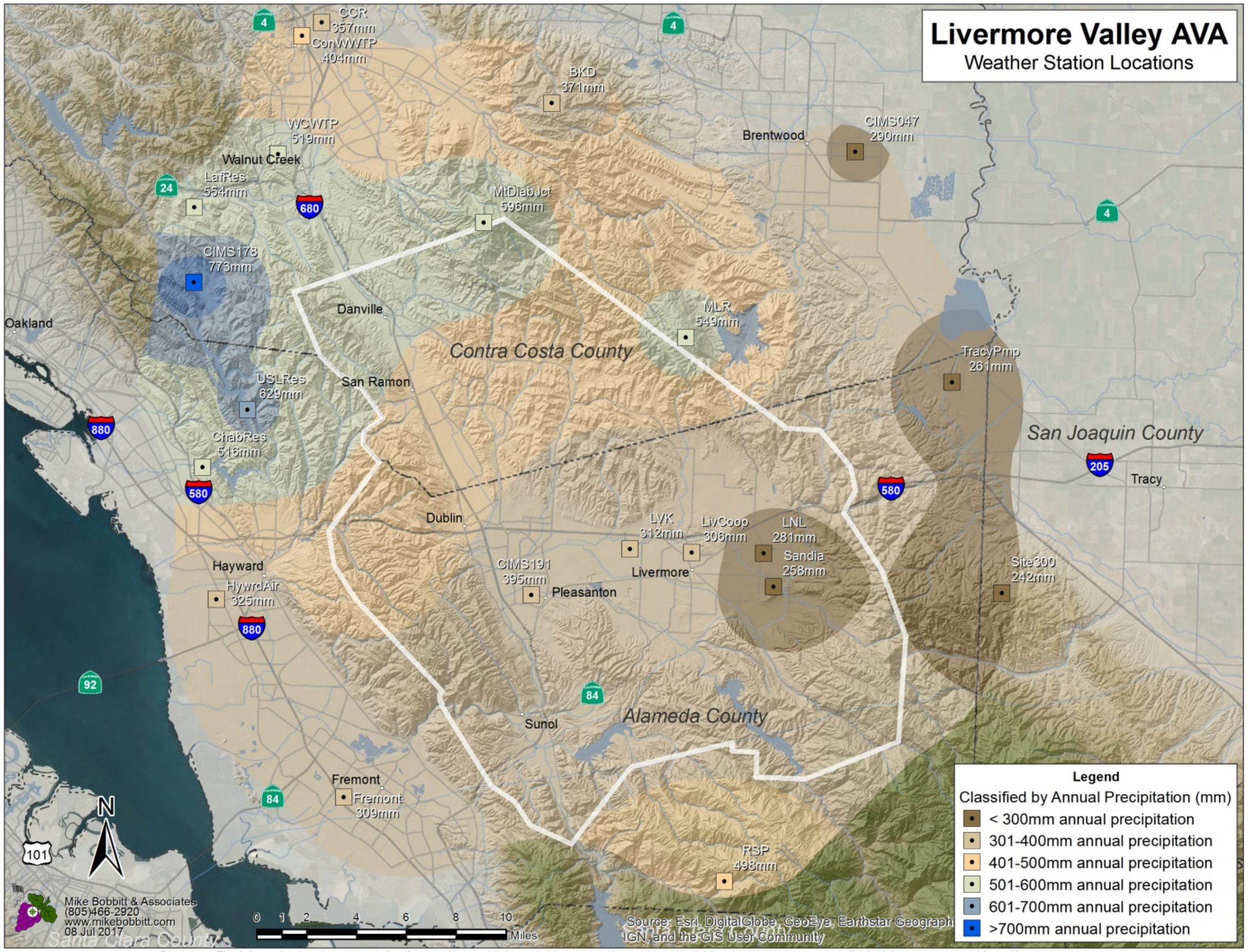
Map 3 – Average Precipitation Interpolated in the Livermore Valley AVA



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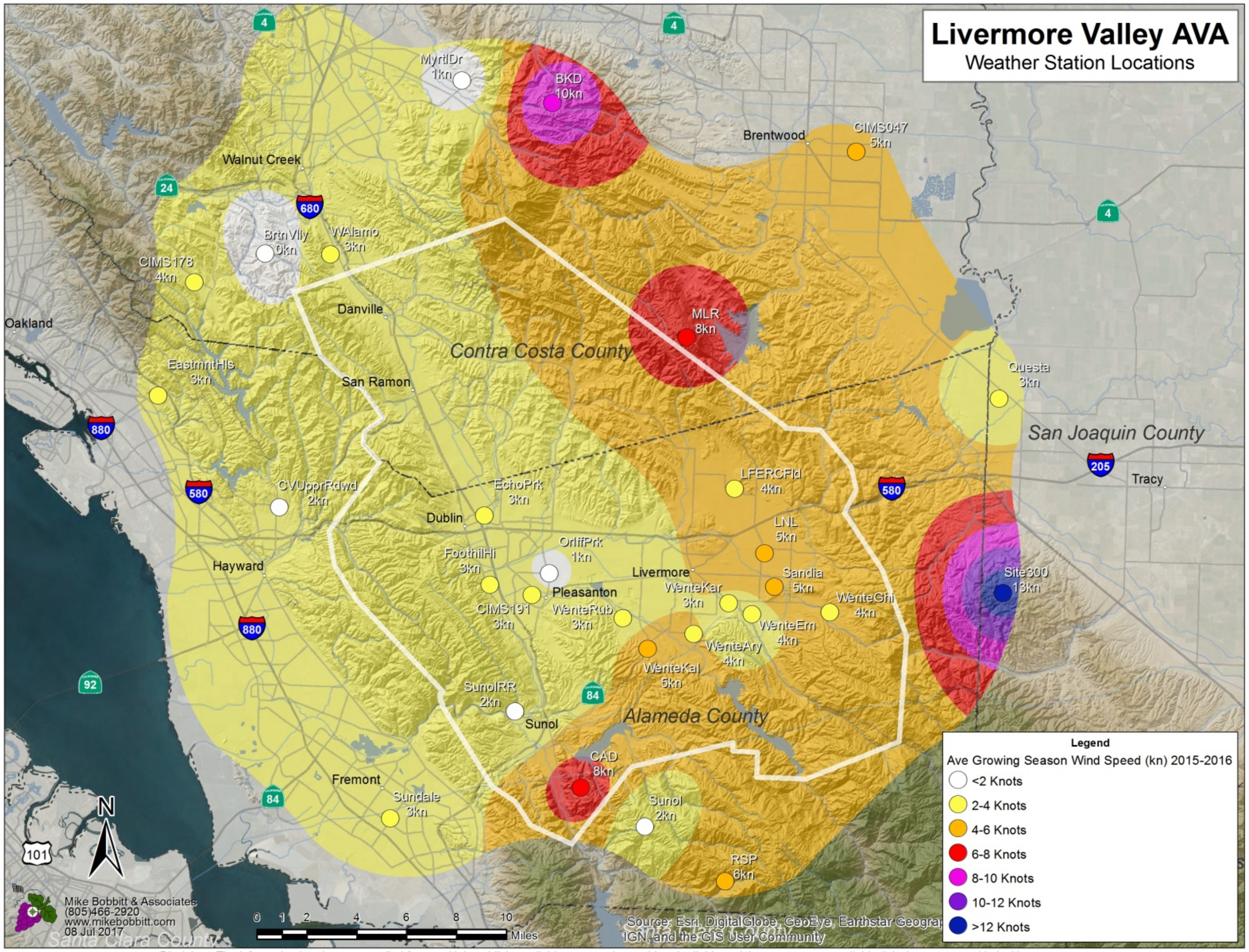
Map 4 – Average Wind Speed Interpolated in the Livermore Valley AVA



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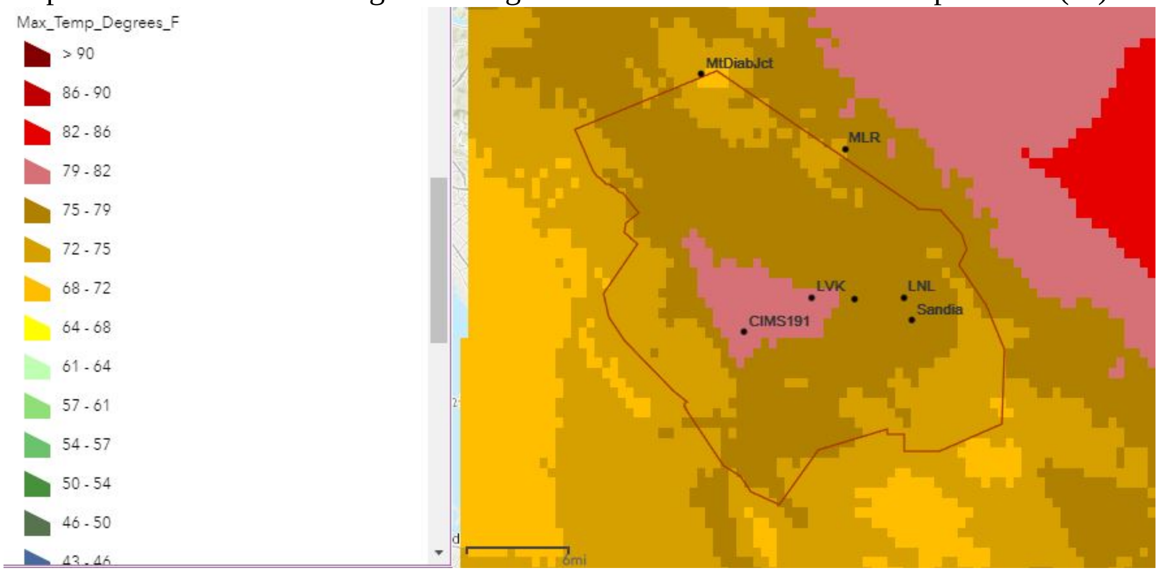
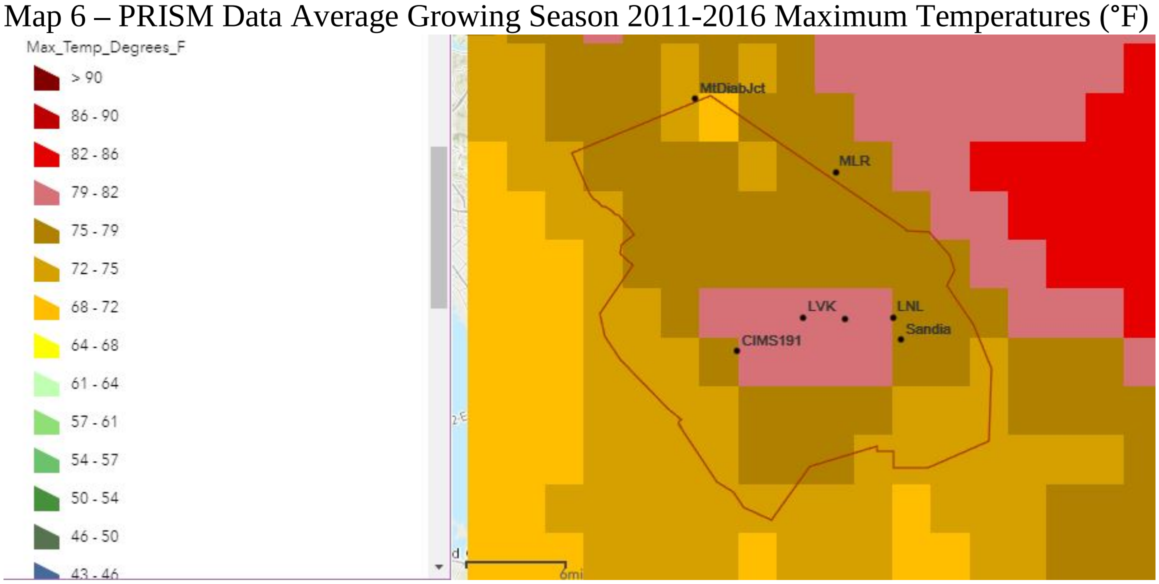
Map 5 – PRISM Data Average Growing Season Normal Maximum Temperatures (˚F)



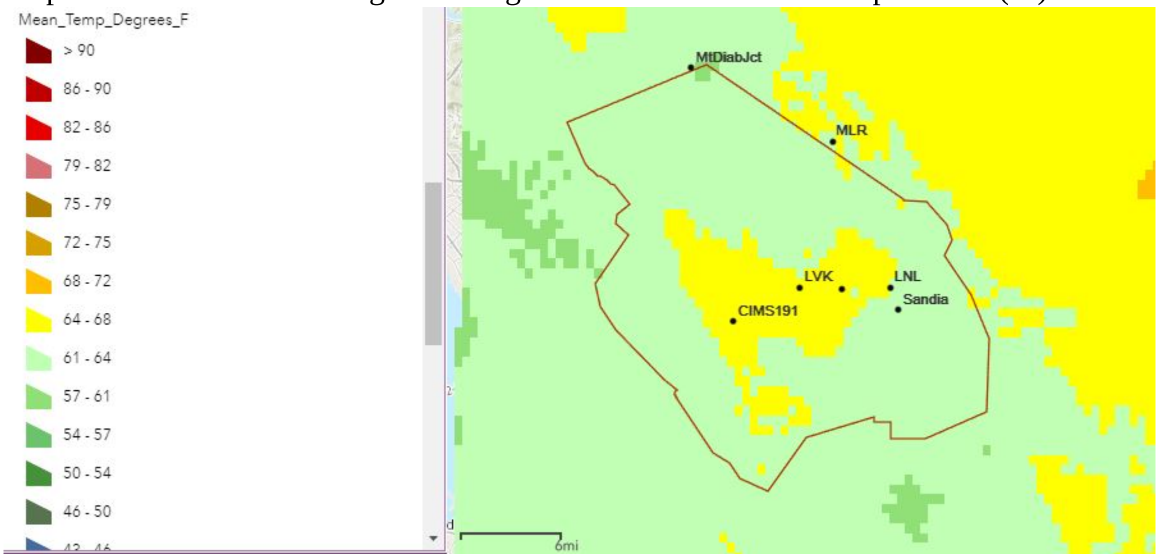
Sourced from Web AppBuilder application created by Vestra. North is at the top of the map.

Map 6 – PRISM Data Average Growing Season 2011-2016 Maximum Temperatures (˚F)



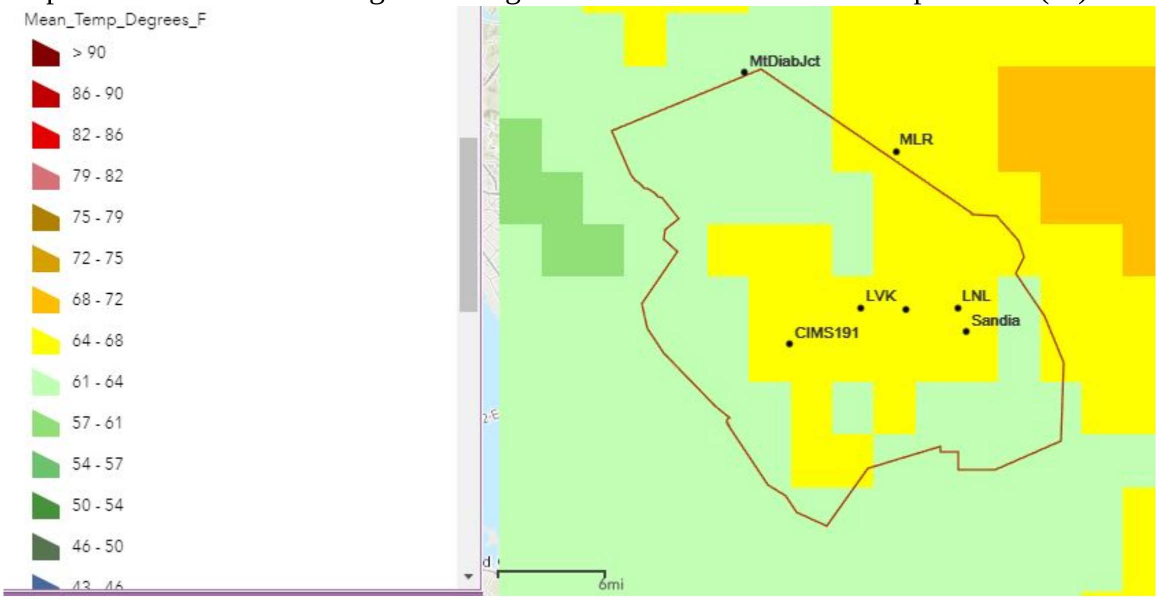
Sourced from Web AppBuilder application created by Vestra. North is at the top of the map.

Map 7 – PRISM Data Average Growing Season Normal Mean Temperatures (°F)



Sourced from Web AppBuilder application created by Vestra. North is at the top of the map.

Map 8 – PRISM Data Average Growing Season 2011-2016 Mean Temperatures (°F)

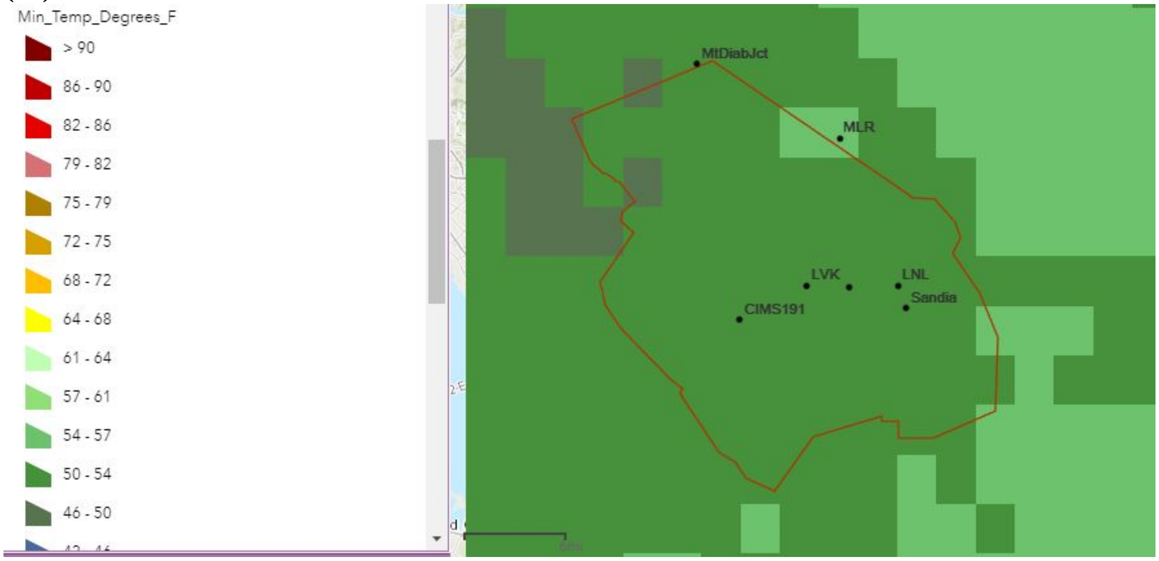


Sourced from Web AppBuilder application created by Vestra. North is at the top of the map.

Map 9 – PRISM Data Average Growing Season Normal Minimum Temperatures (°F)

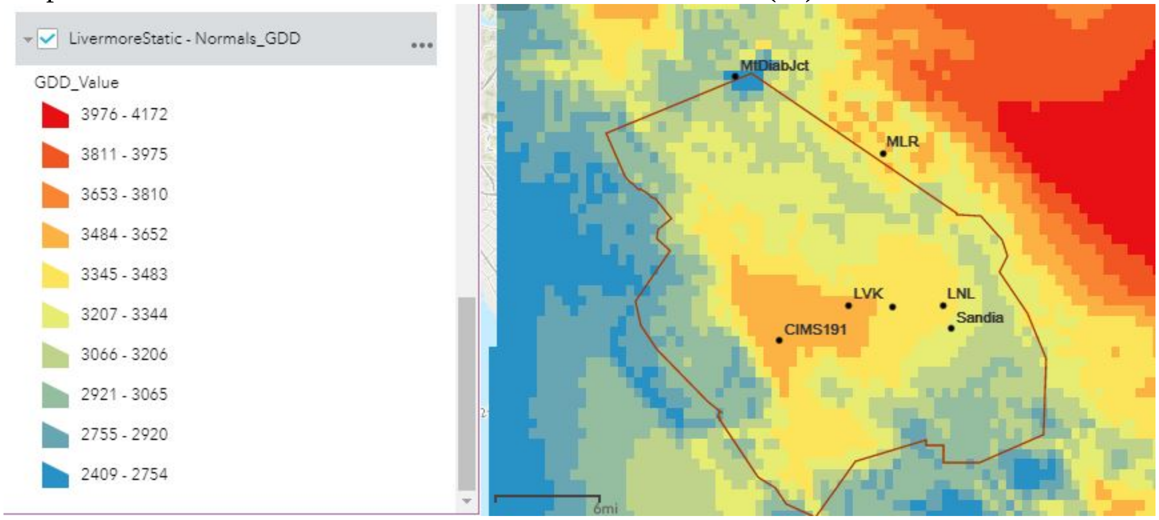
Sourced from Web AppBuilder application created by Vestra. North is at the top of the map.

Map 10 – PRISM Data Average Growing Season 2011-2016 Minimum Temperatures (°F)



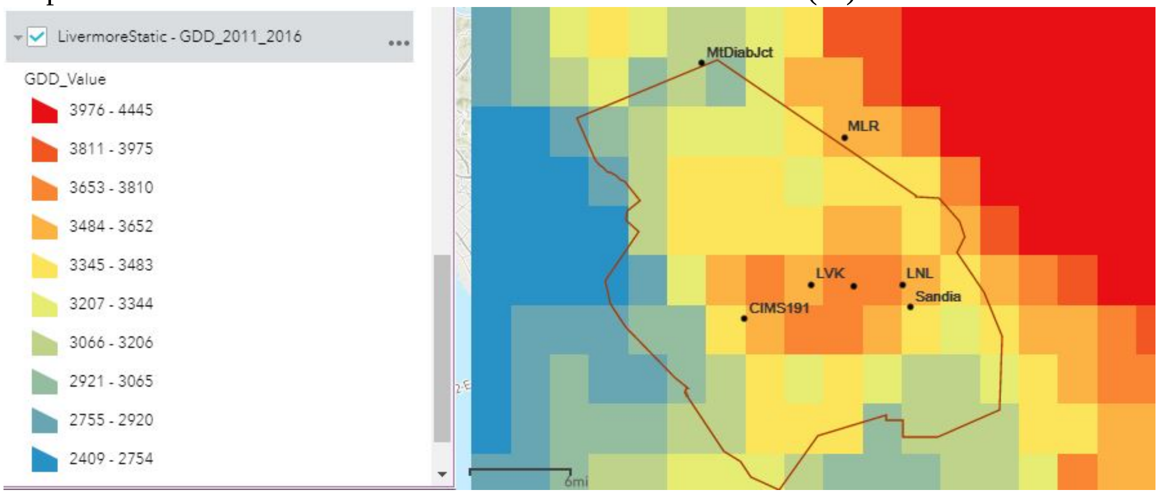
Sourced from Web AppBuilder application created by Vestra. North is at the top of the map.

Map 11 – Normal GDD Calculated from PRISM Data Sets (°F)



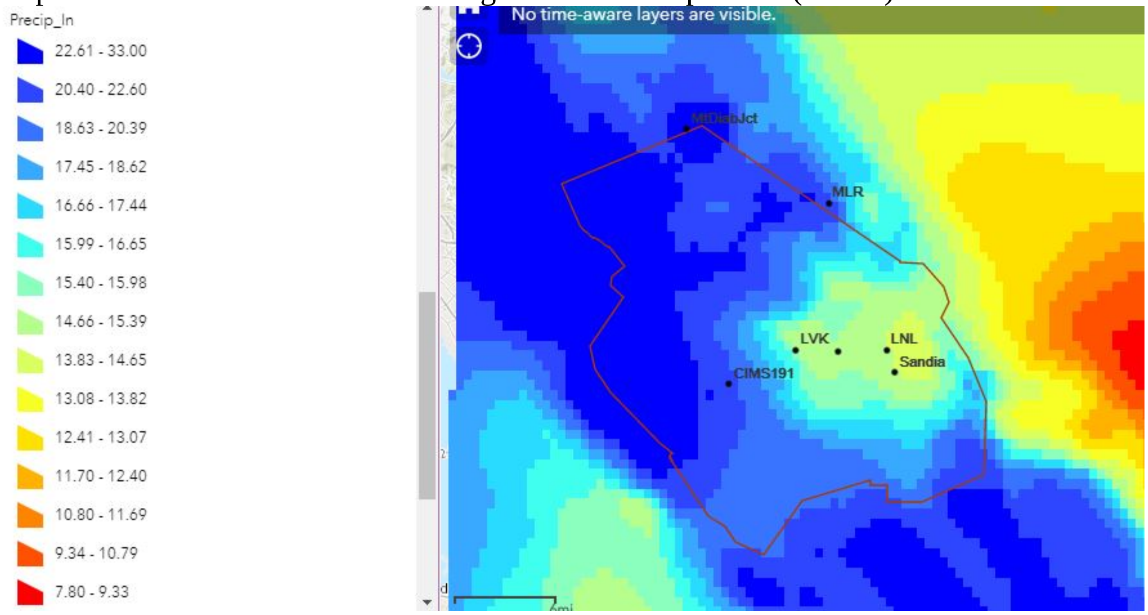
Calculated and sourced from Web AppBuilder application created by Vestra. North is at the top of the map.

Map 12 – 2011-2016 GDD Calculated from PRISM Data Sets (°F)



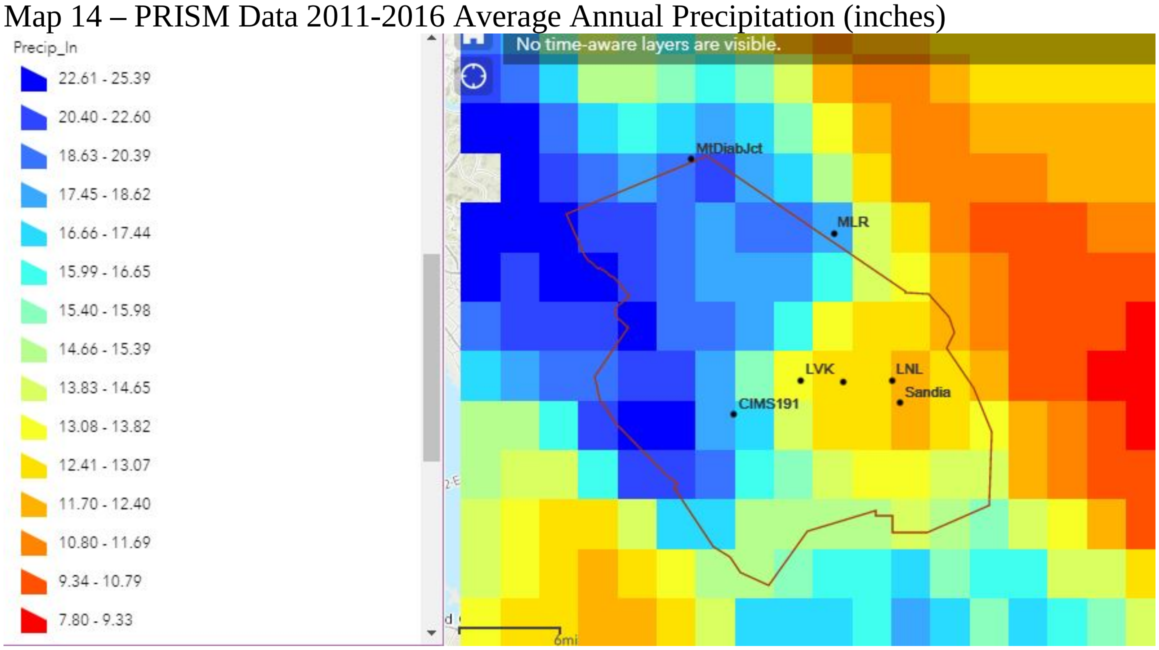
Calculated and sourced from Web AppBuilder application created by Vestra. North is at the top of the map.

Map 13 – PRISM Data Normal Average Annual Precipitation (inches)



Sourced from Web AppBuilder application created by Vestra. North is at the top of the map.

Map 14 – PRISM Data 2011-2016 Average Annual Precipitation (inches)



Sourced from Web AppBuilder application created by Vestra. North is at the top of the map.

APPENDIX 1 – Weather Stations used in this report.

Station	Name	Source	Notes
BKD	Black Diamond Mine (BKD)	California Data Exchange Center	Data missing for 7/2/2008-7/6/2008, 6/13/2012, 10/30/2013-10/31/2013. Precipitation data incomplete for 2008, 2009, and 2016.
BrtnVlly	Burton Valley (KCALAFAY20	Weather Underground	Data missing for 5/23/2015-5/24/2015, 10/16/2015, and 8/9/2016. Data for 10/31/2016 was reported twice.
CAD	Calaveras Road (CAD)	California Data Exchange Center	Data missing for 6/13/2014. Data missing for 2010 and 2011.
CCR	Buchanan Field	Western Region Climate Center	Data missing for 4/23/2016-4/25/2016.
ChabRes	Chabot Reservoir	East Bay Municipal Utility District	
ConWWTP	Concord WWTP (Pacheco)	Western Region Climate Center	
CMIS047	Brentwood (CIMIS 047)	California Irrigation Management Information System	Data missing for 9/11/2012-9/14/2012. Data incomplete for 2009. Temperature data incomplete for 2015. Other data notes available at CIMIS website.
CMIS178	Moraga (CIMIS 178)	California Irrigation Management Information System	Precipitation data incomplete for 2010 and 2011. Other data notes available at CIMIS website.
CMIS191	Pleasanton (CIMIS 191)	California Irrigation Management Information System	Data notes available at CIMIS website.
EastmontHls	Eastmont Hills	Weather Underground	

	(KCAOAKLA45)		
EchoPrk	Echo Park, Dublin (KCADUBLI11)	Weather Underground	Data missing for 10/26/2015-10/27/2015
FoothilHi	Foothill High School (KCAPLEAS15)	Weather Underground	Data missing for 7/22/2015-7/25/2015.
Fremont	Fremont	Western Region Climate Center	Data missing for the following dates: 6/16/2008, 6/28/2008, 8/3/2011, 8/14/2011, 9/4/2011, 9/7/2011-9/8/2011, 4/30/2012, 6/28/2012, 7/11/2012, 7/19/2012-7/21/2012, 8/4/2012, 8/26/2012, 8/30/2012, 9/28/2012 10/13/2012-10/15/2012, 7/16/2014-7/18/2014, 6/7/2014, 6/17/2014-6/21/2014, 6/25/2014, 8/16/2014, 8/20/2014, 8/26/2014, 8/30/2014, 9/13/2014, 9/15/2014, 10/6/2014, 10/9/2014, 6/7/2015 8/25/2015, 9/8/2015. Data incomplete for 2013 and 2016.
HywrdAir	Hayward Airfield	Western Region Climate Center	Data missing for 7/3/2012-7/5/2012. Data incomplete for 2013.
LafRes	Lafayette Reservoir	East Bay Municipal Utility District	Data missing for 6/25/2012.
LFERC	LFERC Field	Weather Underground	

	(KCALIVER22)		
LivCoop	Livermore Co-op Weather Station	Western Region Climate Center	
LNL	Lawrence Livermore Laboratory	Lawrence Livermore Laboratory	Data incomplete for 2007. Wind speed take at 10m.
LVK	Livermore Municipal Airport	Western Region Climate Center	Data missing 10/16/2016.
Lysander	Lysander, San Ramon (KCASANRO52)	Western Region Climate Center	
MLR	Mallory Ridge (MLR)	California Data Exchange Center	Data missing for 10/30/2013-10/31/2013, 6/13/2014. Data incomplete for 2008. Precipitation incomplete for 2015.
MtDiabJct	Mt. Diablo Junction	Western Region Climate Center	Data missing for 9/27/2011. Data incomplete for 2016.
MyrtlDr	Myrtle Drive, Concord (KCAConco9)	Weather Underground	
OrlffPrk	Orloff Park, Pleasanton (KCAPLEAS11)	Weather Underground	Data missing for 9/29/2015 and 5/27/2016-6/2/2016.
Questa	Questa Park, Mountain House (KCAMOUNT44)	Weather Underground	
RSP	Rose Peak (RSP)	California Data Exchange Center	Data missing for the following dates: 10/30/2013-10/31/2013 and 6/13/2014. Data incomplete for 2007. Precipitation data incomplete for 2008 and 2016.
Sandia	Sandia National Laboratories	Laurence Livermore Laboratory	Temperature data incomplete for 2007. Precipitation data incomplete for 2008 and 2015.
Site300	Site 300	Laurence Livermore Laboratory	Wind speed taken at 10m.
Sundale	Sundale, Fremont	Weather Underground	Data missing for

	(KCAFREMO28)		7/26/2014-7/28/2014 and 8/5/2014.
Sunol	Sunol (KCASUNOL6)	Weather Underground	
SunolRR	Sunol Railroad (KCASUNOL8)	Weather Underground	
TracyPmp	Tracy Pumping Station	Western Region Climate Center	Data missing for the following dates: 6/18/2009, 6/30/2011, 9/28/2011, 5/14/2013, 8/22/2013, 5/6/2015, 5/18/2016.
UpprRdwd	Castro Valley Upper Redwood (KCACASTR20)	Weather Underground	Data missing for 5/7/2015-5/11/2015.
USLRes	Upper San Leandro Reservoir	East Bay Municipal Water District	Data missing for 12/31/2014.
WAlamo	West Alamo (KCAALAMO5)	Weather Underground	Data missing for 10/31/2015 and 9/15/2016-9/20/2016.
WenteAry	Arroyo Vineyard	Wente Vineyards	
WenteErn	Ernest Vineyard	Wente Vineyards	
WenteGhi	Ghielmetti Vineyard	Wente Vineyards	
WenteKal	Kalthoff Vineyard	Wente Vineyards	
WenteKar	Karl Vineyard	Wente Vineyards	
WenteRub	Ruby Hills Vineyard	Wente Vineyards	
WTWTP	Walnut Creek Water Treatment Plant	East Bay Municipal Utility District	