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# TECHNICAL MEMORANDUM

To:       Mid-County Groundwater Agency Executive Staff

From:     Georgina King and Cameron Tana

Date:     August 17, 2017

Subject:  Santa Cruz Mid-County Basin Groundwater Flow Model: Future
          Climate for Model Simulations (Task 5)

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Appendix A:  Santa Cruz Coop Station Exceedance Probabilities with Year Type
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# 1.0 INTRODUCTION

This technical memorandum documents our approach for developing an initial future climate scenario to be implemented with simulations using the GSFLOW model of the Santa Cruz Mid-County Groundwater Basin currently under development, and presents two proposed climate scenarios. Climate data used in GSFLOW includes minimum and maximum temperature, and precipitation at the Santa Cruz Co-op and Watsonville Waterworks stations.

The objective of this subtask is to develop a reasonable climate scenario that adequately represents the warmer temperatures that are being predicted due to global climate change. At the August 24, 2016 TAC meeting, Prof. Andrew Fisher suggested using a catalog of historical annual climate instead of one of the multitude of General Circulation Models (GCM) available for future climate scenarios. The premise of this approach is that we use actual historical climate data representing the warmest years on record and not modeled climate data such as GCM. This approach is appropriate because to retain integrity of the climate data, the future climate scenario must have temperature data that corresponds to precipitation data, which is ensured by using historical data. A similar approach using historical data instead of using future climate predictions is used by Metropolitan Water District of Southern California to evaluate its region's future water supply reliability (MWD, 2016).

As discussed in our revised scope of work for fiscal year 2016-2017 approved by the MGA Board, downscaling one or more GCM scenarios to develop additional climate change scenarios has been re-prioritized for implementation in 2017. This is still recommended because the GCMs predict temperatures warmer than even the warmest years on record.

# 2.0 CLIMATE DATASETS

## 2.1 SANTA CRUZ CO-OP STATION

The Santa Cruz Co-op station has climate data available from January 1893 through present. Figure 1 shows the average annual temperature ranges and overall average for Water Years 1894 through 2016. It is visually evident that minimum temperatures have been higher since 1977. Maximum temperatures do not show the same trend, perhaps because of the moderating influence of the ocean. Expectedly, average annual temperatures also show an increase but of a lower magnitude than the minimum temperature increase due to more stable maximum temperatures. Water Years 2013 through 2016 have four of the five hottest average annual temperatures in the record. Table 1 illustrates that post-1977, average annual temperatures at the Santa Cruz Co-op station are 1.3° F

warmer than before 1977.  The 1985-2015 average for the model calibration period is also shown.
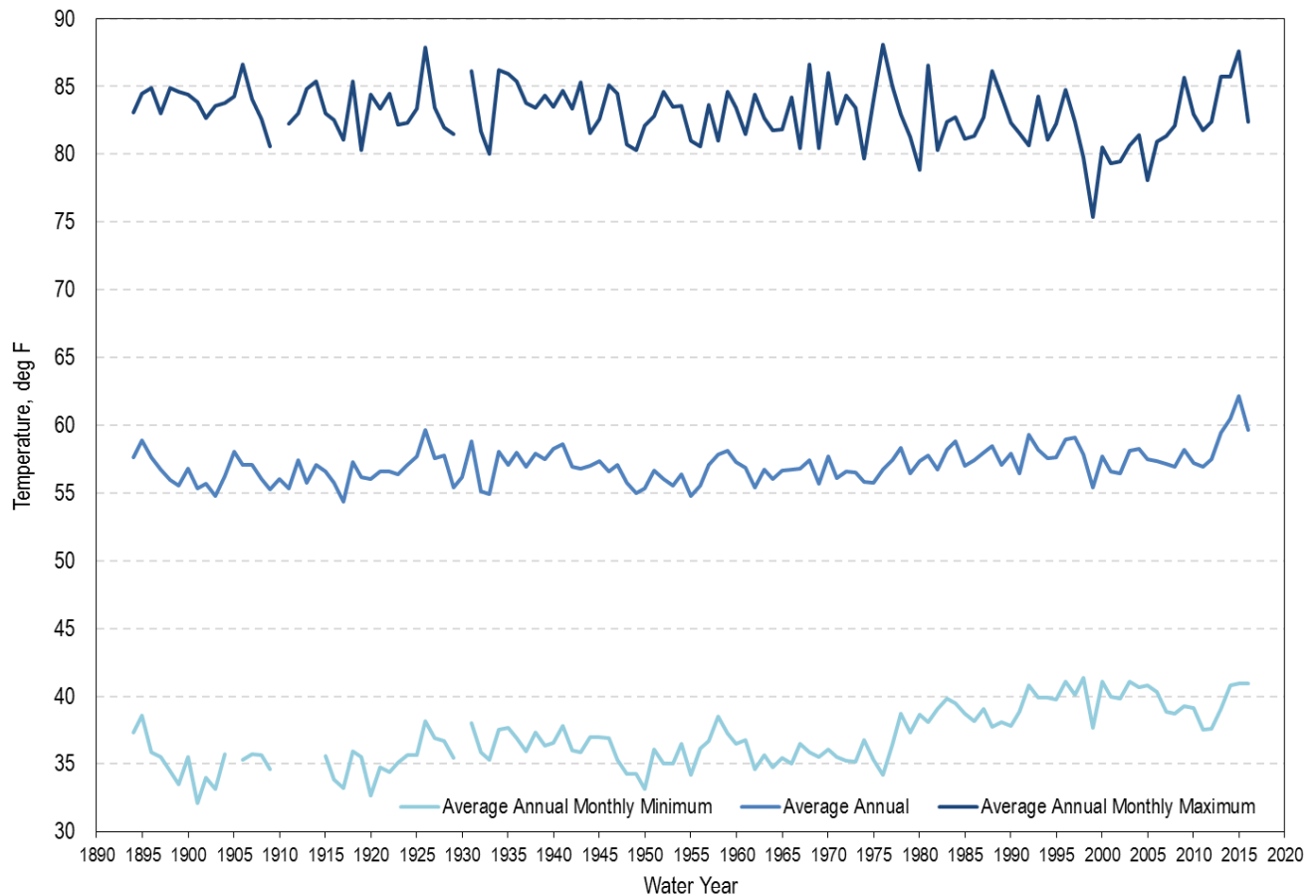


*Figure 1: Measured Minimum, Maximum, and Average Annual Temperatures at the Santa Cruz Co-op Station*

*Table 1: Santa Cruz Co-op Station Average Annual Temperatures for Selected Periods*

| Annual Temperature, °F | |
|---|---|
| 1985-2015 Average | 57.9 |
| 1977-2016 Average | 57.9 |
| Pre-1977 Average | 56.6 |
| 1894-2016 Average | 57.0 |

Figure 2 presents the annual precipitation recorded at the Santa Cruz Co-op station. The average annual   precipitation for various periods of interest are provided in Table 2. Although the chart on Figure 2 does not show any discernible trends, the averages in Table 2 indicate that pre-1977 precipitation was very

slightly lower than that experienced from 1977 onwards. In general however, the data do not show a trend that is visually evident like temperature.
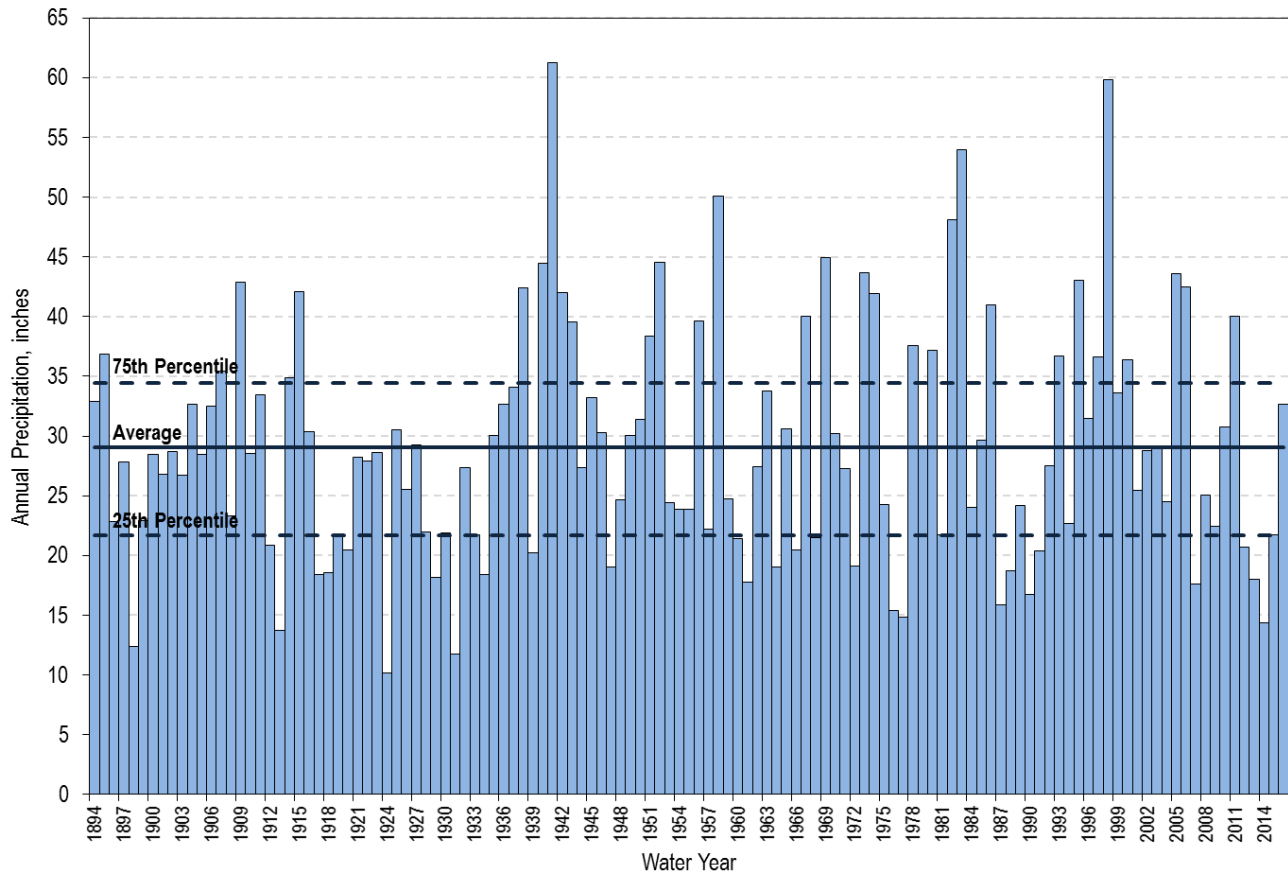


*Figure 2: Annual Precipitation at the Santa Cruz Co-op Station*

*Table 2: Santa Cruz Co-op Station Average*
*Precipitation for Selected Periods*

| Annual Precipitation, inches | |
|---|---|
| 1985-2015 Average | 29.0 |
| 1977-2016 Average | 30.0 |
| Pre-1977 Average | 28.7 |
| 1894-2016 Average | 29.1 |

## 2.2  WATSONVILLE WATERWORKS STATION

The Watsonville Waterworks station has climate data available from January 1908 through present. Figure 3 shows average annual temperature ranges and overall average for Water Years 1909 through 2016; note there were a number of missing records in the monthly data used to generate the annual averages; therefore those years are not included on the chart. The line showing minimum temperatures has a clear increasing trend over the period of record, with a slight jump in

temperatures from 1977 onwards where minimum temperatures mostly remain consistently above pre-1977 temperatures. At this station, maximum temperatures also show an increasing trend like minimum temperatures but they are more muted. The Watsonville Waterworks station is 4.5 miles from the ocean compared to the Santa Cruz Co-op station which is two miles from the ocean, and has less effects from the ocean. Average annual temperatures also show a noticeable increase after 1977. Table 4 illustrates that post-1977, average annual temperatures at the Watsonville Waterworks station are 1.7 °F warmer than before 1977.
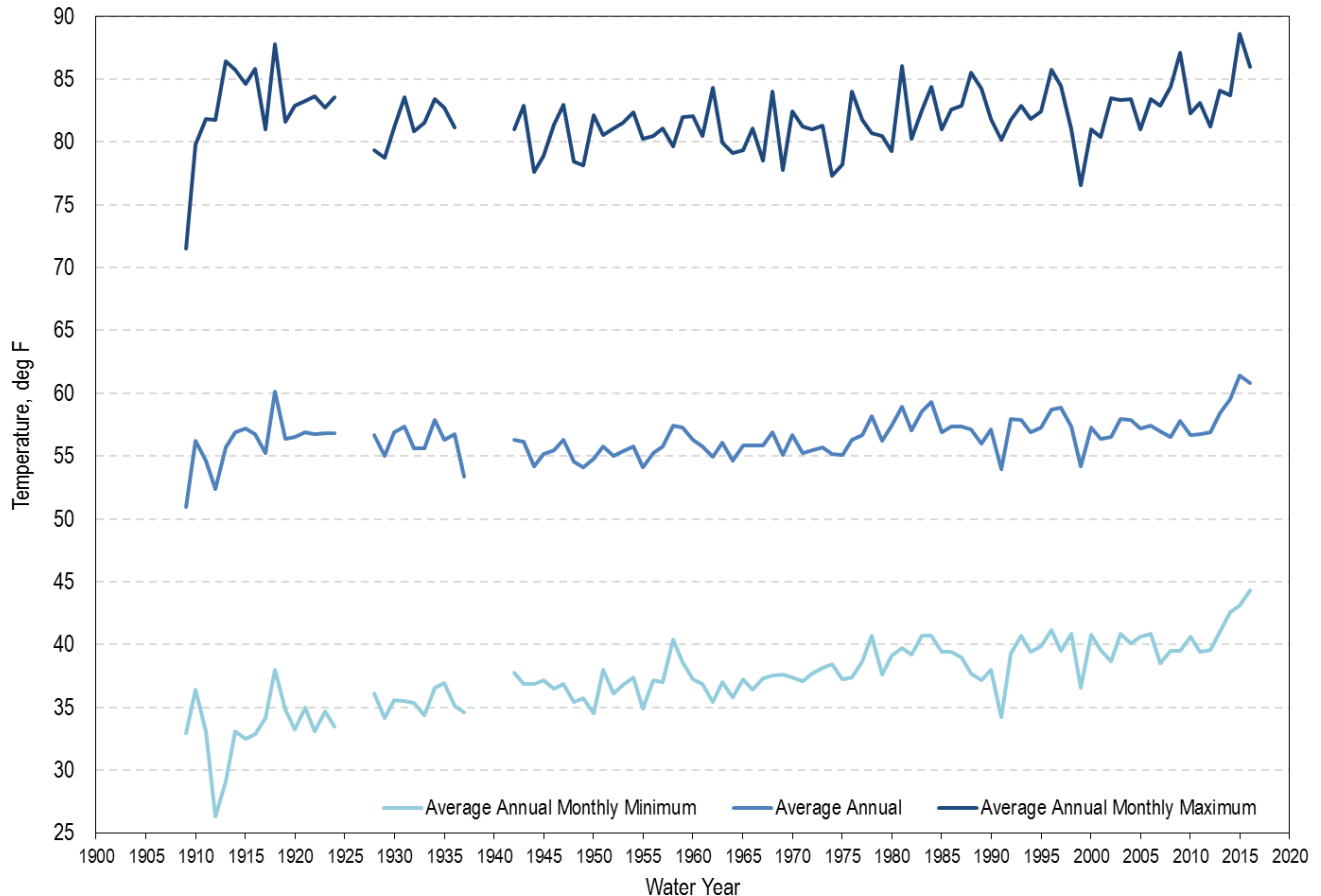


*Figure 3: Measured Minimum, Maximum, and Average Annual Temperatures at the Watsonville Waterworks Station*

*Table 3: Watsonville Waterworks Station Average Annual Temperatures for Selected Periods*

| Annual Temperature, °F | |
| --- | --- |
| 1985-2015 Average | 57.3 |
| 1977-2016 Average | 57.5 |
| Pre-1977 Average | 55.8 |
| 1894-2016 Average | 56.5 |

Figure 4 presents the annual precipitation recorded at the Watsonville Waterworks station. The average annual precipitation for various periods of interest are provided in Table 4. The data suggest that since the 1980s, there has been an increase in the amount of precipitation at this station. This is confirmed in Table 4 where post-1977 precipitation is 2.8 inches more than before 1977.
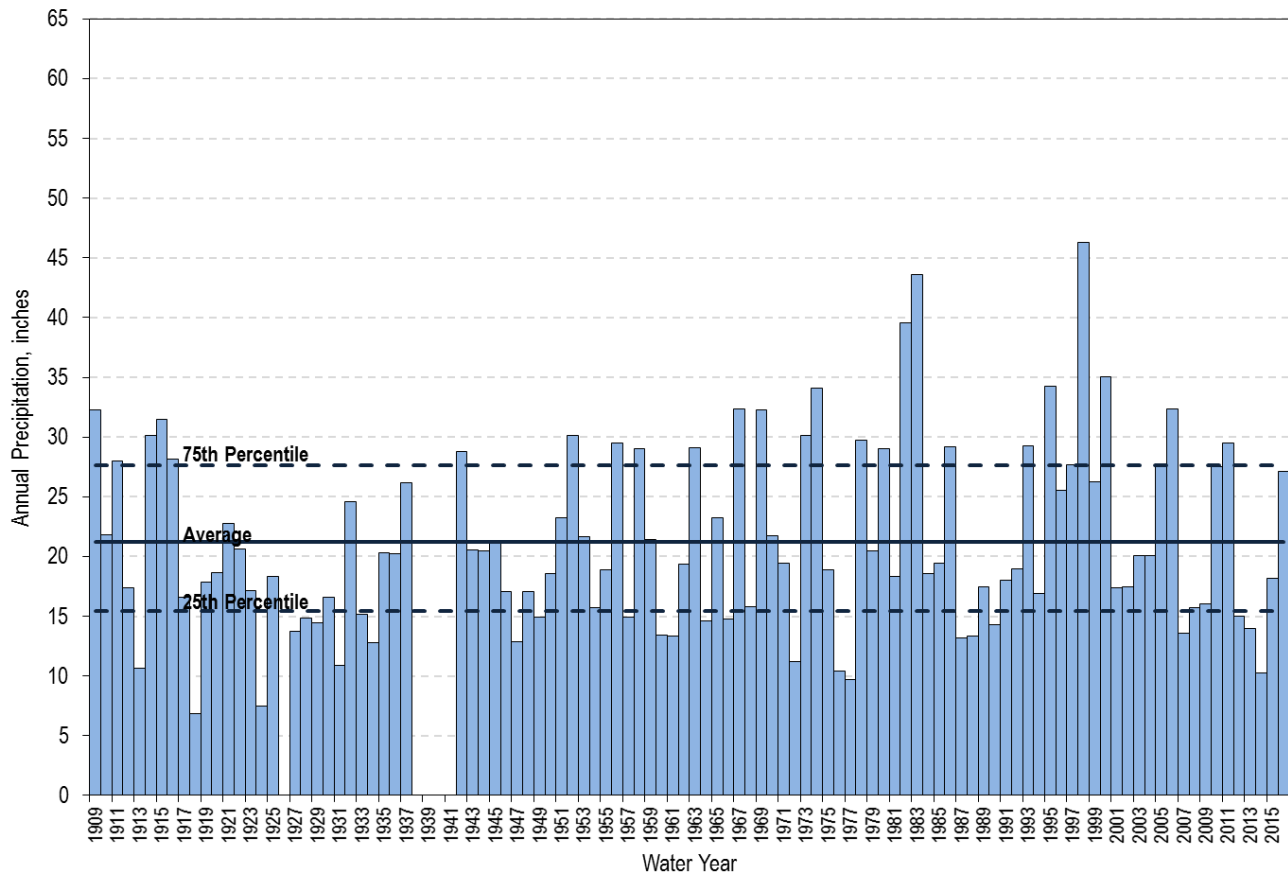


*Figure 4: Annual Precipitation at the Watsonville Waterworks Station*

*Table 4: Watsonville Waterworks Station Average*
*Precipitation for Selected Periods*

| Annual Precipitation, inches | |
|---|---|
| 1985-2015 Average | 21.9 |
| 1977-2015 Average | 22.9 |
| Pre-1977 Average | 20.1 |
| 1909-2015 Average | 21.2 |

## 3.0 APPROACH

### 3.1 CLIMATE CATALOG

Using the general method for creating a catalog of each historical year suggested by Prof. Andrew Fisher (Young, 2016), exceedance probabilities (*p*) for both temperature and precipitation are calculated using the following equation for the full dataset on record for the climate station:

$$p = \frac{m}{n+1}$$

where *m* is the rank based on total precipitation or temperature (from largest to smallest), and *n* is the total number of years in the dataset. A chart of exceedance probabilities for temperature and precipitation at the Santa Cruz Co-op station is provided on Figure 5. The catalog is based on the Santa Cruz Co-op station because the majority of model cells are assigned to it for rainfall distribution in PRMS, the watershed component of the GSFLOW model.
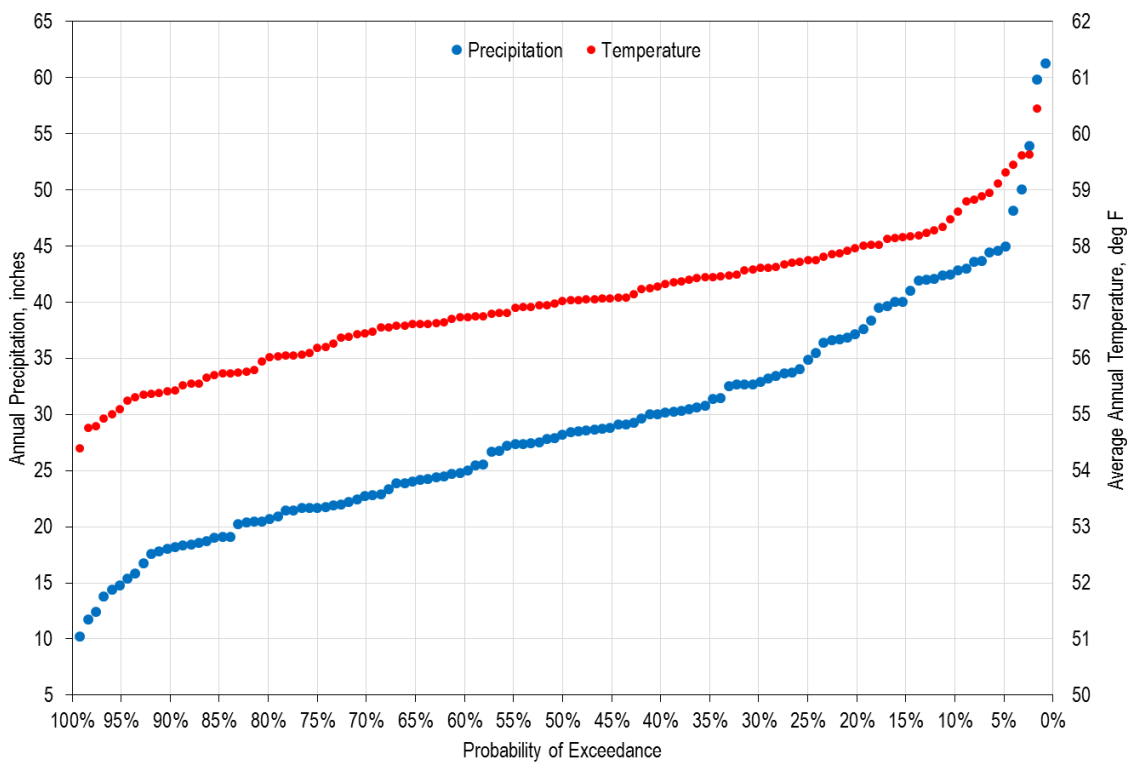


*Figure 5: Probability of Exceedance for Annual Precipitation and Average Annual Temperature, Santa Cruz Co-op Station*

Figure 6 and Figure 7 graphically show consecutive water years' probabilities of exceedance for temperature and precipitation at the Santa Cruz Co-op Station, respectively. Figure 6, similar to Figure 1, shows that since 1977, there has been an increased number of years that have less than a 50% probability of exceedance, i.e., warmer than the rest of the record. Figure 7 shows no visual trend towards either decreasing or increasing precipitation over time like temperature does.
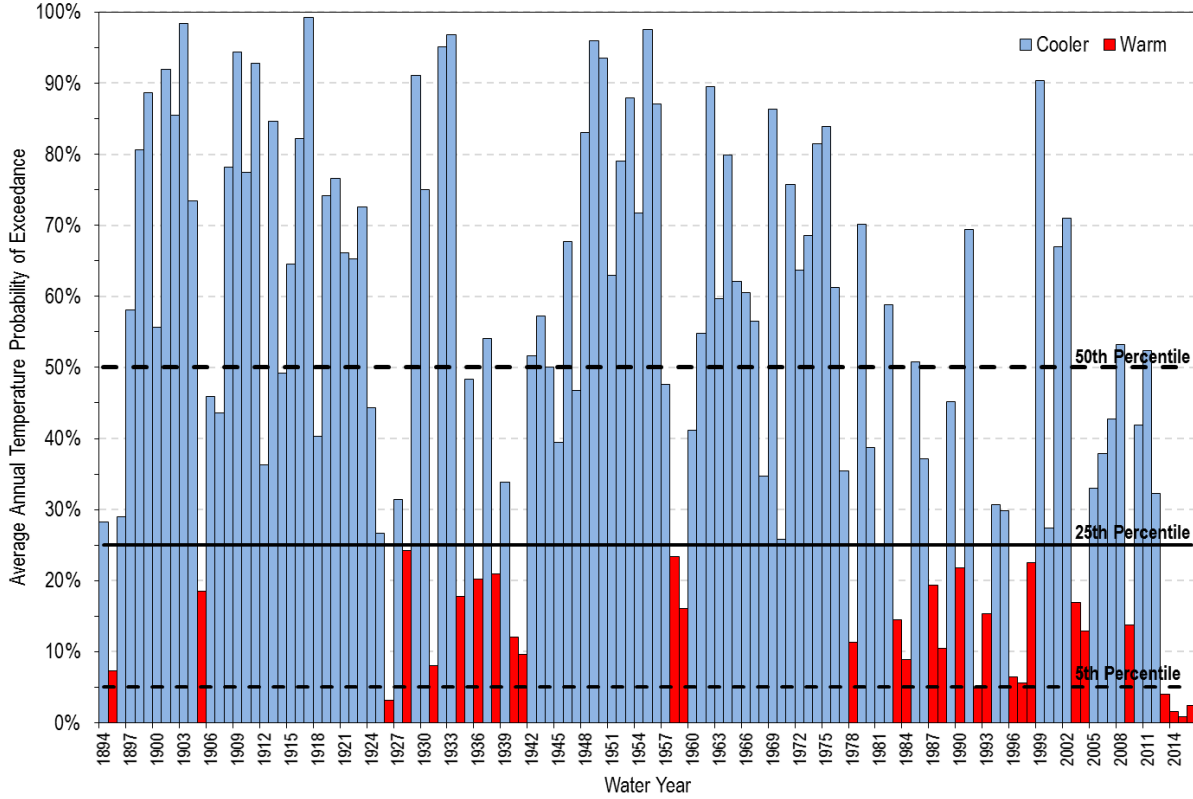
**Figure 6: Average Annual Temperature Probability of Exceedance for the Santa Cruz Co-op Station**
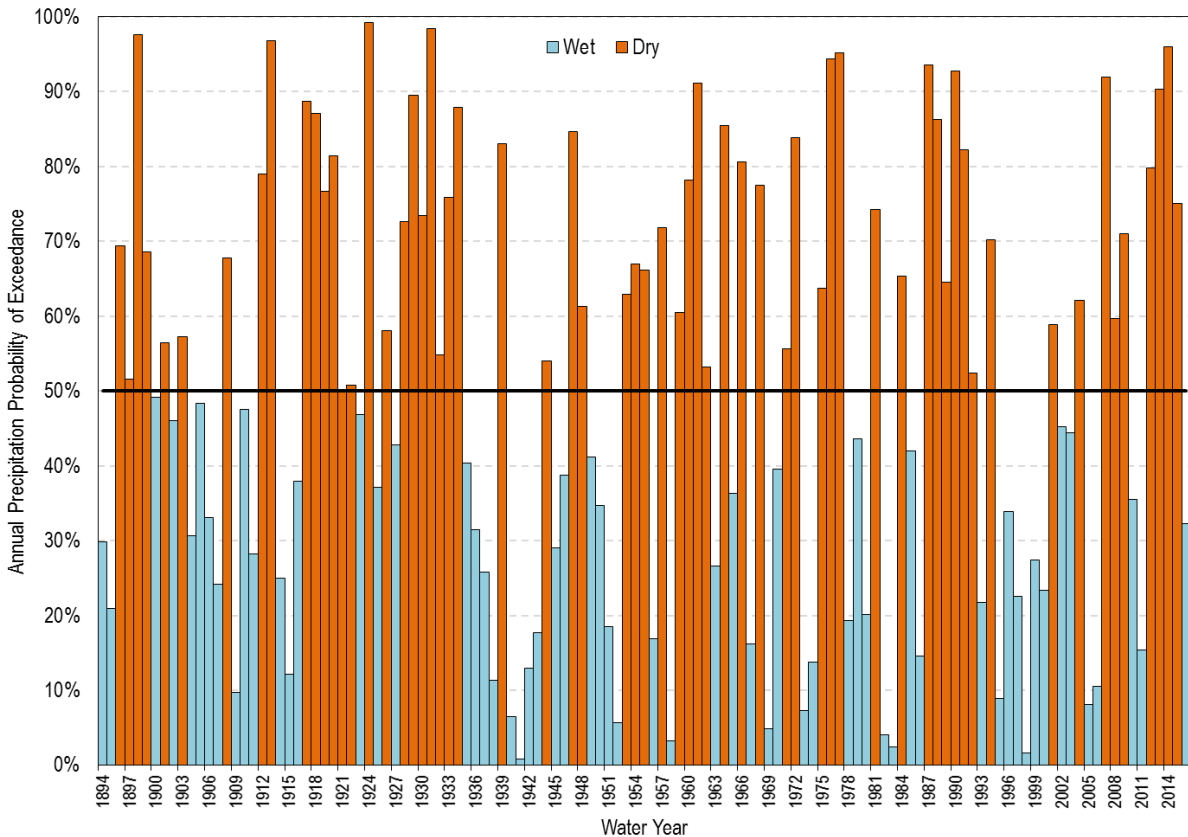


**Figure 7: Annual Precipitation Probability of Exceedance for the Santa Cruz Co-op Station**

Another way to visualize the climate data based on probabilities of exceedance is to classify each water year according to a combination of temperature and precipitation probabilities shown in Table 5. Appendix A provides the probabilities for all water years on record for the Santa Cruz Co-op Station, and Figure 8 presents the historical data color-coded by classification plotted against precipitation.

*Table 5: Classification of Probabilities*

| Probability of Exceedance | | Category |
|---|---|---|
| Precipitation | Average Temperature | |
| >= 50% | < 25% | Warm and Dry |
| < 50% | < 25% | Warm and Wet |
| < 50% | >= 25% | Cooler and Wet |
| >= 50% | >= 25% | Cooler and Dry |
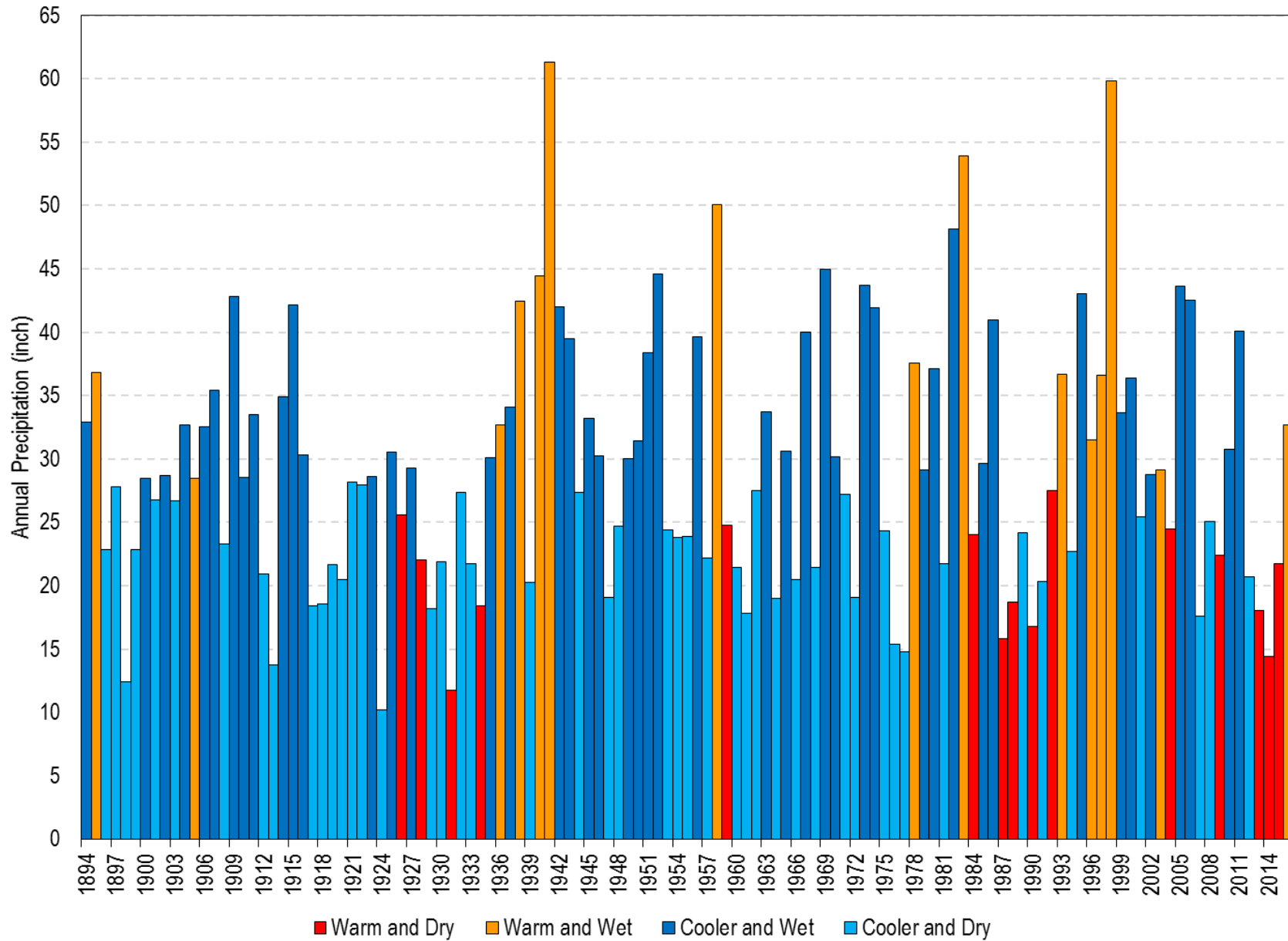
*Figure 8: Santa Cruz Co-op Station Classification of Historical Water Years*

## 3.2    FUTURE CLIMATE SCENARIO GENERATION

The future climate scenario will cover Water Years 2016-2069.  This time span is selected to meet the requirement in California Department of Water Resources regulations for Groundwater Sustainability Plans (GSP) to evaluate sustainability for future climate over fifty years.  Fifty years after the 2020 GSP deadline for the critically overdrafted Santa Cruz Mid-County Groundwater Basin goes through Water Year 2069.  Water Year 2016 will be simulated based on recorded climate data using initial conditions from the end of the calibrated model run of Water Years 1985-2015.   The 53 water years 2017-2069 will be simulated using the approach described below.

As temperature shows a much more evident trend than precipitation, the catalog of annual average temperature at the Santa Cruz Co-op station is used to generate one future climate scenario.  First, a subset of historic climate is selected to form a catalog from which to generate the future climate scenario. The catalog of years selected are all the years from 1977 to 2016 representing the most recent period where warming has been observed, plus six additional years from 1909[1] to 1977 that have a temperature probability of exceedance of 25% or less, i.e., the warmest years and that don't have entire months of missing temperature data in the Watsonville Waterworks station record. See bold records in Appendix A for those years included in the catalog.

The catalog is then randomly ordered using the Random Number Generator in Excel to generate the scenario.  The Random Number Generator uses weights applied to each water year to ensure a pre-determined distribution of temperature exceedance probabilities results from the process. Weights are assigned by categories of exceedance probabilities for temperature shown in Table 6.  For example, the warmest category (<5% exceedance probability) is given a 50% weight and includes Water Years 1992, and 2013-2016.  Warmer years are given greater weights than cooler years to ensure an overall warmer scenario is generated.

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[1] Water Year 1909 was selected because this is the first water year for the Watsonville Waterworks station climate records. If we used prior years, there would be no climate data for the Watsonville Waterworks station for the future climate scenario for those years.

### Table 6: Weights Assigned to Catalog of Water Years Based on Temperature Exceedance Probabilities

| Exceedance Probability Category | Weight |
|---|---|
| < 5% | 0.5 |
| 5 – 25% | 0.3 |
| >=25 – 50% | 0.1 |
| > = 50% | 0.1 |

After the water year sequence is selected based on the Santa Cruz Co-op temperature data, climate data for the future climate scenario for the Watsonville Waterworks station is selected based on the same water year sequence. Climate data for both the Santa Cruz Co-op and Watsonville Waterworks stations are input into the GSFLOW model.

# 4.0 PROPOSED CLIMATE SCENARIOS

## 4.1  TEMPERATURE WEIGHTED

The first scenario is generated using the temperature weights shown in Table 6 and the Random Number Generator to arrive at a sequence of 53 water years with an average temperature that is as high as we could get without manually selecting the warmest years.  Figure 9 shows the color-coded distribution of water years for the Santa Cruz Co-op station representing a potential future climate scenario that is on average 2.4 °F warmer than the long-term average and 1.6 °F warmer than the average annual temperature from 1977-2016. The scenario also has 3.1 inches less precipitation per year than the long-term historical average as 4 of the 5 hottest years used for 50% of the scenario are dry years. Appendix B provides a list of the randomly selected historic years generated for this scenario.
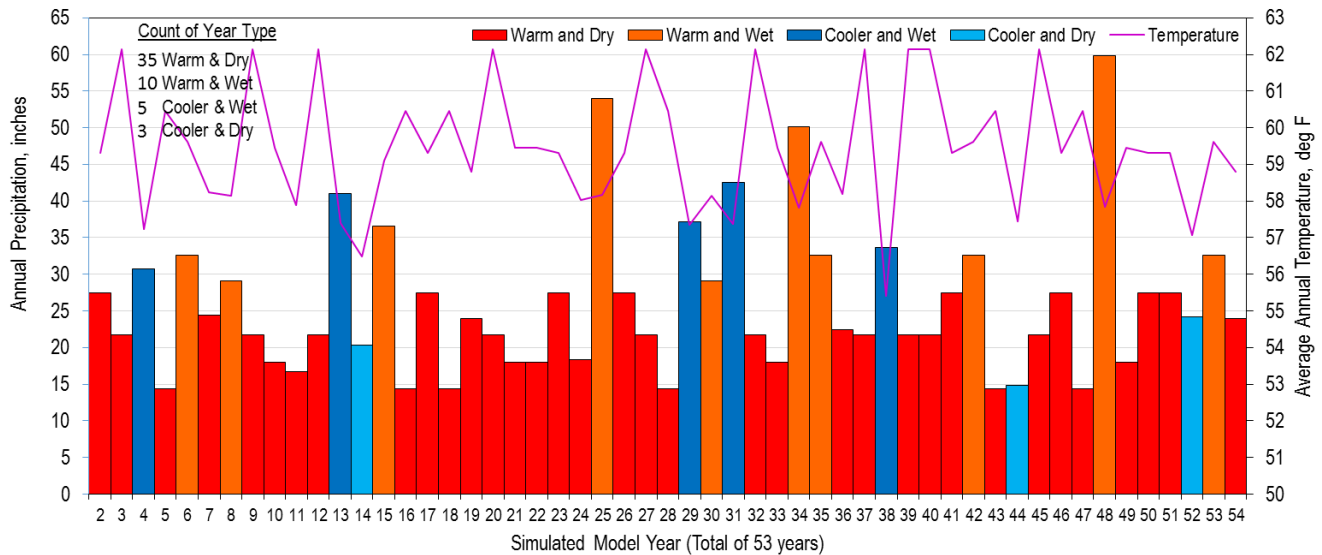


| Annual Temperature, deg F | | Annual Precipitation, inches | |
|---|---|---|---|
| Scenario Average | 59.4 | Scenario Average | 26.0 |
| 1985-2015 Average | 57.9 | 1985-2015 Average | 29.0 |
| 1977-2016 Average | 57.8 | 1977-2016 Average | 29.9 |
| Pre-1977 Average | 56.6 | Pre-1977 Average | 28.7 |
| 1894-2016 Average | 57.0 | 1894-2016 Average | 29.1 |

*Figure 9: Temperature Weighted Climate Scenario for Santa Cruz Co-op Station*

Using the same sequence of 53 water years used for the Santa Cruz Co-op station temperature weighted climate scenario.  Figure 10 shows a potential future climate scenario for the Watsonville Waterworks station that is on average 2.4 °F warmer than the long-term average and 1.4°F warmer than the average annual

temperature from 1977-2016. The scenario also has 1.3 inches less precipitation per year than the long-term historical average.
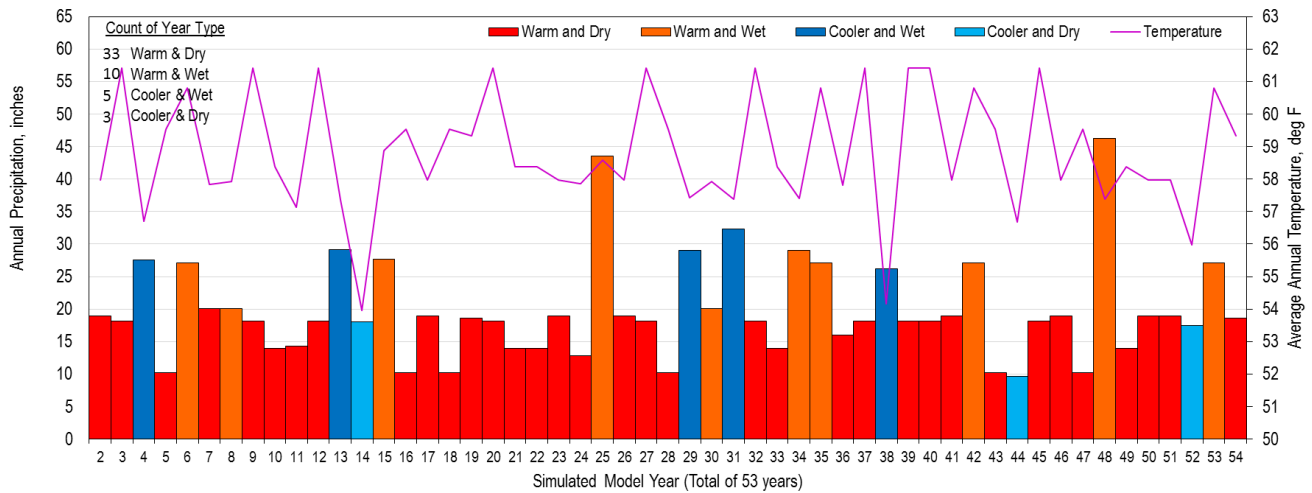


| Annual Temperature, deg F | | Annual Precipitation, inches | |
|---|---|---|---|
| Scenario Average | 58.8 | Scenario Average | 19.8 |
| 1985-2015 Average | 57.3 | 1985-2015 Average | 21.9 |
| 1977-2016 Average | 57.4 | 1977-2016 Average | 22.8 |
| Pre-1977 Average | 55.8 | Pre-1977 Average | 20.1 |
| 1894-2016 Average | 56.4 | 1894-2016 Average | 21.1 |

*Figure 10: Temperature Weighted Climate Scenario for Watsonville Waterworks Station*

## 4.2   TEMPERATURE WEIGHTED AND PRECIPITATION ADJUSTED

Although there is no trend of decreased precipitation in the Santa Cruz area, a drier scenario than that generated by weighting temperature only is also generated for consideration. We avoided randomly generating a new dataset based on both temperature and precipitation weights as we want a scenario that we can compare with the temperature weighted climate scenario. To arrive at this scenario, we start with the temperature weighted scenario and then adjust the four wettest "Warm and Wet" years to "Warm and Dry" by substituting the "Warm and Wet" years with "Warm and Dry" years with similar temperatures but less precipitation. Figure 11 shows the color-coded distribution of water years for the Santa Cruz Co-op station representing a potential future climate scenario that has the same average temperature as the temperature weighted scenario but has 5.4 inches less precipitation per year than the long-term average. Appendix B provides a list of the randomly selected historic years generated for this scenario.  Figure 12 shows this potential future climate scenario applied to the Watsonville Waterworks station that results in the same average temperature as the temperature weighted scenario but has 2.9 inches less precipitation per year than the long-term average.
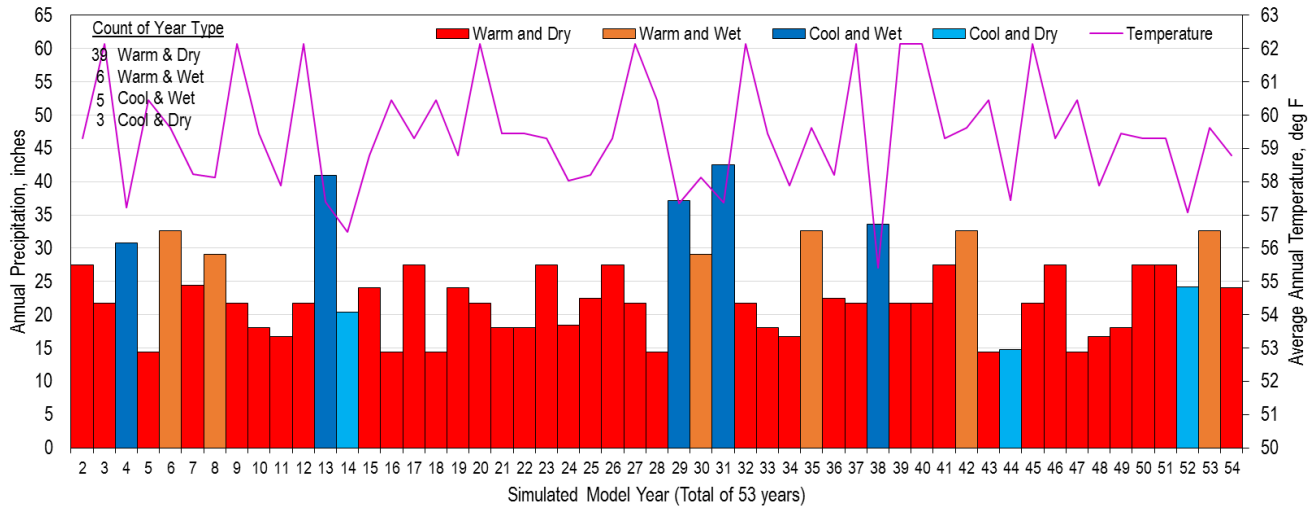
| Annual Temperature, deg F | | Annual Precipitation, inches | |
|---|---|---|---|
| Scenario Average | 59.4 | Scenario Average | 23.7 |
| 1985-2015 Average | 57.9 | 1985-2015 Average | 29.0 |
| 1977-2016 Average | 57.8 | 1977-2016 Average | 29.9 |
| Pre-1977 Average | 56.6 | Pre-1977 Average | 28.7 |
| 1894-2016 Average | 57.0 | 1894-2016 Average | 29.1 |

*Figure 11: Temperature Weighted Climate Scenario for Santa Cruz Co-op Station with Decreased Precipitation Adjustment*



| Annual Temperature, deg F | | Annual Precipitation, inches | |
|---|---|---|---|
| Scenario Average | 58.8 | Scenario Average | 18.2 |
| 1985-2015 Average | 57.3 | 1985-2015 Average | 21.9 |
| 1977-2016 Average | 57.4 | 1977-2016 Average | 22.8 |
| Pre-1977 Average | 55.8 | Pre-1977 Average | 20.1 |
| 1894-2016 Average | 56.4 | 1894-2016 Average | 21.1 |

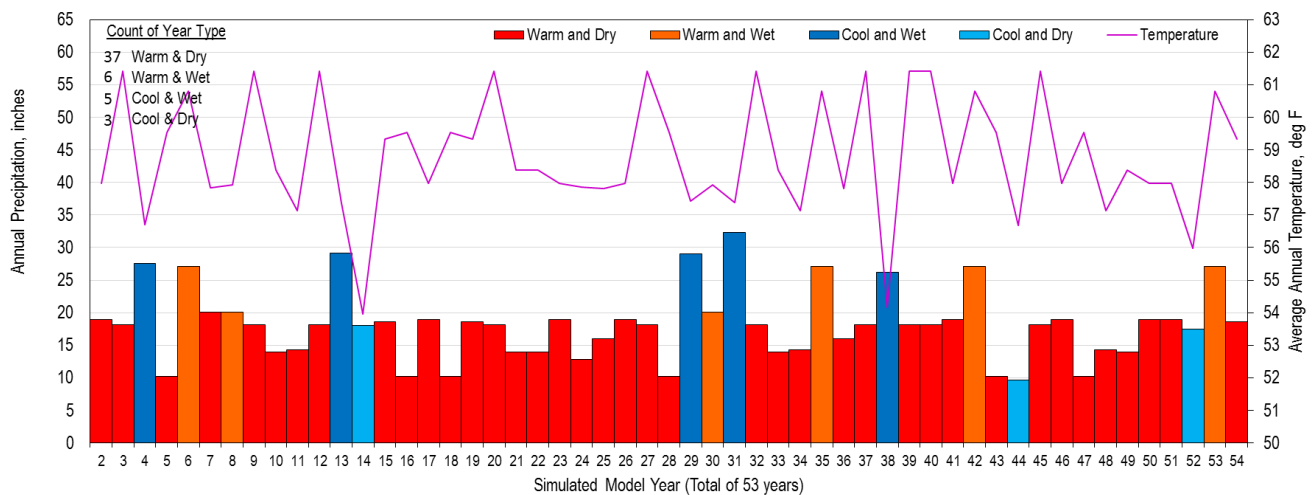*Figure 12: Temperature Weighted Climate Scenario for Watsonville Waterworks with Decreased Precipitation Adjustment*

# 5.0 DISCUSSION AND LIMITATIONS

One of the two scenarios presented in this memo will be selected to run simulations using the GSFLOW model. The selection will be made based on input from MGA member agency staff, the model Technical Advisory Committee, and possibly the MGA Board.

This approach of using historical climate allows us to generate climate scenarios that are warmer than the past 40 years but it does not increase temperatures to the degree that some of the GCMs predict global warming. For example, GCMs (Flint and Flint, 2014) have been downscaled to the San Lorenzo-Soquel Basin, which includes the Santa Cruz Mid-County Groundwater Basin. The downscaled predictions include warming of up to 4.1 °F (GFDL A2, a moderately warmer, drier future) and 6.2°F (MIROC-esm RCP 8.5, the warmest, driest future) over our simulated model period (54 years from Water Year 2016 – 2069). It is important to note that these GCM predicted temperatures are for minimum temperatures which, as shown above, tend to have a greater increase than average temperatures. We used average temperature in our analysis. Additionally, the GCM downscaled predictions are for the entire San Lorenzo-Soquel Basin which extends much farther inland than the Santa Cruz Co-op and Watsonville Waterworks stations.

Assigning lower weights to the "Cooler and dry" and "Cooler and wet" classifications will raise the scenario's average temperature slightly but still not as high as those in the GCMs described above because the hottest years in the historical record are not as hot as what is projected by the GCMs.

Simulating GCM projections will require downscaling GCM results to the Santa Cruz Co-op and Watsonville Waterworks stations for distribution to the model grid by the PRMS watershed component of GSFLOW. The USGS has recommended that the Jensen-Haise formulation for potential evapotranspiration used in the model be changed to Priestly-Taylor or Penman-Monteith when using hotter GCM projections. The Priestly-Taylor and Penman-Monteith evapotranspiration formulations have only recently been added to PRMS so will take additional work to implement with the likelihood of issues implementing new capabilities. Therefore, we will use one of the scenarios described in this memo to represent future climate to perform the initial evaluation of groundwater management alternatives. Implementation of downscaled GCM projections has been re-prioritized to 2017.

This approach also does not project trends for temporal precipitation patterns as previously evaluated by Daniels (2014)[2]. Daniels identified long-term trends in storm intensity, duration, and pauses between storms and assessed effects on groundwater recharge and streamflow of those trends projected into the future. Since those projections are not part of the historical record, they are not part of the climate scenario described in this memo. However, 83% of historical years randomly selected for the future climate scenario in this memo are from 1990-2016, so the historical trends for these patterns are reflected in the scenario.

[2] Dr. Bruce Daniels is Board President of Soquel Creek Water District, a member of the Santa Cruz Mid-County Agency that is funding development of this GSFLOW model. Dr. Daniels also serves on the Technical Advisory Committee for this model.

## 6.0 REFERENCES

Daniels, B.K. 2014. *Hydrologic response to climate change in California: observational and modeling studies.* Ph.D. dissertation, University of California, Santa Cruz. December.

Flint L.E. and A.L. Flint. 2014. *California basin characterization model: a dataset of historical and future hydrologic response to climate change*, U.S. Geological Survey Data Release, doi:10.5066/F76T0JPB

Metropolitan Water District of Southern California (MWD). 2016. *Integrated Water Resources Plan, 2015 Update*. Report No. 1518. January.

Young, K. 2016. *A high-resolution, regional-scale analysis of stormwater runoff in the San Lorenzo river basin for managed aquifer recharge decision making*. Masters of Science Thesis, University of California, Santa Cruz. June.

# Appendix A

## Santa Cruz Co-op Station Exceedance Probabilities
## with Year Type Classification

| Water Year | Temperature | | | Precipitation | | | Classification 1 = Warm & dry 2 = Warm & wet 3 = Cooler & dry 4 = Cooler & wet |
|---|---|---|---|---|---|---|---|
| | Average (°F) | Rank | Probability of Exceedance | Total (inches) | Rank | Probability of Exceedance | |
| 1894 | 57.6 | 35 | 28.2% | 32.9 | 37 | 29.8% | 3 |
| 1895 | 58.9 | 9 | 7.3% | 36.8 | 26 | 21.0% | 2 |
| 1896 | 57.6 | 36 | 29.0% | 22.9 | 86 | 69.4% | 4 |
| 1897 | 56.8 | 72 | 58.1% | 27.8 | 64 | 51.6% | 4 |
| 1898 | 55.9 | 100 | 80.6% | 12.4 | 121 | 97.6% | 4 |
| 1899 | 55.5 | 110 | 88.7% | 22.9 | 85 | 68.5% | 4 |
| 1900 | 56.8 | 69 | 55.6% | 28.4 | 61 | 49.2% | 3 |
| 1901 | 55.4 | 114 | 91.9% | 26.8 | 70 | 56.5% | 4 |
| 1902 | 55.7 | 106 | 85.5% | 28.7 | 57 | 46.0% | 3 |
| 1903 | 54.8 | 122 | 98.4% | 26.7 | 71 | 57.3% | 4 |
| 1904 | 56.3 | 91 | 73.4% | 32.7 | 38 | 30.6% | 3 |
| 1905 | 58.0 | 23 | 18.5% | 28.5 | 60 | 48.4% | 2 |
| 1906 | 57.1 | 57 | 46.0% | 32.5 | 41 | 33.1% | 3 |
| 1907 | 57.1 | 54 | 43.5% | 35.5 | 30 | 24.2% | 3 |
| 1908 | 56.0 | 97 | 78.2% | 23.3 | 84 | 67.7% | 4 |
| 1909 | 55.2 | 117 | 94.4% | 42.9 | 12 | 9.7% | 3 |
| 1910 | 56.1 | 96 | 77.4% | 28.6 | 59 | 47.6% | 3 |
| 1911 | 55.3 | 115 | 92.7% | 33.5 | 35 | 28.2% | 3 |
| 1912 | 57.4 | 45 | 36.3% | 20.9 | 98 | 79.0% | 4 |
| 1913 | 55.7 | 105 | 84.7% | 13.8 | 120 | 96.8% | 4 |
| 1914 | 57.0 | 61 | 49.2% | 34.9 | 31 | 25.0% | 3 |
| 1915 | 56.6 | 80 | 64.5% | 42.1 | 15 | 12.1% | 3 |
| 1916 | 55.8 | 102 | 82.3% | 30.4 | 47 | 37.9% | 3 |
| 1917 | 54.4 | 123 | 99.2% | 18.4 | 110 | 88.7% | 4 |
| 1918 | 57.3 | 50 | 40.3% | 18.6 | 108 | 87.1% | 4 |
| 1919 | 56.2 | 92 | 74.2% | 21.7 | 95 | 76.6% | 4 |
| 1920 | 56.1 | 95 | 76.6% | 20.5 | 101 | 81.5% | 4 |
| 1921 | 56.6 | 82 | 66.1% | 28.2 | 62 | 50.0% | 4 |
| 1922 | 56.6 | 81 | 65.3% | 27.9 | 63 | 50.8% | 4 |
| 1923 | 56.4 | 90 | 72.6% | 28.6 | 58 | 46.8% | 3 |
| 1924 | 57.1 | 55 | 44.4% | 10.2 | 123 | 99.2% | 4 |
| 1925 | 57.7 | 33 | 26.6% | 30.5 | 46 | 37.1% | 3 |
| 1926 | 59.6 | 4 | 3.2% | 25.6 | 72 | 58.1% | 1 |
| 1927 | 57.6 | 39 | 31.5% | 29.3 | 53 | 42.7% | 3 |

| Water Year | Temperature | | | Precipitation | | | Classification 1 = Warm & dry 2 = Warm & wet 3 = Cooler & dry 4 = Cooler & wet |
| | Average (°F) | Rank | Probability of Exceedance | Total (inches) | Rank | Probability of Exceedance | |
|---|---|---|---|---|---|---|---|
| **1928** | **57.8** | **30** | **24.2%** | **22.0** | **90** | **72.6%** | 1 |
| 1929 | 55.4 | 113 | 91.1% | 18.2 | 111 | 89.5% | 4 |
| 1930 | 56.2 | 93 | 75.0% | 21.9 | 91 | 73.4% | 4 |
| **1931** | **58.8** | **10** | **8.1%** | **11.7** | **122** | **98.4%** | 1 |
| 1932 | 55.1 | 118 | 95.2% | 27.4 | 68 | 54.8% | 4 |
| 1933 | 54.9 | 120 | 96.8% | 21.7 | 94 | 75.8% | 4 |
| **1934** | **58.0** | **22** | **17.7%** | **18.4** | **109** | **87.9%** | 1 |
| 1935 | 57.0 | 60 | 48.4% | 30.1 | 50 | 40.3% | 3 |
| **1936** | **58.0** | **25** | **20.2%** | **32.7** | **39** | **31.5%** | 2 |
| 1937 | 56.9 | 67 | 54.0% | 34.1 | 32 | 25.8% | 3 |
| 1938 | 57.9 | 26 | 21.0% | 42.4 | 14 | 11.3% | 2 |
| 1939 | 57.5 | 42 | 33.9% | 20.2 | 103 | 83.1% | 4 |
| 1940 | 58.3 | 15 | 12.1% | 44.5 | 8 | 6.5% | 2 |
| 1941 | 58.6 | 12 | 9.7% | 61.3 | 1 | 0.8% | 2 |
| 1942 | 57.0 | 64 | 51.6% | 42.0 | 16 | 12.9% | 3 |
| 1943 | 56.8 | 71 | 57.3% | 39.5 | 22 | 17.7% | 3 |
| 1944 | 57.0 | 62 | 50.0% | 27.4 | 67 | 54.0% | 4 |
| 1945 | 57.3 | 49 | 39.5% | 33.2 | 36 | 29.0% | 3 |
| 1946 | 56.6 | 84 | 67.7% | 30.3 | 48 | 38.7% | 3 |
| 1947 | 57.1 | 58 | 46.8% | 19.1 | 105 | 84.7% | 4 |
| 1948 | 55.7 | 103 | 83.1% | 24.7 | 76 | 61.3% | 4 |
| 1949 | 55.0 | 119 | 96.0% | 30.0 | 51 | 41.1% | 3 |
| 1950 | 55.3 | 116 | 93.5% | 31.4 | 43 | 34.7% | 3 |
| 1951 | 56.6 | 78 | 62.9% | 38.4 | 23 | 18.5% | 3 |
| 1952 | 56.0 | 98 | 79.0% | 44.6 | 7 | 5.6% | 3 |
| 1953 | 55.6 | 109 | 87.9% | 24.4 | 78 | 62.9% | 4 |
| 1954 | 56.4 | 89 | 71.8% | 23.8 | 83 | 66.9% | 4 |
| 1955 | 54.8 | 121 | 97.6% | 23.9 | 82 | 66.1% | 4 |
| 1956 | 55.6 | 108 | 87.1% | 39.7 | 21 | 16.9% | 3 |
| 1957 | 57.0 | 59 | 47.6% | 22.2 | 89 | 71.8% | 4 |
| **1958** | **57.8** | **29** | **23.4%** | **50.1** | **4** | **3.2%** | 2 |
| **1959** | **58.1** | **20** | **16.1%** | **24.8** | **75** | **60.5%** | 1 |
| 1960 | 57.3 | 51 | 41.1% | 21.4 | 97 | 78.2% | 4 |
| 1961 | 56.9 | 68 | 54.8% | 17.8 | 113 | 91.1% | 4 |
| 1962 | 55.4 | 111 | 89.5% | 27.5 | 66 | 53.2% | 4 |
| 1963 | 56.7 | 74 | 59.7% | 33.7 | 33 | 26.6% | 3 |
| 1964 | 56.0 | 99 | 79.8% | 19.0 | 106 | 85.5% | 4 |
| 1965 | 56.6 | 77 | 62.1% | 30.6 | 45 | 36.3% | 3 |
| 1966 | 56.7 | 75 | 60.5% | 20.5 | 100 | 80.6% | 4 |
| 1967 | 56.8 | 70 | 56.5% | 40.0 | 20 | 16.1% | 3 |

| Water Year | Temperature | | | Precipitation | | | Classification<br>1 = Warm & dry<br>2 = Warm & wet<br>3 = Cooler & dry<br>4 = Cooler & wet |
| | Average (°F) | Rank | Probability of Exceedance | Total (inches) | Rank | Probability of Exceedance | |
| --- | --- | --- | --- | --- | --- | --- | --- |
| 1968 | 57.4 | 43 | 34.7% | 21.5 | 96 | 77.4% | 4 |
| 1969 | 55.7 | 107 | 86.3% | 44.9 | 6 | 4.8% | 3 |
| 1970 | 57.7 | 32 | 25.8% | 30.2 | 49 | 39.5% | 3 |
| 1971 | 56.1 | 94 | 75.8% | 27.2 | 69 | 55.6% | 4 |
| 1972 | 56.6 | 79 | 63.7% | 19.1 | 104 | 83.9% | 4 |
| 1973 | 56.5 | 85 | 68.5% | 43.7 | 9 | 7.3% | 3 |
| 1974 | 55.8 | 101 | 81.5% | 42.0 | 17 | 13.7% | 3 |
| 1975 | 55.7 | 104 | 83.9% | 24.3 | 79 | 63.7% | 4 |
| 1976 | 56.7 | 76 | 61.3% | 15.4 | 117 | 94.4% | 4 |
| 1977 | 57.4 | 44 | 35.5% | 14.8 | 118 | 95.2% | 4 |
| 1978 | 58.3 | 14 | 11.3% | 37.6 | 24 | 19.4% | 2 |
| 1979 | 56.5 | 87 | 70.2% | 29.2 | 54 | 43.5% | 3 |
| 1980 | 57.4 | 48 | 38.7% | 37.1 | 25 | 20.2% | 3 |
| 1981 | 57.7 | 31 | 25.0% | 21.7 | 92 | 74.2% | 4 |
| 1982 | 56.7 | 73 | 58.9% | 48.1 | 5 | 4.0% | 3 |
| 1983 | 58.2 | 18 | 14.5% | 53.9 | 3 | 2.4% | 2 |
| 1984 | 58.8 | 11 | 8.9% | 24.0 | 81 | 65.3% | 1 |
| 1985 | 57.0 | 63 | 50.8% | 29.7 | 52 | 41.9% | 3 |
| 1986 | 57.4 | 46 | 37.1% | 41.0 | 18 | 14.5% | 3 |
| 1987 | 58.0 | 24 | 19.4% | 15.9 | 116 | 93.5% | 1 |
| 1988 | 58.5 | 13 | 10.5% | 18.7 | 107 | 86.3% | 1 |
| 1989 | 57.1 | 56 | 45.2% | 24.2 | 80 | 64.5% | 4 |
| 1990 | 57.9 | 27 | 21.8% | 16.8 | 115 | 92.7% | 1 |
| 1991 | 56.5 | 86 | 69.4% | 20.4 | 102 | 82.3% | 4 |
| 1992 | 59.3 | 6 | 4.8% | 27.5 | 65 | 52.4% | 1 |
| 1993 | 58.2 | 19 | 15.3% | 36.7 | 27 | 21.8% | 2 |
| 1994 | 57.6 | 38 | 30.6% | 22.7 | 87 | 70.2% | 4 |
| 1995 | 57.6 | 37 | 29.8% | 43.0 | 11 | 8.9% | 3 |
| 1996 | 59.0 | 8 | 6.5% | 31.5 | 42 | 33.9% | 2 |
| 1997 | 59.1 | 7 | 5.6% | 36.6 | 28 | 22.6% | 2 |
| 1998 | 57.9 | 28 | 22.6% | 59.8 | 2 | 1.6% | 2 |
| 1999 | 55.4 | 112 | 90.3% | 33.7 | 34 | 27.4% | 3 |
| 2000 | 57.7 | 34 | 27.4% | 36.4 | 29 | 23.4% | 3 |
| 2001 | 56.6 | 83 | 66.9% | 25.5 | 73 | 58.9% | 4 |
| 2002 | 56.4 | 88 | 71.0% | 28.8 | 56 | 45.2% | 3 |
| 2003 | 58.1 | 21 | 16.9% | 29.1 | 55 | 44.4% | 2 |
| 2004 | 58.2 | 16 | 12.9% | 24.5 | 77 | 62.1% | 1 |
| 2005 | 57.5 | 41 | 33.1% | 43.6 | 10 | 8.1% | 3 |
| 2006 | 57.4 | 47 | 37.9% | 42.5 | 13 | 10.5% | 3 |
| 2007 | 57.1 | 53 | 42.7% | 17.6 | 114 | 91.9% | 4 |

| Water Year | Temperature | | | Precipitation | | | Classification 1 = Warm & dry 2 = Warm & wet 3 = Cooler & dry 4 = Cooler & wet |
| | Average (°F) | Rank | Probability of Exceedance | Total (inches) | Rank | Probability of Exceedance | |
|---|---|---|---|---|---|---|---|
| 2008 | 56.9 | 66 | 53.2% | 25.0 | 74 | 59.7% | 4 |
| 2009 | 58.2 | 17 | 13.7% | 22.4 | 88 | 71.0% | 1 |
| 2010 | 57.2 | 52 | 41.9% | 30.8 | 44 | 35.5% | 3 |
| 2011 | 57.0 | 65 | 52.4% | 40.1 | 19 | 15.3% | 3 |
| 2012 | 57.5 | 40 | 32.3% | 20.7 | 99 | 79.8% | 4 |
| 2013 | 59.4 | 5 | 4.0% | 18.0 | 112 | 90.3% | 1 |
| 2014 | 60.5 | 2 | 1.6% | 14.4 | 119 | 96.0% | 1 |
| 2015 | 62.2 | 1 | 0.8% | 21.7 | 93 | 75.0% | 1 |
| 2016 | 59.6 | 3 | 2.4% | 32.6 | 40 | 32.3% | 2 |

Bold records denote water years included in the catalog for future climate scenario generation

# Appendix B

# Proposed Climate Scenarios

The Weighted Temperature Scenario with Precipitation Adjustment columns only show those water years where records are manually adjusted to be drier. For the remaining years, data from the Weighted Temperature Scenario apply.

| Model Water Year | Historic Water Year | Weighted Temperature Scenario | | | | Weighted Temperature Scenario with Precipitation Adjustment (Drier) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Temperature | | Precipitation | | | Temperature | | Precipitation | |
| | | Average (°F) | Probability of Exceedance | Average (inches) | Probability of Exceedance | Historic Year if changed | Average (°F) | Probability of Exceedance | Average (inches) | Probability of Exceedance |
| 1 | 2016 | 59.6 | 2.4% | 32.6 | 32.3% | | | | | |
| 2 | 1992 | 59.3 | 4.8% | 27.5 | 52.4% | | | | | |
| 3 | 2015 | 62.2 | 0.8% | 21.7 | 75.0% | | | | | |
| 4 | 2010 | 57.2 | 41.9% | 30.8 | 35.5% | | | | | |
| 5 | 2014 | 60.5 | 1.6% | 14.4 | 96.0% | | | | | |
| 6 | 2016 | 59.6 | 2.4% | 32.6 | 32.3% | | | | | |
| 7 | 2004 | 58.2 | 12.9% | 24.5 | 62.1% | | | | | |
| 8 | 2003 | 58.1 | 16.9% | 29.1 | 44.4% | | | | | |
| 9 | 2015 | 62.2 | 0.8% | 21.7 | 75.0% | | | | | |
| 10 | 2013 | 59.4 | 4.0% | 18.0 | 90.3% | | | | | |
| 11 | 1990 | 57.9 | 21.8% | 16.8 | 92.7% | | | | | |
| 12 | 2015 | 62.2 | 0.8% | 21.7 | 75.0% | | | | | |
| 13 | 1986 | 57.4 | 37.1% | 41.0 | 14.5% | | | | | |
| 14 | 1991 | 56.5 | 69.4% | 20.4 | 82.3% | | | | | |
| 15 | 1997 | 59.1 | 5.6% | 36.6 | 22.6% | 1984 | 58.8 | 8.9% | 24.0 | 65.3% |
| 16 | 2014 | 60.5 | 1.6% | 14.4 | 96.0% | | | | | |
| 17 | 1992 | 59.3 | 4.8% | 27.5 | 52.4% | | | | | |
| 18 | 2014 | 60.5 | 1.6% | 14.4 | 96.0% | | | | | |
| 19 | 1984 | 58.8 | 8.9% | 24.0 | 65.3% | | | | | |
| 20 | 2015 | 62.2 | 0.8% | 21.7 | 75.0% | | | | | |
| 21 | 2013 | 59.4 | 4.0% | 18.0 | 90.3% | | | | | |
| 22 | 2013 | 59.4 | 4.0% | 18.0 | 90.3% | | | | | |
| 23 | 1992 | 59.3 | 4.8% | 27.5 | 52.4% | | | | | |
| 24 | 1934 | 58.0 | 17.7% | 18.4 | 87.9% | | | | | |
| 25 | 1983 | 58.2 | 14.5% | 53.9 | 2.4% | 2009 | 58.2 | 13.7% | 22.4 | 71.0% |
| 26 | 1992 | 59.3 | 4.8% | 27.5 | 52.4% | | | | | |
| 27 | 2015 | 62.2 | 0.8% | 21.7 | 75.0% | | | | | |
| 28 | 2014 | 60.5 | 1.6% | 14.4 | 96.0% | | | | | |

| Model Water Year | Historic Water Year | Weighted Temperature Scenario | | | | Weighted Temperature Scenario with Precipitation Adjustment (Drier) | | | | |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| | | Temperature | | Precipitation | | | Temperature | | Precipitation | |
| | | Average (°F) | Probability of Exceedance | Average (inches) | Probability of Exceedance | Historic Year if changed | Average (°F) | Probability of Exceedance | Average (inches) | Probability of Exceedance |
| 29 | 1980 | 57.4 | 38.7% | 37.1 | 20.2% | | | | | |
| 30 | 2003 | 58.1 | 16.9% | 29.1 | 44.4% | | | | | |
| 31 | 2006 | 57.4 | 37.9% | 42.5 | 10.5% | | | | | |
| 32 | 2015 | 62.2 | 0.8% | 21.7 | 75.0% | | | | | |
| 33 | 2013 | 59.4 | 4.0% | 18.0 | 90.3% | | | | | |
| 34 | 1958 | 57.8 | 23.4% | 50.1 | 3.2% | 1990 | 57.9 | 21.8% | 16.8 | 92.7% |
| 35 | 2016 | 59.6 | 2.4% | 32.6 | 32.3% | | | | | |
| 36 | 2009 | 58.2 | 13.7% | 22.4 | 71.0% | | | | | |
| 37 | 2015 | 62.2 | 0.8% | 21.7 | 75.0% | | | | | |
| 38 | 1999 | 55.4 | 90.3% | 33.7 | 27.4% | | | | | |
| 39 | 2015 | 62.2 | 0.8% | 21.7 | 75.0% | | | | | |
| 40 | 2015 | 62.2 | 0.8% | 21.7 | 75.0% | | | | | |
| 41 | 1992 | 59.3 | 4.8% | 27.5 | 52.4% | | | | | |
| 42 | 2016 | 59.6 | 2.4% | 32.6 | 32.3% | | | | | |
| 43 | 2014 | 60.5 | 1.6% | 14.4 | 96.0% | | | | | |
| 44 | 1977 | 57.4 | 35.5% | 14.8 | 95.2% | | | | | |
| 45 | 2015 | 62.2 | 0.8% | 21.7 | 75.0% | | | | | |
| 46 | 1992 | 59.3 | 4.8% | 27.5 | 52.4% | | | | | |
| 47 | 2014 | 60.5 | 1.6% | 14.4 | 96.0% | | | | | |
| 48 | 1998 | 57.9 | 22.6% | 59.8 | 1.6% | 1990 | 57.9 | 21.8% | 16.8 | 92.7% |
| 49 | 2013 | 59.4 | 4.0% | 18.0 | 90.3% | | | | | |
| 50 | 1992 | 59.3 | 4.8% | 27.5 | 52.4% | | | | | |
| 51 | 1992 | 59.3 | 4.8% | 27.5 | 52.4% | | | | | |
| 52 | 1989 | 57.1 | 45.2% | 24.2 | 64.5% | | | | | |
| 53 | 2016 | 59.6 | 2.4% | 32.6 | 32.3% | | | | | |
| 54 | 1984 | 58.8 | 8.9% | 24.0 | 65.3% | | | | | |