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Appendix 3-D
Sonoma Water Climate Scenario Assessment for Groundwater Sustainability Planning

JACOBS

Sonoma Water Climate Scenario Assessment for Groundwater Sustainability Planning

Technical Assessment of Climate Scenarios for Sonoma Water Groundwater Sustainability Planning

February 24, 2020

Sonoma Water

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Appendix A. Recommendations for Defining Water Year Types for Groundwater Sustainability Planning

1. Introduction

Sonoma Water is utilizing climate information for a number of regional water planning, sustainability, and resiliency efforts. As part of regional efforts to develop Groundwater Sustainability Plans (GSPs), future climate information is required to assess the sustainability of groundwater management over conditions that may be different than historical climate. This technical memorandum provides information on an evaluation of twenty individual climate model projections of simulated key metrics related to regional climate and hydrology that can be used to support identification of a subset of scenarios for use in water planning efforts. Figure 1 shows Russian River watershed and the 3 Groundwater sub-basins.

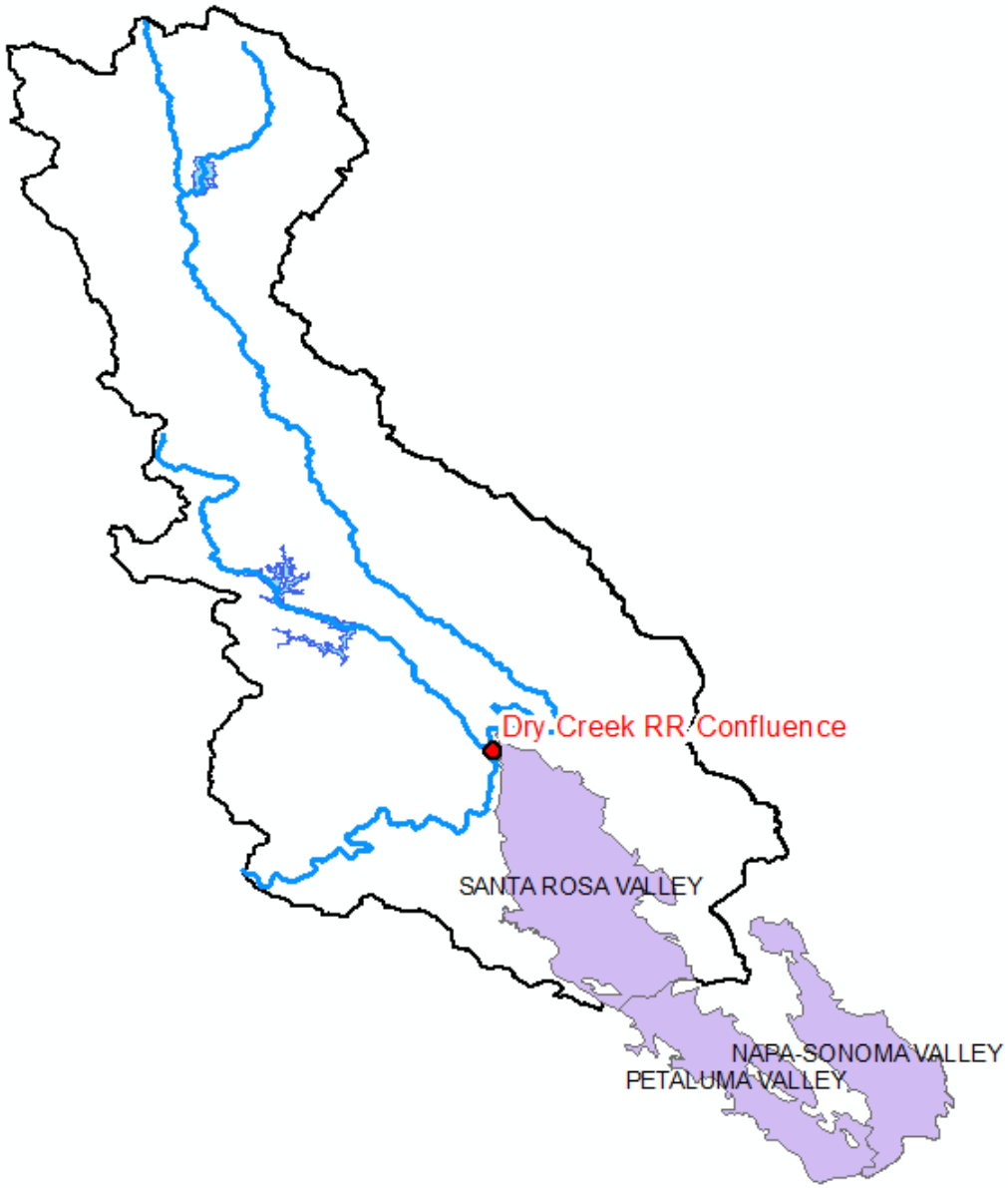


Figure 1. Russian River Hydrologic Basin and Santa Rosa Valley, Petaluma Valley, and Napa-Sonoma Groundwater Sub-Basins

2. Approach and Methods

Over the past several decades, air temperatures have increased globally and throughout the western United States, including California. While the Sonoma County region is complex with several microclimates, historical patterns of warming have occurred in near all monitoring stations in the region (Erkstrom and Moser 2012). Precipitation over most of California, including the Sonoma County region, is dominated by extreme variability, both seasonally, annually, and over decadal time scales.

Projections of future climate conditions are generally performed through general circulation models (GCMs) forced with specific global greenhouse gas (GHG) emission scenarios (IPCC 2013). The projections included in this summary rely upon available climate projections using the models and emissions scenarios included in the Coupled Model Intercomparison Project 5 (CMIP5). Twenty individual downscaled GCM projections were selected from ten different GCMs and two different Representative Concentration Pathways (RCPs), RCP4.5 and RCP8.5. The ten GCMs were chosen by the DWR Climate Change Technical Advisory Group (CCTAG) based on a regional evaluation of climate model ability to reproduce a range of historical climate conditions (DWR CCTAG, 2015). The 20 climate projections were downscaled using a statistical downscaling method called LOCA at 1/16th degree (~6 km) (~3.75 miles) spatial resolution by Scripps Institution of Oceanography (Pierce et al., 2014) and subsequently further downscaled to a 270-meter resolution by the USGS as part of the Basin Characterization Model (BCM) data set. These data form the basis for this assessment.

As part of California's Fourth Climate Change Assessment, four of the GCMs were identified as "cool/wet", "middle", "warm/dry", and "diversity" based on an evaluation of climate metrics for northern California coast region (Pierce et al. 2018). The individual GCMs, RCPs, and Fourth Climate Change Assessment identifiers are shown in Table 1.

Table 1. GCMs Selected by DWR CCTAG and Used in this Assessment

GCM	RCP 4.5	RCP 8.5	CA Fourth Climate Change Assessment "Northern CA Coast" Identifier
ACCESS1-0	X	X	
CCSM4	X	X	
CESM1-BGC	X	X	
HadGEM2-CC	X	X	
CMCC-CMS	X	X	
CNRM-CM5	X	X	Cool/Wet
CanESM2	X	X	Middle
GFDL-CM3	X	X	
HadGEM2-ES	X	X	Warm/Dry
MIROC5	X	X	Diversity

Since modeling efforts for the Sonoma GSPs may not be able to support the characterization of groundwater basin outcomes based on all 20 projections, a subset of climate projections may be needed to provide a representation of the future climate conditions. Two possible approaches are recommended: (1) selection of an individual climate projection such as HadGEM2-ES to represent a scenario of future climate or (2) use of a sub-ensemble of projections to map projected changes in temperature and precipitation to an underlying historical time series. The individual projection approach has advantages in that it will present one outcome of the climate model projections and will contain internally-consistent variability and change. Dry and wet periods (seasonal, annual, and inter-annual) of differing durations and severity can be explored. The second approach is termed an

ensemble-informed process and adjusts historical time series to reflect the projected changes associated with the sub-ensemble. The ensemble-informed process is included in the climate change data documented in Guidance Document for the Sustainable Management of Groundwater by California Department of Water Resources (CA DWR, 2018). This process provides a stable depiction of the central tendency of the ensemble of climate models and is capable of capturing seasonal and annual changes, but significant changes in interannual variability are not captured due to its reliance on an underlying historical time series. This technical report focuses on the evaluation of individual climate projections.

In addition, for GSP planning purposes, it is desirable to identify projected climate scenarios that more specifically represent the climate and hydrologic conditions within the Russian River watershed and Sonoma County. Based on the discussions with regional water managers, we have identified five major climate, hydrologic, and water supply metrics that could support assessment of specific climate scenarios. These metrics are listed below:

- Mean change in annual temperature and precipitation
- Mean annual Russian River streamflow
- 1- and 3-yr Russian River streamflow variability
- Lake Sonoma annual minimum reservoir storage conditions
- Sonoma Water delivery capability

For each future climate projection, each of the resulting metrics was assessed. Climate information was averaged for the Russian River watershed area. Naturalized streamflow was derived from BCM simulations and subsequently corrected for historical biases. Reservoir and water delivery outcomes were derived from HEC-ResSim simulations using the future climate and naturalized streamflow inputs.

Climate projection outcomes were assessed for two future periods. In order to capture variability in precipitation and streamflow a period of sufficient length was required. For this assessment, the mid-century period is defined as the period of 2006-2060 and late century is the period of 2045-2099 and results are compared to the historical period of 1951-2005. Each of these periods includes 55-years of variability, and the historical period represents the same period for which BCM streamflow results were bias-corrected. For climate information (temperature and precipitation change), we also present changes for shorter 30-year periods in addition to the longer 55-year periods for comparison. These additional periods are 2035-2065 for mid-century and 2070-2099 for late century compared to the historical period of 1976-2005 and are those presented in Pierce et al. (2018), a report prepared for the California Fourth Climate Change Assessment.

3. Results

The sections that follow present the results for projected changes in precipitation, temperature, streamflow, storage, and Sonoma Water diversion for mid-century conditions.

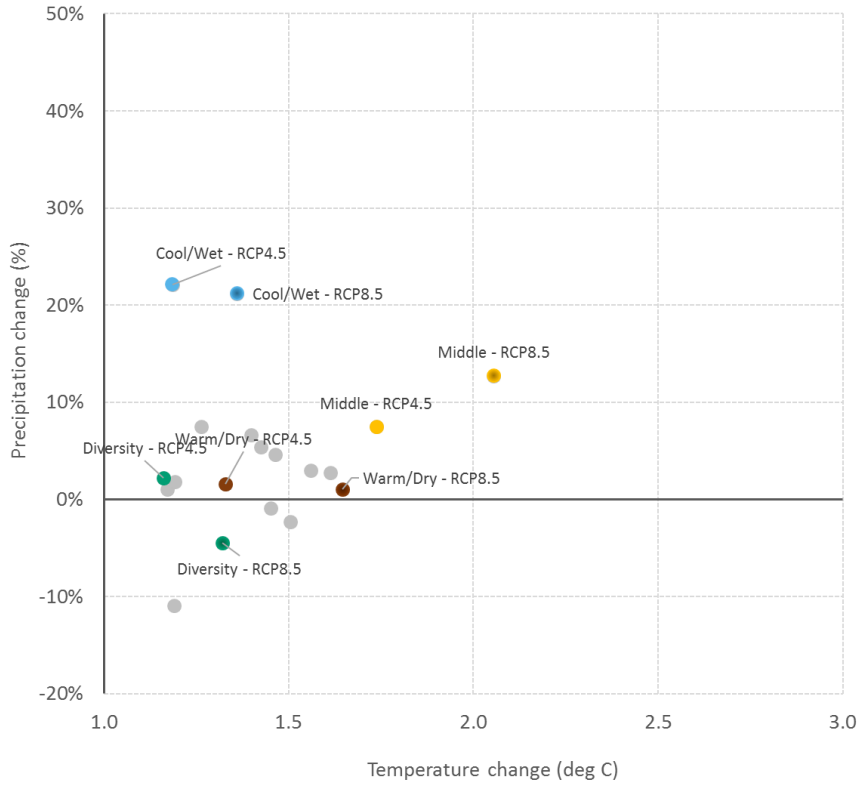
3.1 Projected Changes in Precipitation and Temperature

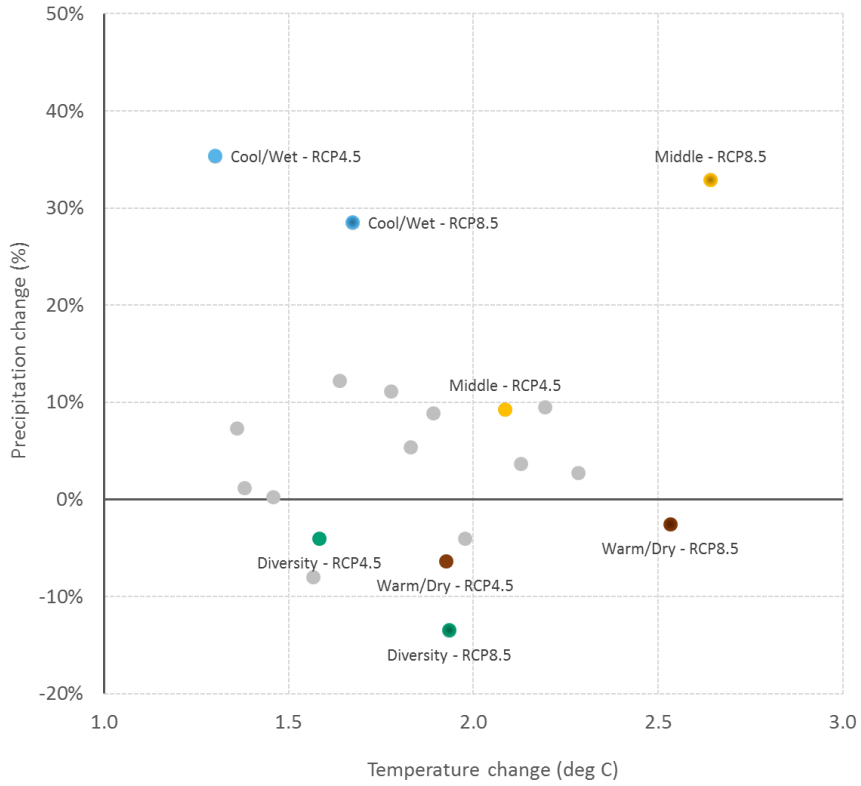
Figure 2 shows the temperature and precipitation changes projected by ten different GCMs for both RCP 4.5 and 8.5 scenarios for mid-century. The GCMs with a “Northern CA Coast” identifiers are colored and labeled with other GCMs shown in grey. The top panel shows the changes using the 55-year period of 2006-2060, while the bottom panel shows the changes for the 30-year period of 2035-2065. All models project temperature to increase between 1.2 and 2.6 degree Celsius. HadGEM2-ES (Warm/Dry model) and CanESM2 (Middle model) project the highest temperature increase, while CNRM-CM5 (Cool/Wet model) projects the lowest increase with about 1.2 degree Celsius among all model projections. In addition, most of the model projections (16 out of 20) suggest a slightly wetter future for the region. CNRM-CM5 and CanESM2 show the largest increases among all model projections. On the other hand, MIROC5 (Diversity model) suggests reduction in precipitation by mid-century.

Figure 3 shows the same information for late century. The top panel shows the changes using the 55-year period of 2045-2099, while the bottom panel shows the changes for the 30-year period of 2070-2099. All models project temperature to increase between 1.4 and 4.7 degree Celsius. HadGEM2-ES (Warm/Dry model) and CanESM2 (Middle model) project the highest temperature increase, while CNRM-CM5 (Cool/Wet model) projects the lowest increase. In addition, most of the model projections suggest a wetter future for the region. CNRM-CM5 and CanESM2 show larger increases among all model projections. On the other hand, MIROC5 (Diversity model) suggests reductions in precipitation starting in mid-century and becoming more pronounced by late-century.

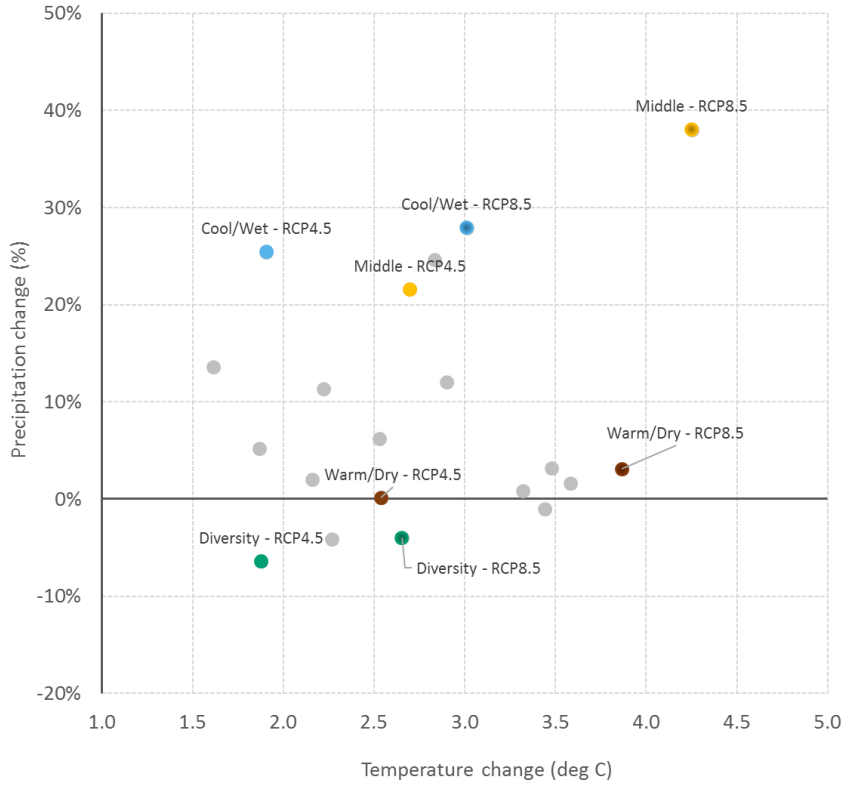
Based on this assessment, the CanESM2 model, which was labeled as “middle” in DWR’s Fourth Climate Change Assessment, can only be considered as “warm/wet” for the Russian River domain. The “warm/dry” HadGEM2-ES model tends more to the middle, and the “diversity” MIROC5 continues to be the driest model. The CNRM-CM5 model appears consistent with “cool/wet” identifier.

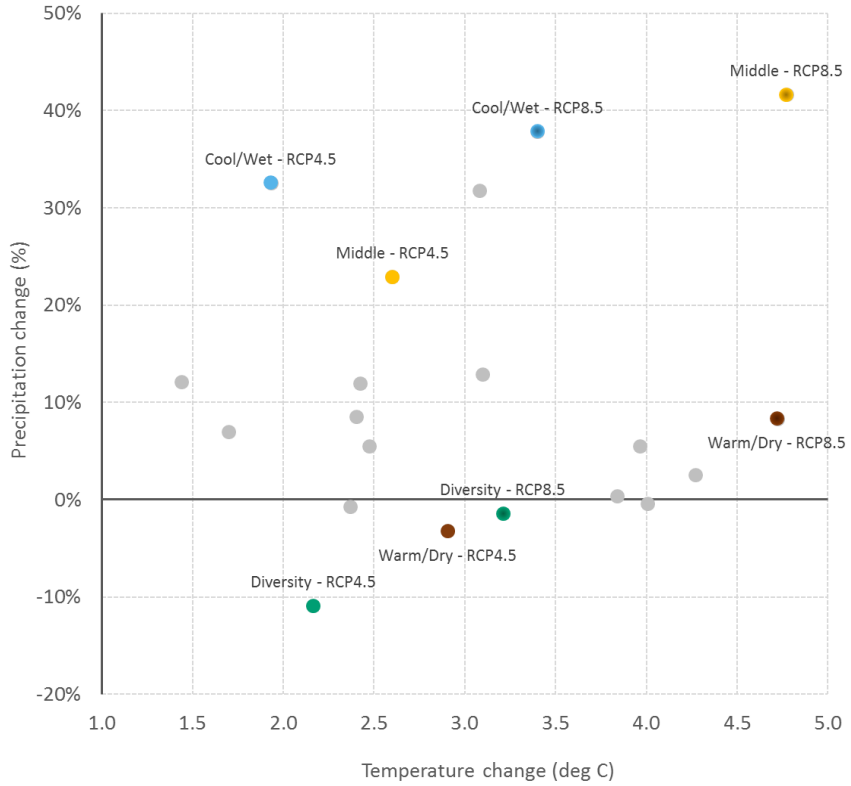
Figure 2. Projected Changes in Mean Annual Temperature and Precipitation (top panel: 2006-2060 and lower panel: 2035-2065)





igure 3. Projected Changes in Mean Annual Temperature and Precipitation (top panel: 2045-2099 and lower panel: 2070-2099)





3.2 Projected Changes in Annual Streamflow

Figure 4 shows the annual natural streamflow exceedance probability curves for historical and future scenarios at the Russian River downstream of the Dry Creek confluence for the period of 2006-2060. The results indicate the potential for streamflow reductions, particularly during the drier years (lower percentiles) and potential increases during wetter years (higher percentiles). The “cool/wet” and “middle” projections show much higher increases in streamflow increases than the “diversity” and “warm/dry” projections. It appears that the so-called “warm/dry” projections fall more towards the center of the ensemble of results and produce wetter wet years and drier dry years as compared to the historical distribution.

Figure 5 shows the annual natural streamflow exceedance probability curves for historical and future scenarios at the Russian River downstream of the Dry Creek confluence for the period of 2045-2099. Under this later future period, the differences between scenarios is magnified but shows similar relative ordering as the earlier period. The so-called “middle” projections exhibit the greatest change in streamflow, while the “warm/dry” once again tends toward the actual middle of the distribution.

Figure 4. Projected Changes in Annual Russian River Streamflow for Period of 2006-2060.

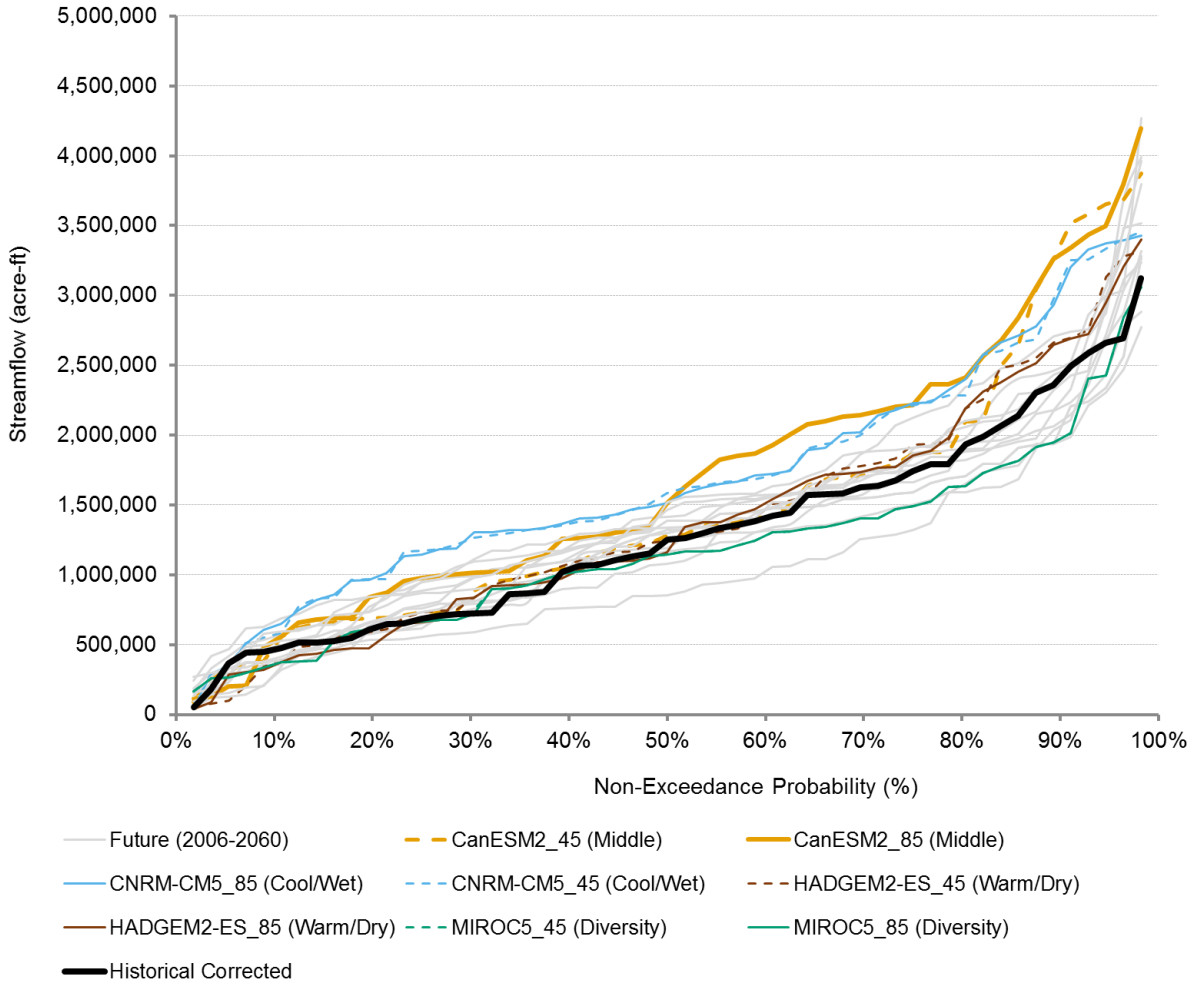
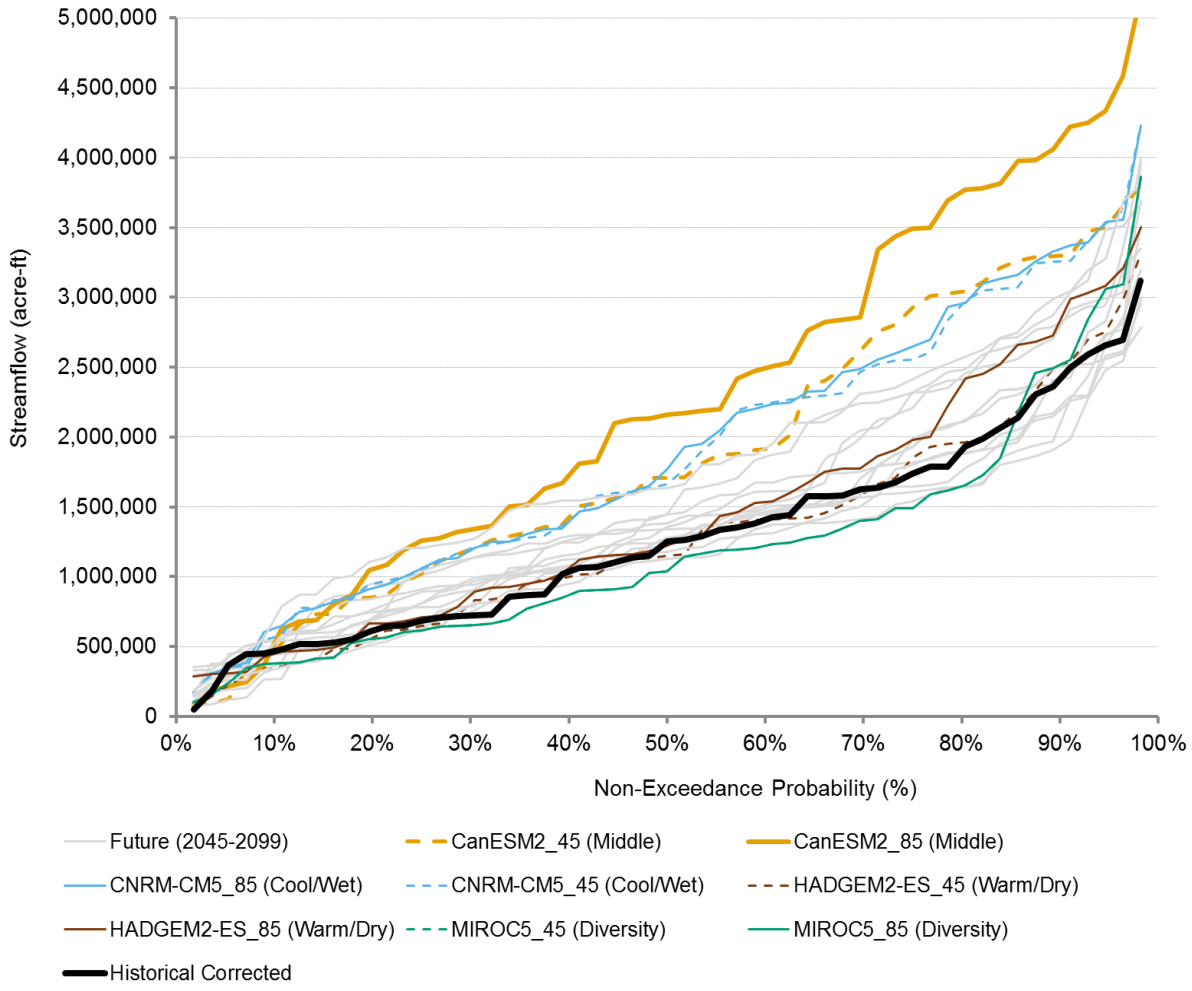


Figure 5. Projected Changes in Annual Russian River Streamflow for Period of 2045-2099.



3.3 Projected Changes in 3-Year Annual Streamflow

Figure 6 shows the 3-year annual natural streamflow exceedance probability curves for historical and future scenarios at the Russian River downstream of the Dry Creek confluence for the period of 2006-2060. The results indicate an expansion in variability for the moderate to wet periods but only modest changes in variability for the driest periods. The “cool/wet” and “middle” projections show the largest increases in 3-year streamflow, while the “diversity” and “warm/dry” projections indicate the greatest reductions in 3-year streamflow. Similar to annual streamflow, the so-called “warm/dry” projections fall more towards the center of the ensemble of results and produce wetter wet years and some drier dry years as compared to the historical distribution. The “diversity” projection continues to exhibit the lowest 3-year annual streamflow.

Figure 7 shows the 3-year annual natural streamflow exceedance probability curves for historical and future scenarios at the Russian River downstream of the Dry Creek confluence for the period of 2045-2099. Under this later future period, the differences between scenarios is magnified but shows similar relative ordering as the

earlier period. The so-called “middle” projections exhibit the greatest change in streamflow, while the “warm/dry” once again tends toward the actual middle of the distribution.

Figure 6. Projected Changes in 3-Year Annual Russian River Streamflow for Period of 2006-2060.

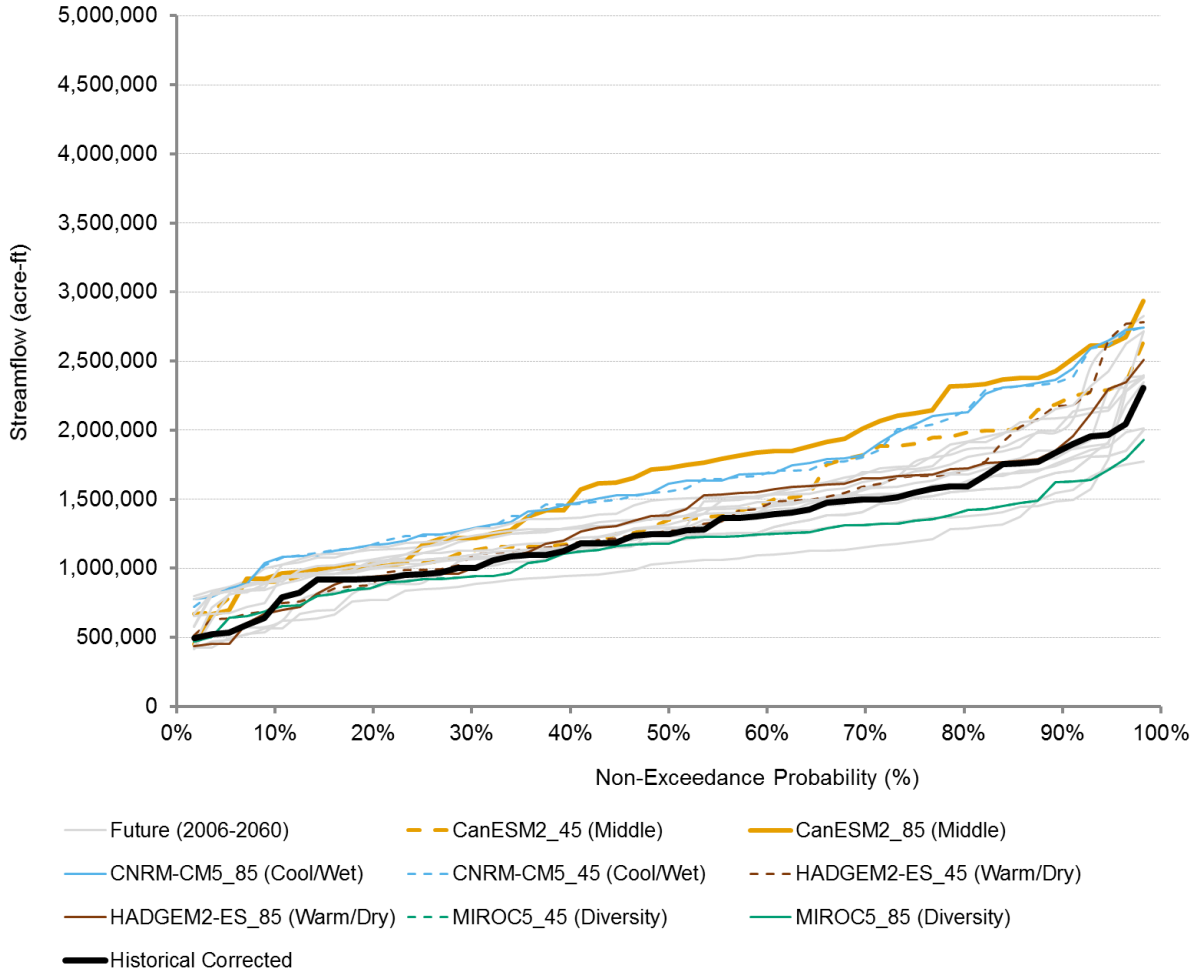
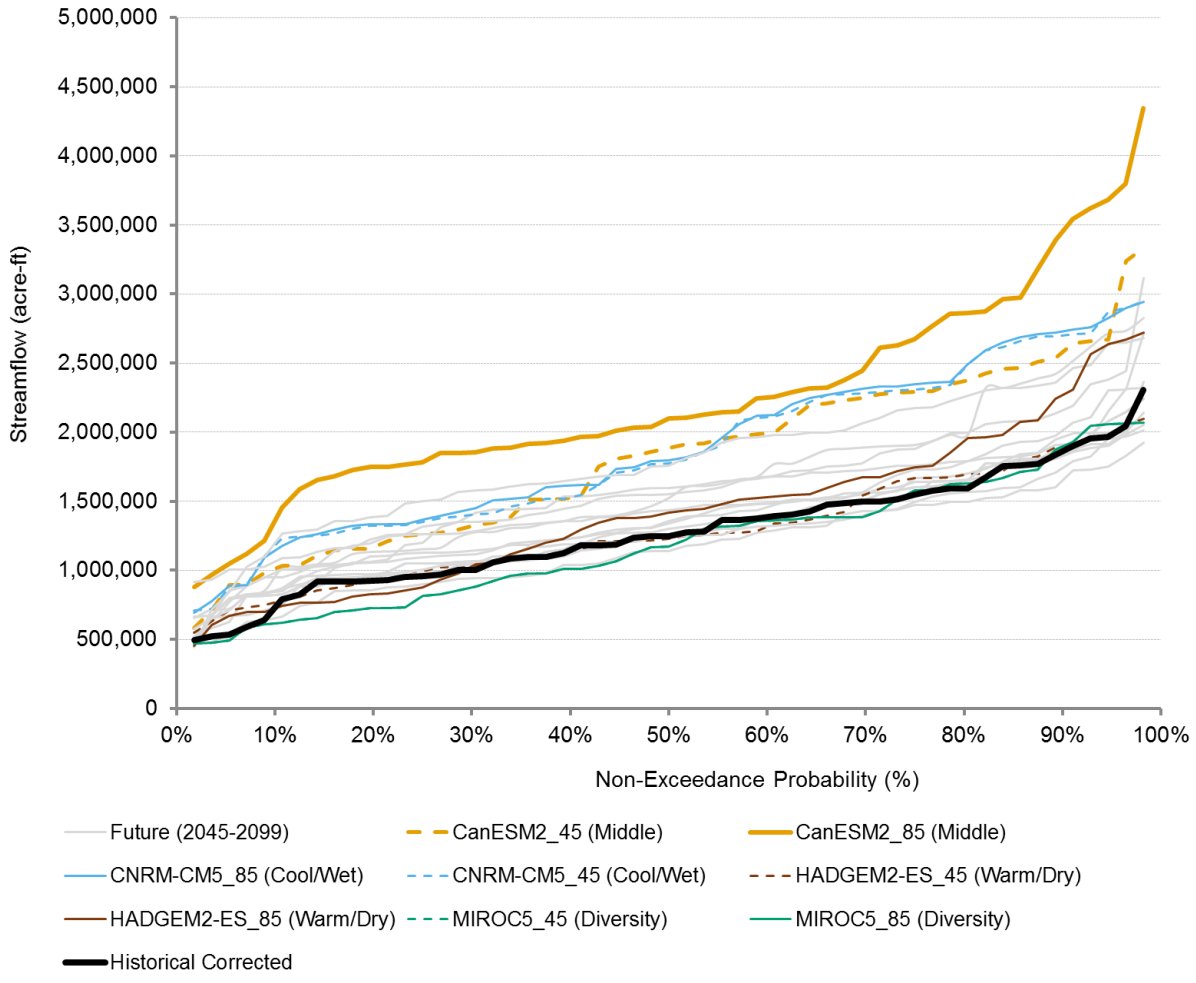


Figure 7. Projected Changes in 3-Year Annual Russian River Streamflow for Period of 2045-2099.



3.4 Projected Changes in Lake Sonoma Storage

Figure 8 shows the end of September storage exceedance probability curves for baseline and future scenarios at Lake Sonoma for the period of 2006-2060. Most future projections project decreases in storage across all exceedance values due to the projected increase in water demand in the basin and by Sonoma Water contractors. Note that the historical projections and “current operations” assume historical water demands. The range of outcomes for the lowest 30-40% of years is driven by the climate projections. Some projections suggest lower storage conditions than that projected under historical operations and indicate a few extreme challenging years.

Figure 9 shows the end of September storage exceedance probability curves for baseline and future scenarios at Lake Sonoma for the period of 2045-2099. Most future projections show decreases in storage across all exceedance values due to the projected increase in water demand in the basin and by Sonoma Water contractors. During this period, most of the projections suggest lower storage conditions than that projected under historical operations and indicate at least 10% of years lower than historical low levels.

Figure 8. Projected End of September Lake Sonoma Storage for Period of 2006-2060.

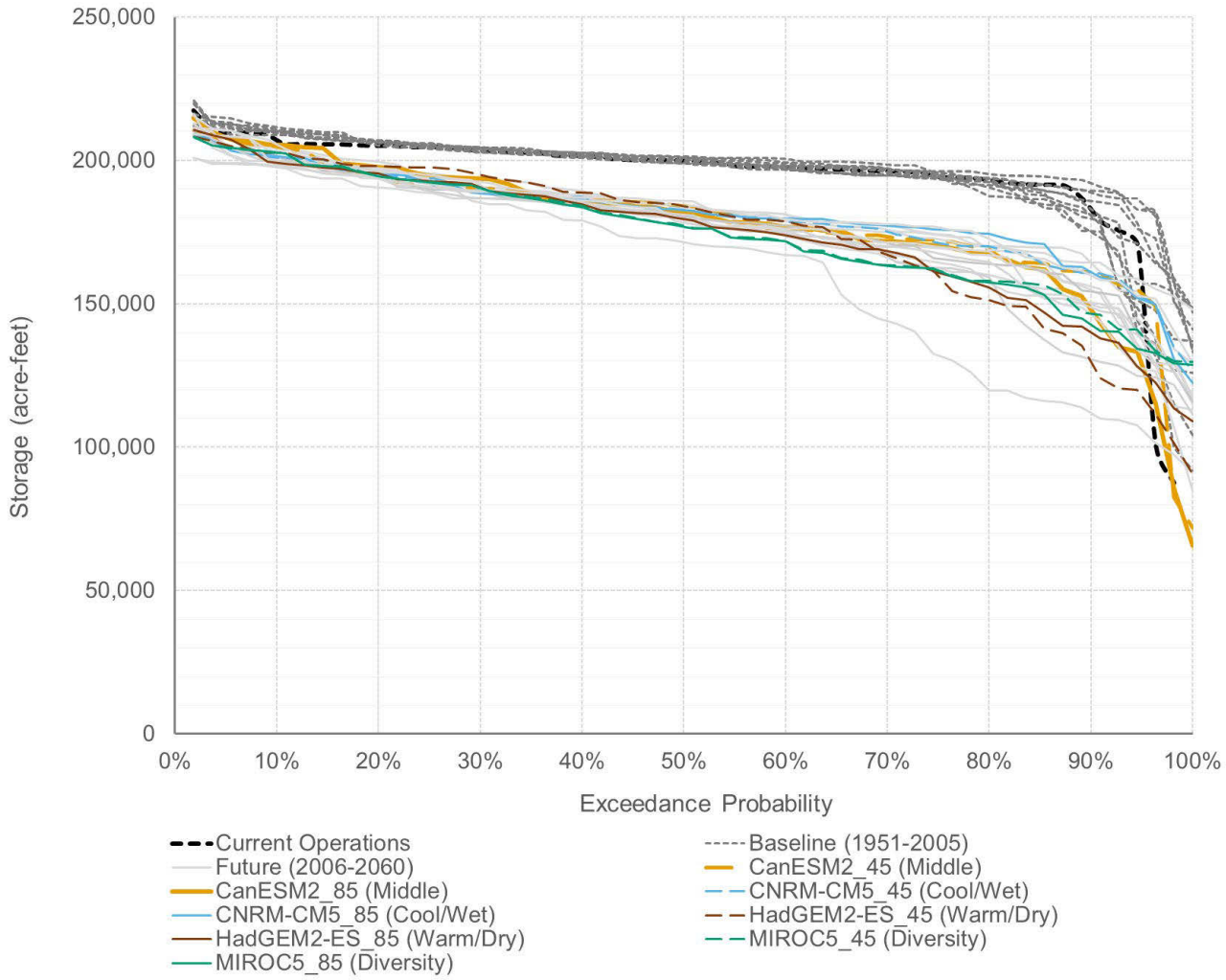
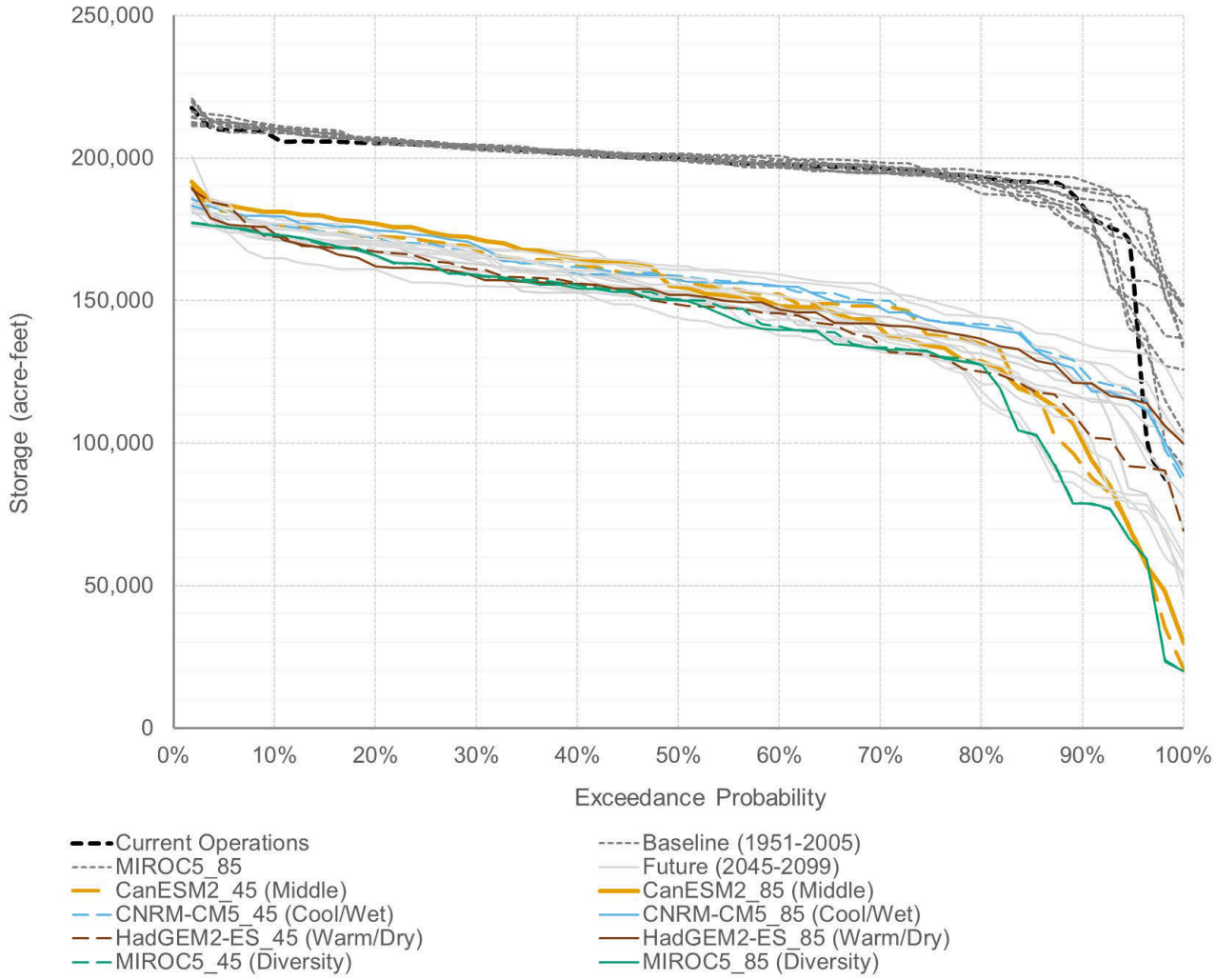


Figure 9. Projected End of September Lake Sonoma Storage for Period of 2045-2099.



3.5 Projected Changes in Sonoma Water Diversion Capability

Figures 10 and 11 show the exceedance probability curves for annual Sonoma Water diversion (acre-feet) under both baseline and future conditions. Due to increase in water demand, the Sonoma Water diversion is increased in all simulations. In general, HEC-ResSim simulations suggest nearly identical results for all GCM model projections which indicates similar delivery capability. The Sonoma Water system appears to be able to adapt to the climate and hydrologic changes projected in the scenarios.

Figure 10. Projected Sonoma Water Annual Diversion Capability for Period of 2006-2060.

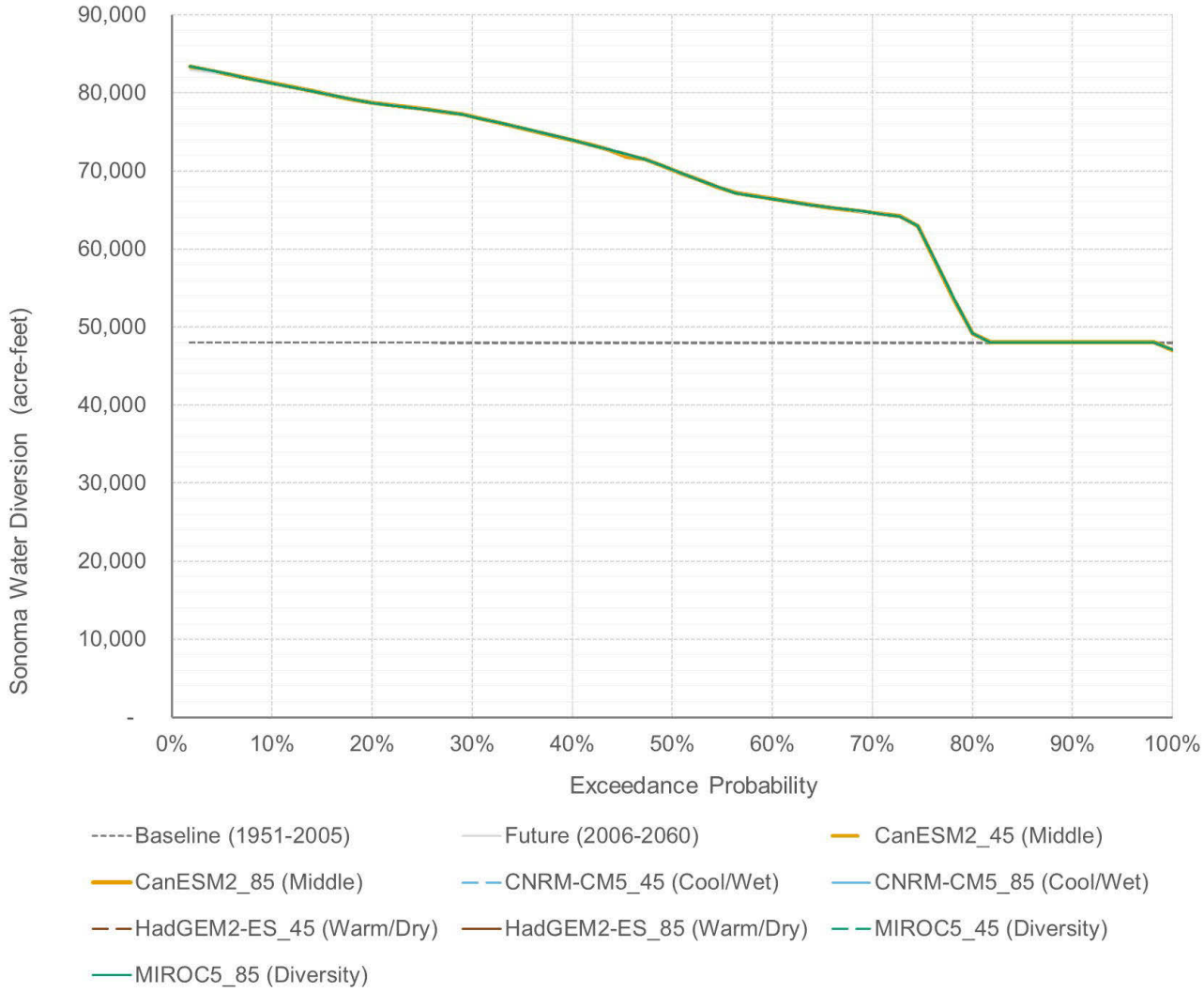
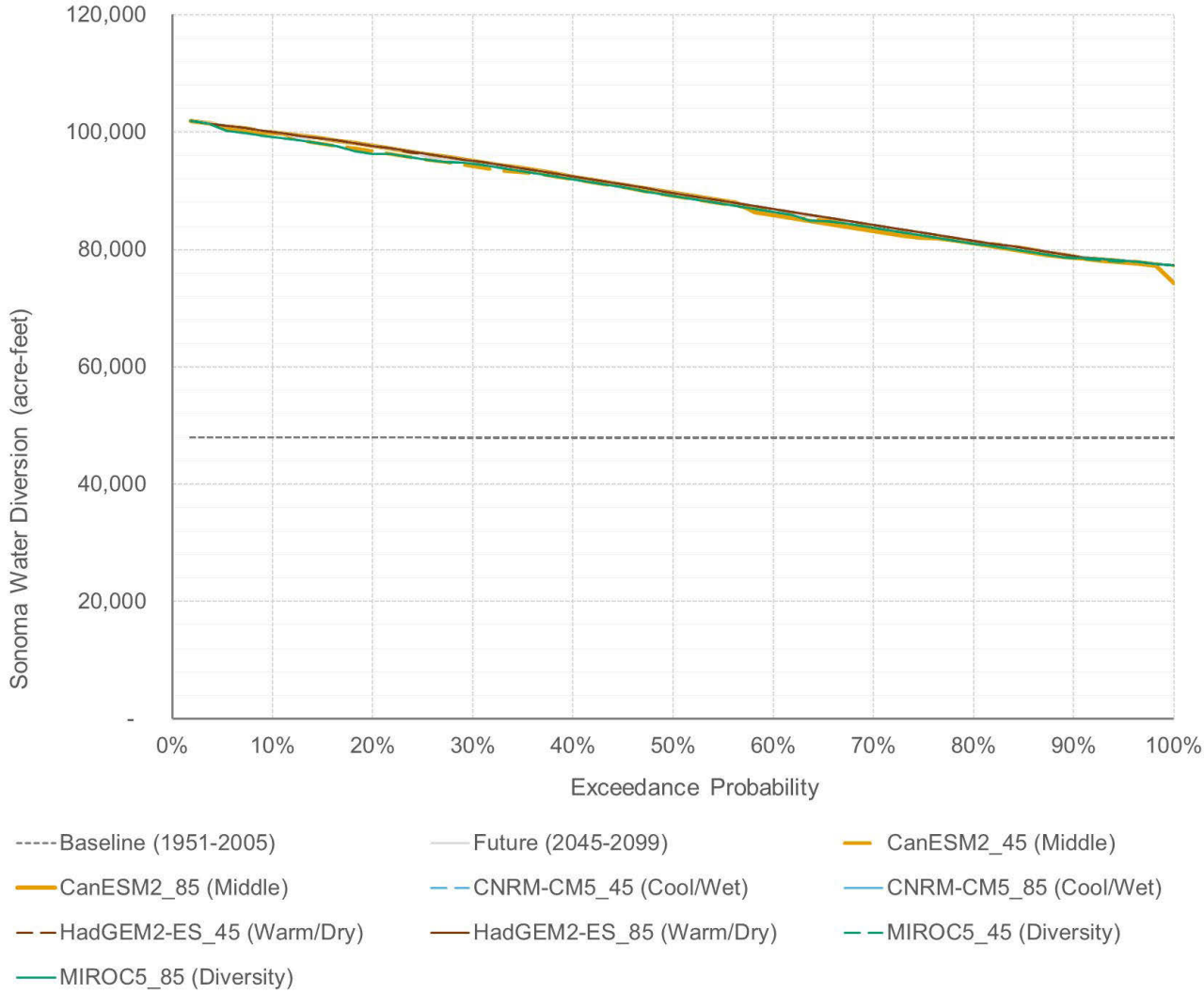


Figure 11. Projected Sonoma Water Annual Diversion Capability for Period of 2045-2099.



4. Scenario Rankings

For each of the climate, hydrologic, and water supply metrics, the model projection rank was determined by ordering the resulting metric values for the 2006-2060 period. A projection that had the largest increase amongst the 20 projections would indicate rank equal to 1, while the largest decrease/smallest increase projection would indicate rank equal to 20. The middle-most projections would indicate rank equal to 9, 10, or 11.

Table 2 shows the resulting rank of each GCM for each metric. Since each GCM includes simulations for both RCP 4.5 and 8.5, two rank values are shown.

The CanESM2 model, indicated by the CA Fourth Climate Change Assessment as "middle", ranks among the warmest, wettest, and highest annual streamflow projections. Similarly, the CNRM-CM5 model ranks among the wettest with high annual streamflow projections compared to the ensemble. Conversely, the CMCC-CMS, HadGEM2-CC, and MIROC5 models rank among the driest of the models when comparing streamflow. The CCSM4, GFDL-CM3, and HadGEM2-ES models rank closest to the middle when comparing the mean climate and hydrologic metrics.

Streamflow variability and storage metrics did not present substantial differentiation between scenarios, and since water diversion was essentially the same for all projections, no rank was assigned for this metric.

Table 2. Rank of GCM (RCP 4.5/8.5) for Metrics Used in this Assessment Based on 2006-2060 Period

GCM	T	P	Q mean (average streamflow)	Q var 1-yr (coefficient of variation of annual streamflow)	Q var 3-yr (coefficient of variation of 3-year annual streamflow)	Lake Sonoma Storage	Sonoma Water Diversion
ACCESS1-0	18/7	14/8	14/5	3/8	1/7	2/9	N/A
CCSM4	15/5	12/9	10/13	1/11	2/9	20/12	N/A
CESM1-BGC	10/14	6/5	6/7	12/17	14/16	1/6	N/A
HadGEM2-CC	20/8	19/16	15/16	15/14	19/18	13/11	N/A
CMCC-CMS	16/6	20/17	20/17	6/13	8/17	18/8	N/A
CNRM-CM5 (Cool/Wet)	17/11	1/2	3/1	19/18	11/10	5/4	N/A
CanESM2 (Middle)	2/1	4/3	4/2	2/7	6/5	7/10	N/A
GFDL-CM3	9/4	7/10	9/11	20/17	20/15	3/19	N/A
HadGEM2-ES (Warm/Dry)	12/3	13/15	15/12	5/4	3/4	16/17	N/A
MIROC5 (Diversity)	19/13	11/18	18/19	10/9	13/12	14/15	N/A

5. Summary and Recommendations

This assessment of projected climate scenarios reviewed important climatic, hydrologic, and water supply metrics that would be used to evaluate the relative performance of individual GCM projections within the Russian River watershed. For basin-wide planning projects and programs, such as the GSPs, for which the use of dozens of individual climate scenarios is not practical, this assessment was intended to inform which scenarios may be used to represent the 20-scenario ensemble and provide realistic climate change evaluations for (groundwater) planning purposes.

Through this assessment, we found that the CanESM2 model, indicated by the CA Fourth Climate Change Assessment as “middle” for the North Coast, ranks among the warmest, wettest, and highest streamflow projections for the Russian River watershed area. Use of this projection to represent the middle of the ensemble is not recommended for the Sonoma County GSPs. The CNRM-CM5 model also ranks among the wettest with high streamflow projections compared to the ensemble.

Conversely, the CMCC-CMS, HadGEM2-CC, and MIROC5 models rank among the driest of the models when comparing streamflow. The MIROC5 model was identified as a “diversity” model in the CA Fourth Climate Change Assessment, and we concur that this GCM includes projections that will likely test water supply and water management the most. This GCM could be considered for providing a “stress test” for Sonoma Water and regional water resource systems.

The CCSM4, GFDL-CM3, and HadGEM2-ES models rank closest to the middle of the ensemble when comparing the mean climate and hydrologic metrics. While the HadGEM2-ES model was identified as a “warm/dry” model in the CA Fourth Climate Change Assessment report, it likely best represents the middle of the ensemble for mean climate and hydrologic metrics for the Russian River watershed. While somewhat arbitrary to select this model from the other middle models, the HadGEM2-ES model did not stray to any of the extremes for other metric rankings. For example, the CCSM4 indicated the highest annual coefficient of variation for streamflow, while the GFDL-CM3 indicated the lowest. The HadGEM2-ES results may suggest that it was “more in the middle” than others, and thus may be appropriate for use in Sonoma County GSP development.

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