BUREAU OF RECLAMATION

Appendix H

Lower American River Water Temperature Modeling Documentation and Results

American River Basin Study
Interior Region 10 – California-Great Basin

Note: This appendix is a record of analysis for the ongoing study (2018 - 2022).
The main report may have updated information that is not reflected in this appendix.

City of Folsom · City of Roseville · City of Sacramento · El Dorado Water Agency · PCWA · Regional Water Authority · Sacramento Area Flood Control Agency

U.S. Department of the Interior

March 2022

American River Basin Study Water Temperature Modeling Documentation and Results

CARDNO, MAY 2020

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List of Acronyms

ATSP	Automated Temperature Selection Procedure
LAR	Lower American River
MET	Meteorological

1.0 INTRODUCTION

This section describes the water temperature modeling for the Existing Conditions 2015, Future Baseline 2070, and Proposed Action options (Alder Creek Reservoir and Conservation Project Sacramento River Diversion Project, and Modified Flow Management Standard) CalSim III model scenarios. The Future Baseline 2070 and Proposed Action options were modeled under three climate change scenarios (2070 Central Tendency, 2070 Hot-Dry, and 2070 Warm-Wet). Water Temperature modeling included modeling the water temperature of inflows to Folsom Reservoir (North Fork American River, South Fork American River), Folsom Reservoir, and the Lower American River (LAR), including Lake Natoma. A total of thirteen climate and hydrology operations scenarios were modeled as shown in Table 1.

Table 1. Summary of Water Temperature Modeling Scenarios

Model Run	2015 Level of Development	2070 Central Tendency	2070 Hot-Dry	2070 Warm-Wet
Existing Conditions 2015	X	-	-	-
Future Baseline 2070	-	X	X	X
Alder Creek Reservoir and Conservation Project	-	X	X	X
Sacramento River Diversion Project	-	X	X	X
Modified Flow Management Standard	-	X	X	X

2.0 METHODS

2.1 Hydrologic Scenario Inputs

The thirteen CalSim III hydrology operations scenarios were provided by Stantec. The period of record was October 1920 through September 2015. Monthly average flows from the CalSim III runs were used to generate daily average flow inputs to the water temperature models. Daily flows were constant for the month and equivalent to the CalSim III monthly average flows, except a five day linear interpolation transition period at each month transition was used to avoid dramatic (instantaneous) daily flow changes in the inflows and outflows to Folsom Reservoir. The water temperature models were run from January 1, 1922 through September 30, 2015.

Exceedance graphs of end-of-month Folsom Reservoir storage for January through December for each of the CalSim III model scenarios (Table 1) is provided in Figure 1. Figure 2, Figure 3, and Figure 4 provide the same exceedance graphs, but separated and grouped for the for Central Tendency, Hot-Dry and Warm-Wet Climate change scenarios, respectively.

2.2 Meteorological Inputs

The meteorological datasets used with the water temperature models are discussed in the following sections.

2.2.1 Historical Meteorological Data Set

Historical hourly meteorological (MET) data from the vicinity of Folsom Reservoir for the 1922-2015 model period were compiled from various stations within about 30 miles of the reservoir and, where appropriate, adjusted (scaled) to the Fair Oaks California Irrigation Management Information System (CIMIS) 131 station for air temperature, and dew point temperature; Mather AFB station for cloud cover; and Folsom (FLD) / Dyke 8 (FLSC1) station for wind speed. A full summary of the process of selecting stations, processing the data, and applying corrections to better match historical conditions at Folsom Reservoir is provided in Attachment A.

2.2.2 2015 and 2070 Climate Change Scenarios

2015 and 2070 climate model datasets (monthly minimum and maximum air temperature) were provided by Stantec. The Stantec air temperature data sets were used to apply a correction to the historical MET data used in the water temperature models in order to simulate anticipated climate change in 2070. The climate model 2015 and 2070 air temperature data were imported into Excel and the monthly average air temperature was calculated using the average of the monthly minimum and maximum temperatures. The difference in monthly air temperature between the 2015 and 2070 climate model runs was then calculated.

The historical MET dataset was then adjusted for 2070 climate change by adding the difference in monthly average air temperature to the hourly temperatures. This was done for each of the 2070 climate change options (Central Tendency, Hot-Dry, Warm-Wet). To apply the monthly air temperature adjustments to the hourly data, the monthly adjustments were interpolated between the mid-point of each month.

In addition to adding a climate change modification to historical MET air temperature data to simulate 2070 climate, the dew point temperature was also recalculated based on the climate change modified air temperatures. This was done using a formula that that links air temperature, dew point, and relative humidity.[1]

Relative humidity, wind speed, wind direction, solar radiation and cloud cover were not modified from historical for the 2070 climate change scenarios because data were not available for these parameters.

2.3 Folsom Reservoir Inflow Water Temperature Model

A multiple regression water temperature model was developed to estimate North Fork American River inflow temperatures for the hydrology model scenarios using a 15-year dataset of (1) daily air temperature; (2) daily North Fork American River flow (above confluence with the Middle Fork); and (3) daily Middle Fork American River flow. A full description of the development of this regression, as well as measured data versus regression data comparisons are provided in Attachment B.

Another multiple regression model was developed to estimate South Fork American River inflow temperatures for the model scenarios using a 15-year dataset of (1) daily air temperature; and (2) daily South Fork American River flow. A full description of the development of this regression, as well as measured data versus regression data comparisons, is provided in Attachment B.

Minor tributaries and local inflows were not explicitly modeled in CalSim III, and therefore no local inflow temperature calculation was necessary.

2.4 Folsom Reservoir CE-QUAL-W2 Model

A CE-QUAL-W2 hydrodynamic and temperature model was developed for Folsom Reservoir to be used in conjunction with regression models for the LAR that calculate daily average (and daily maximum) water temperature at Hazel Avenue, William B Pond Recreation Area, and Watt Avenue. This allows for an iterative approach to be used where the CE-QUAL-W2 reservoir model seeks the best Automated Temperature Schedule Procedure (ATSP) schedule[2] that can be achieved given each year's hydrologic and meteorological conditions. A description of the CE-QUAL-W2 reservoir temperature model development and calibration is provided in Attachment C.

2.5 Lower American River Water Temperature Models

Multiple regression water temperature models were developed to predict water temperatures at Hazel Avenue, Watt Avenue and at any river mile along the LAR for the hydrology model

1 Dew Point Temperature is calculated using the relationship outlined in Singh (1992) Elementary Hydrology

$$RH = \left[\frac{112 - 0.1T + T_d}{112 + 0.9T}\right]^8$$ where RH= Relative Humidity (%) T= Air Temperature (°C) T_d= Dew Point Temperature (°C)

2 The iterative temperature modeling approach in the Water Forum's American River Flow Management Standard balances the seasonal use of Folsom Reservoir's coldwater availability and provides the best attainable temperature in the lower American to protect juvenile steelhead over-summer rearing while balancing the needs of fall-run Chinook salmon spawning.

scenarios using a 10 year calibration and 7 year validation data set of (1) daily air temperature; (2) daily average LAR flow; (3) daily average water temperature below Folsom Dam; and (4) river mile location (for the rivermile regression). A full description of the development of these regressions, as well as measured data versus regression data comparisons are provided in Attachment D. Only results from the Watt Avenue regression are presented in this document.

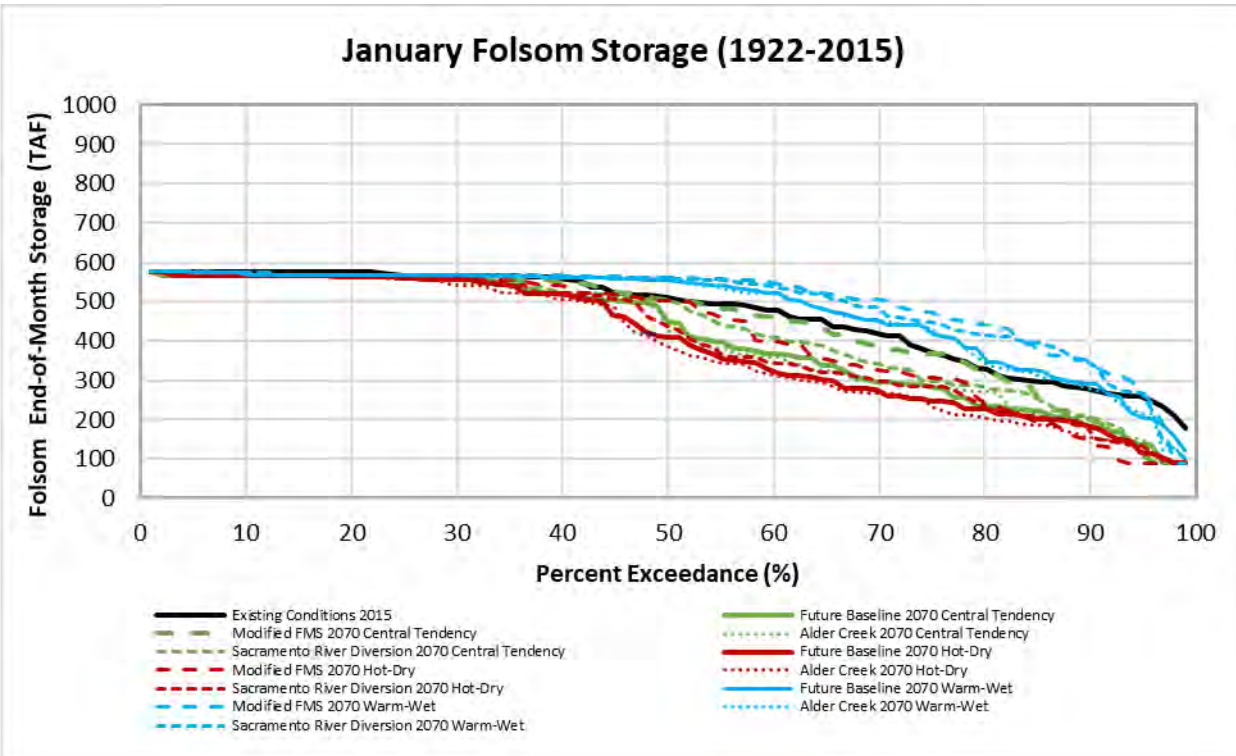
3.0 RESULTS

3.1 Water Temperature Model

Monthly exceedance plots of average daily temperature at Watt Avenue for all thirteen scenarios are provided in Figure 5. Figure 6, Figure 7, and Figure 8 provide the same exceedance plots, but separated and grouped for the Central Tendency, Hot-Dry and Warm-Wet climate change scenarios, respectively.

Figure 9, Figure 10, Figure 11, and Figure 12 show plots of the relationship between July storage and annual maximum 7-day average temperature at Watt Avenue for the (1) Existing Condition 2015 scenario; (2) Future Baseline and Modified FMS - Central Tendency 2070 climate change scenarios; (3) Future Baseline and Modified FMS - Hot-Dry 2070 climate change scenarios; and (4) Future Baseline and Modified FMS - Warm-Wet climate change scenarios, respectively.

4.0 FIGURES



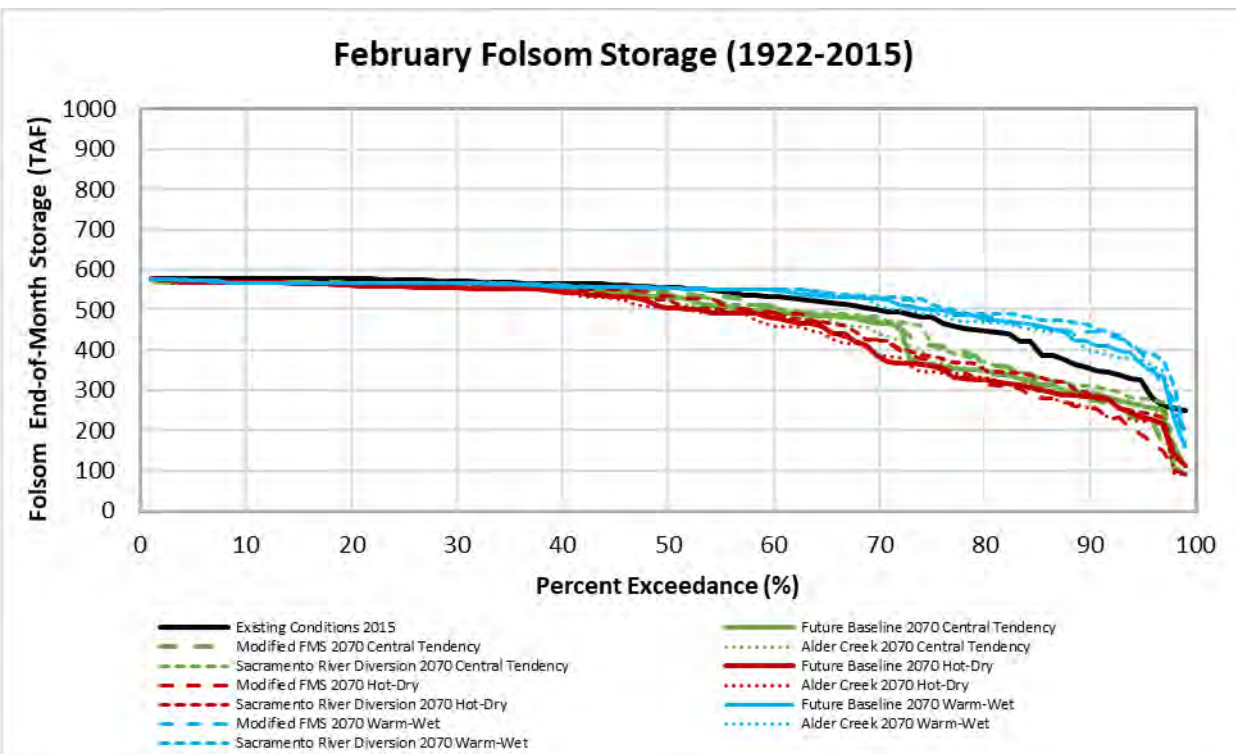
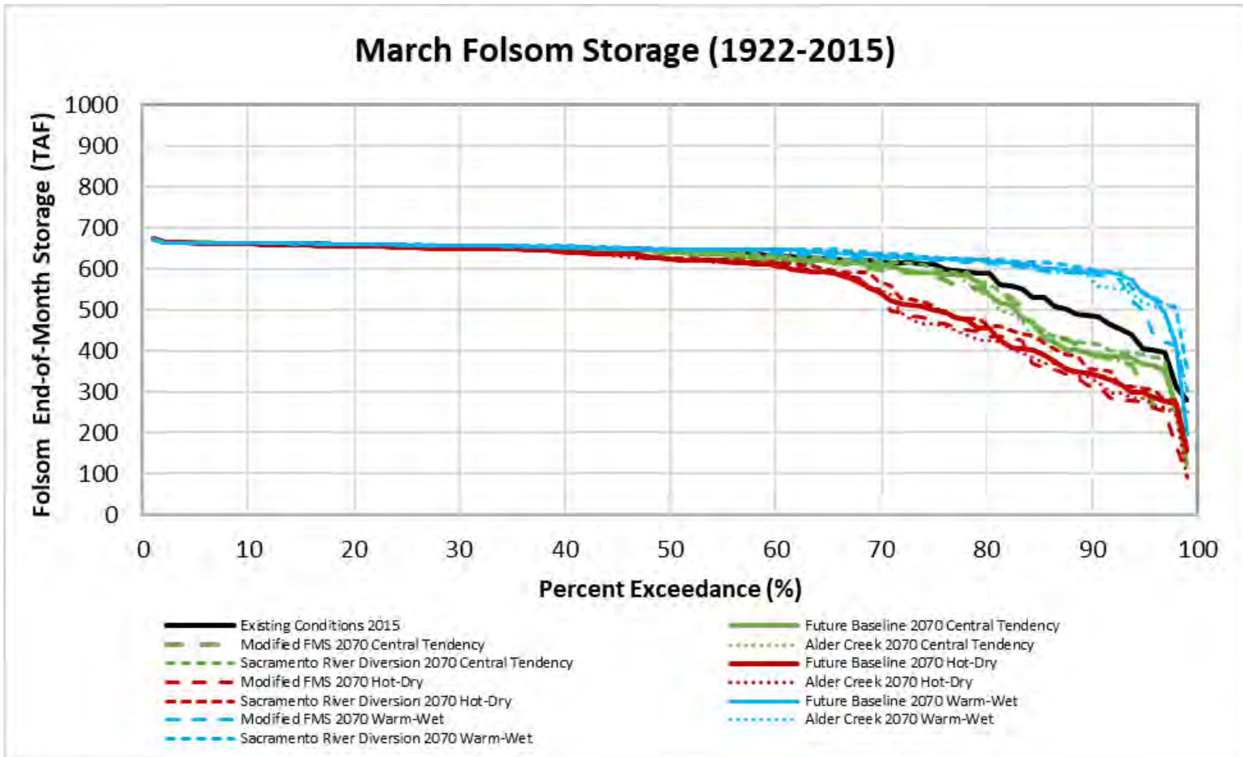
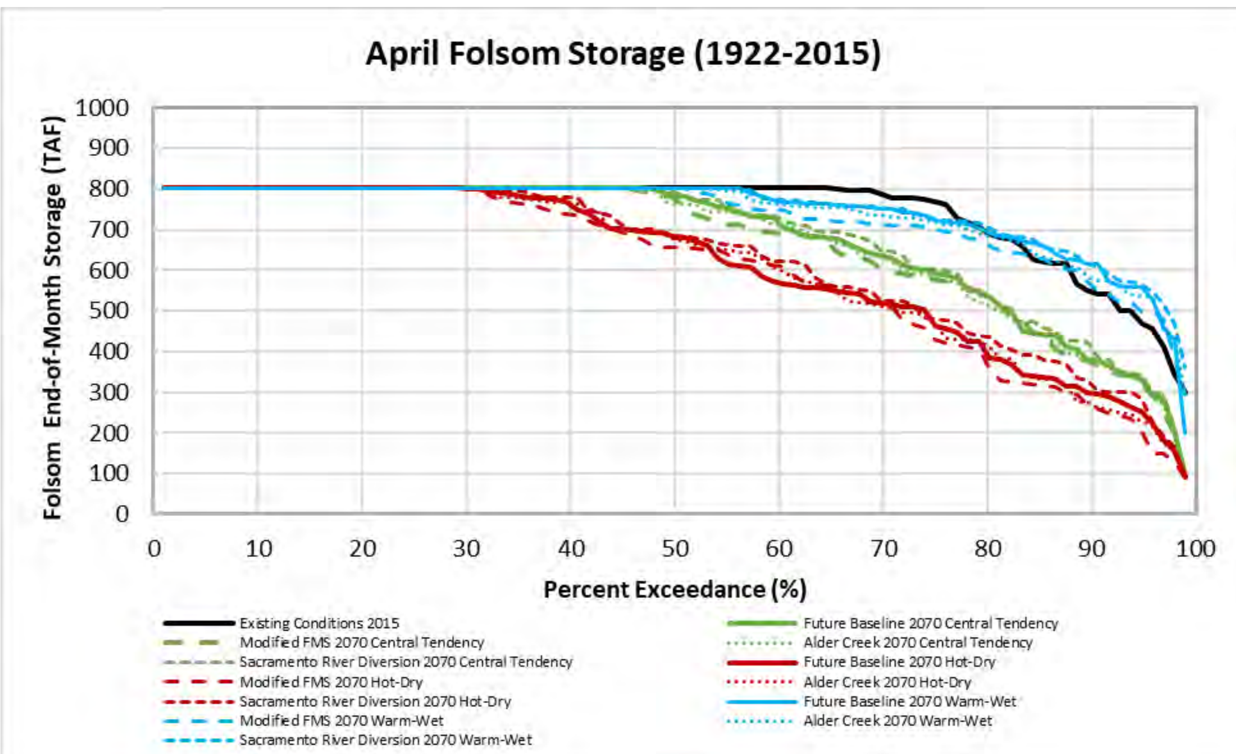


Figure 1. Folsom End-of-Month Storage for all Scenarios





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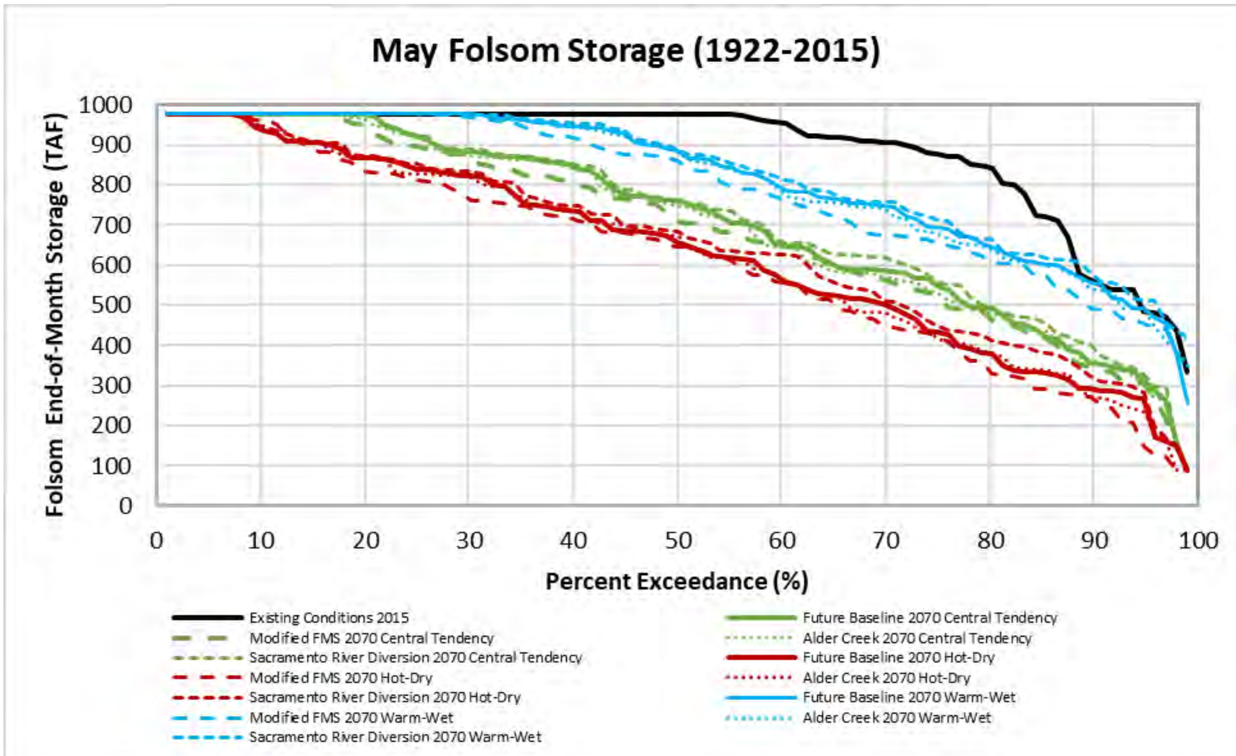

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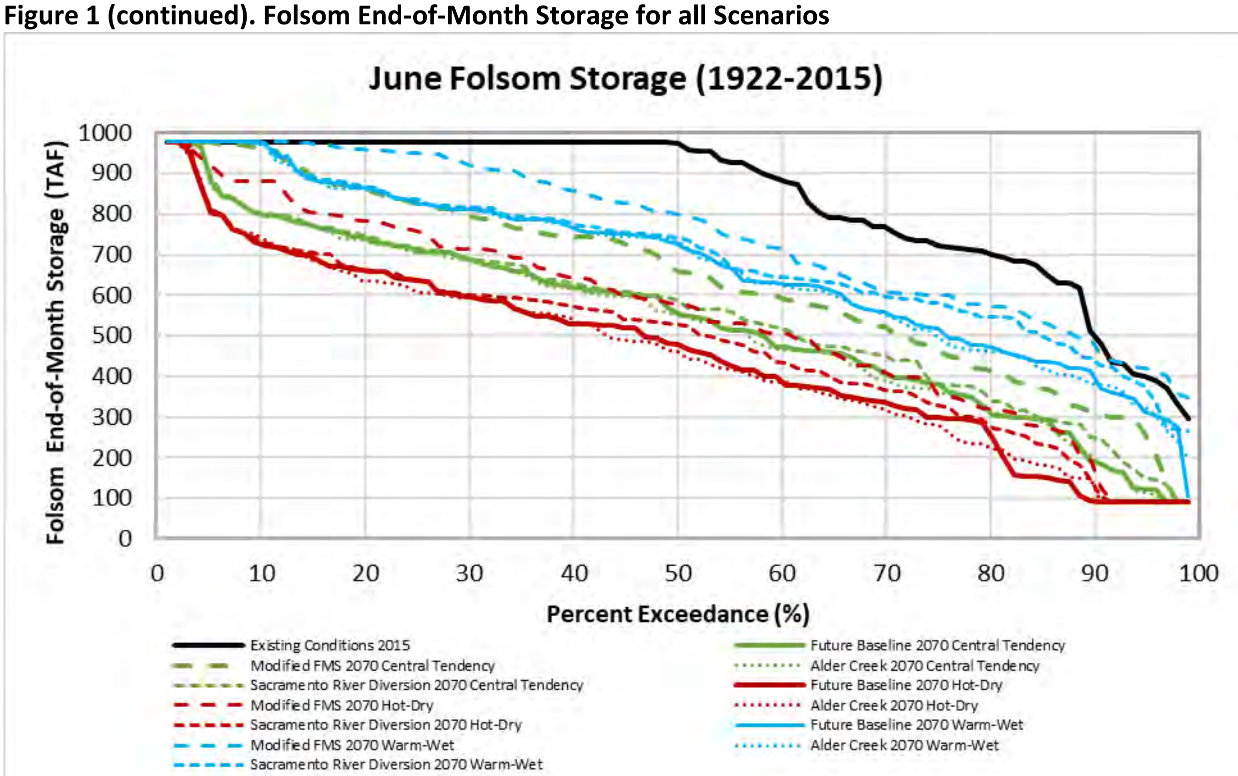

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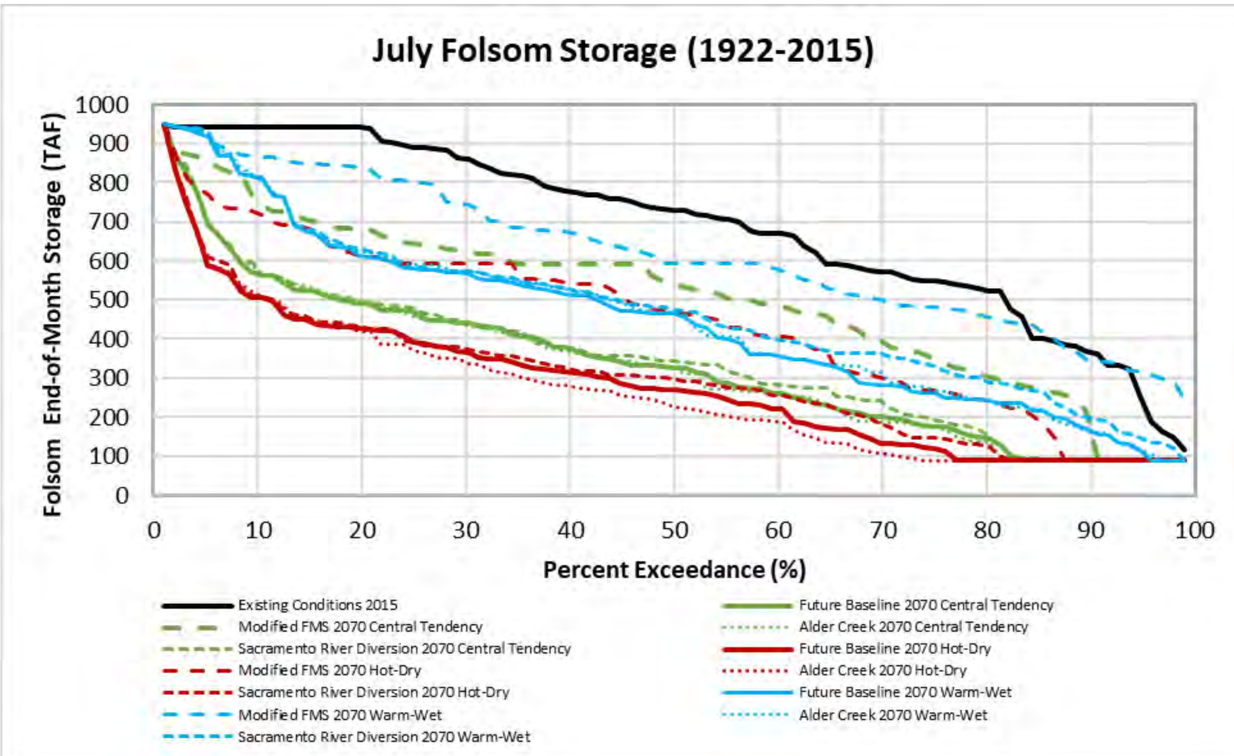

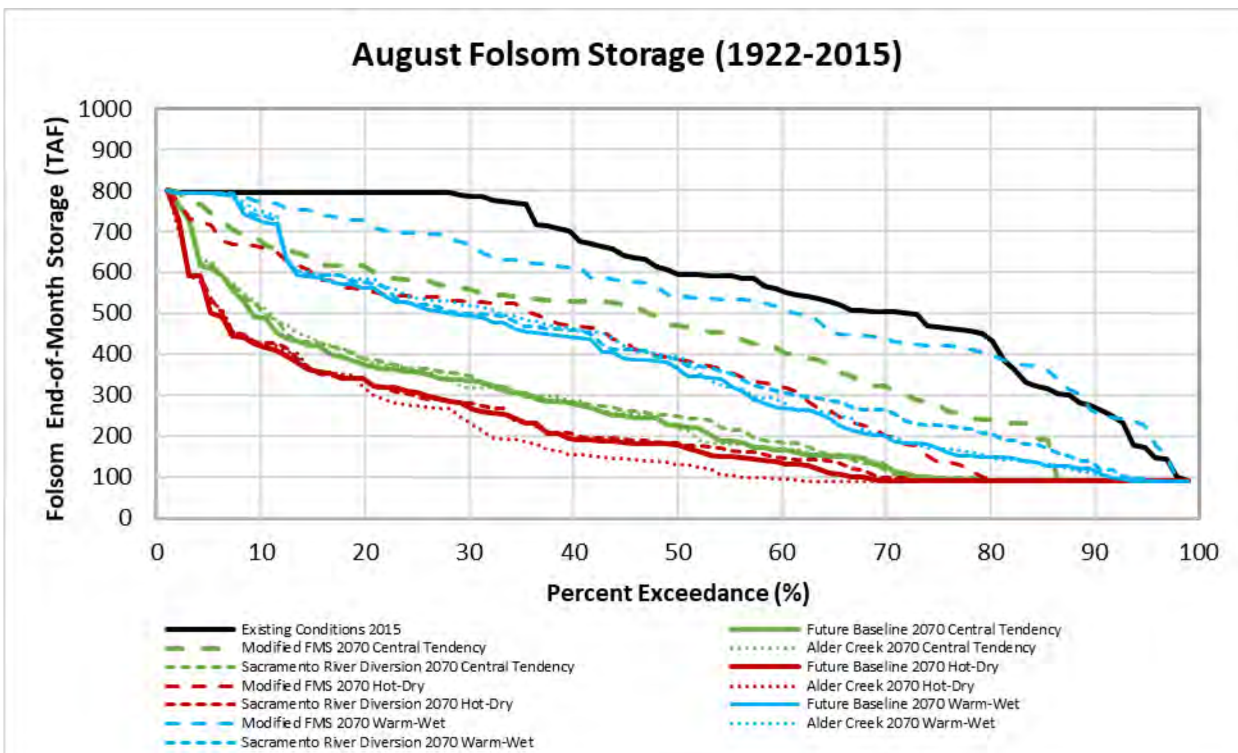

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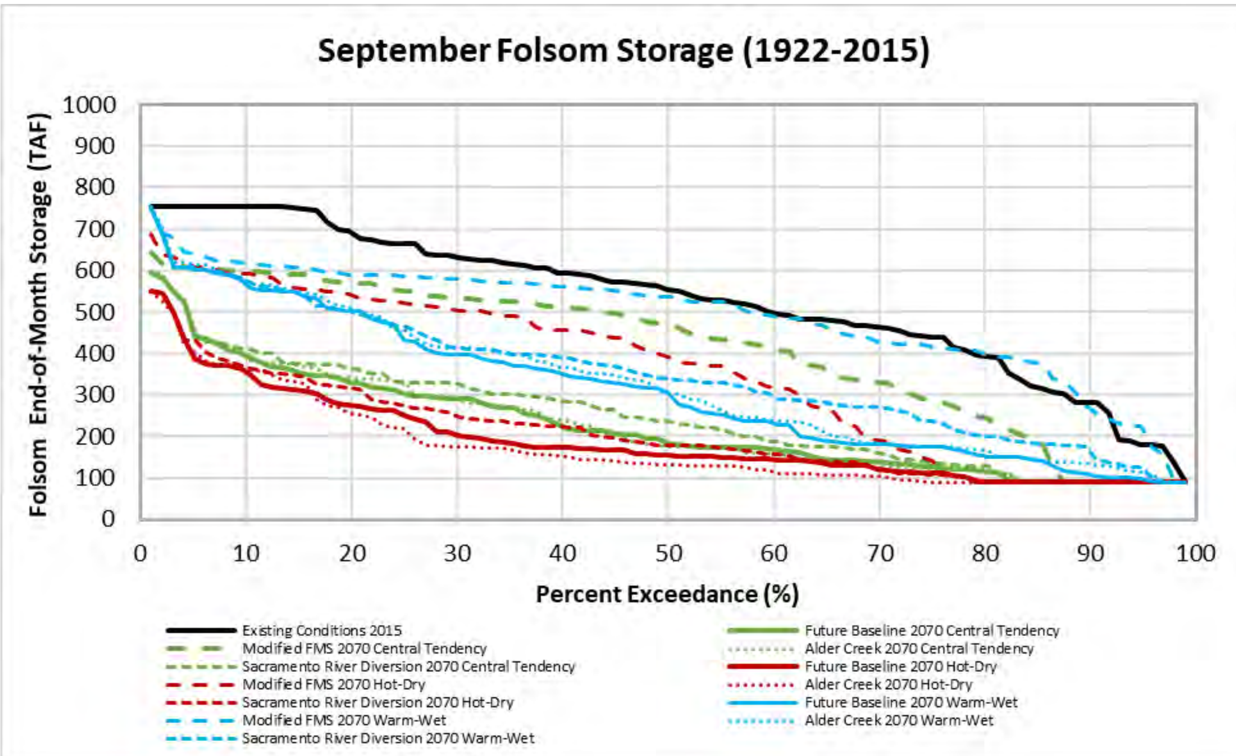

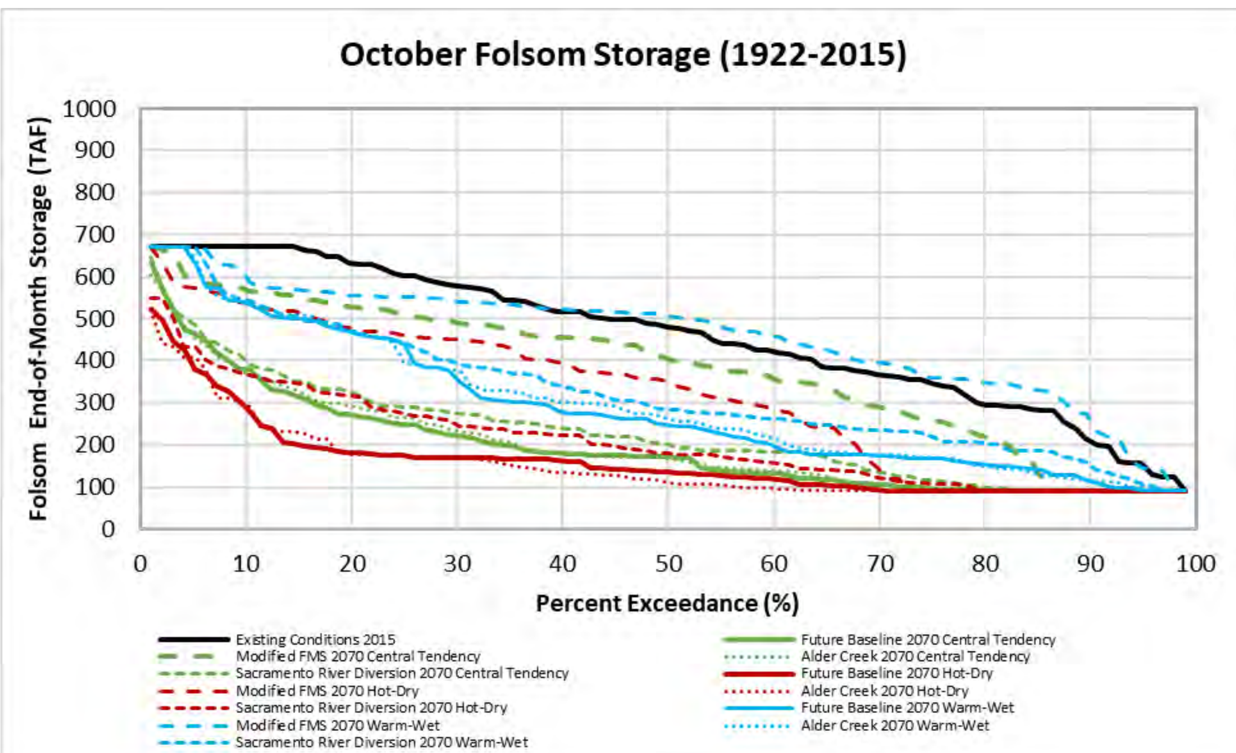

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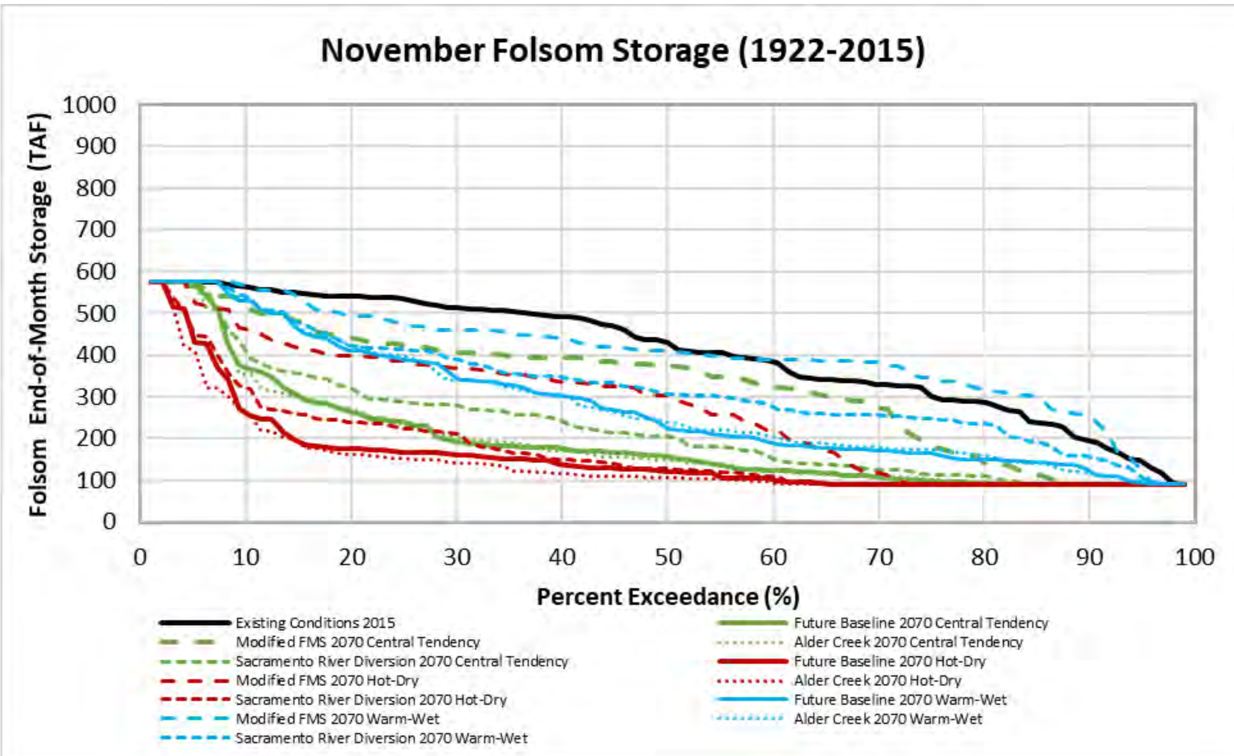

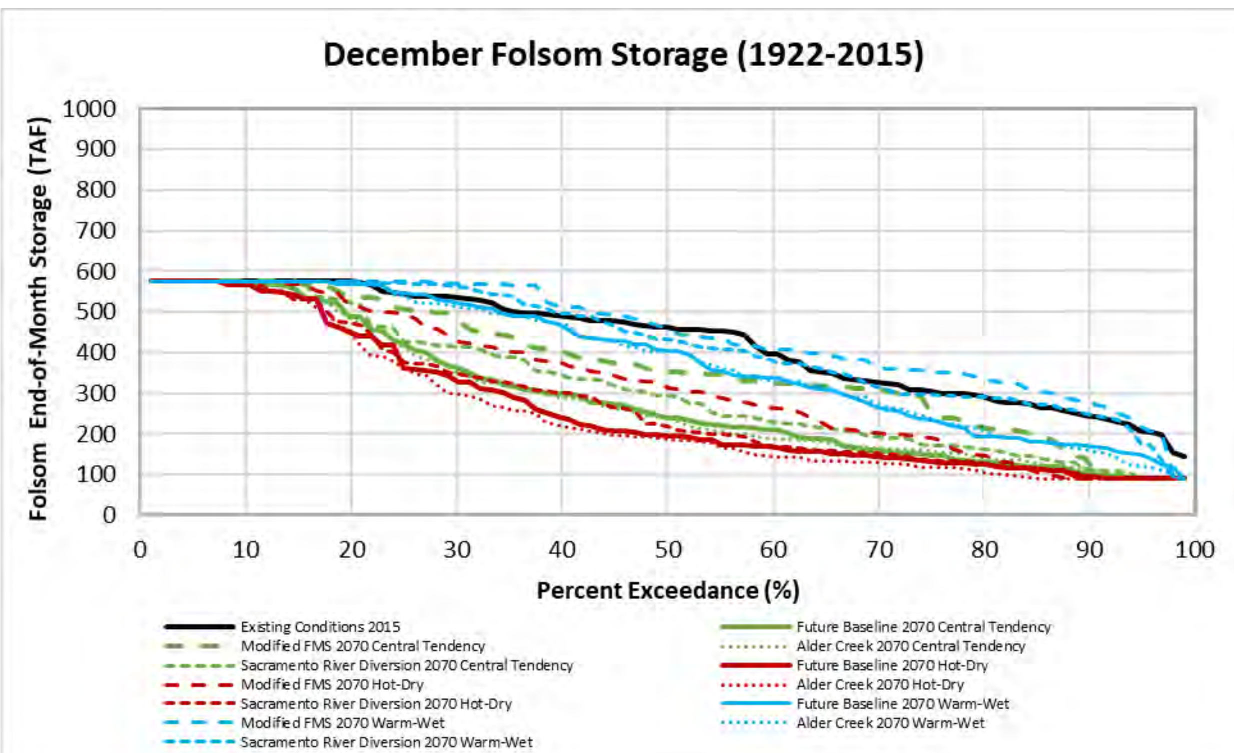

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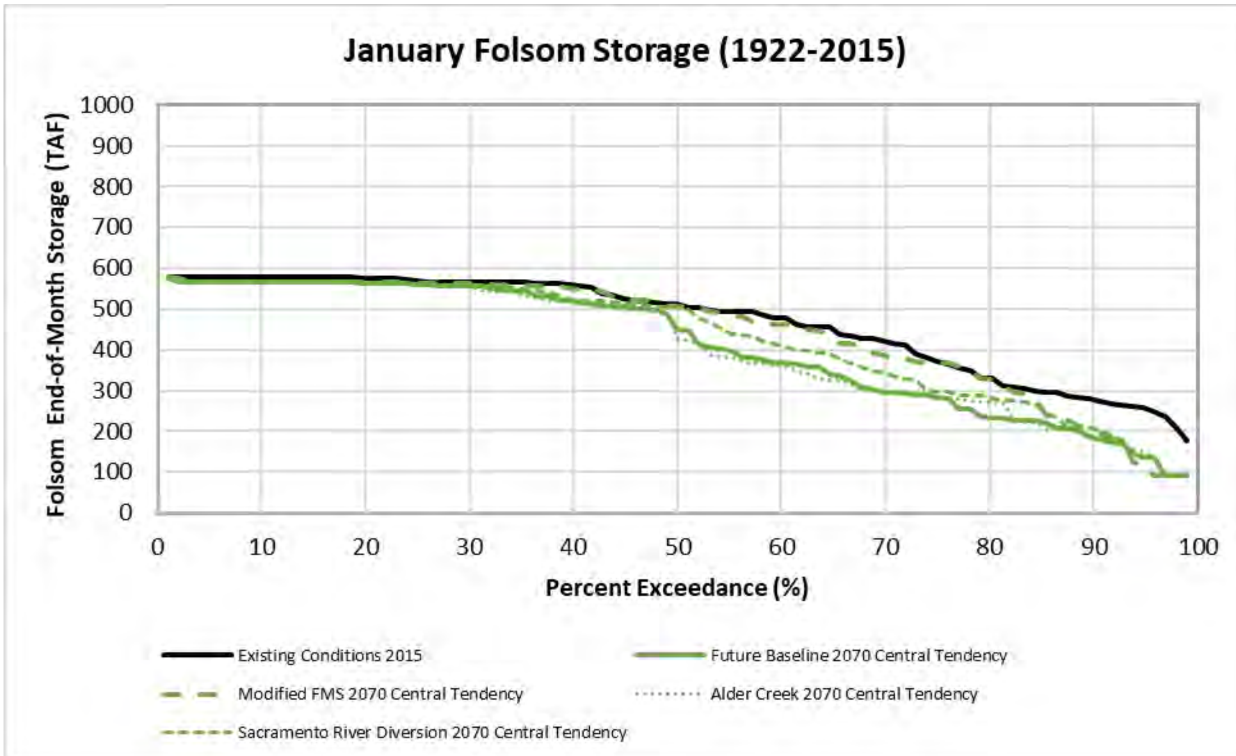


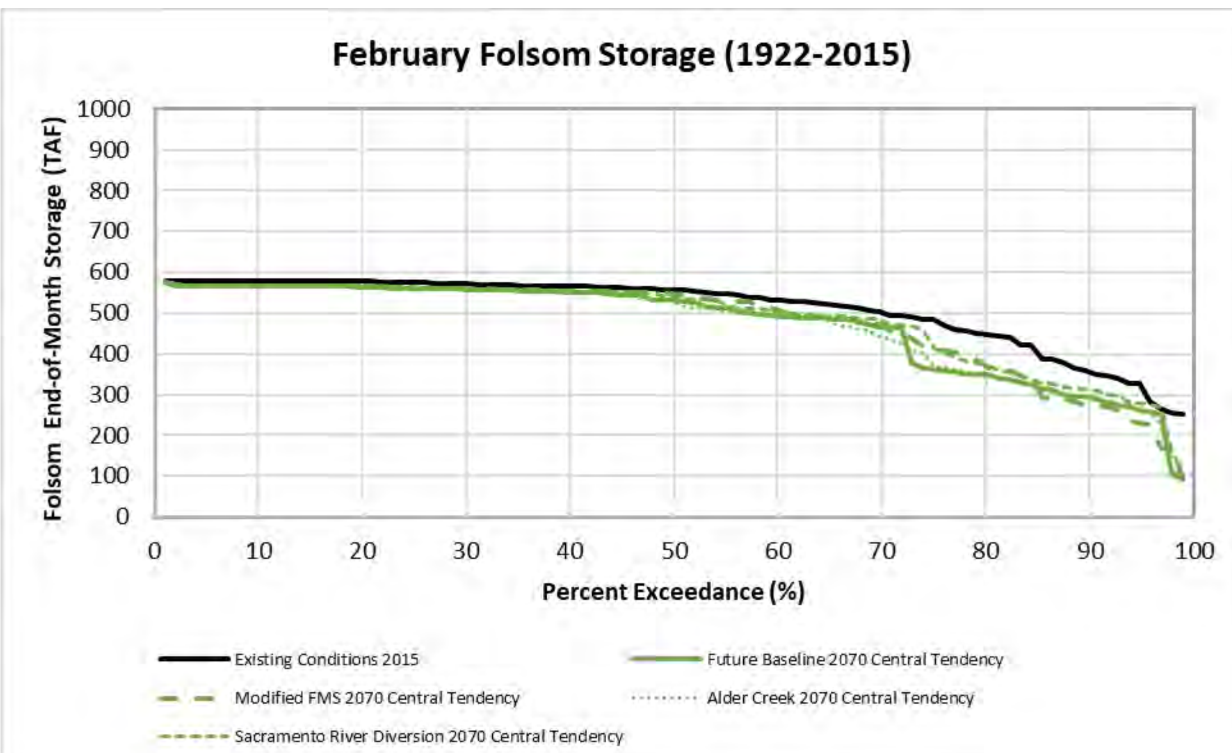
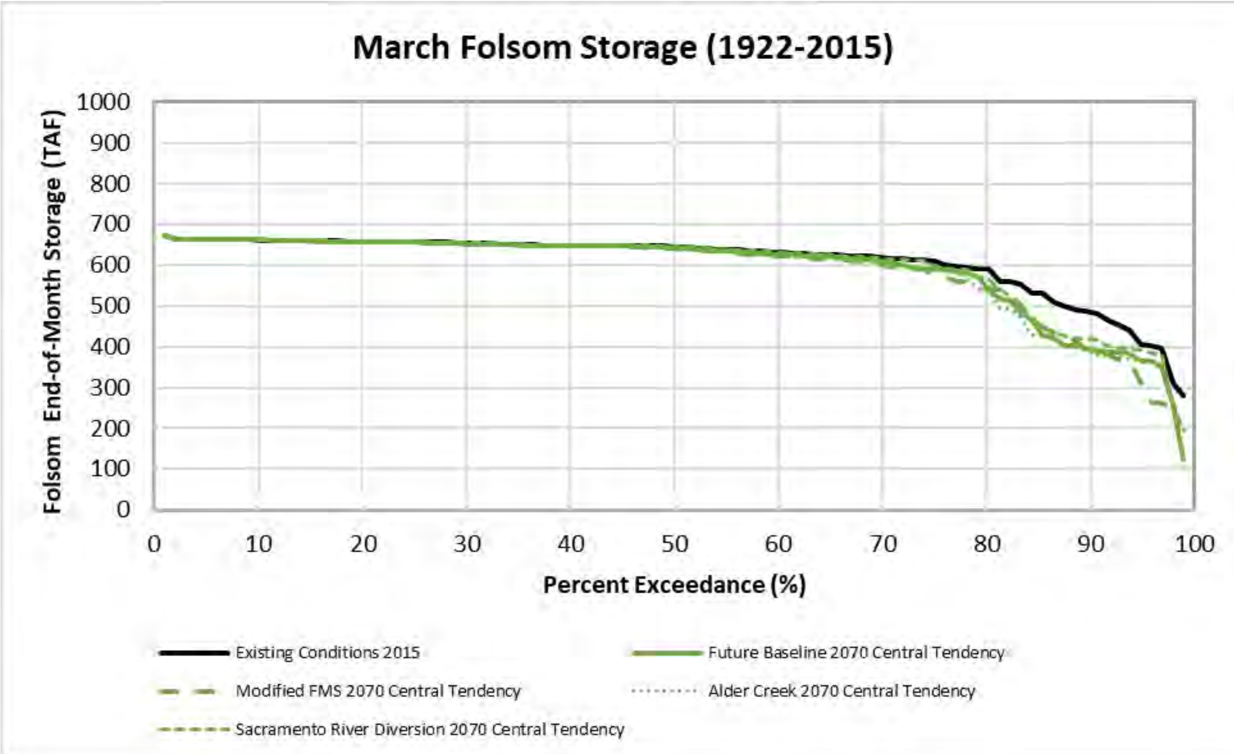
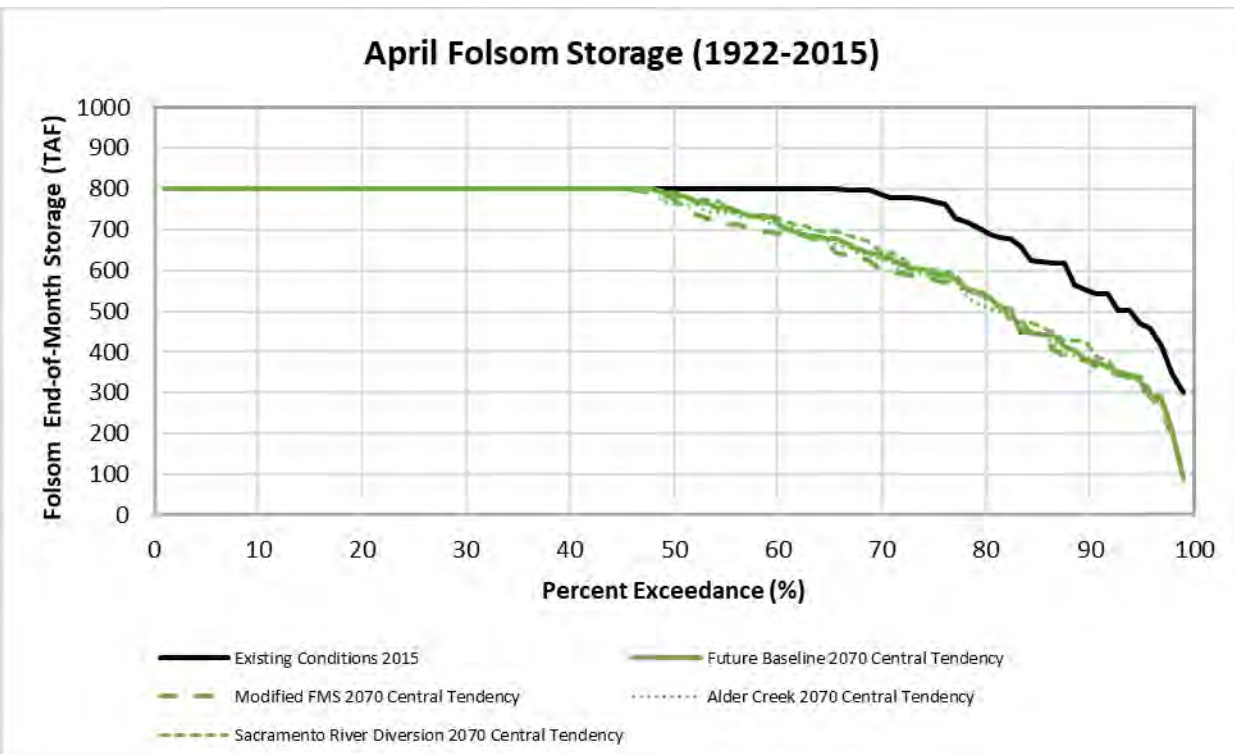


Figure 2. Folsom End-of-Month Storage for Central Tendency Climate Change Scenarios





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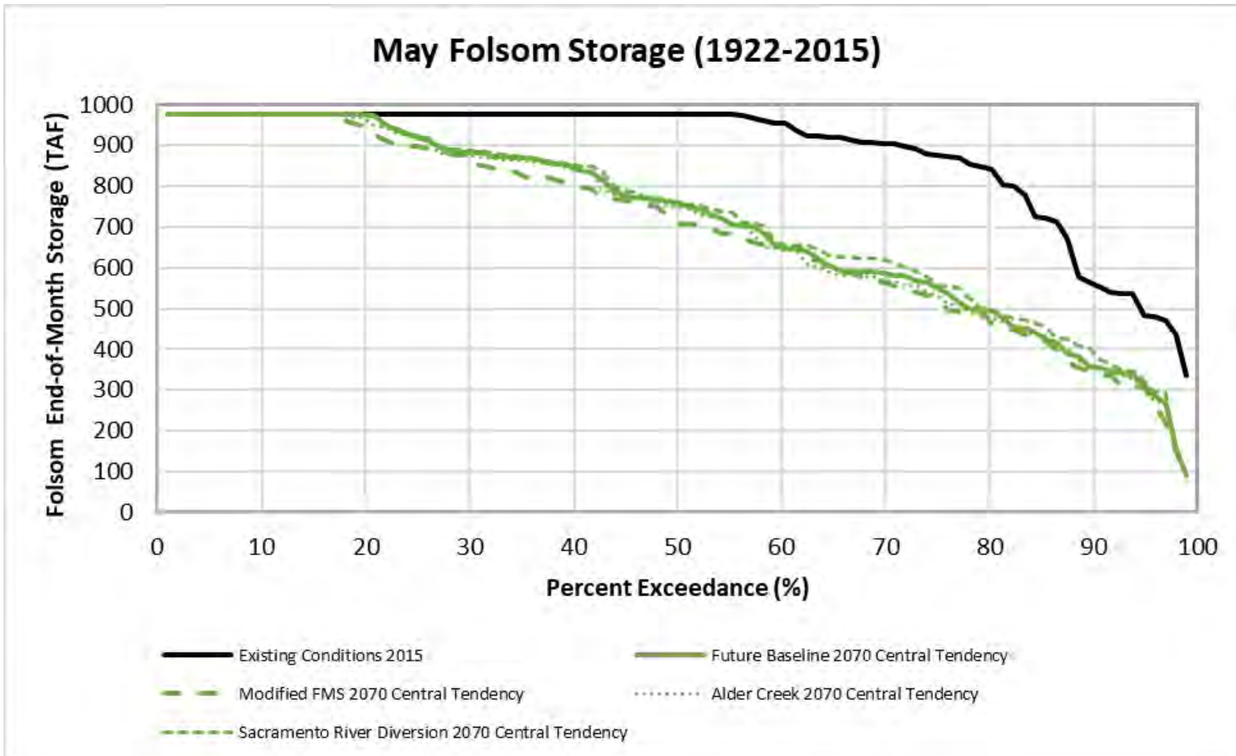

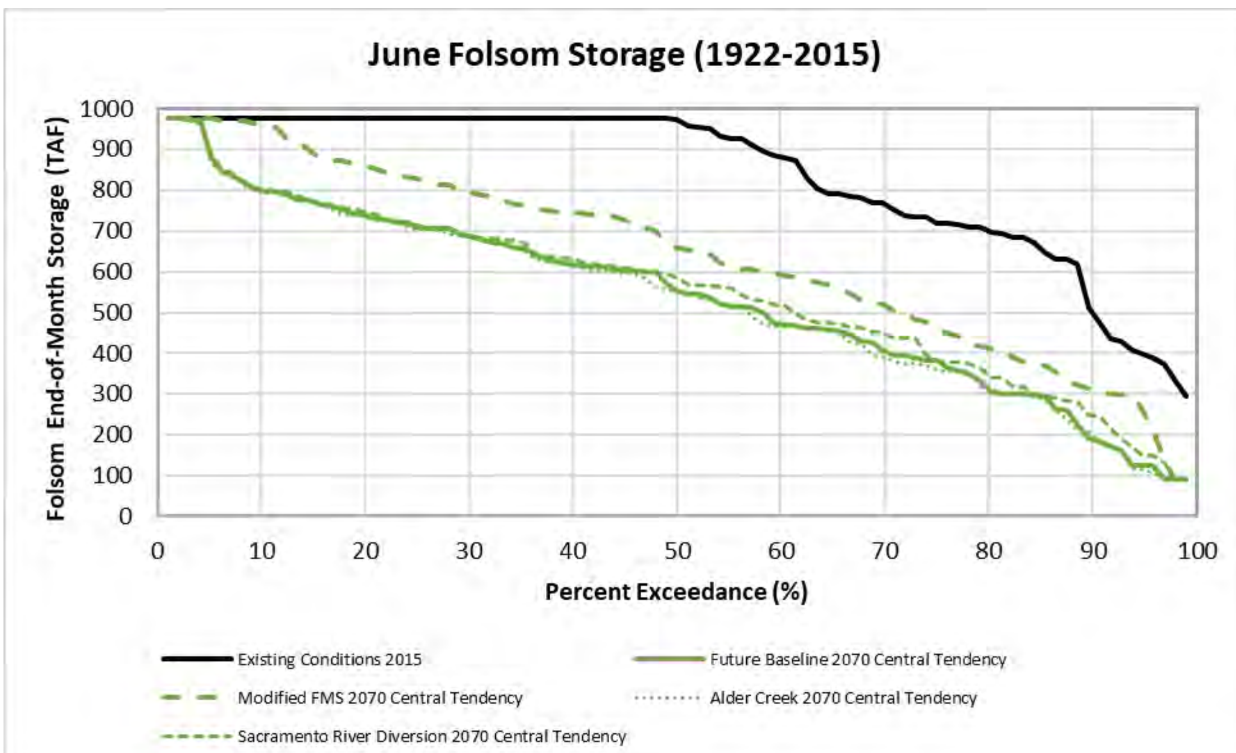

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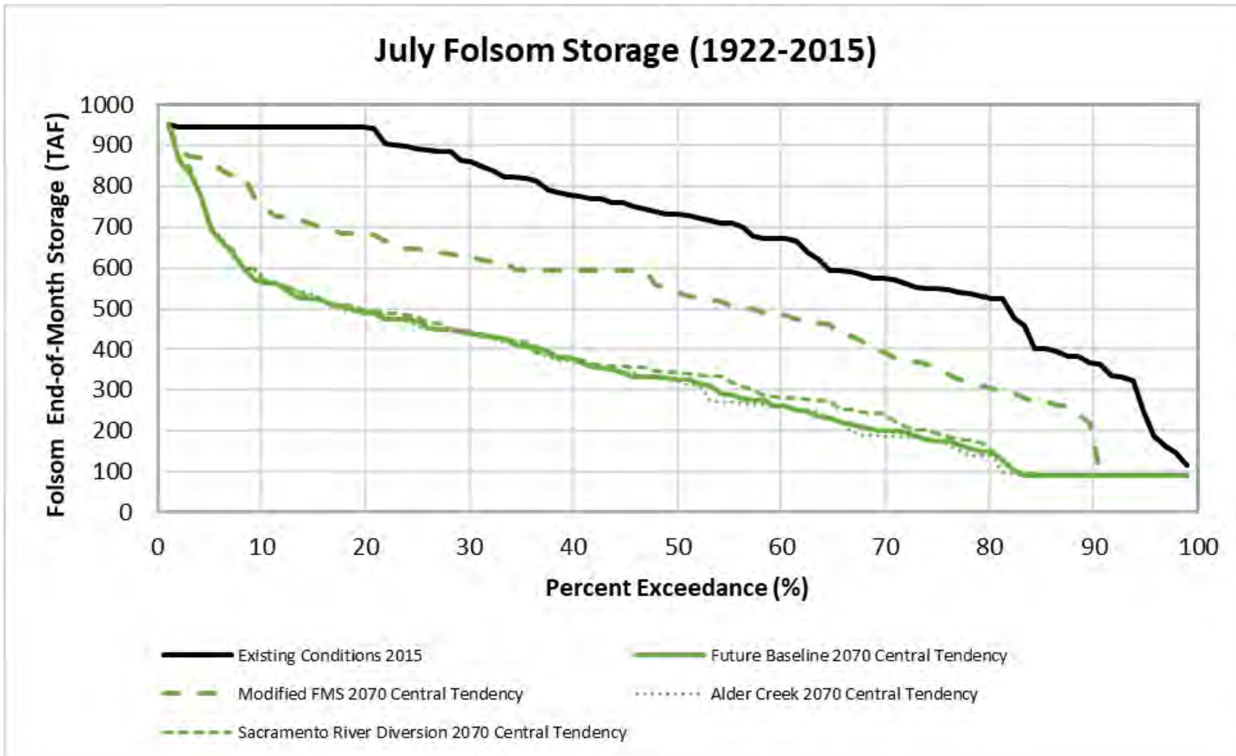

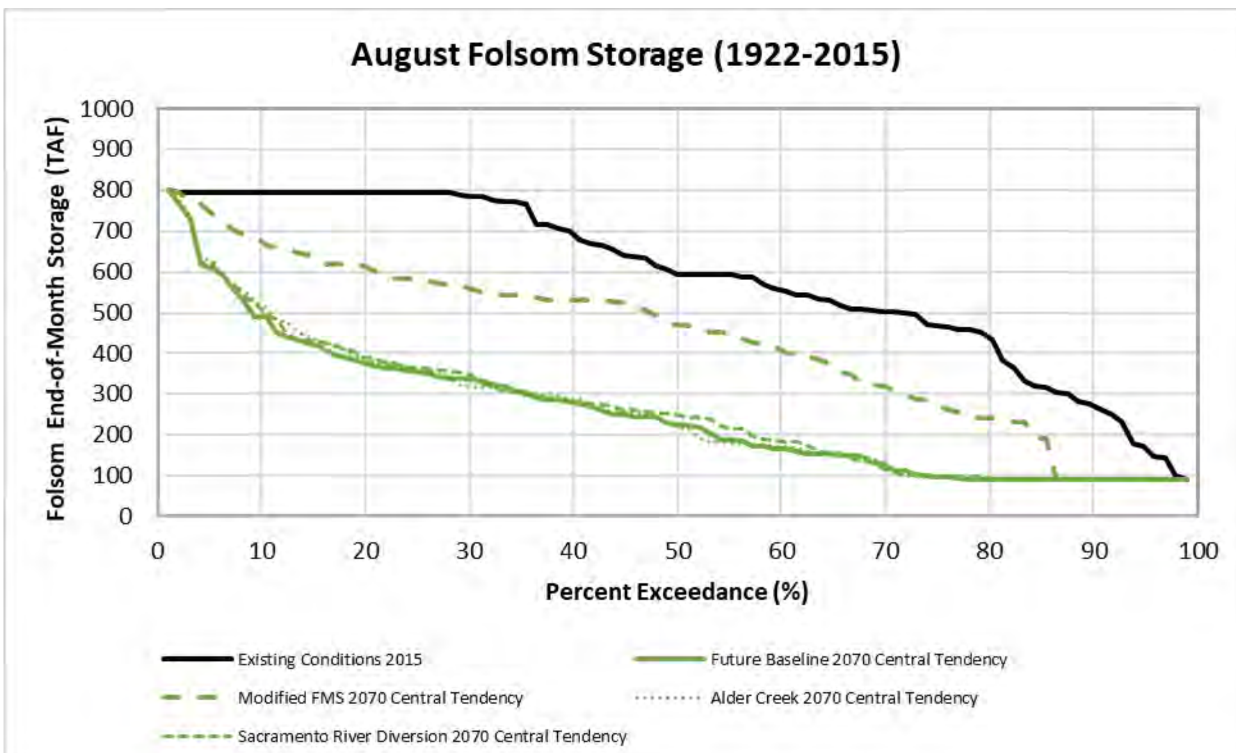

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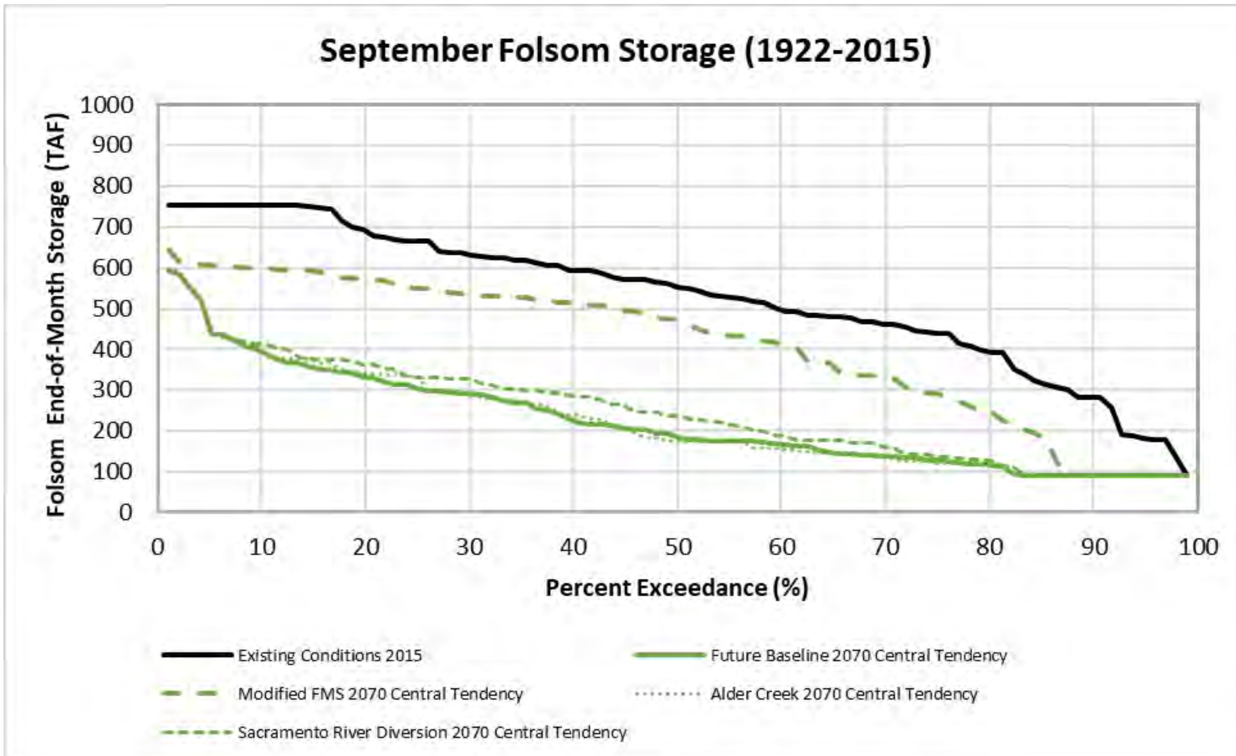

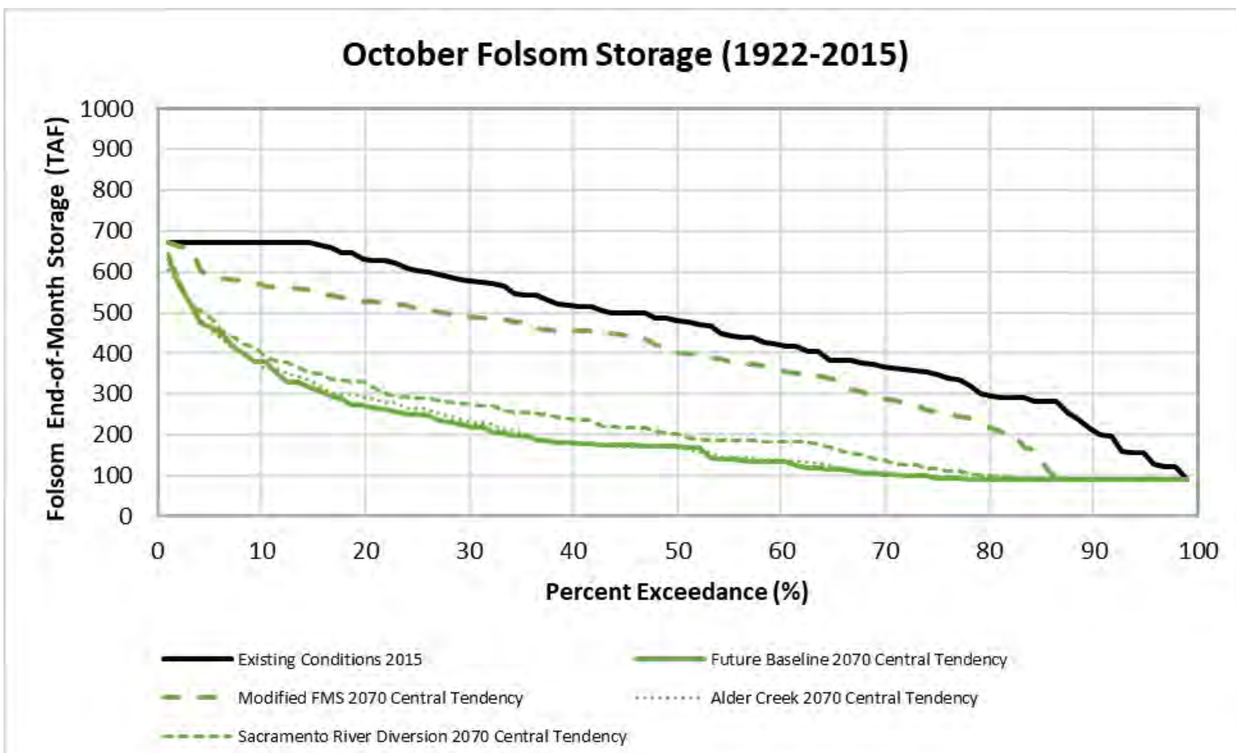

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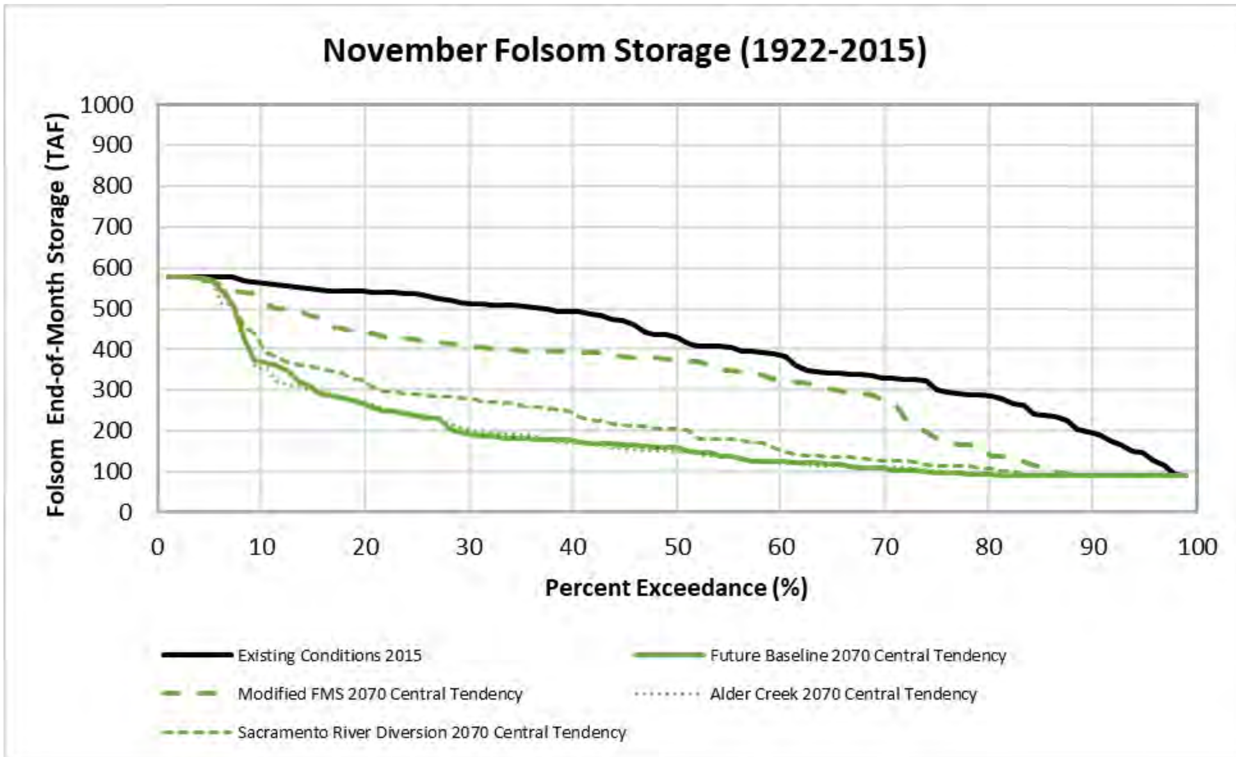

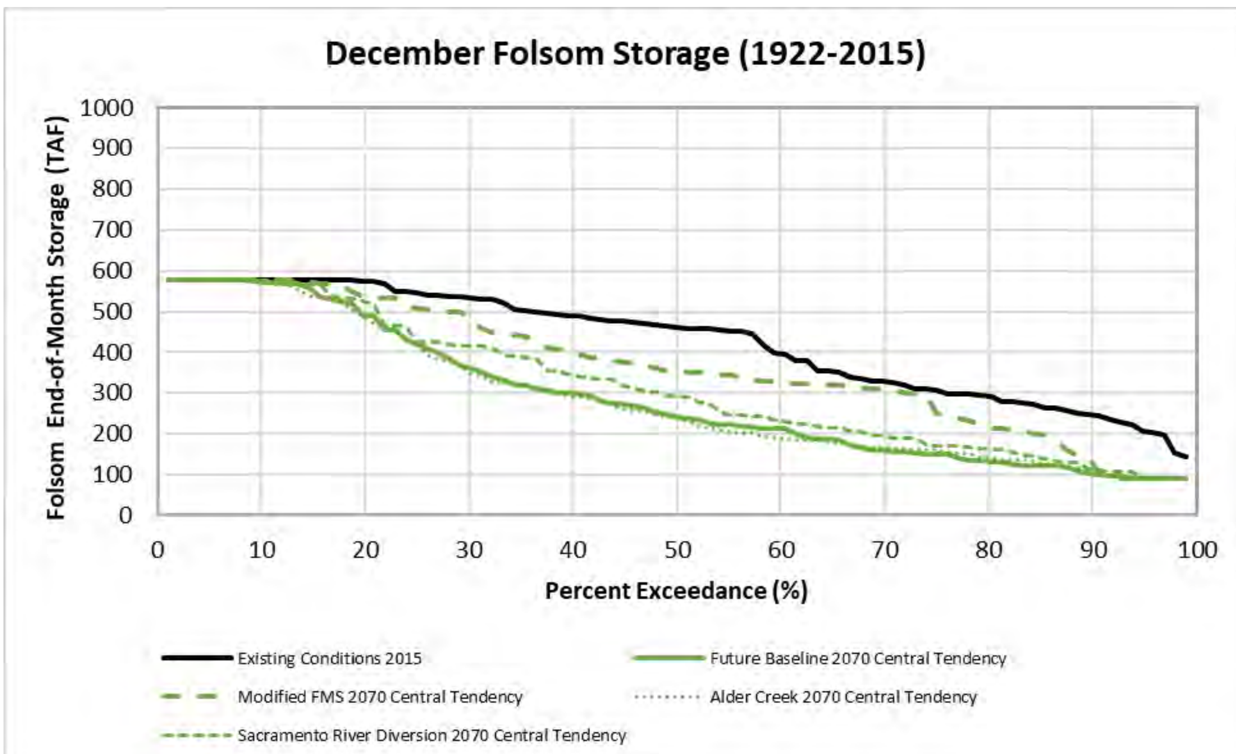

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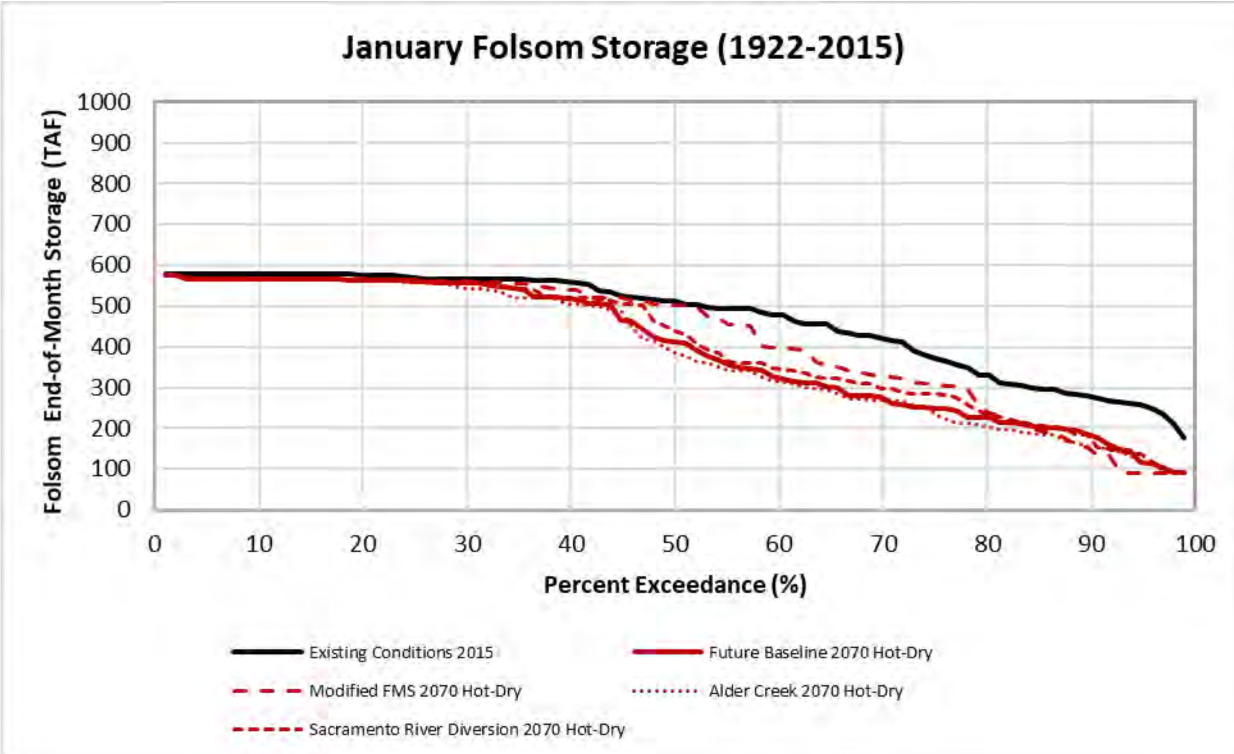


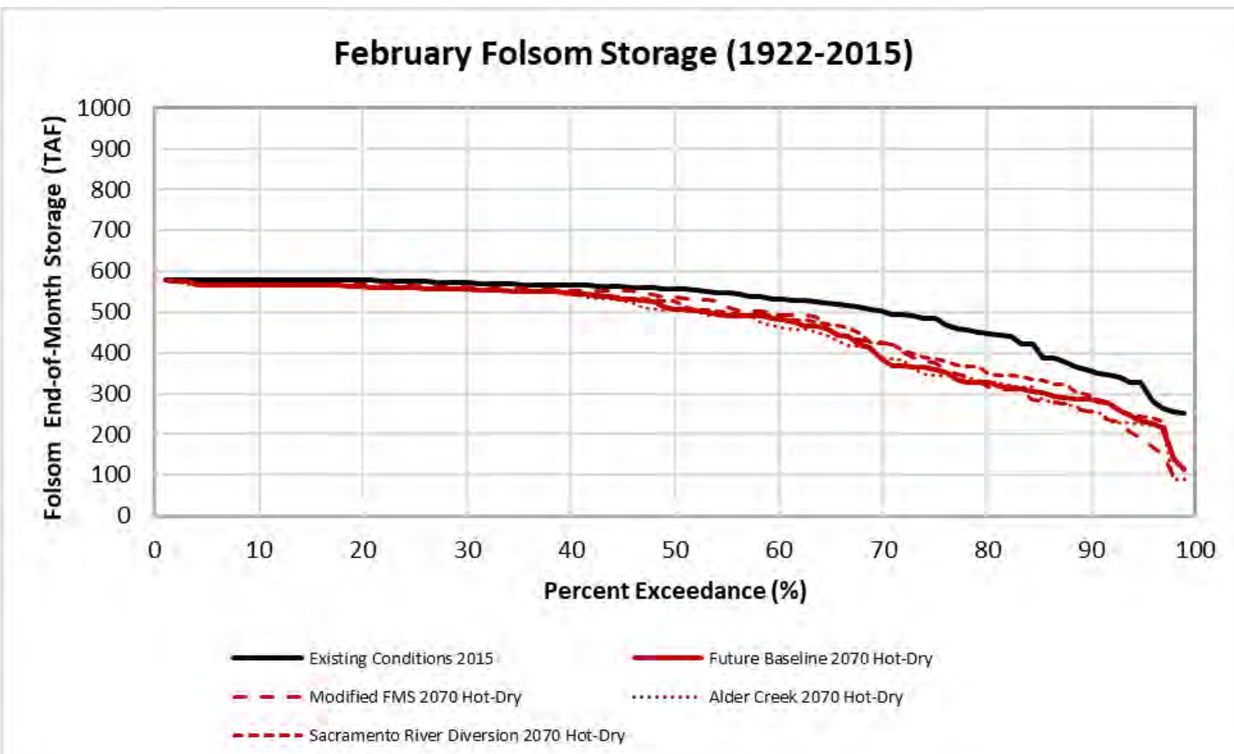
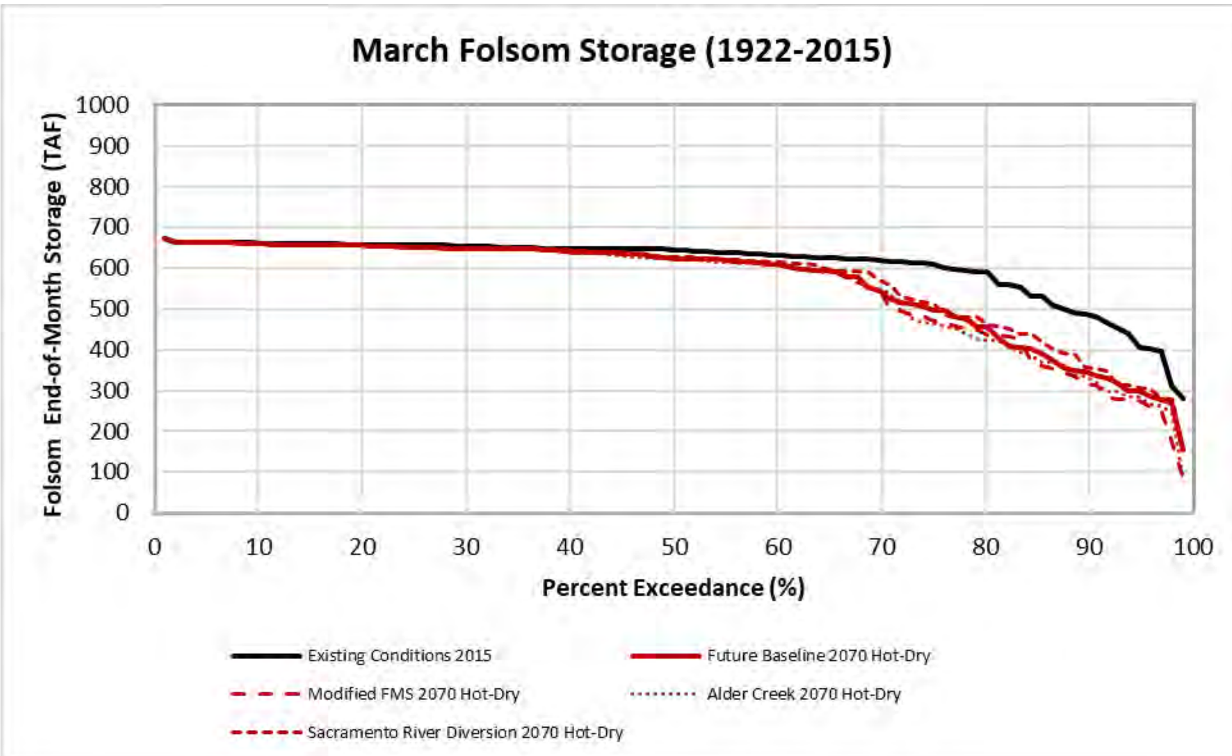
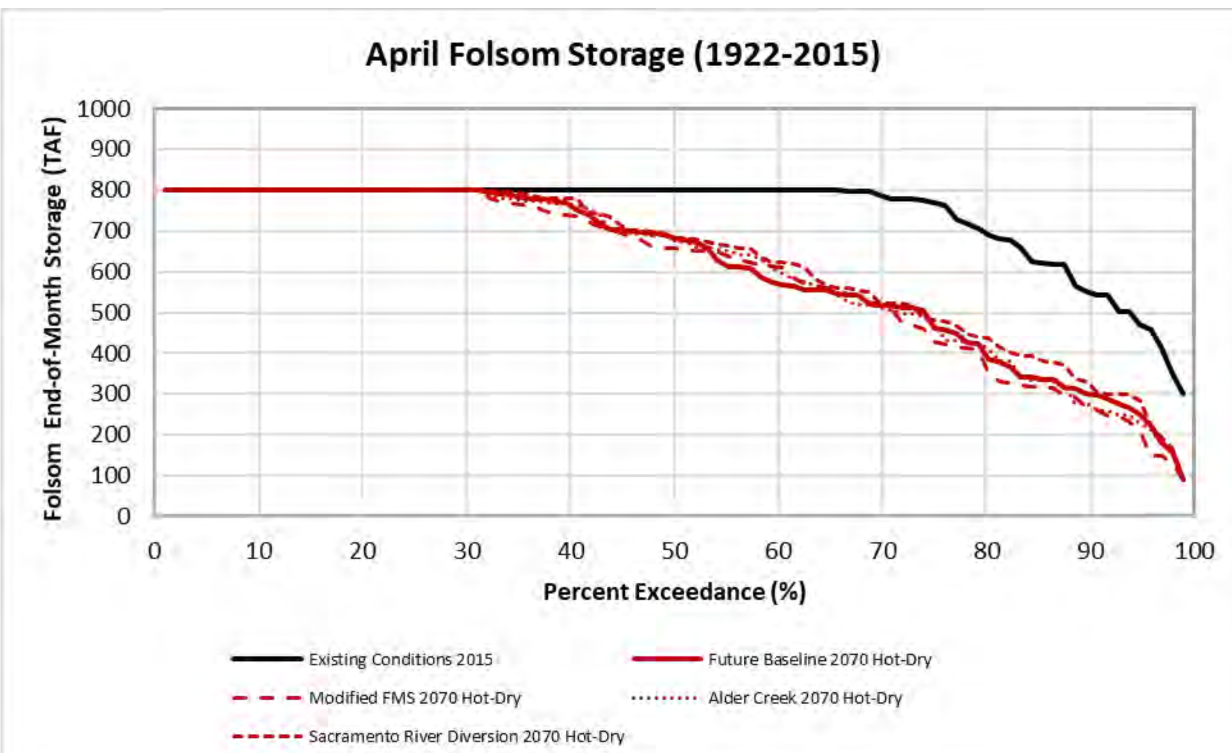


Figure 3. Folsom End-of-Month Storage for Hot-Dry Climate Change Scenarios





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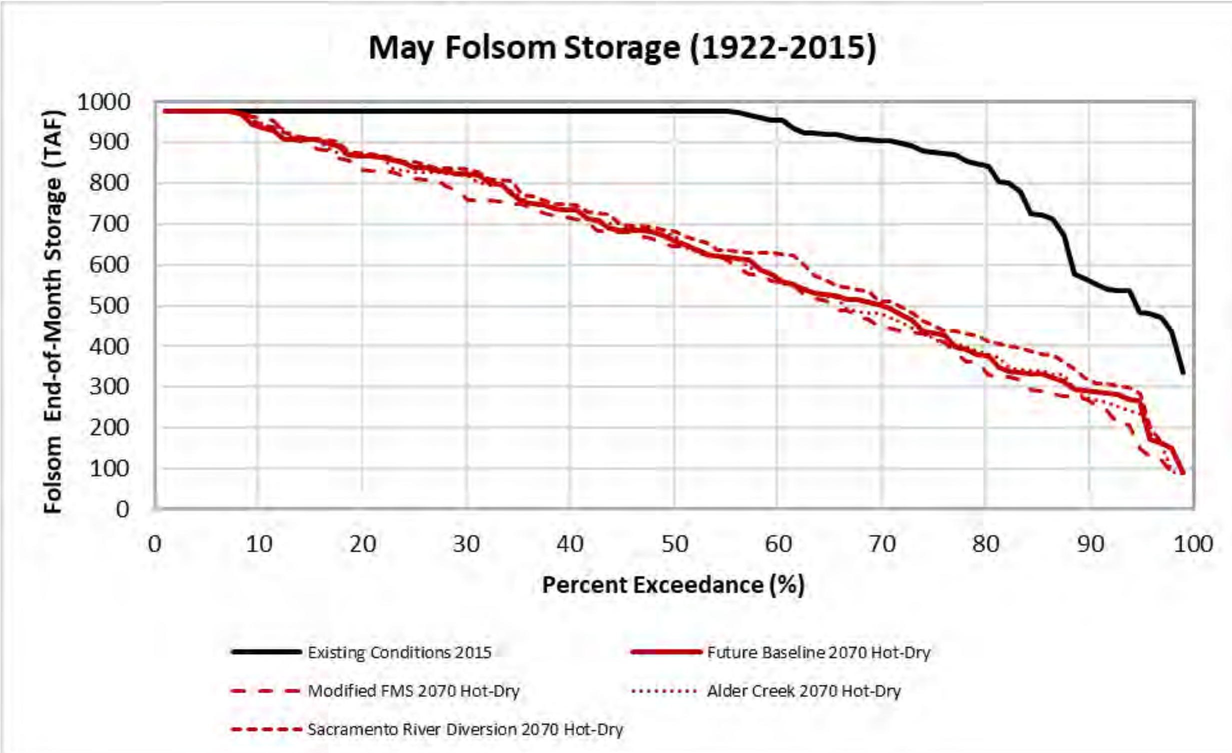

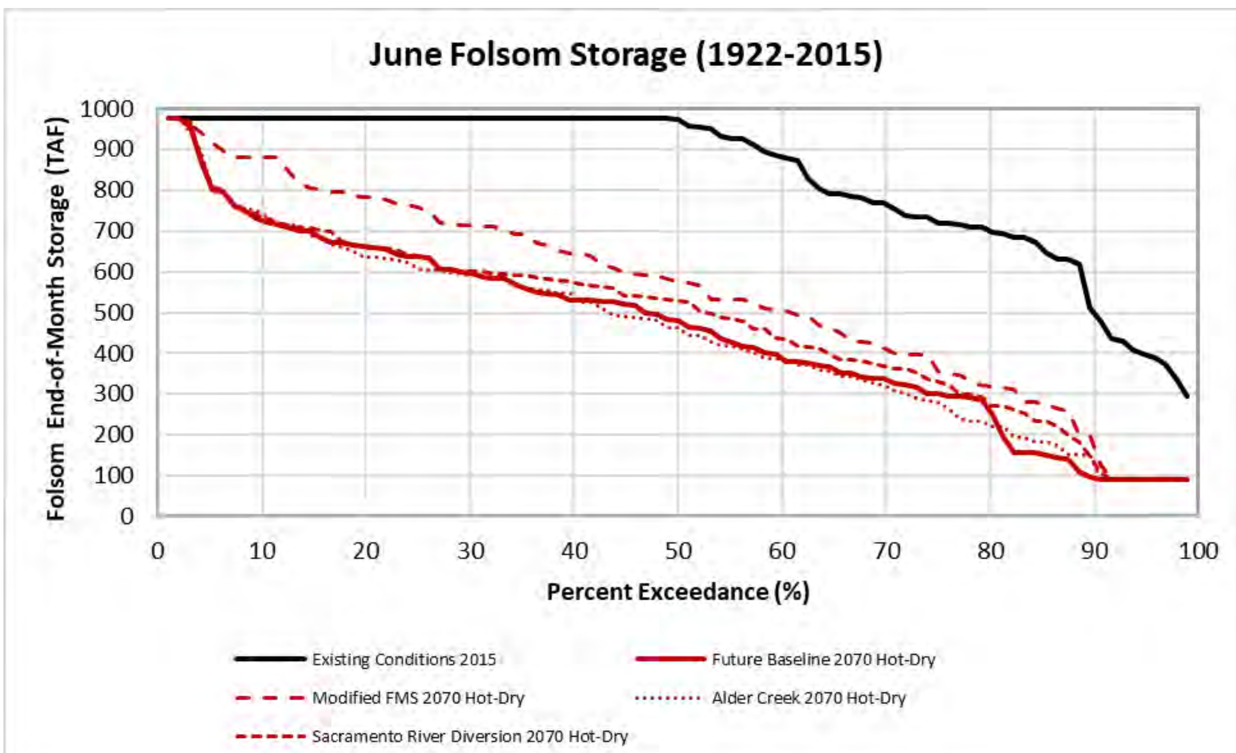

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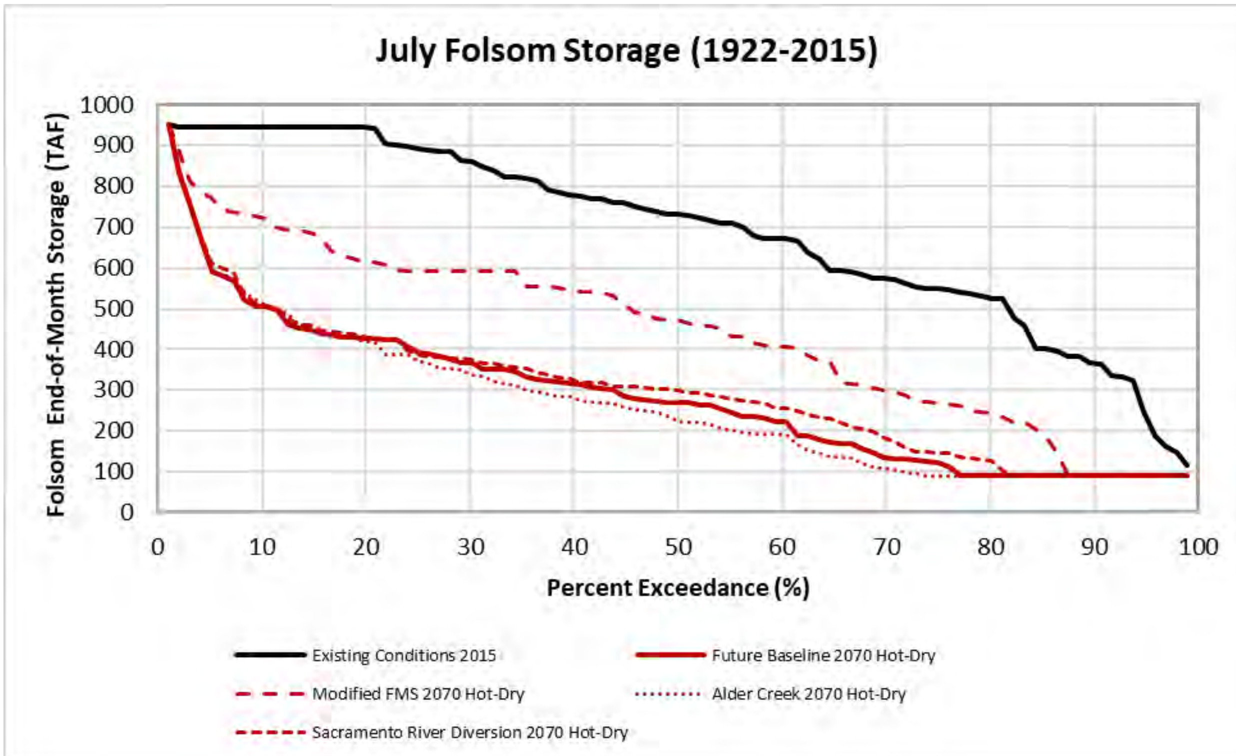

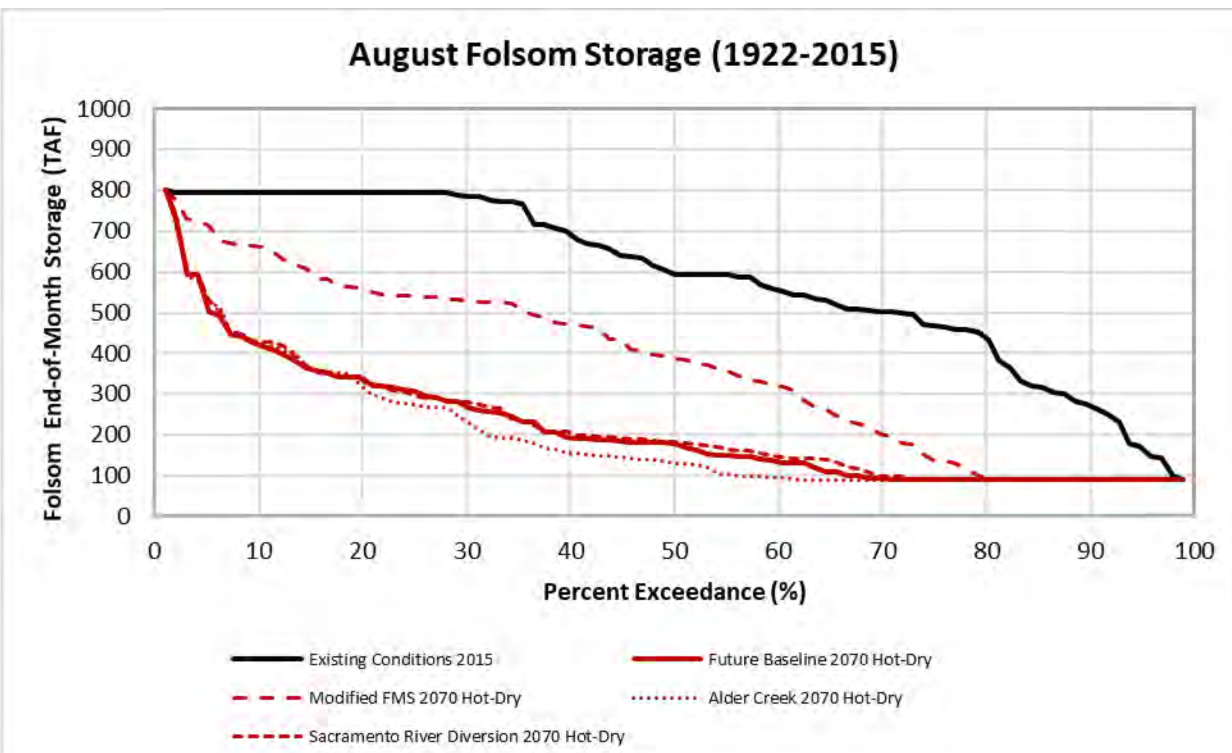

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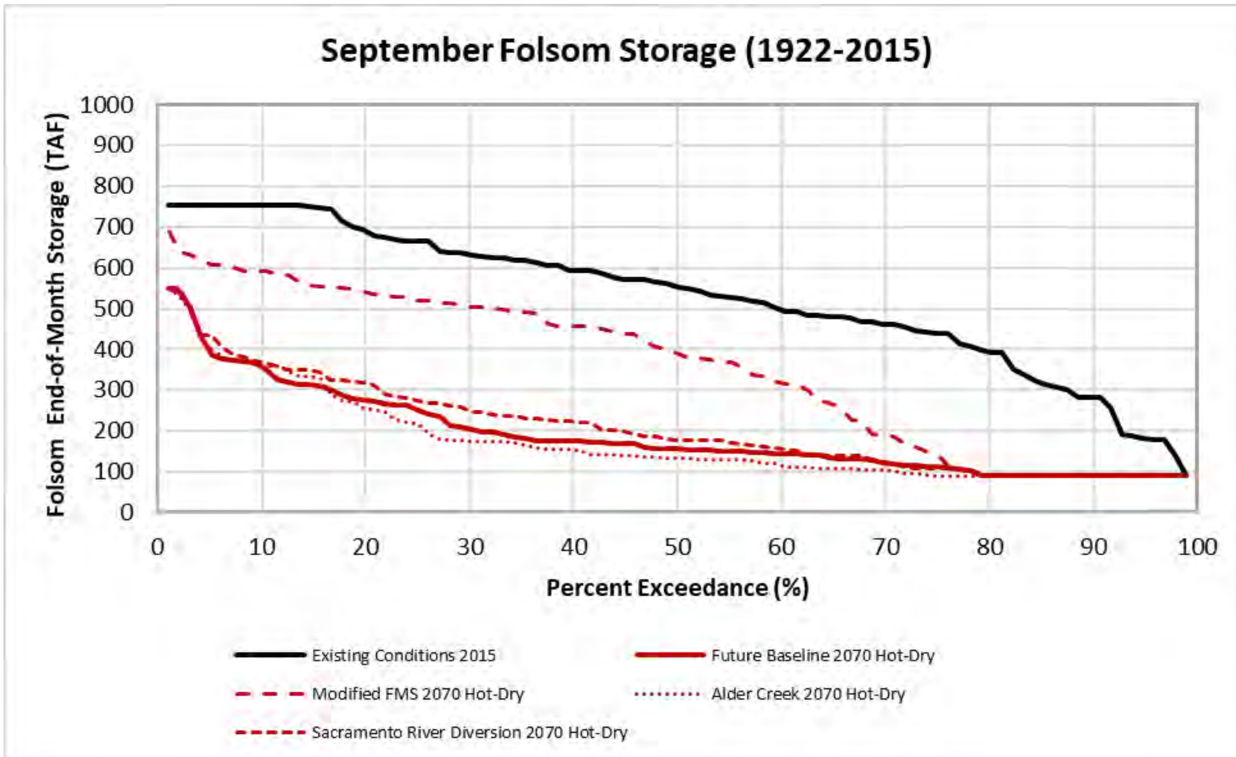

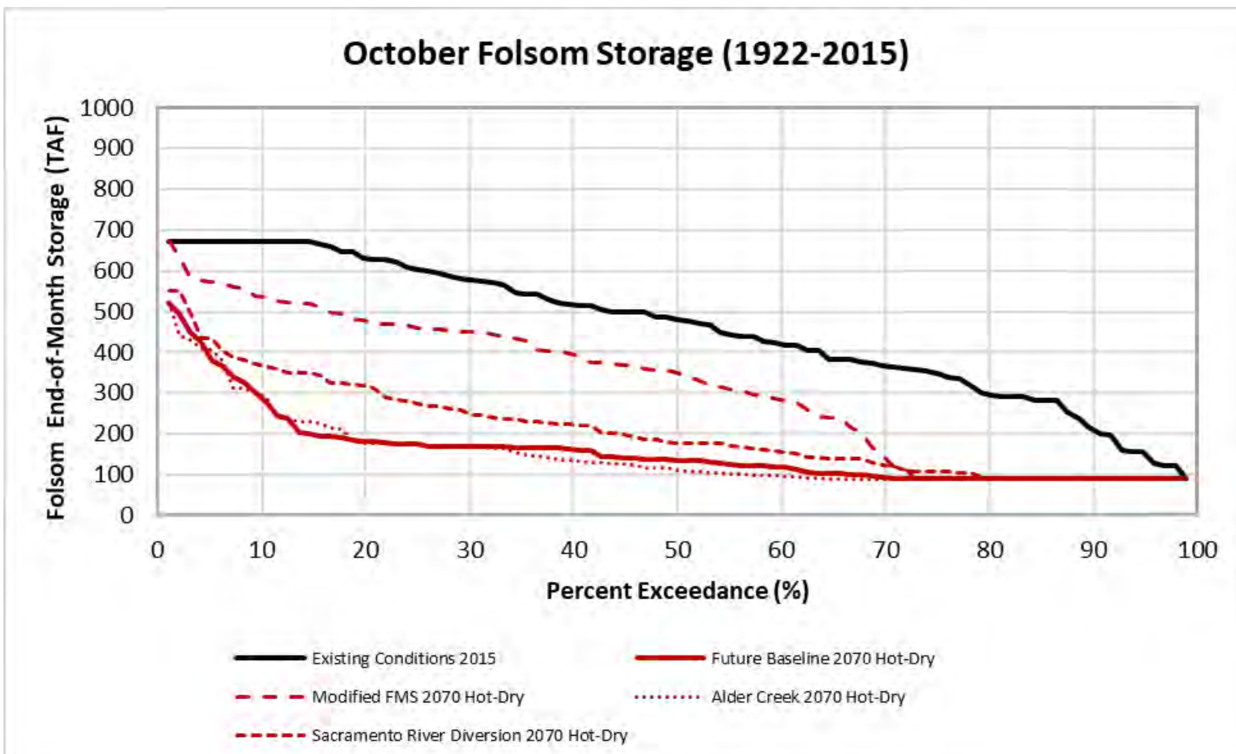

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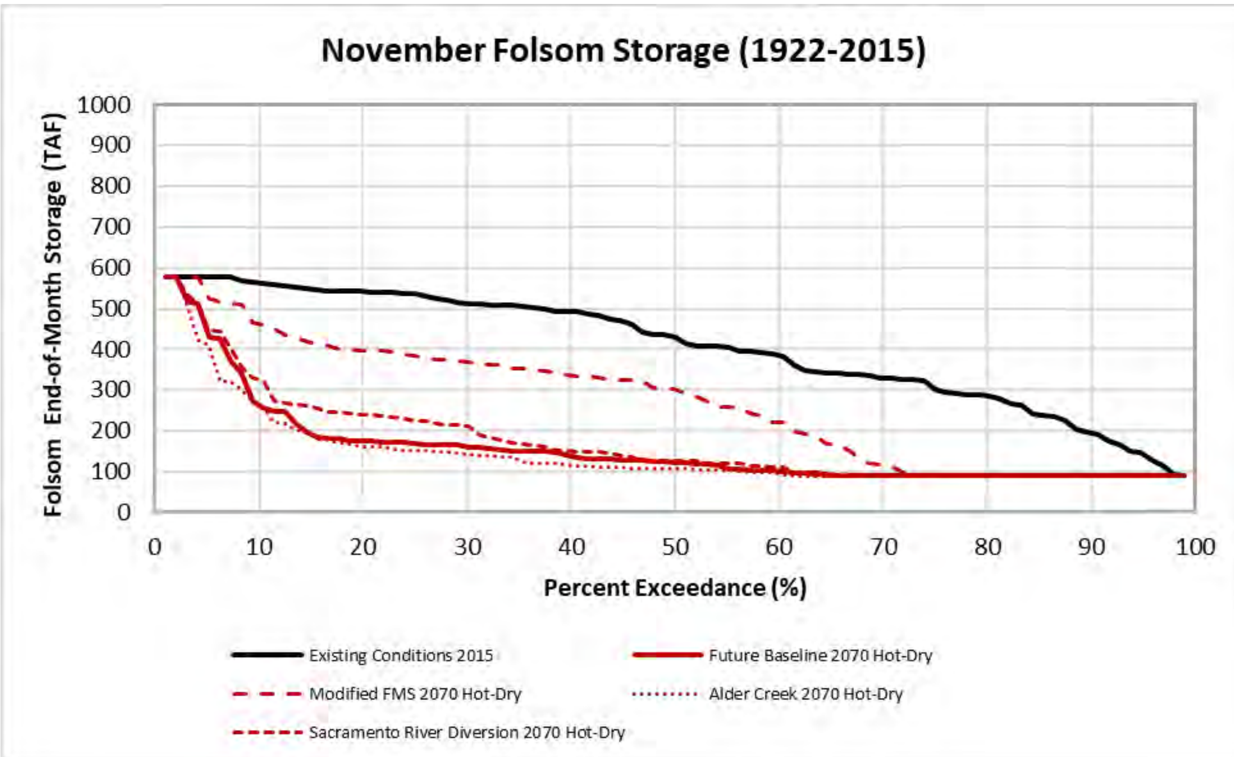

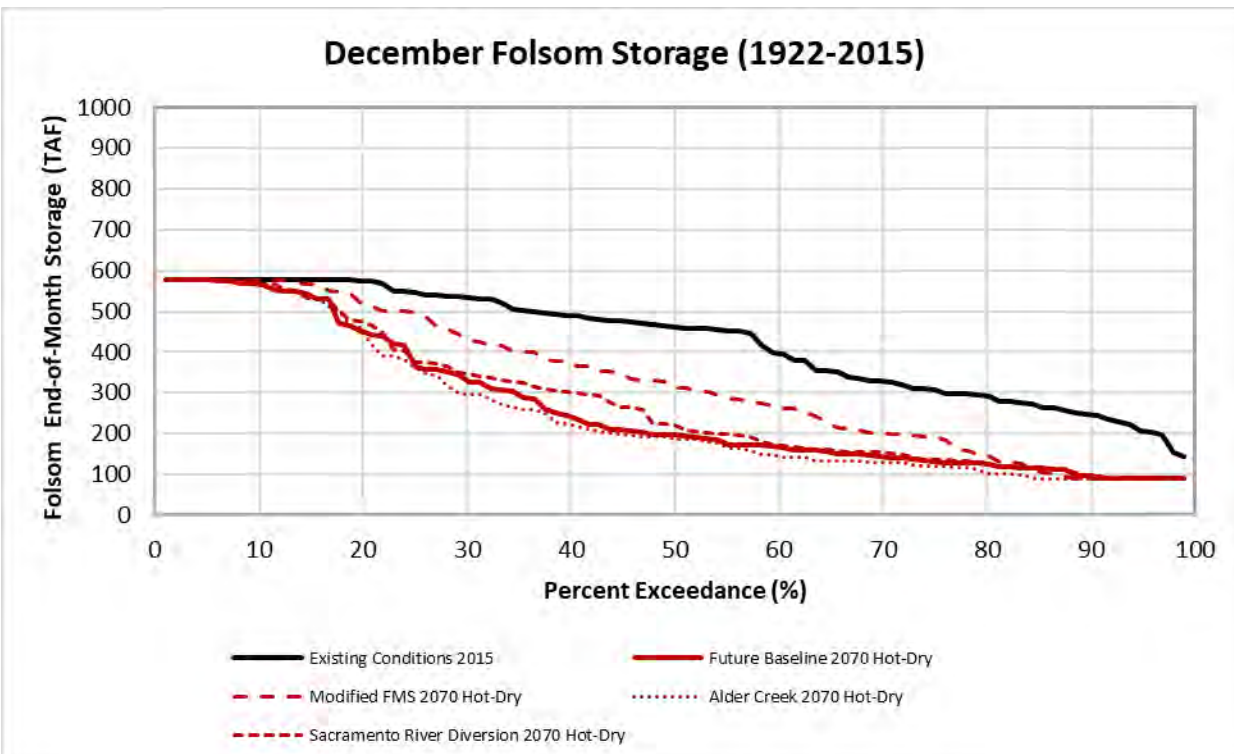

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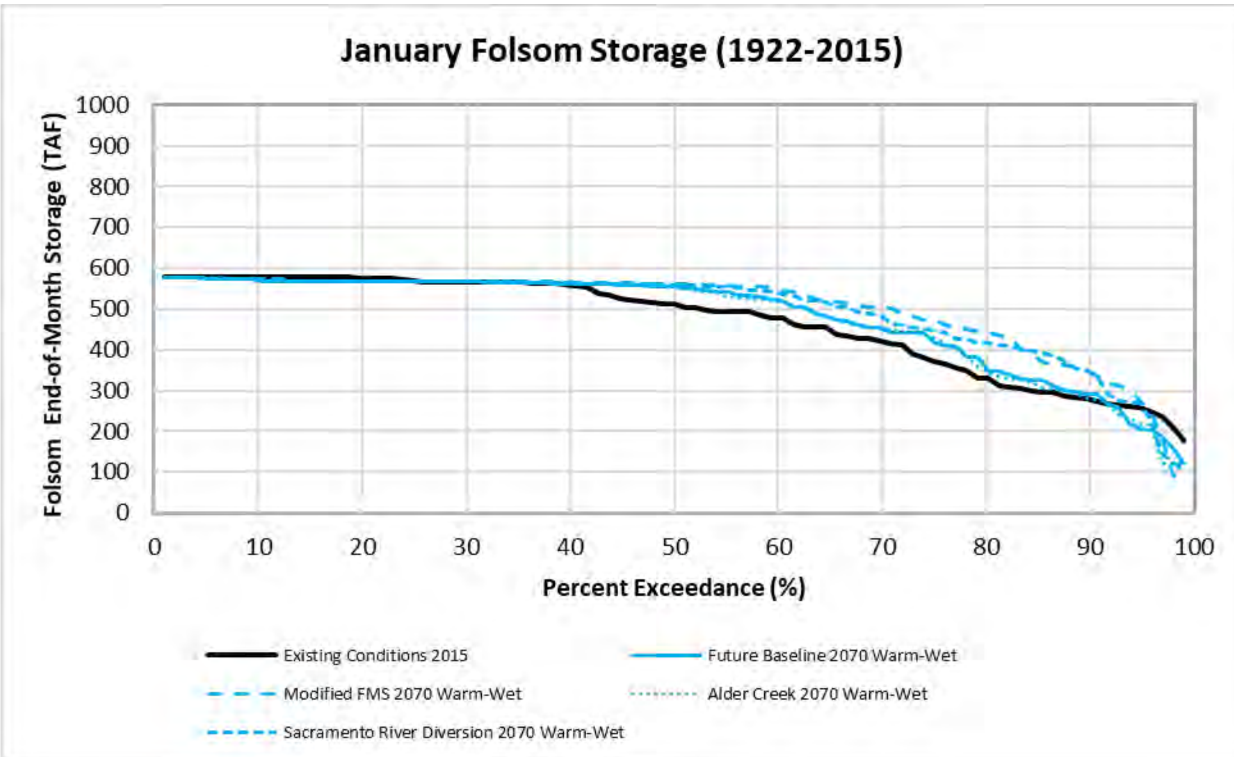


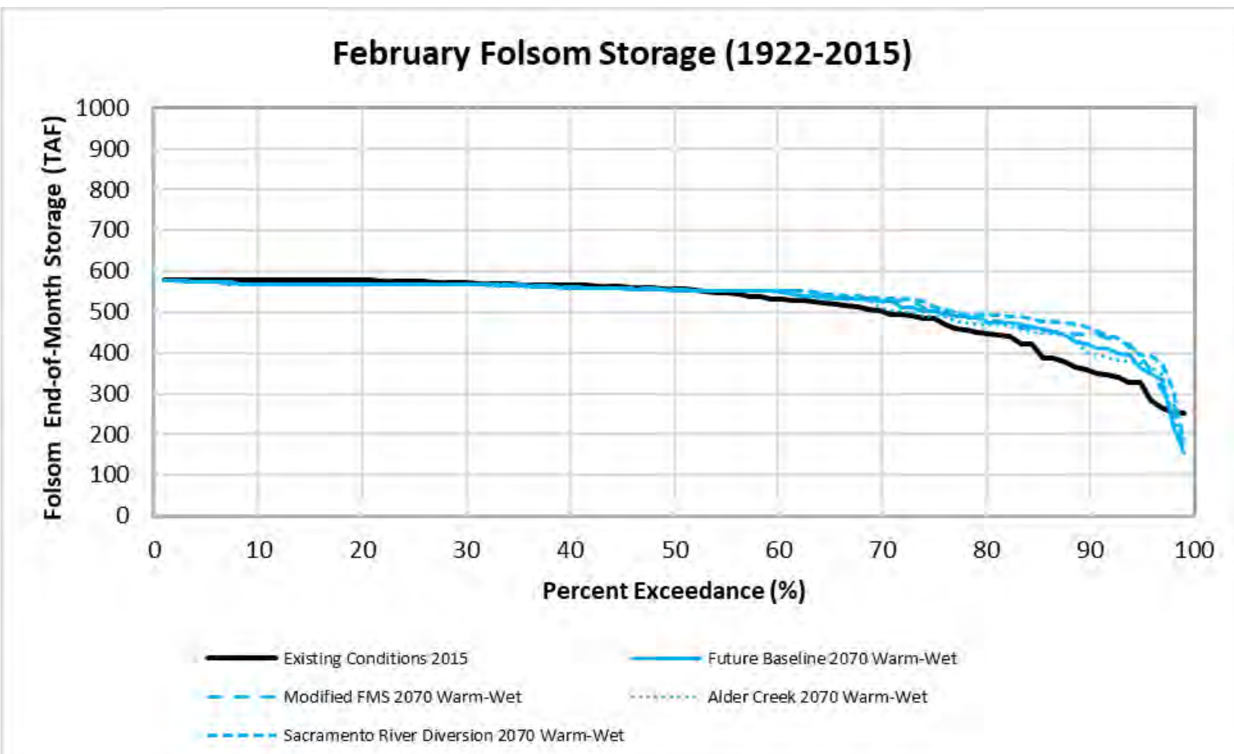
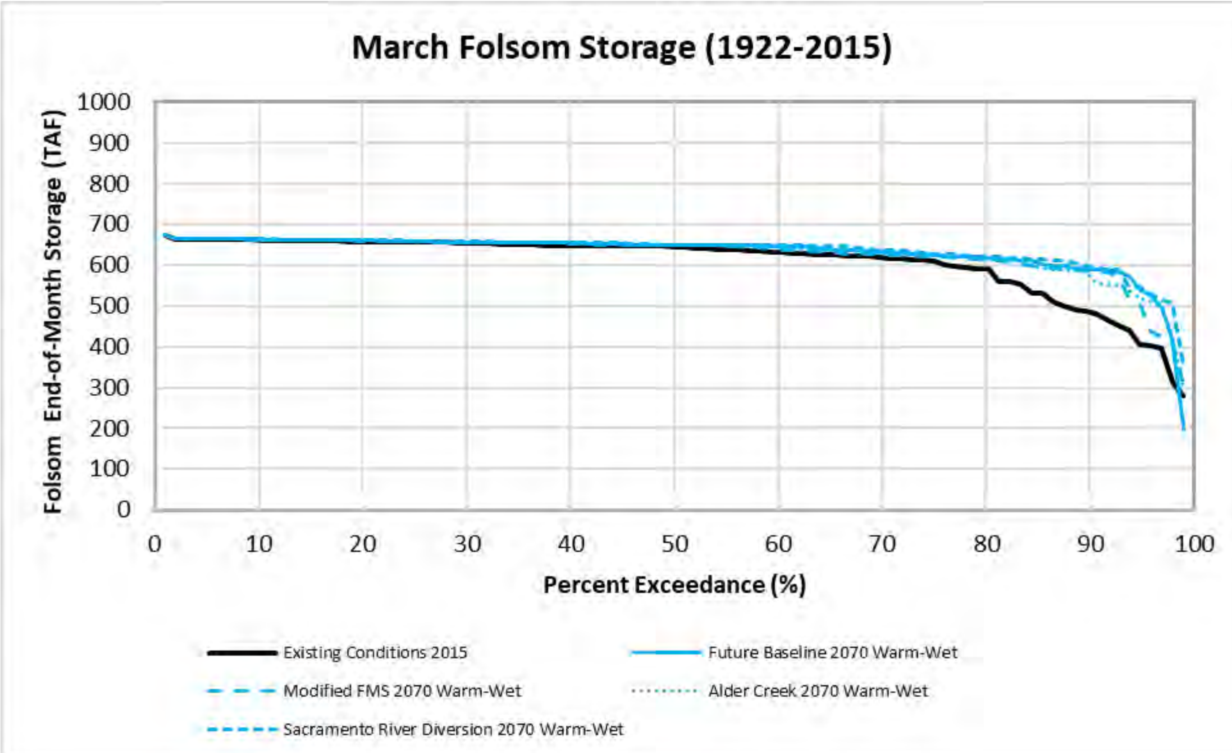
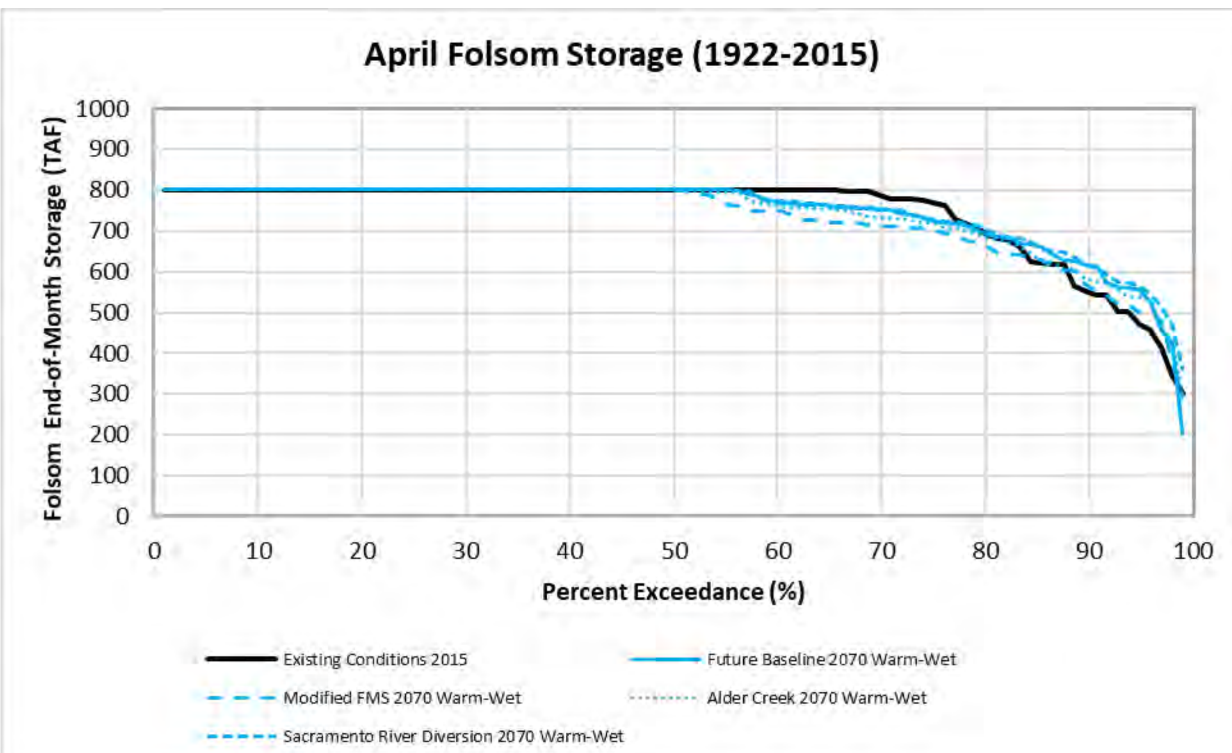


Figure 4. Folsom End-of-Month Storage for Warm-Wet Climate Change Scenarios





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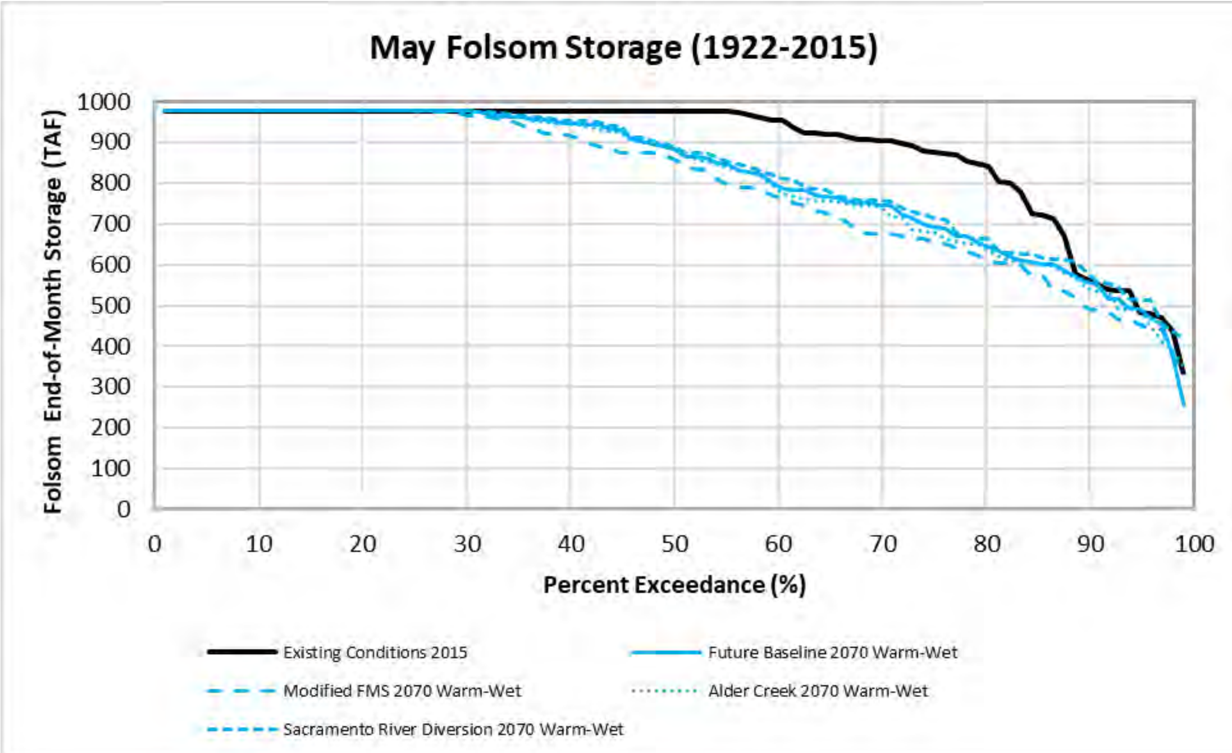

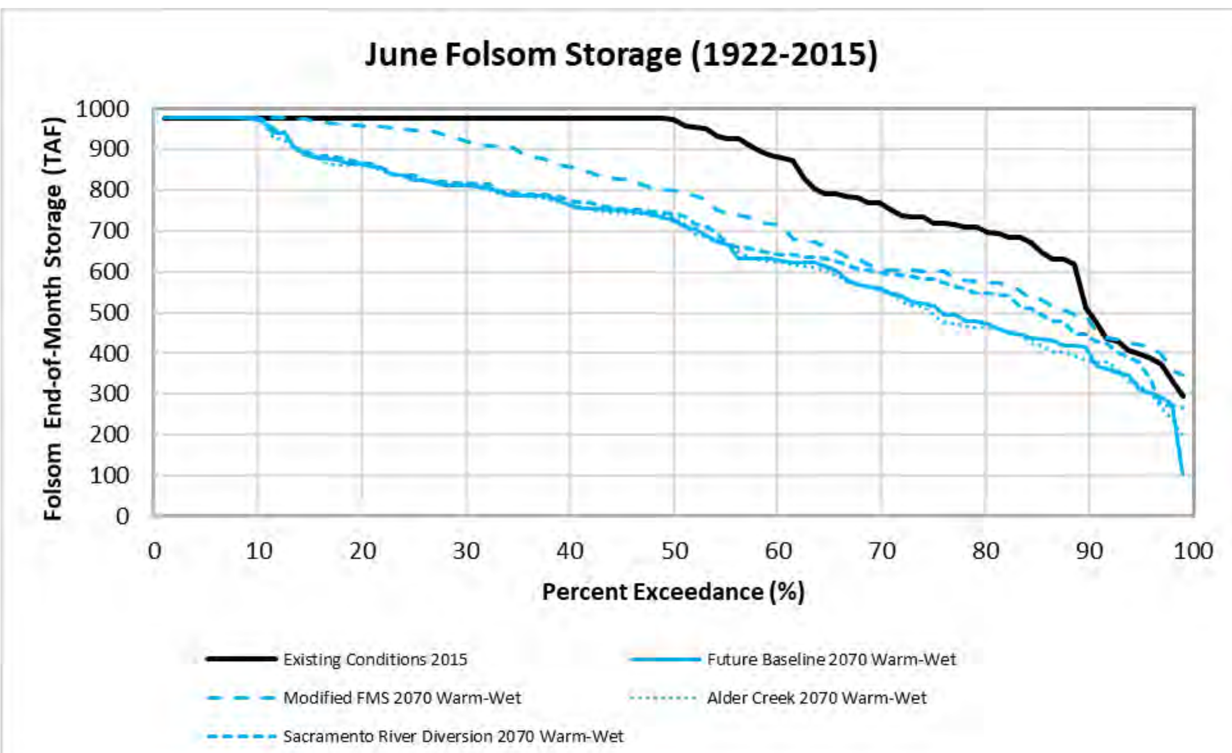

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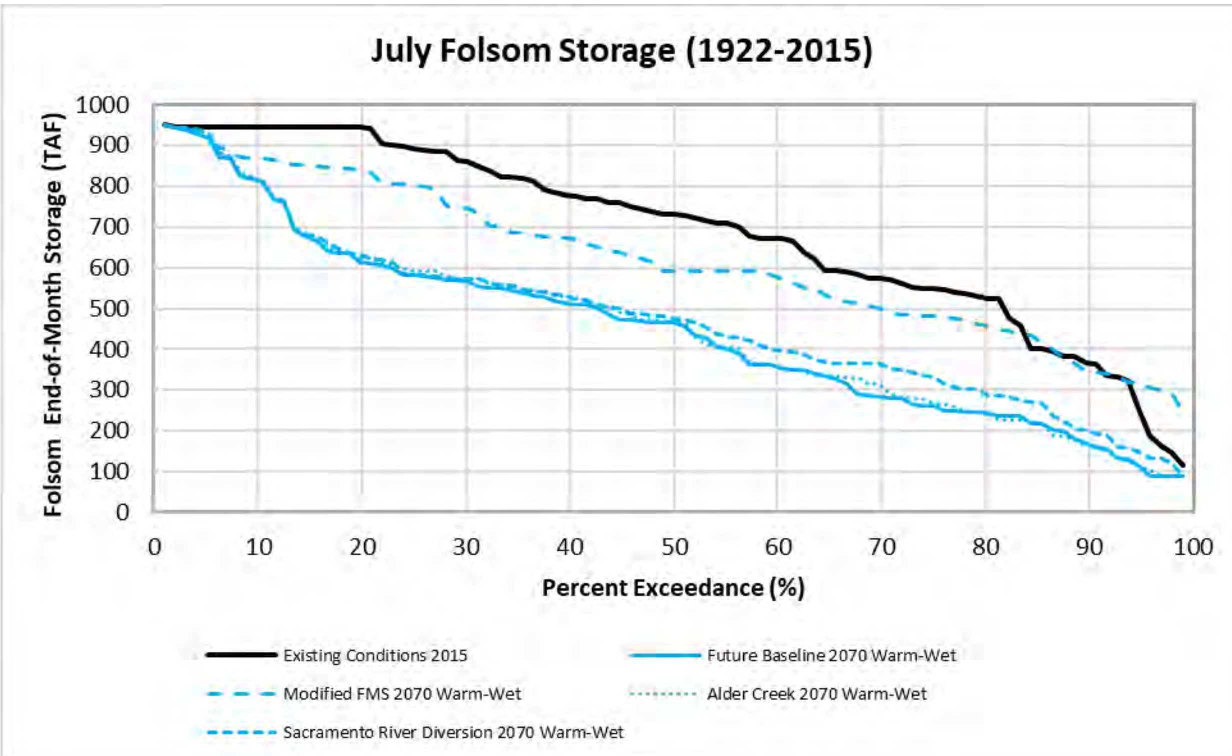

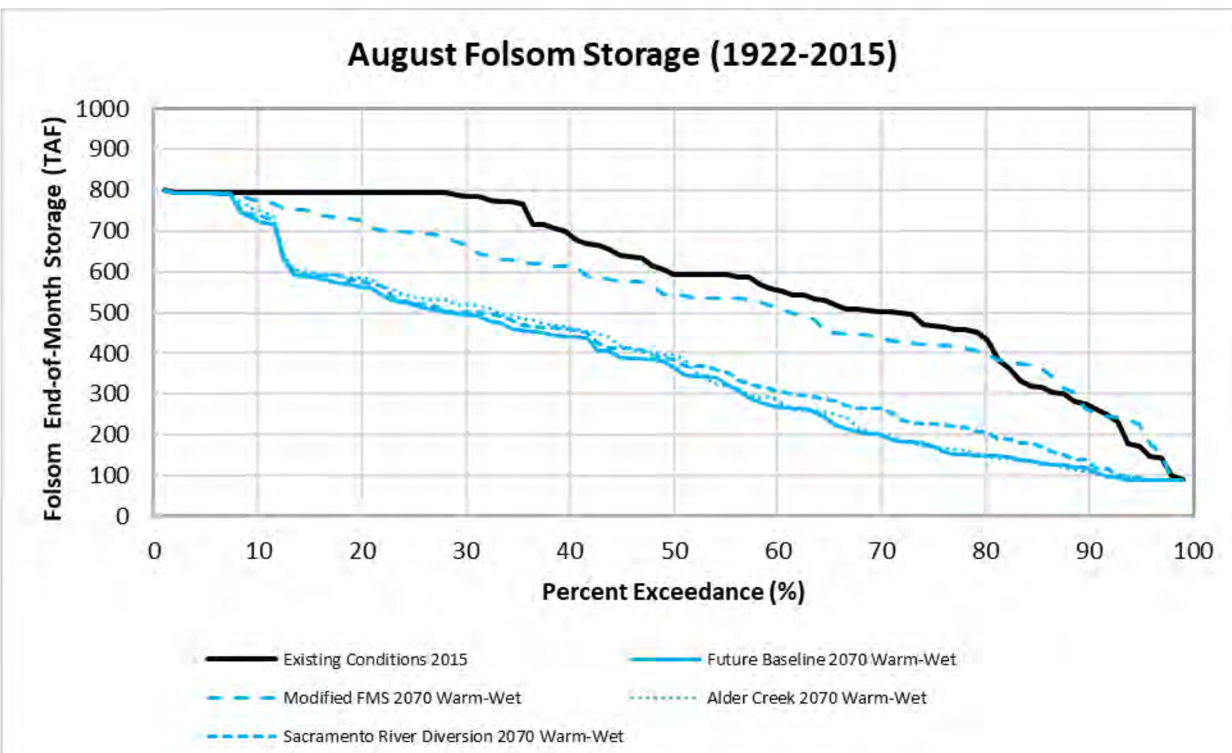

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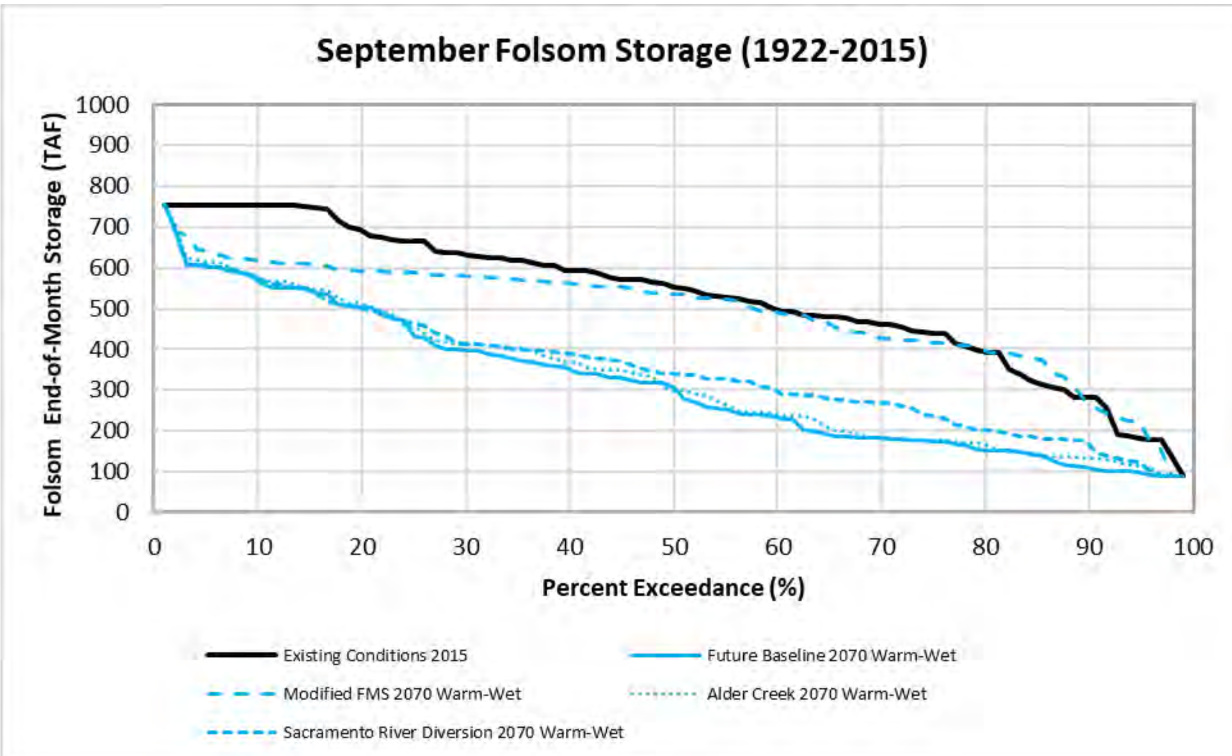

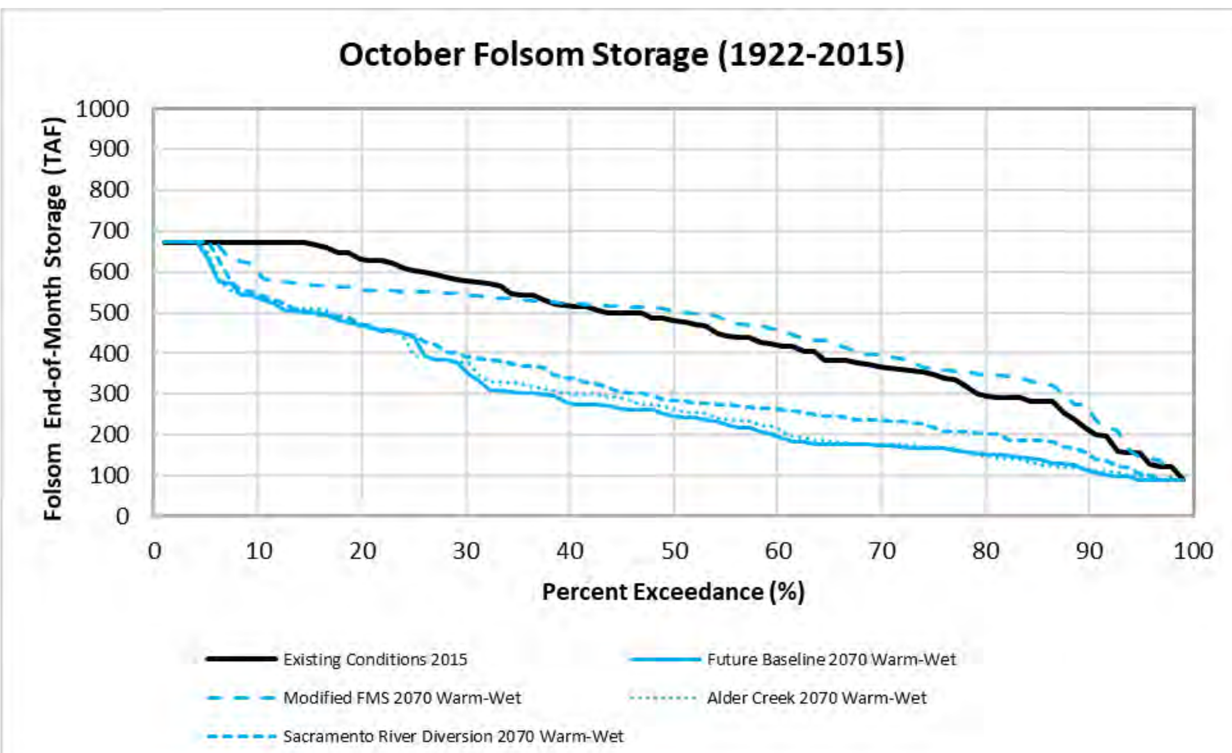

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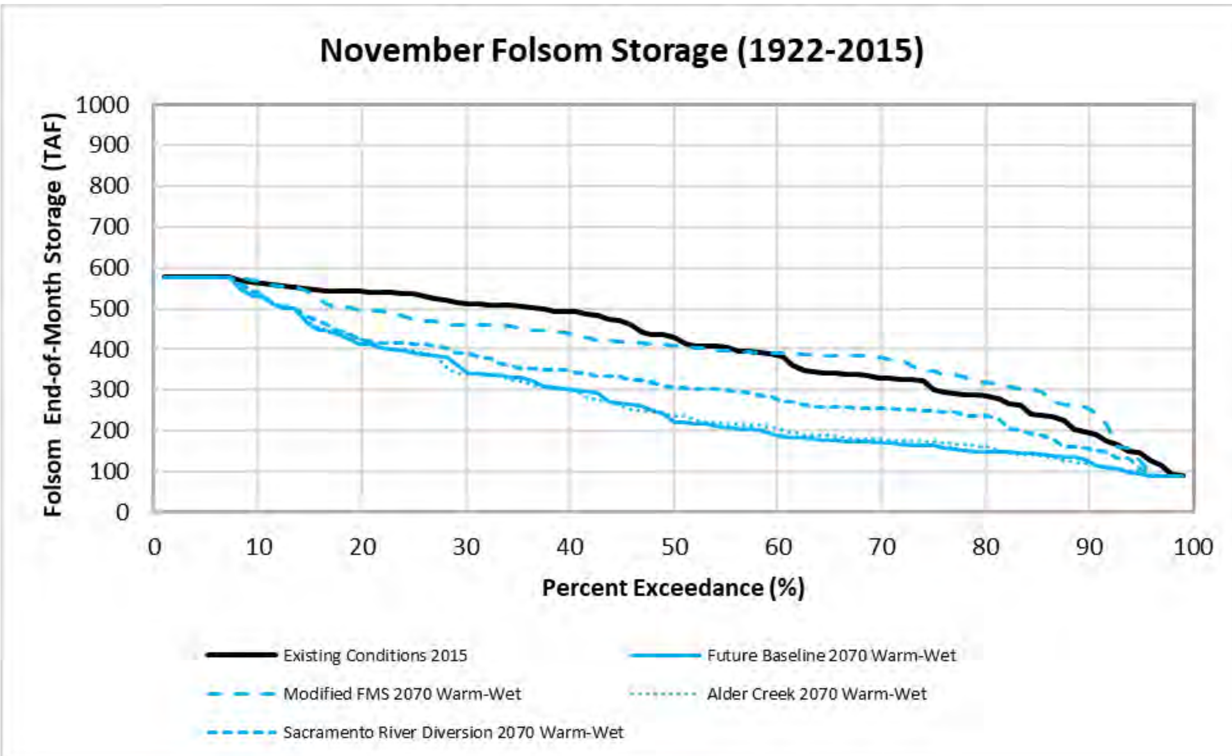

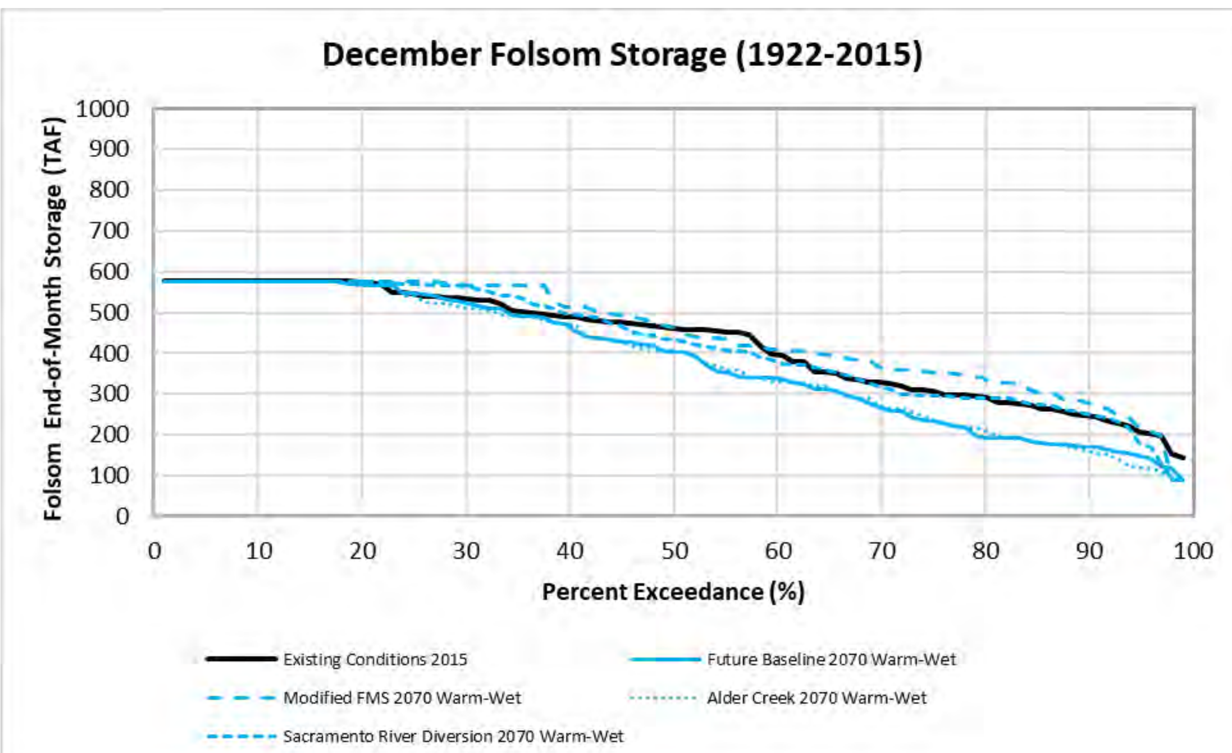

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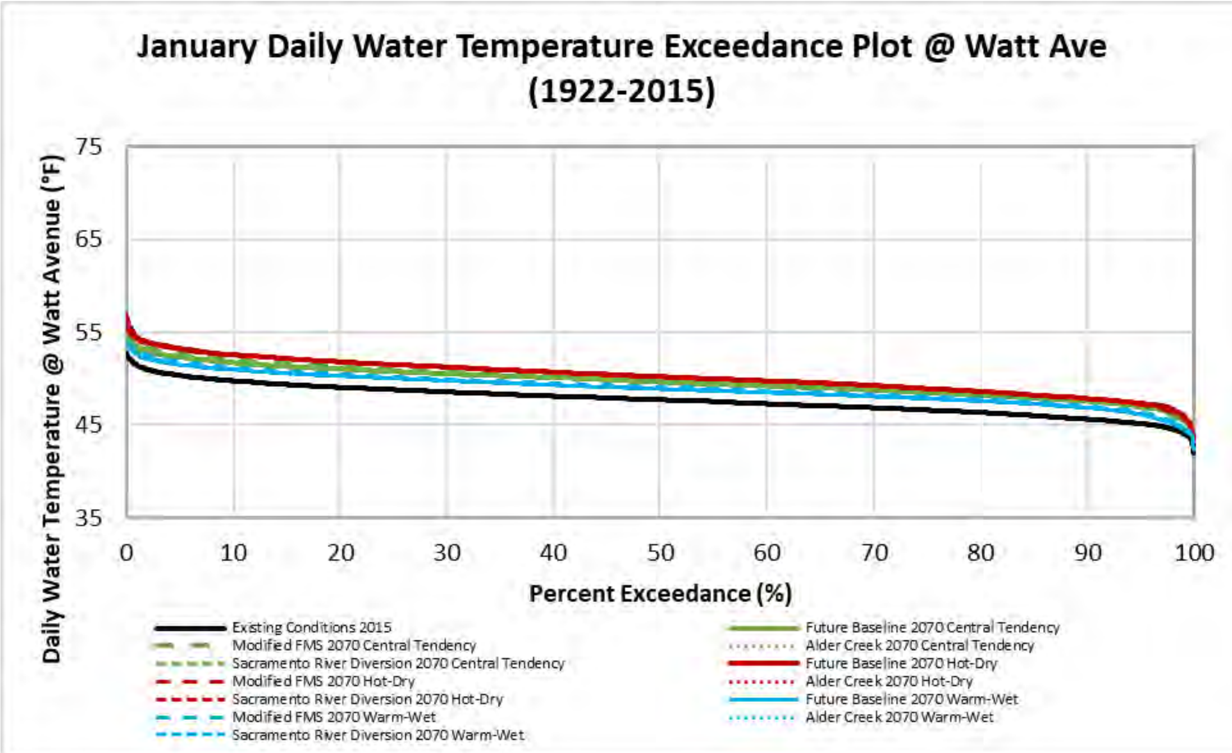


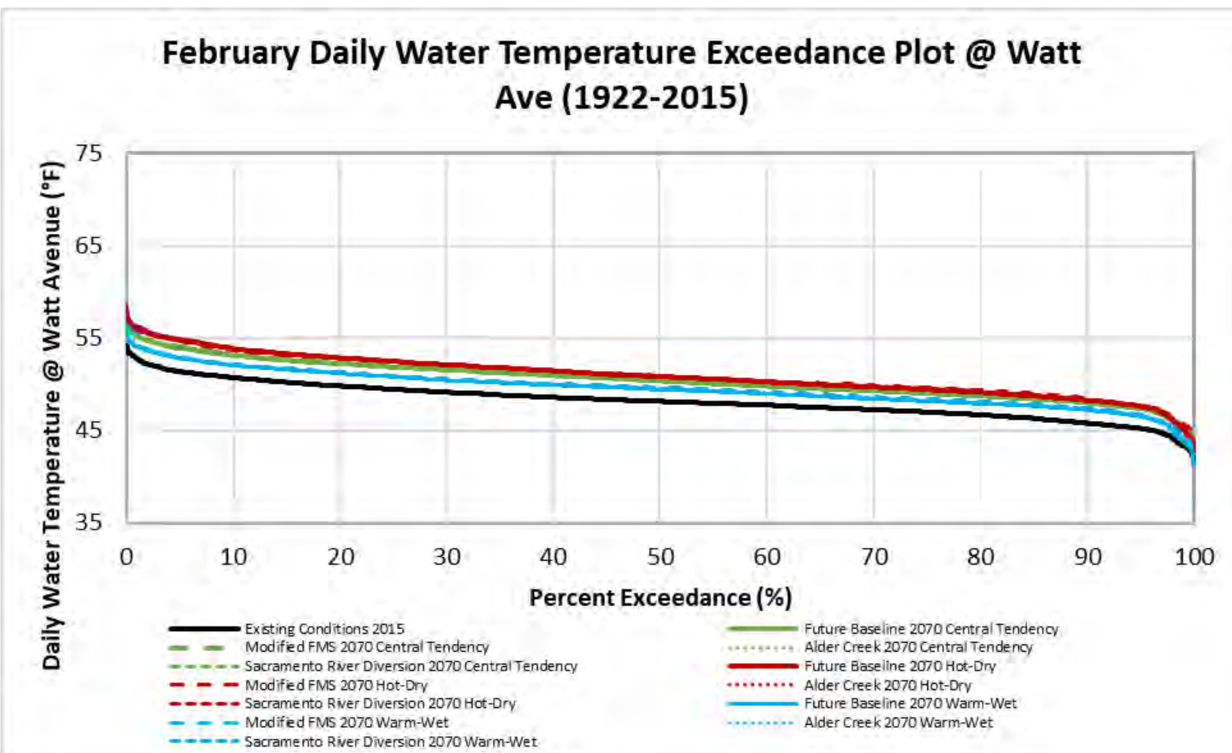


Figure 5. Monthly Exceedance Plots of Daily Water Temperature at Watt Avenue – All Scenarios

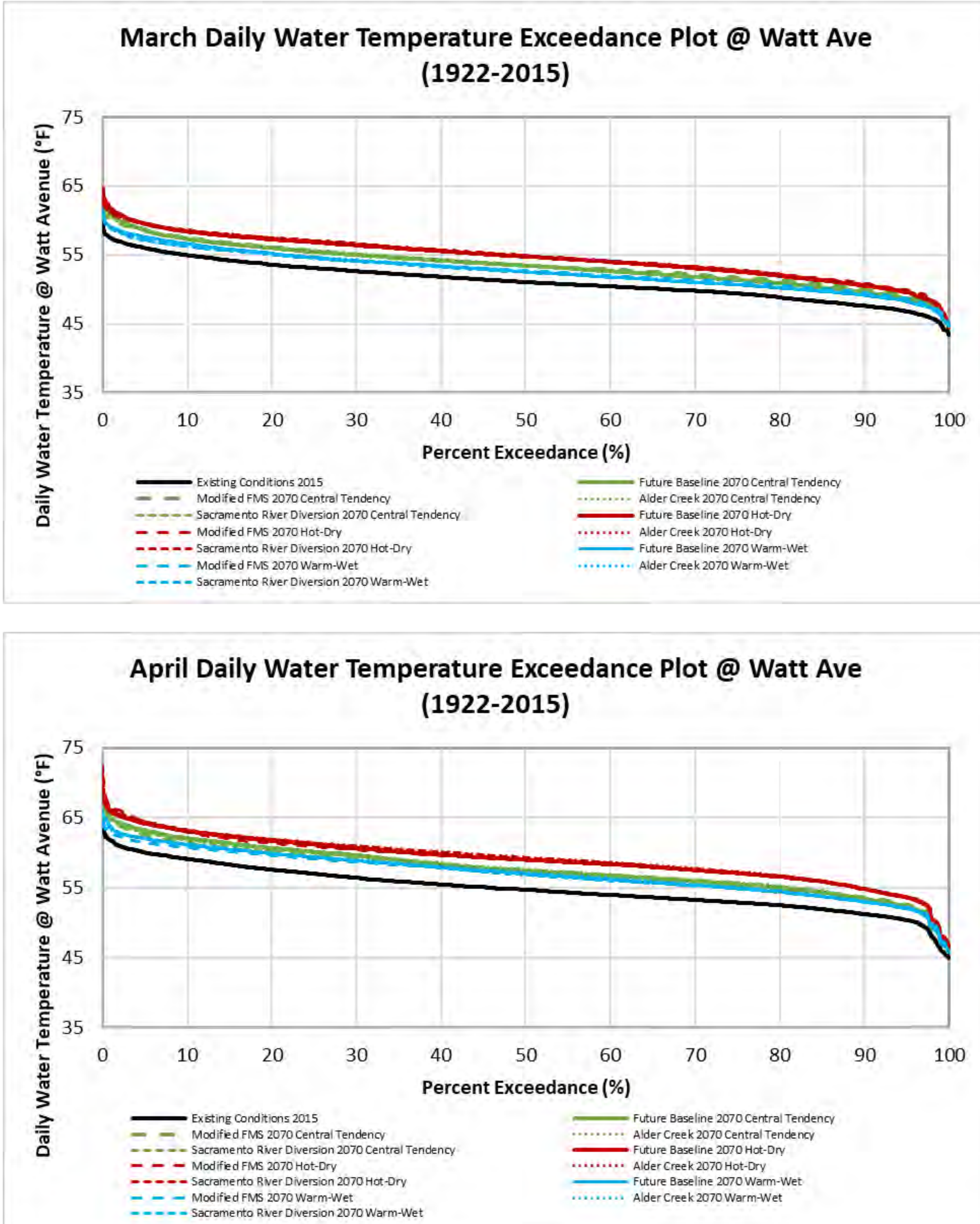
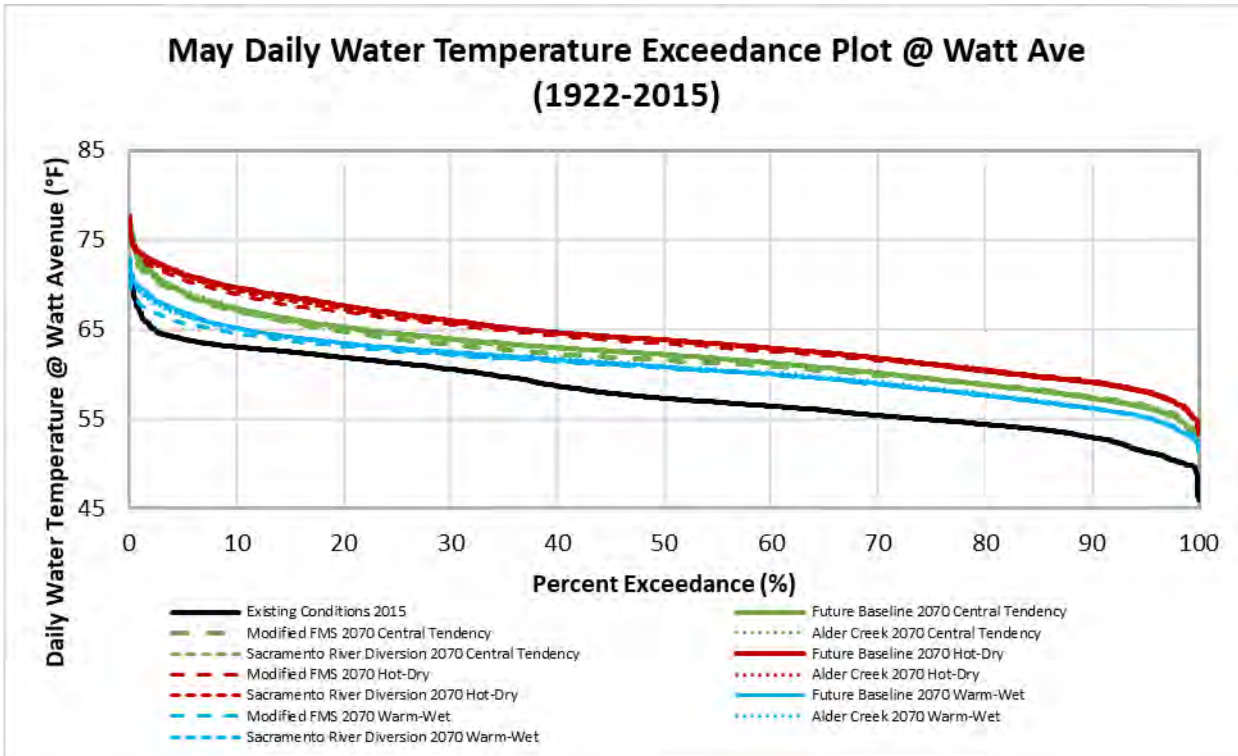


Figure 5 (continued). Monthly Exceedance Plots of Daily Water Temperature at Watt Avenue – All Scenarios



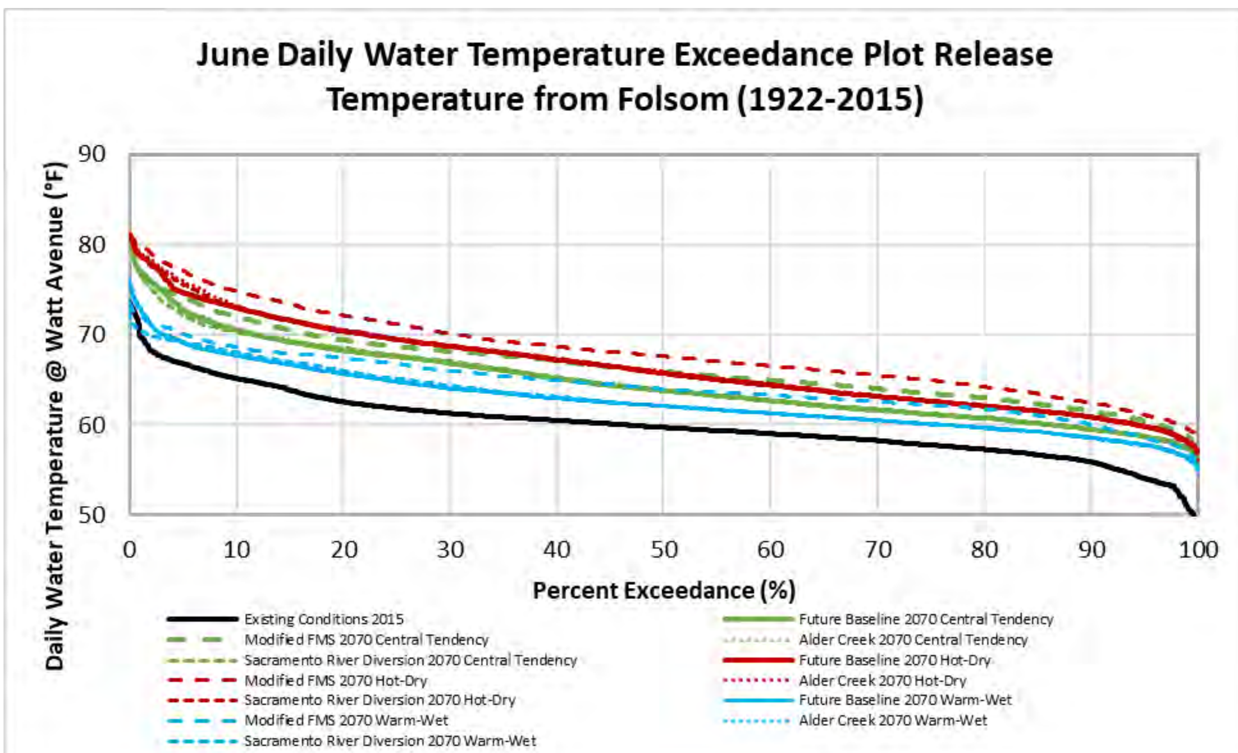
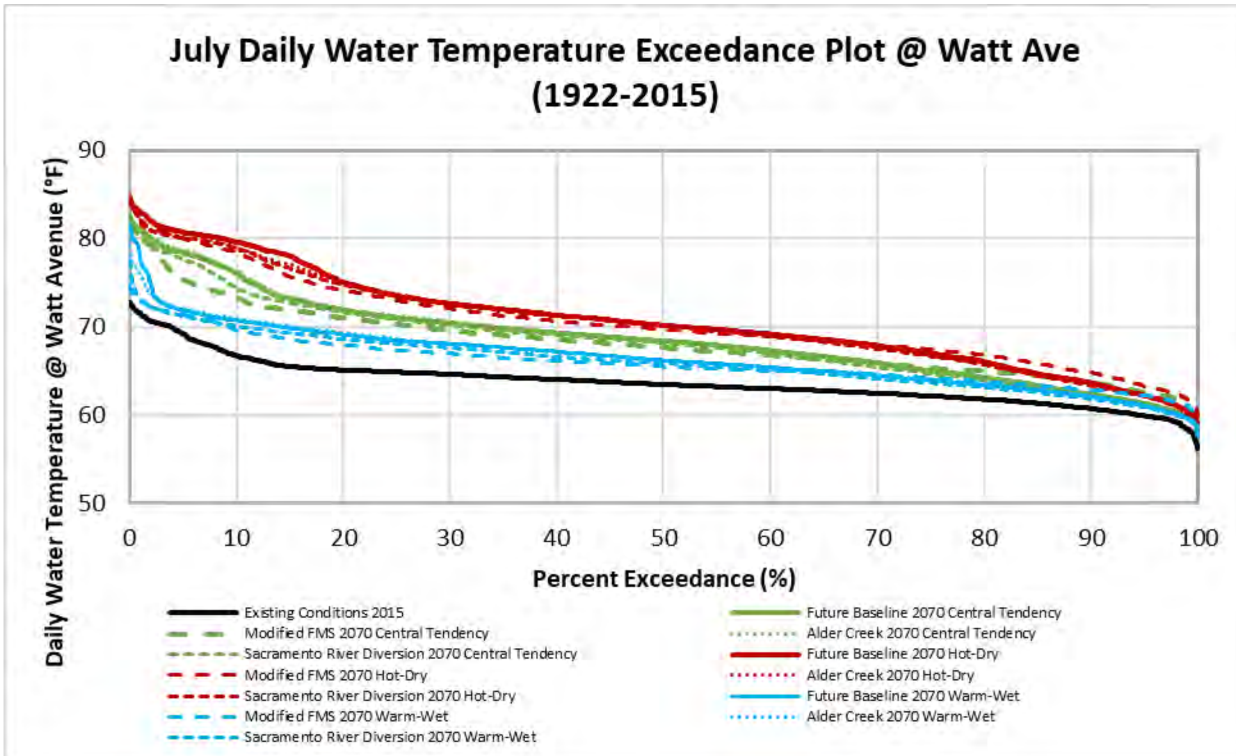
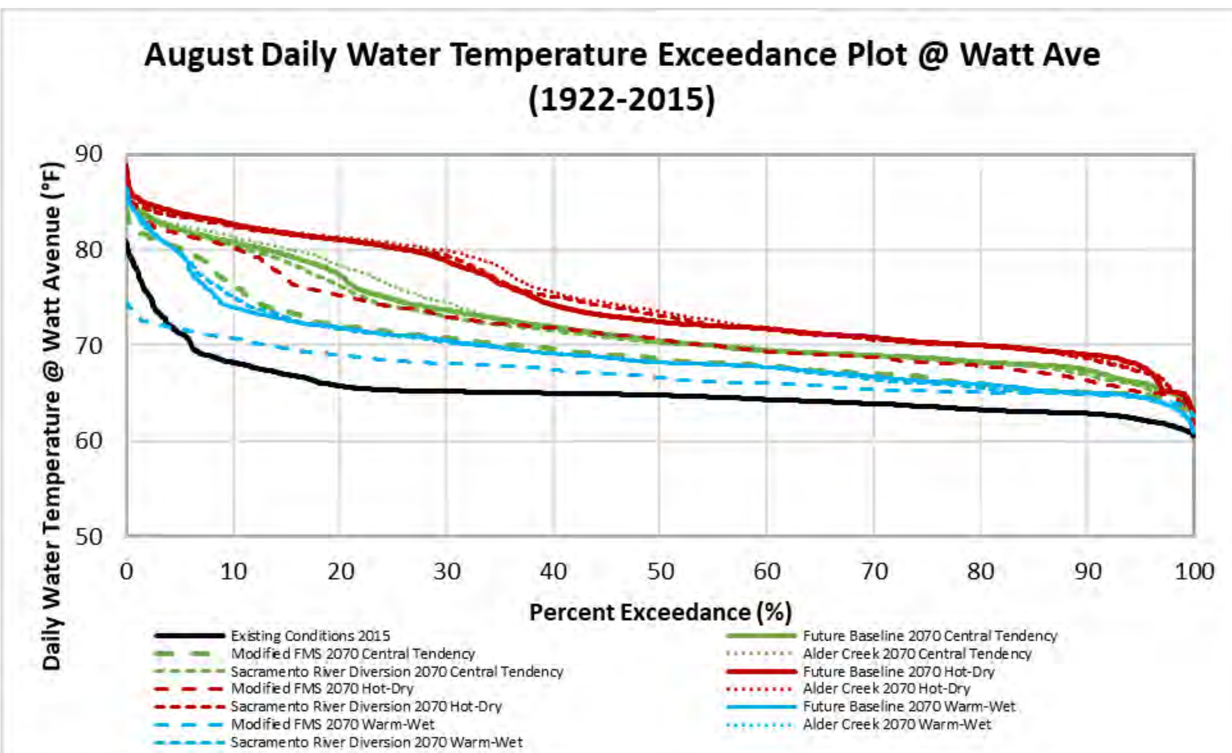


Figure 5 (continued). Monthly Exceedance Plots of Daily Water Temperature at Watt Avenue – All Scenarios





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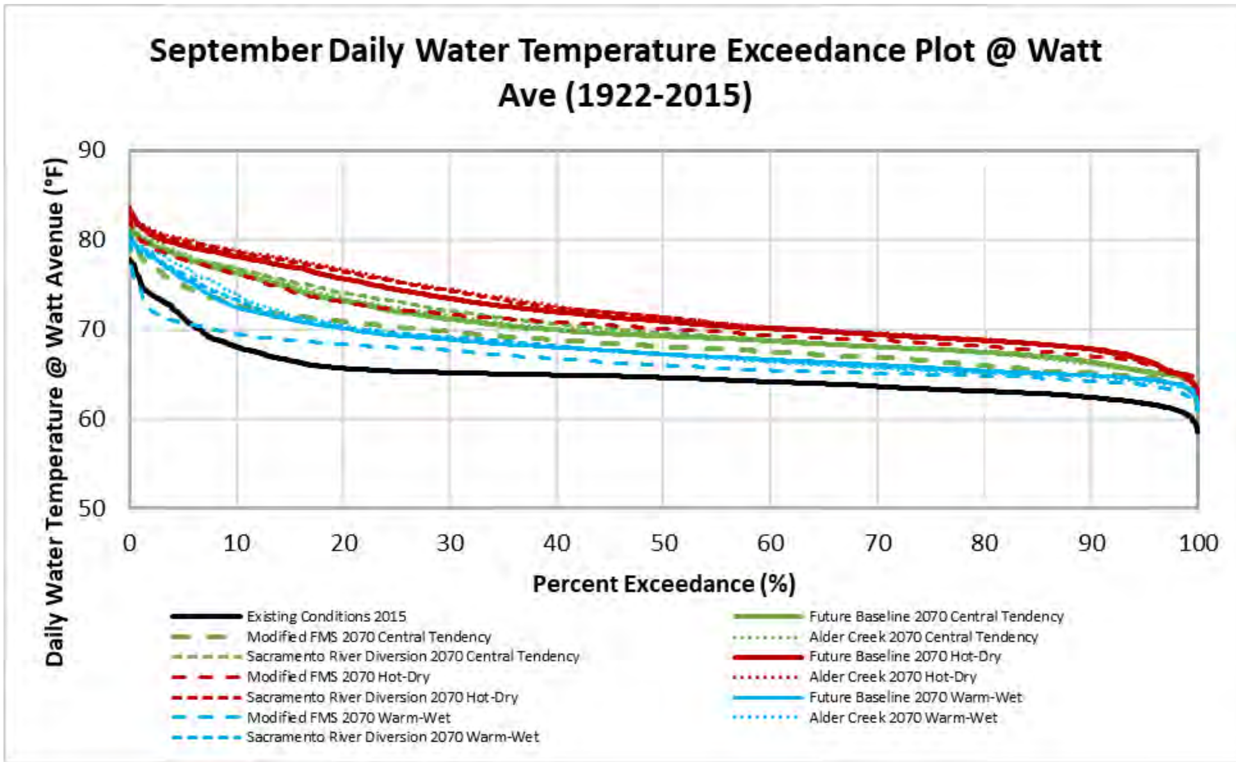

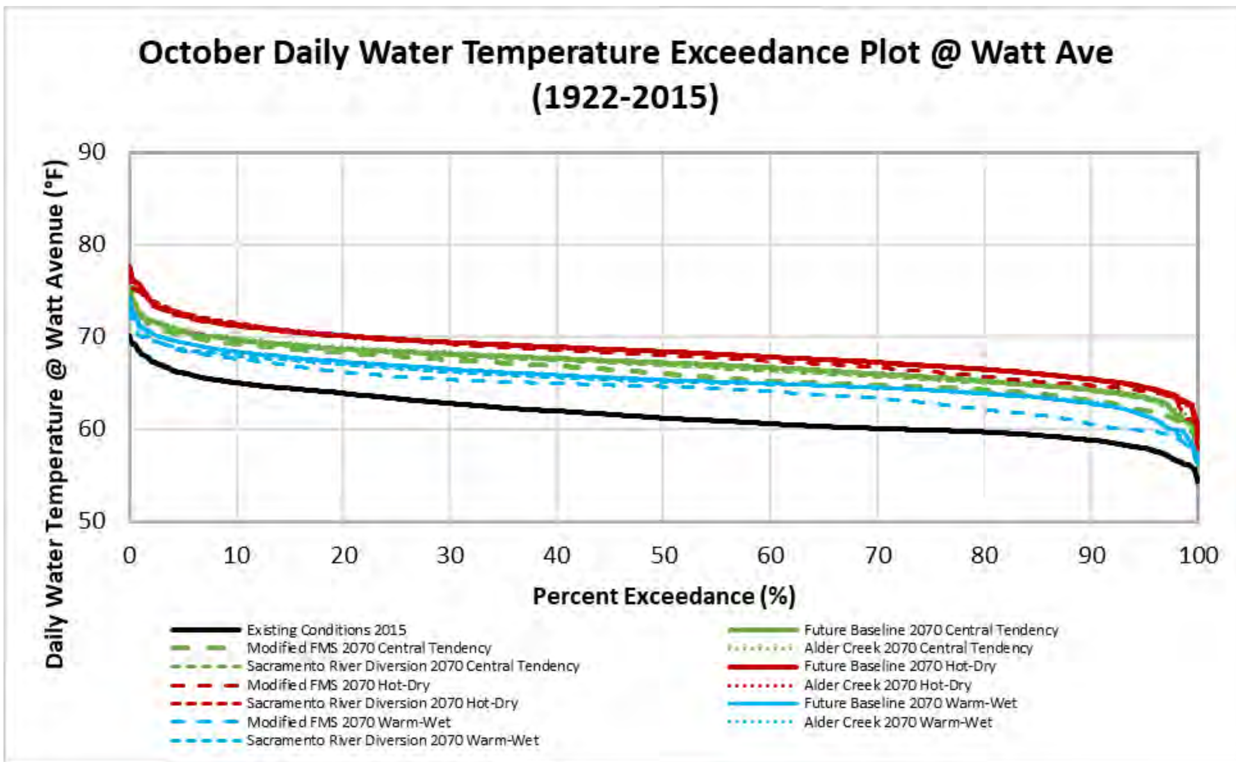

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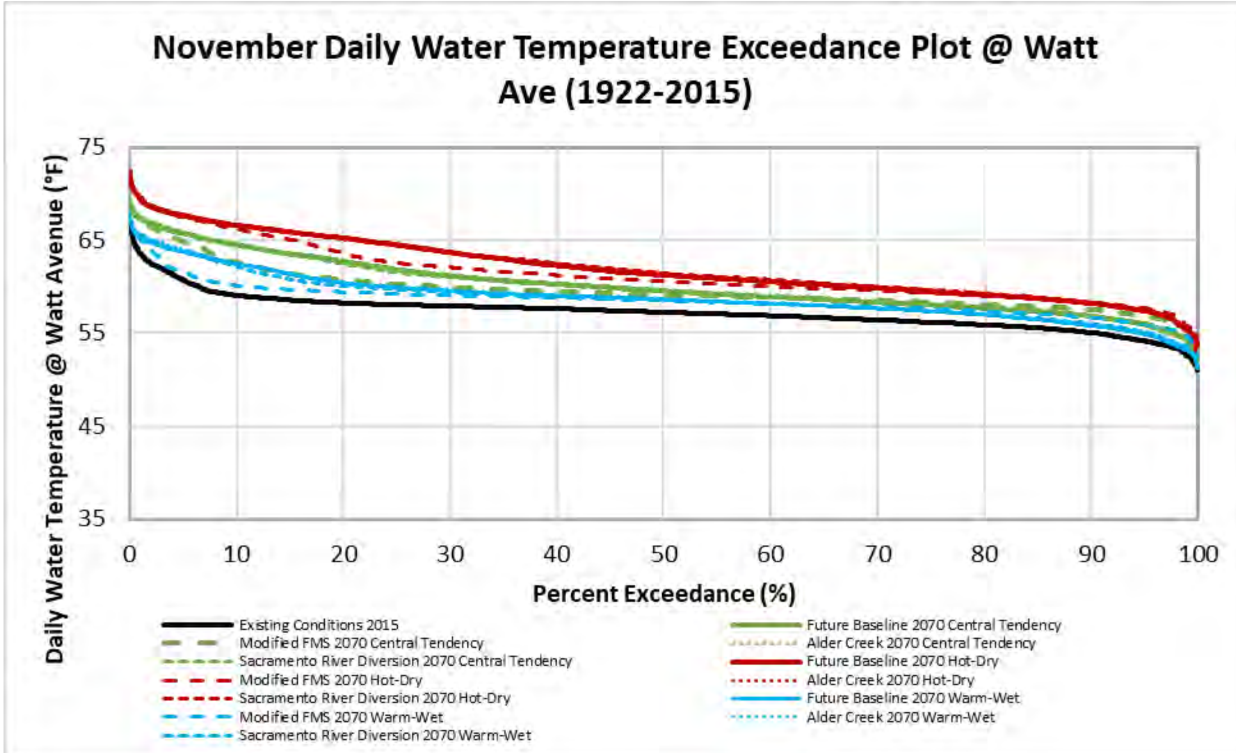

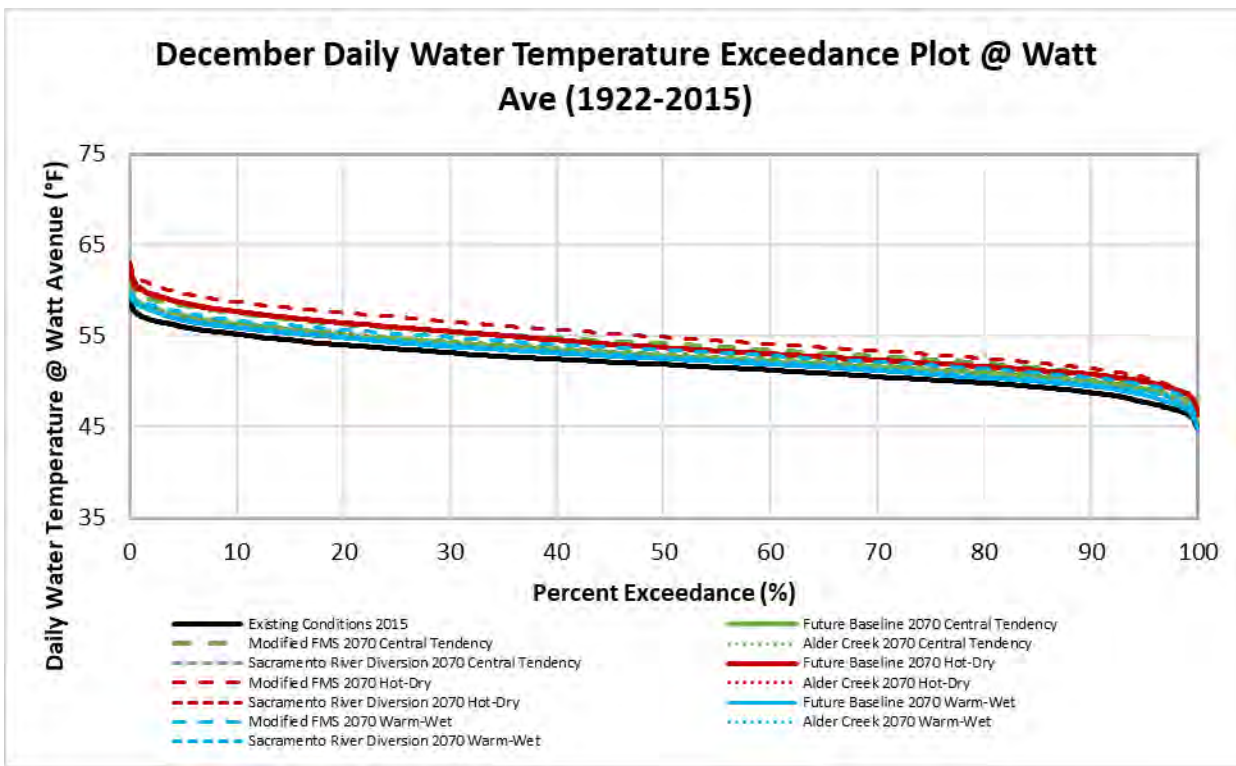

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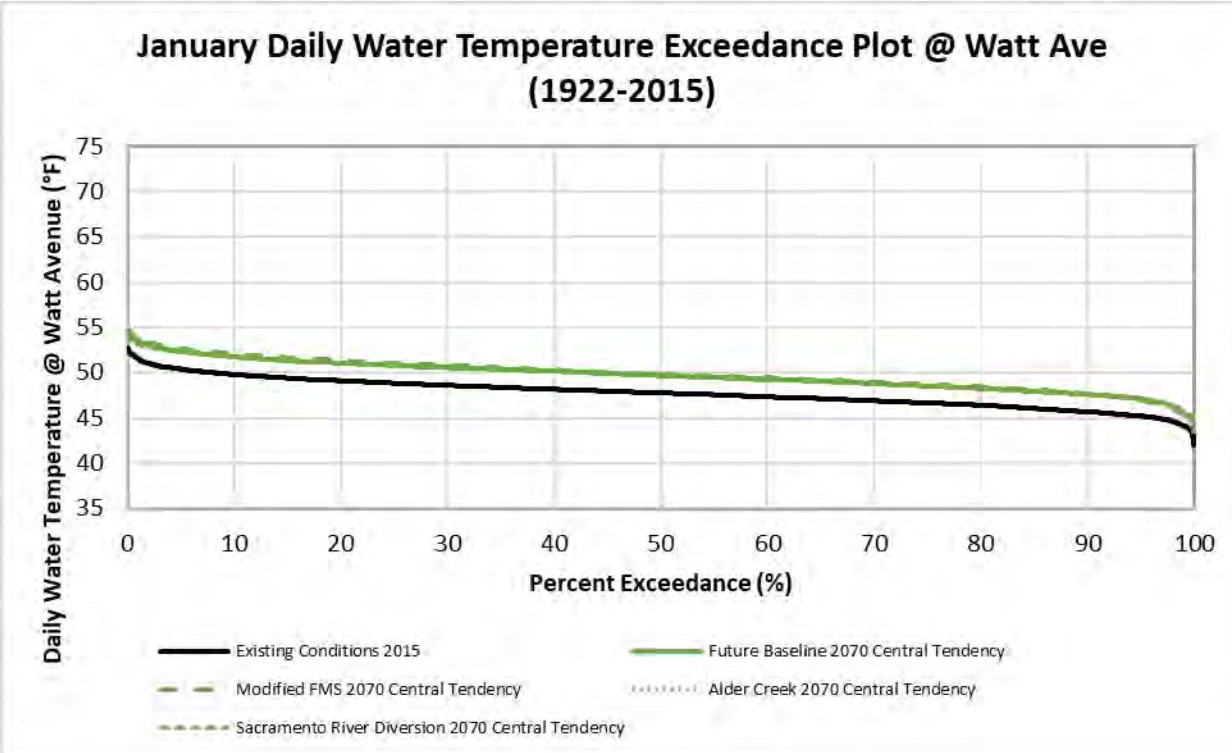


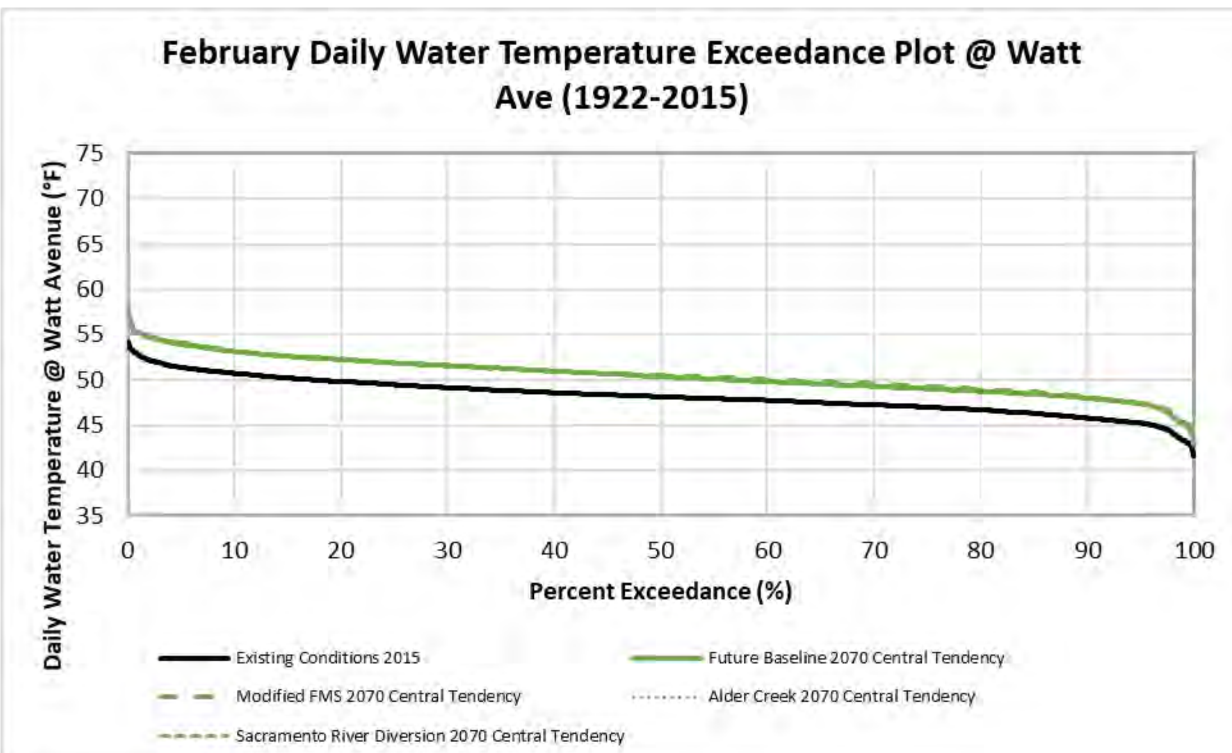
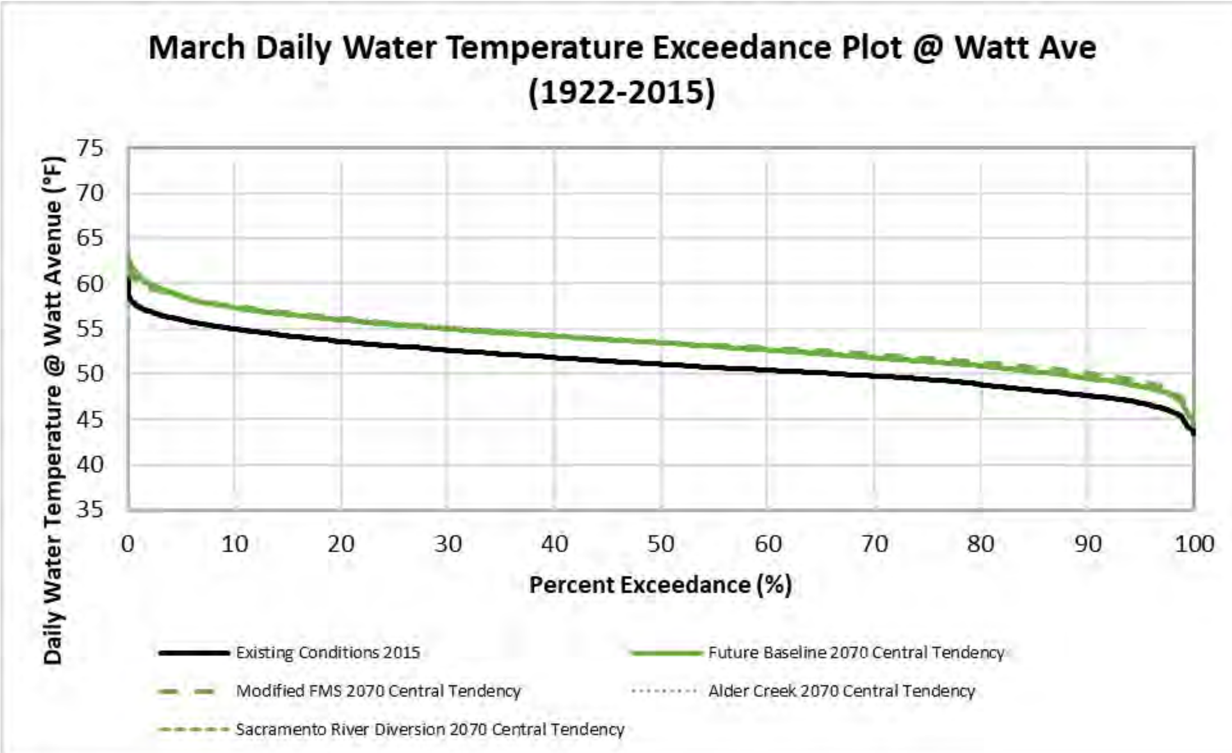
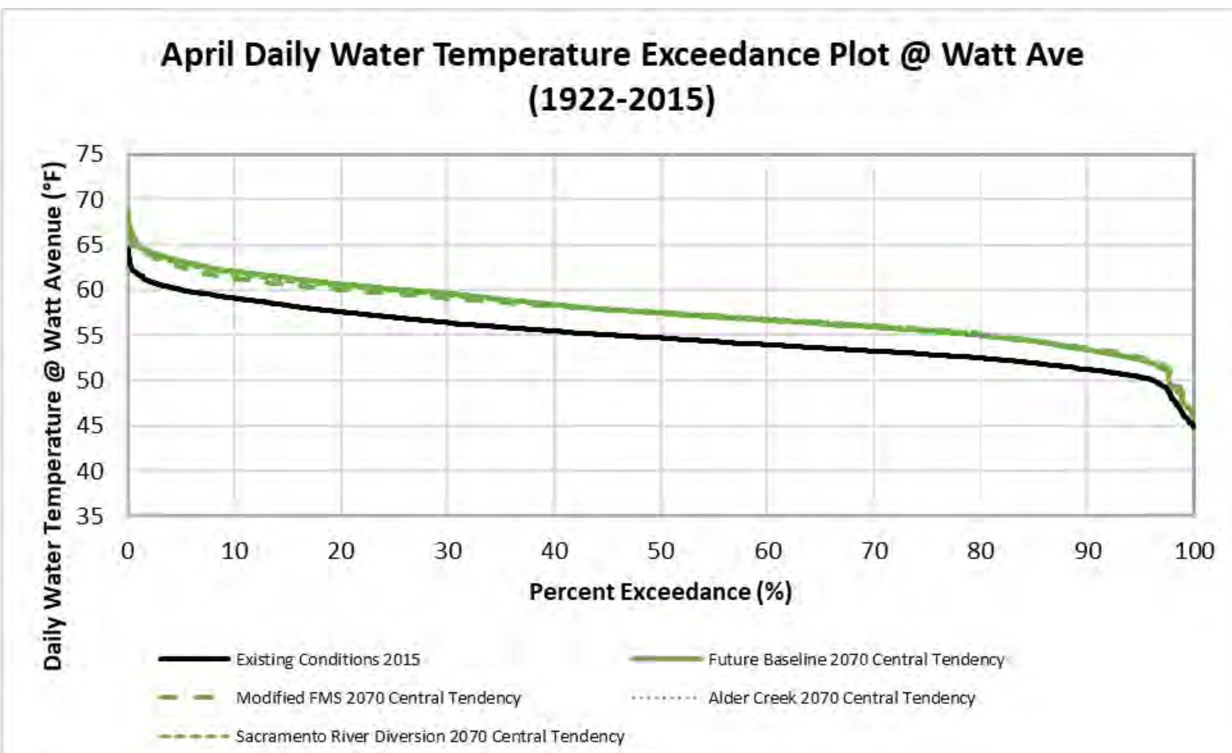


Figure 6. Monthly Exceedance Plots of Daily Water Temperature at Watt Avenue – Central Tendency Climate Change Scenarios





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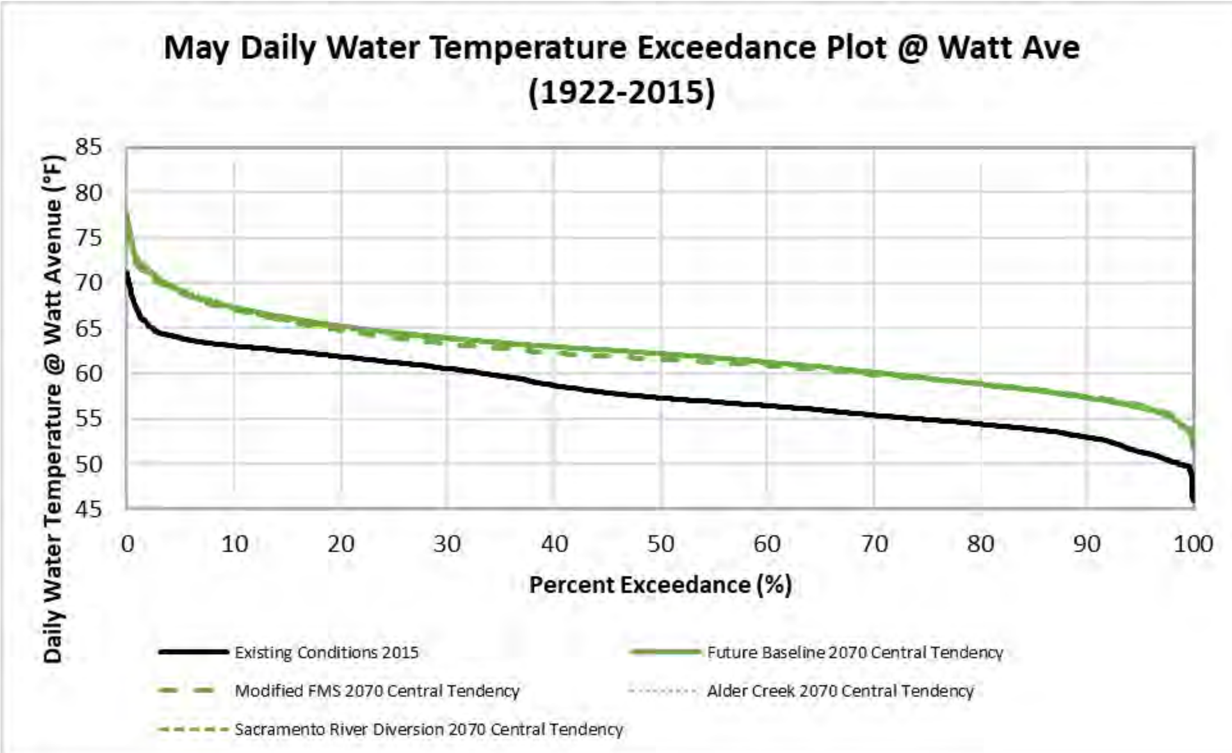

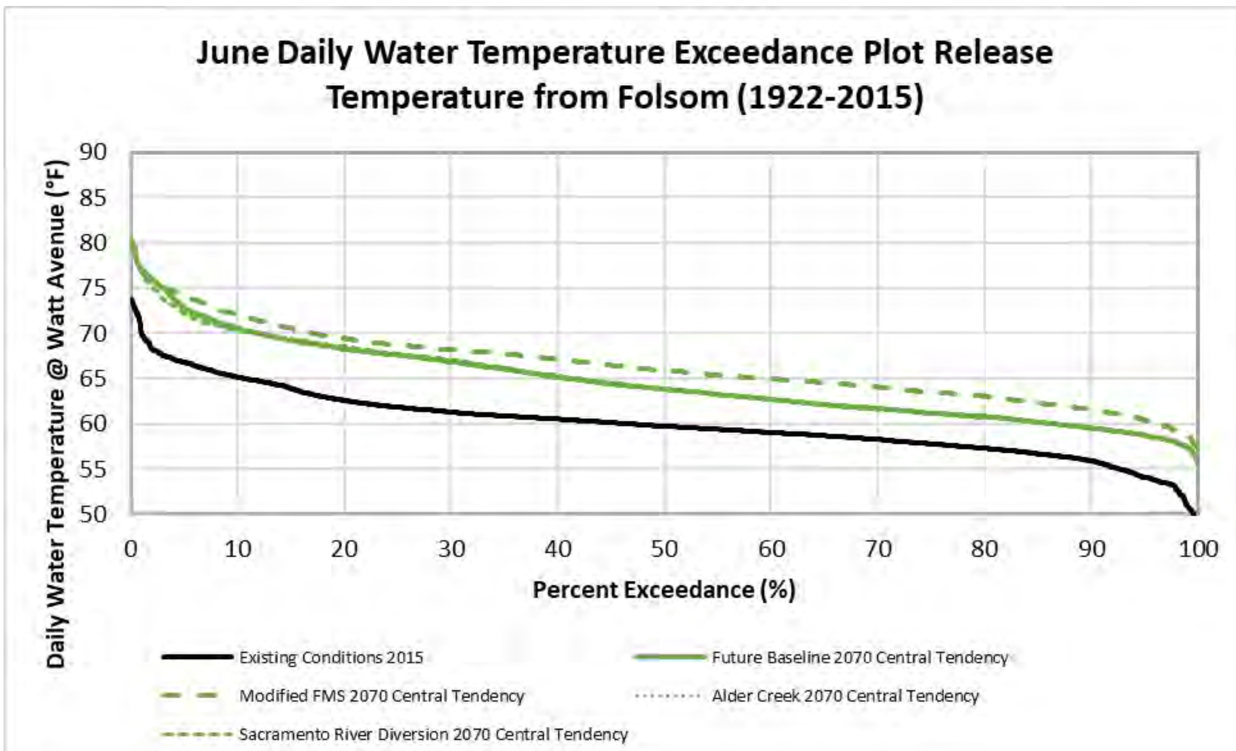

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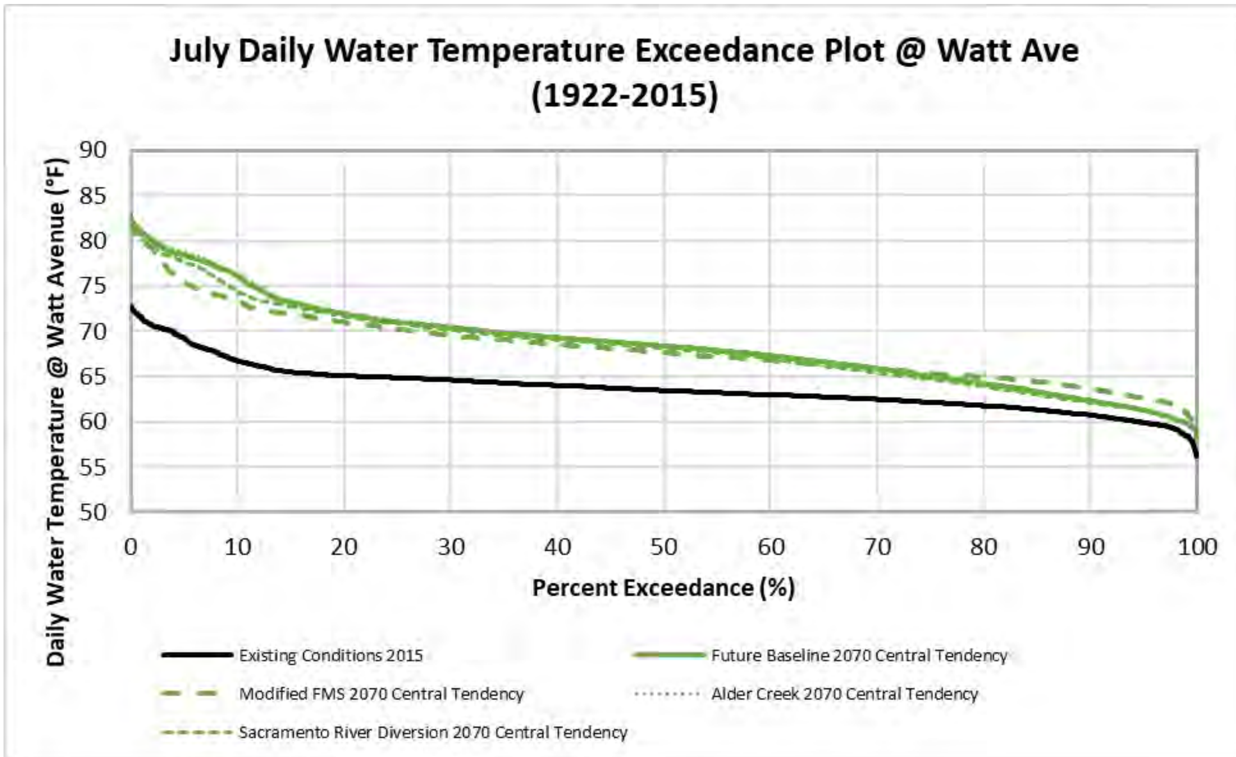

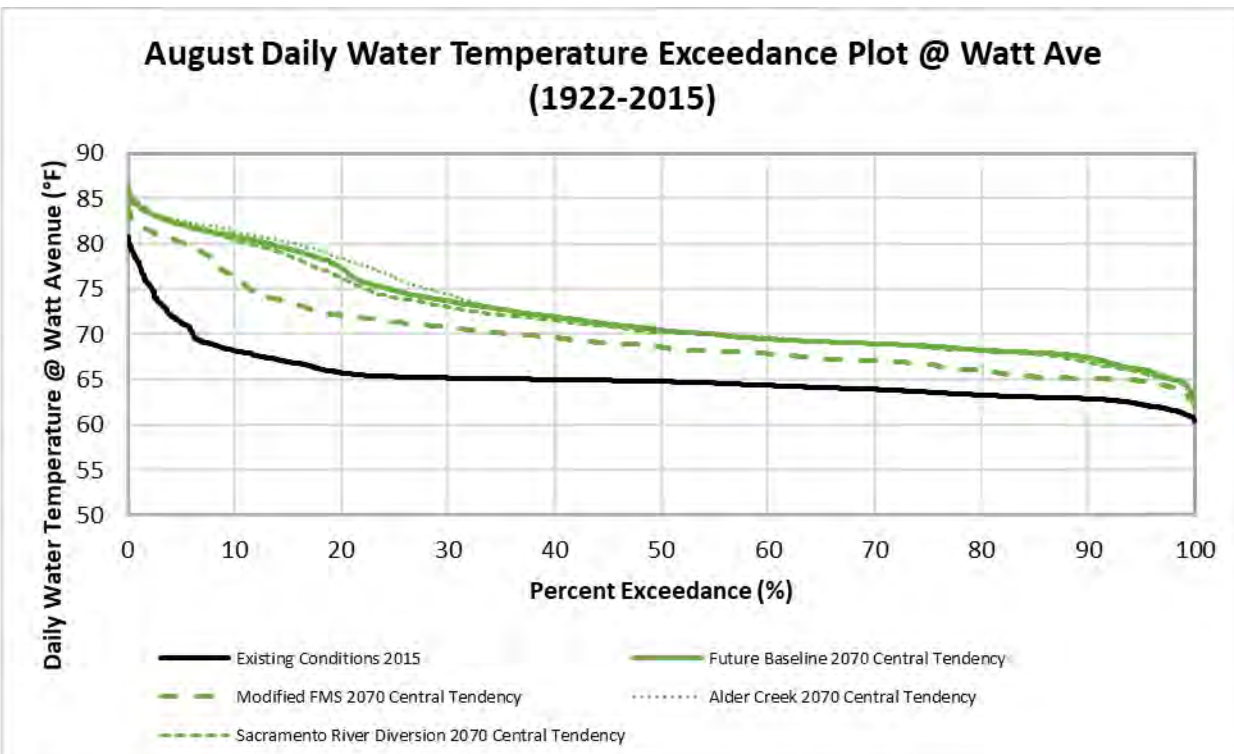

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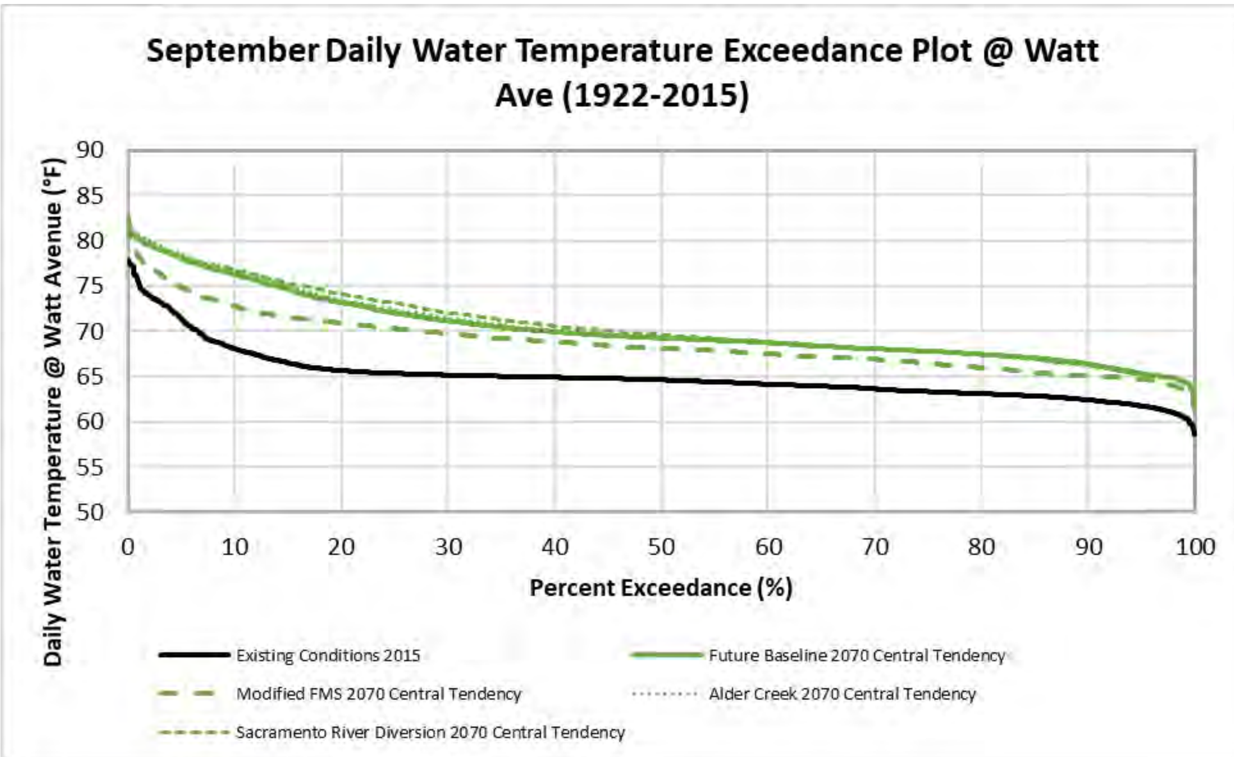

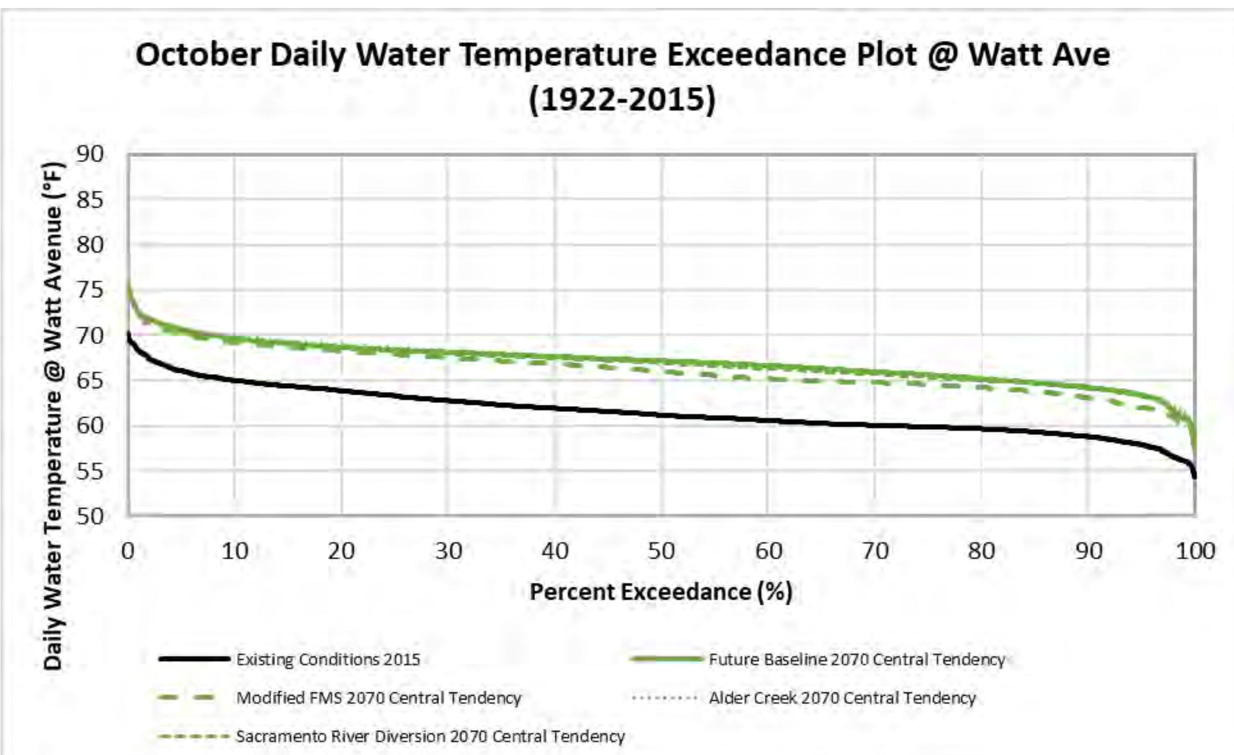

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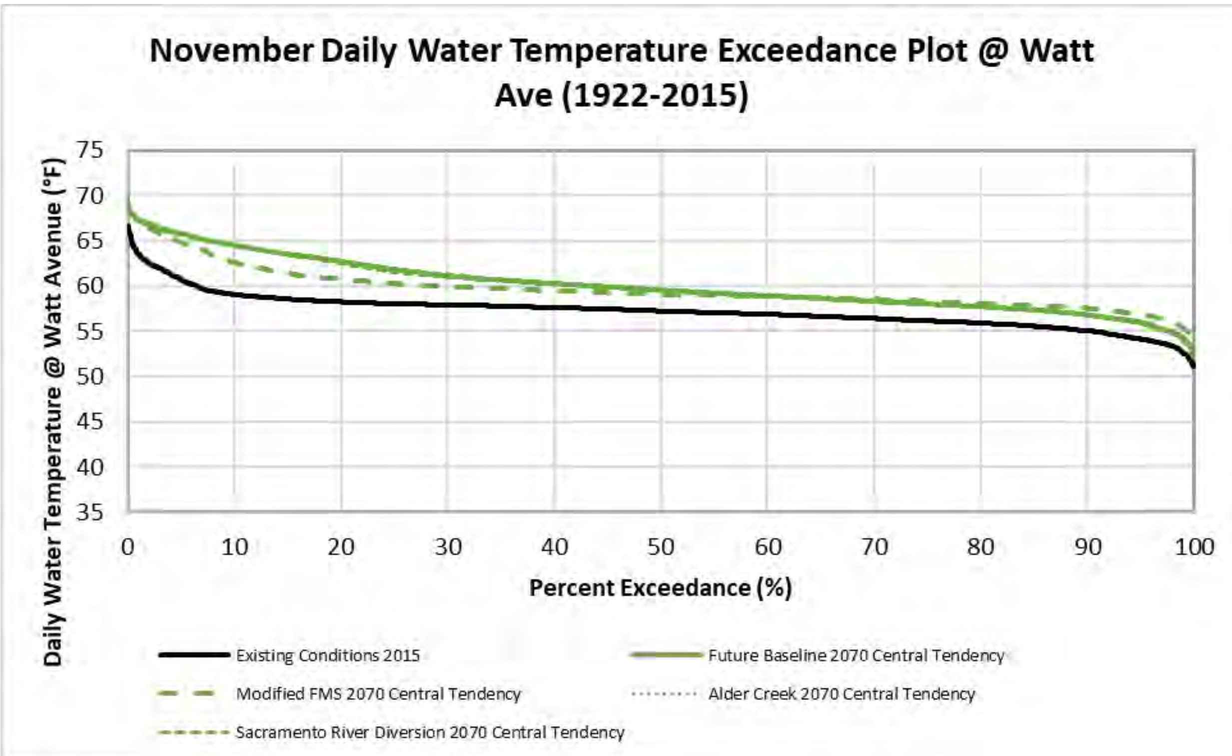

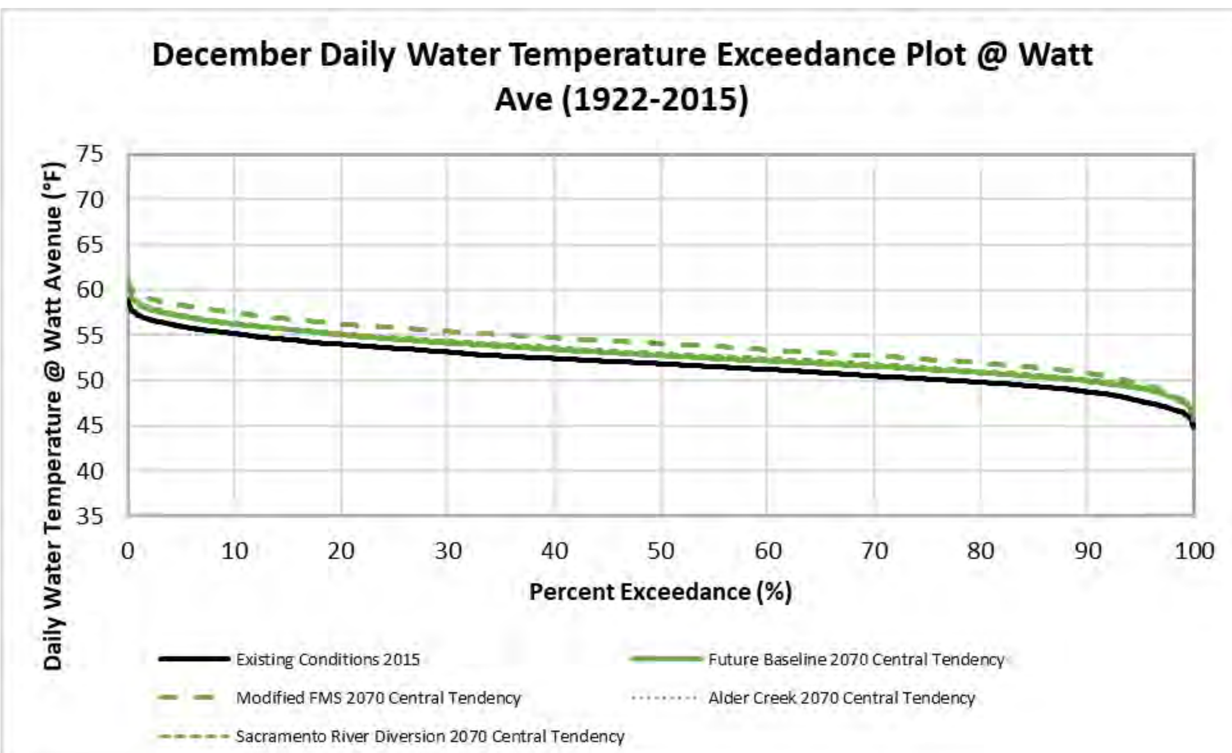

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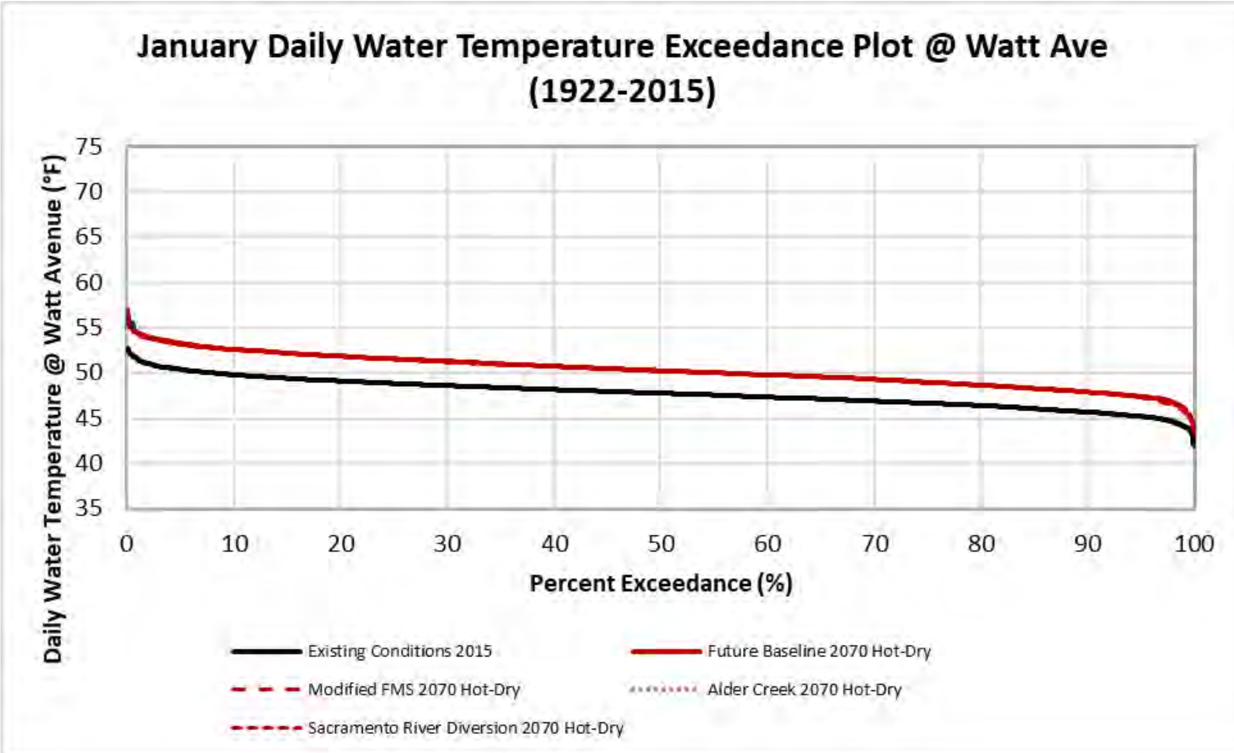


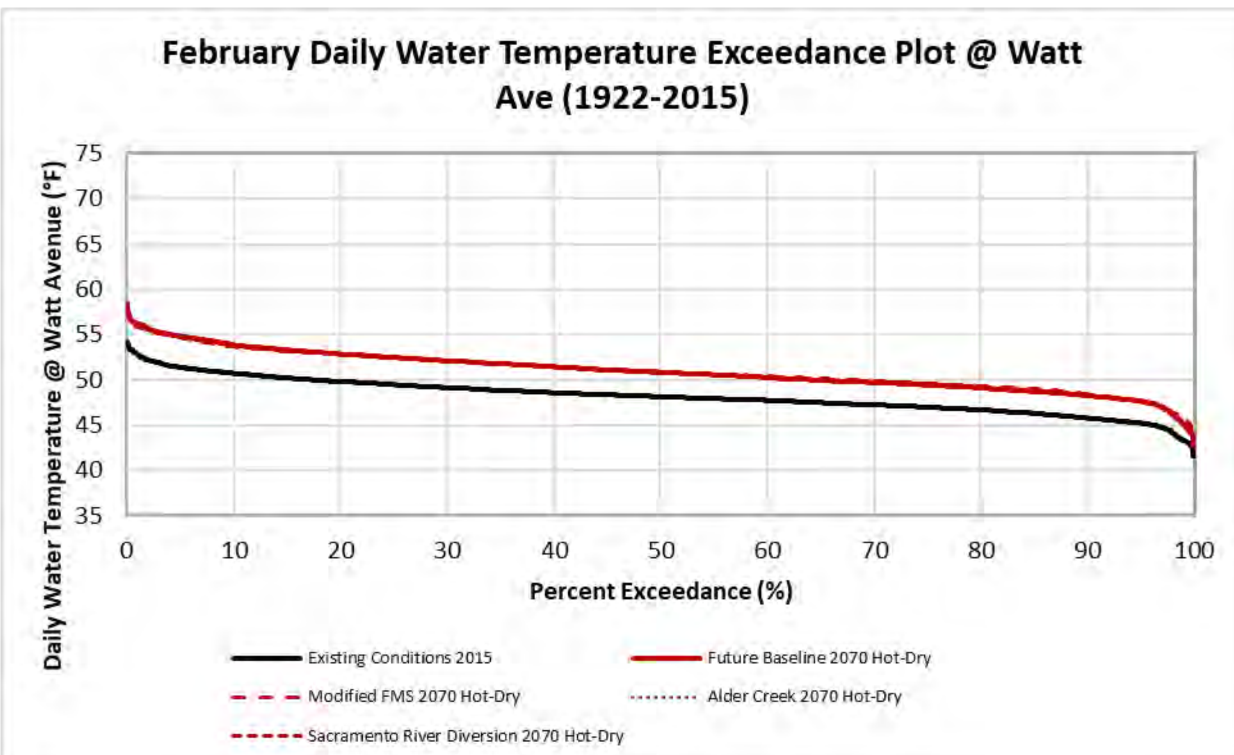
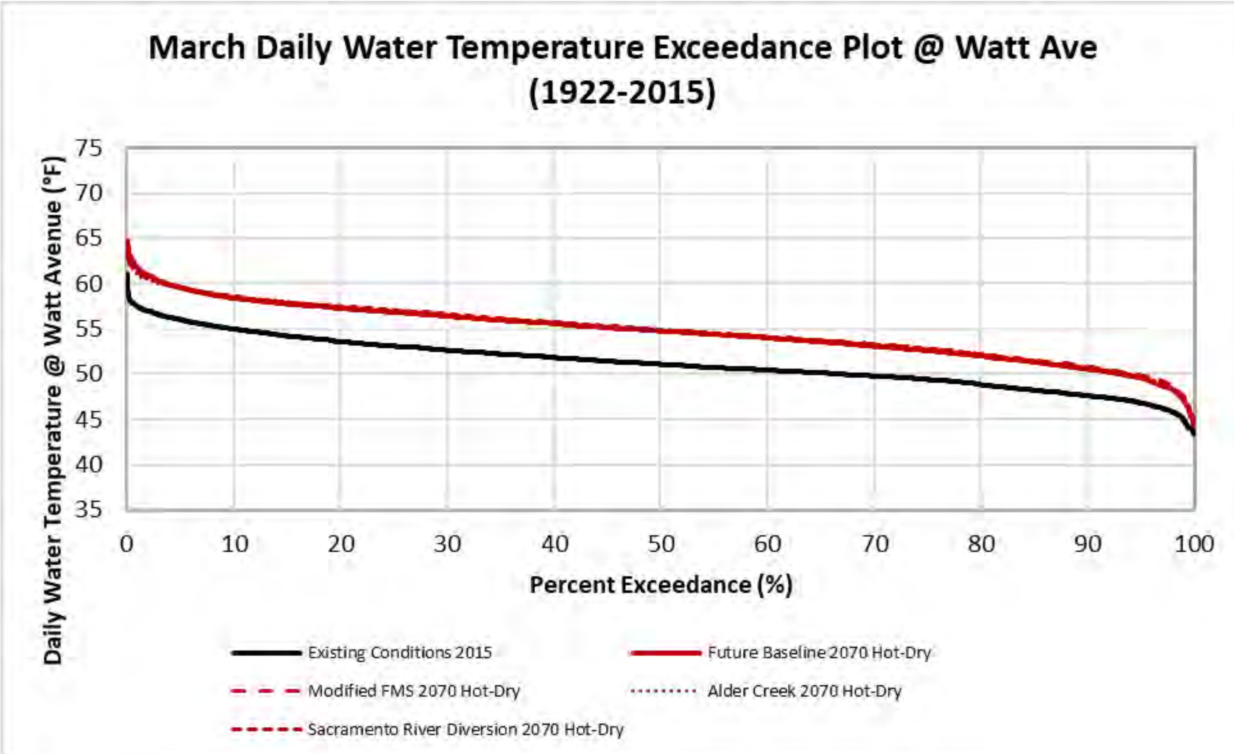
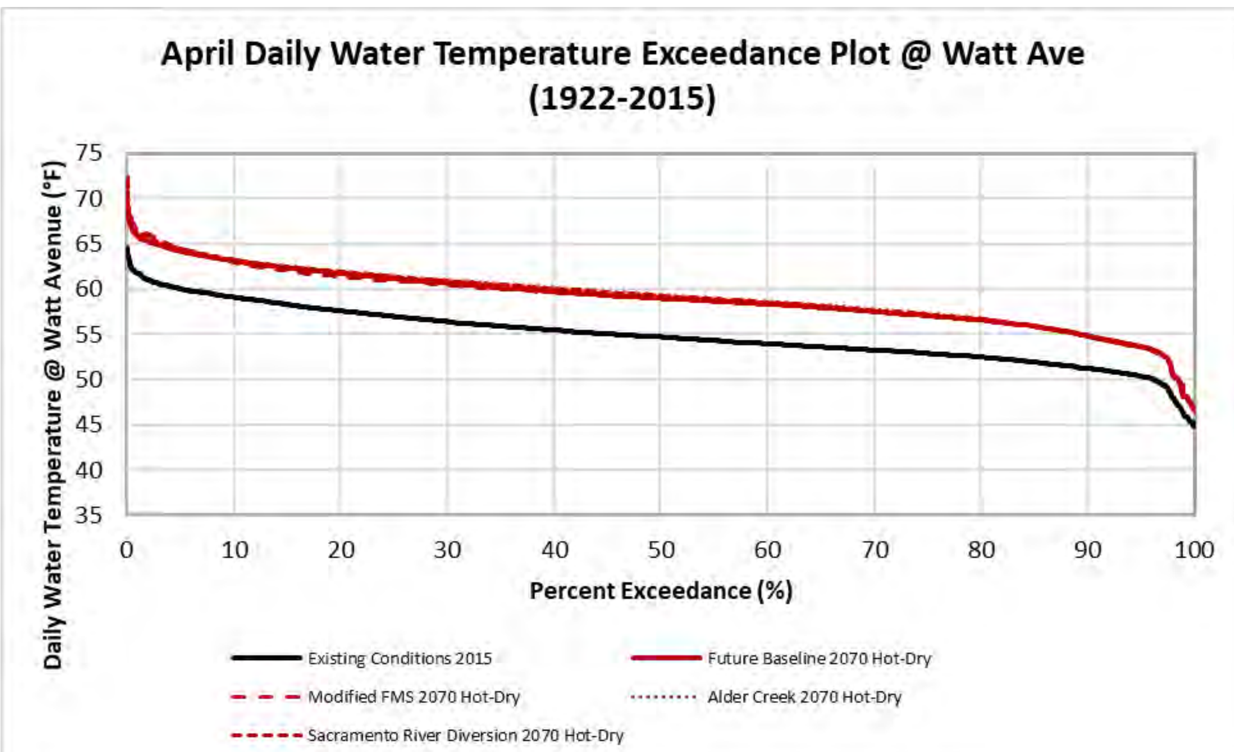


Figure 7. Monthly Exceedance Plots of Daily Water Temperature at Watt Avenue – Hot-Dry Climate Change Scenarios





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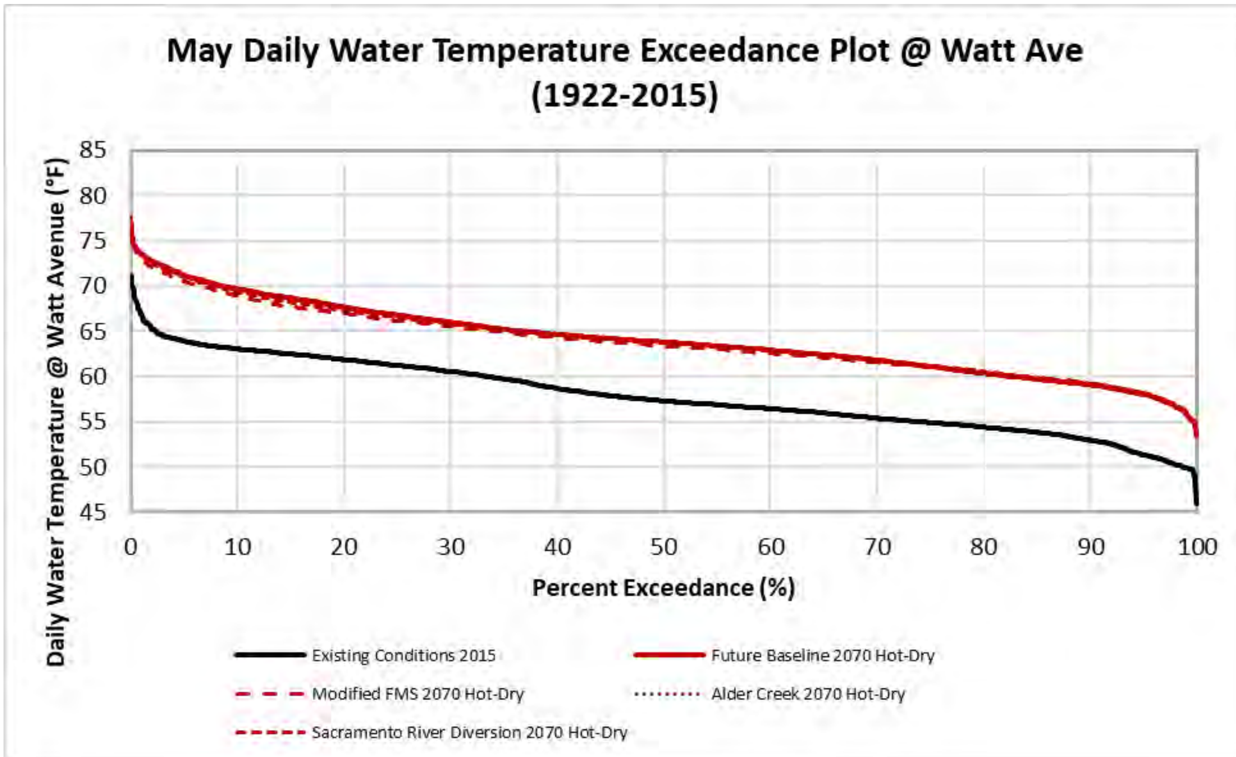

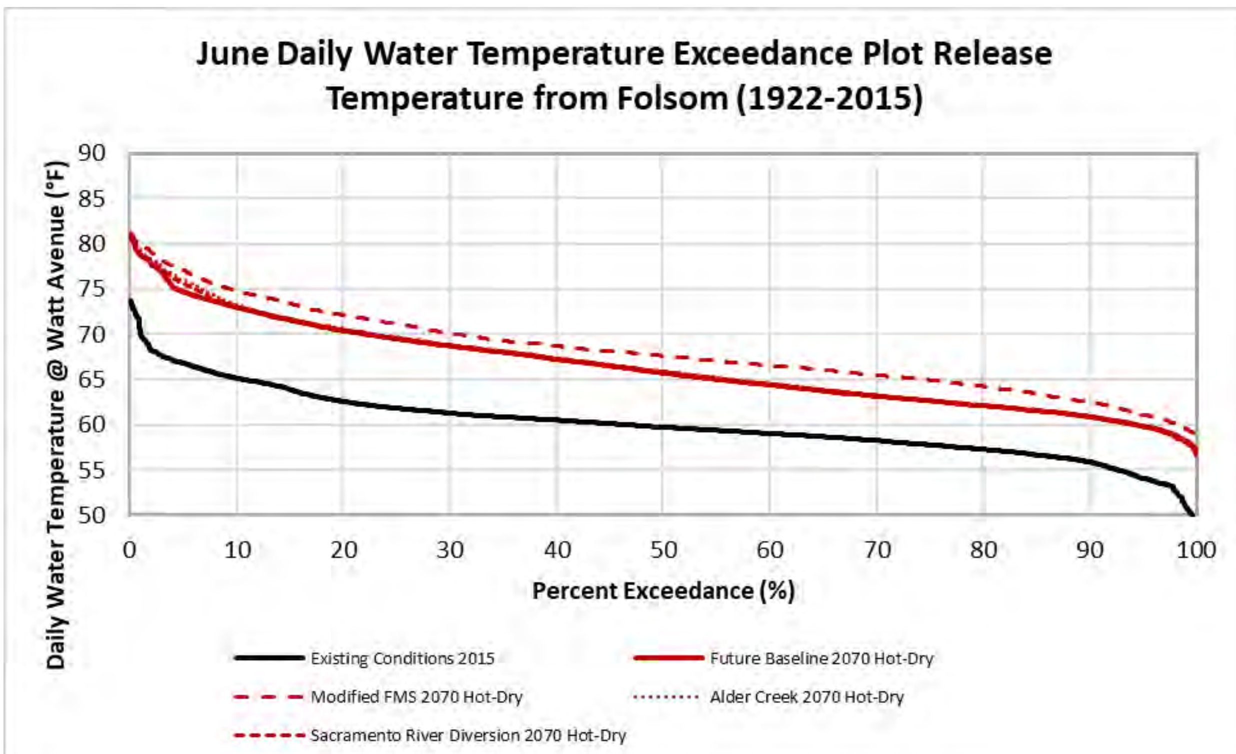

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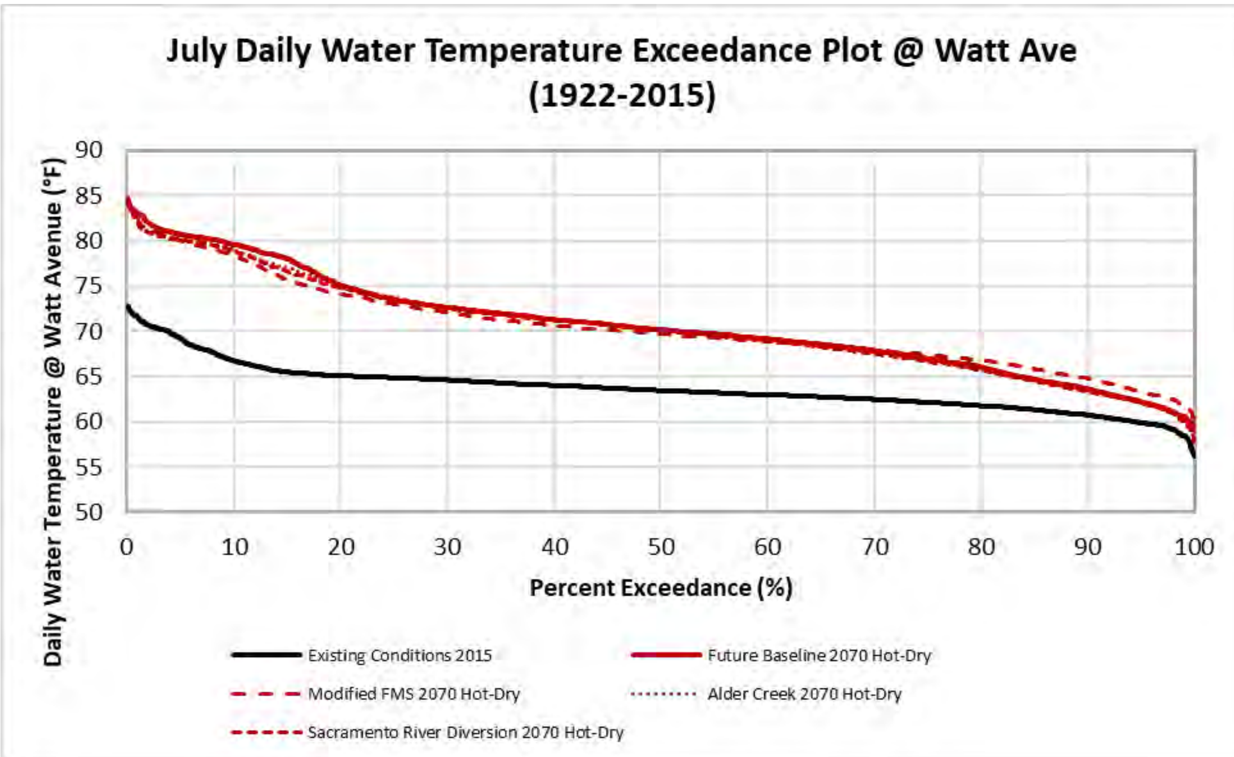

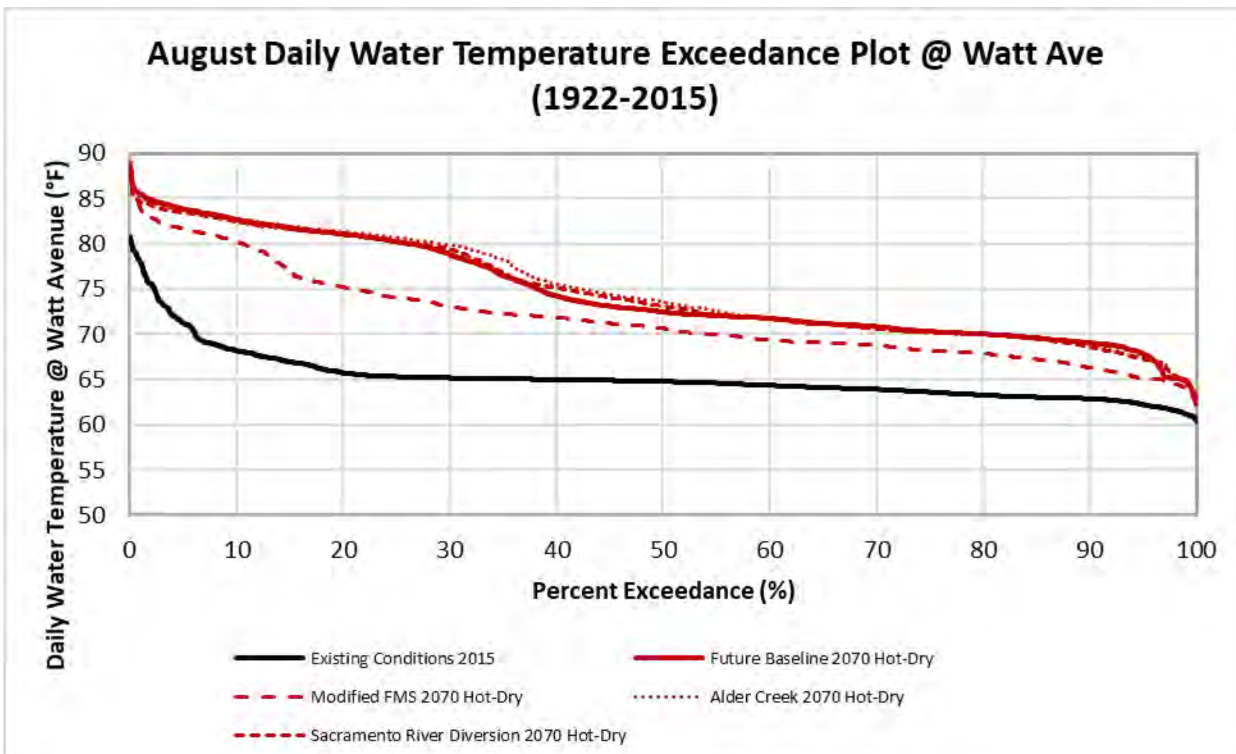

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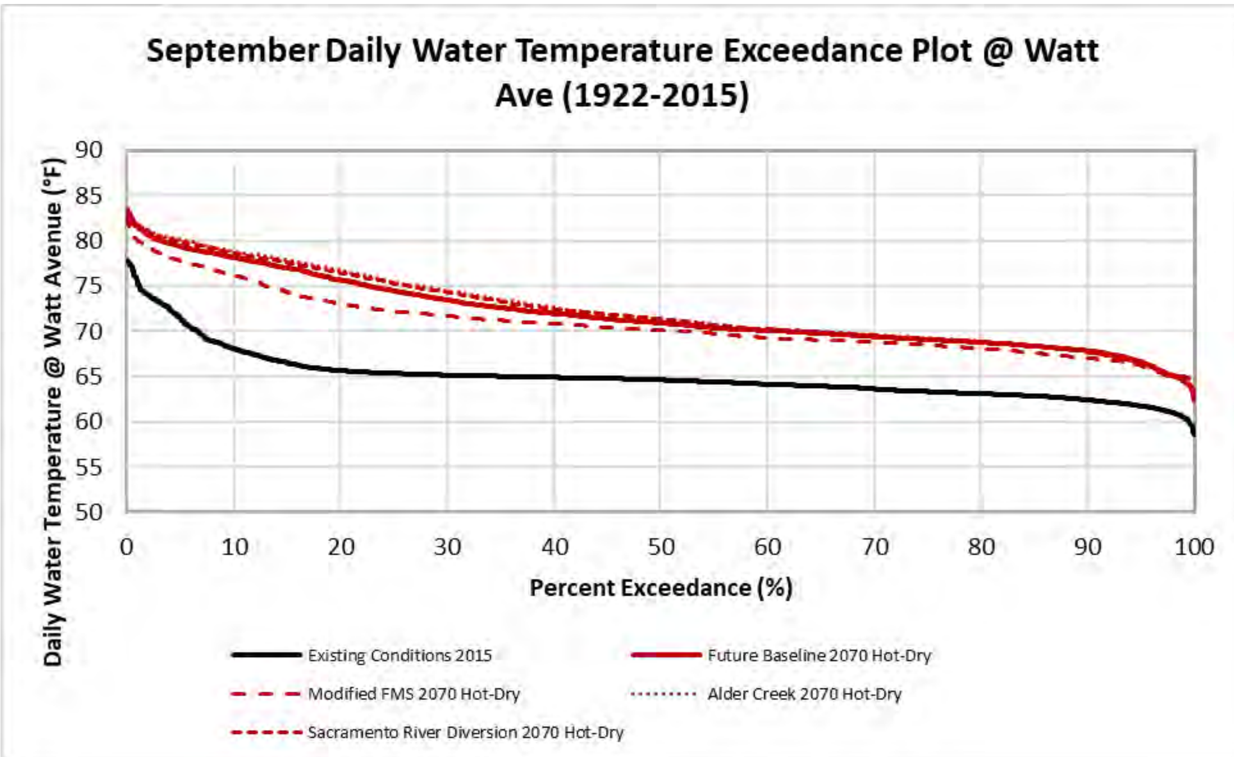

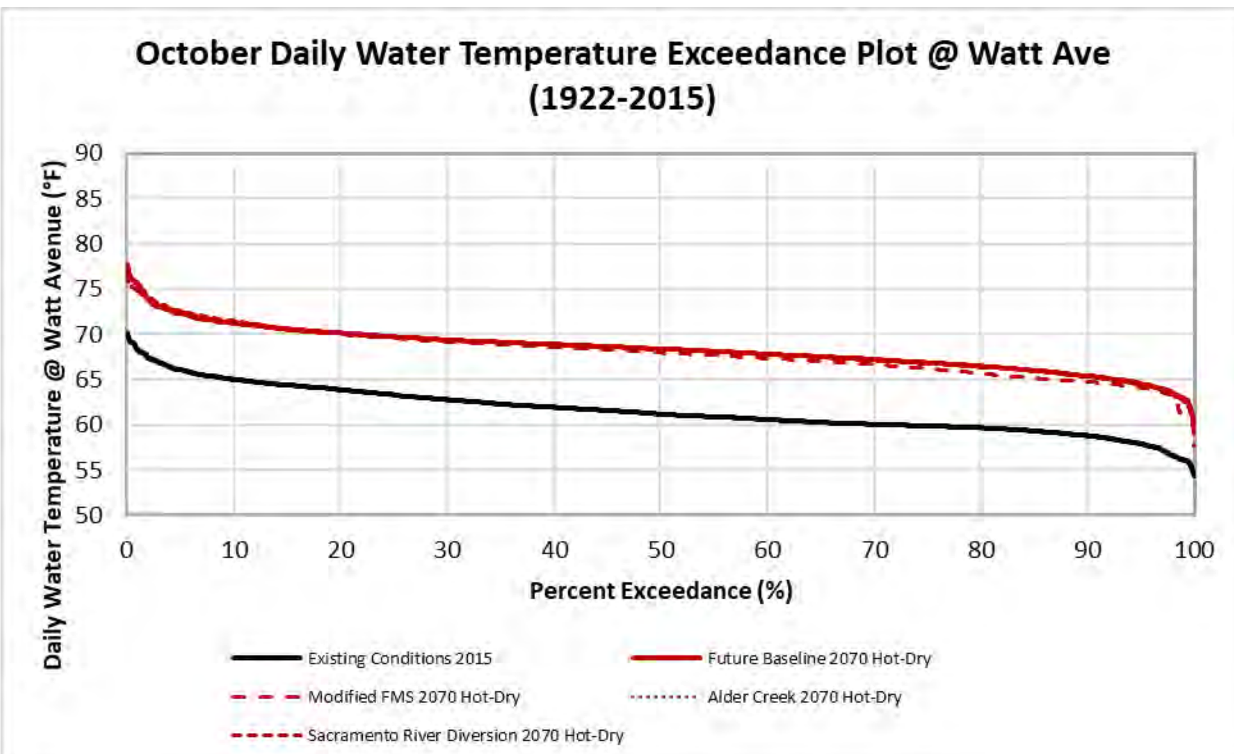

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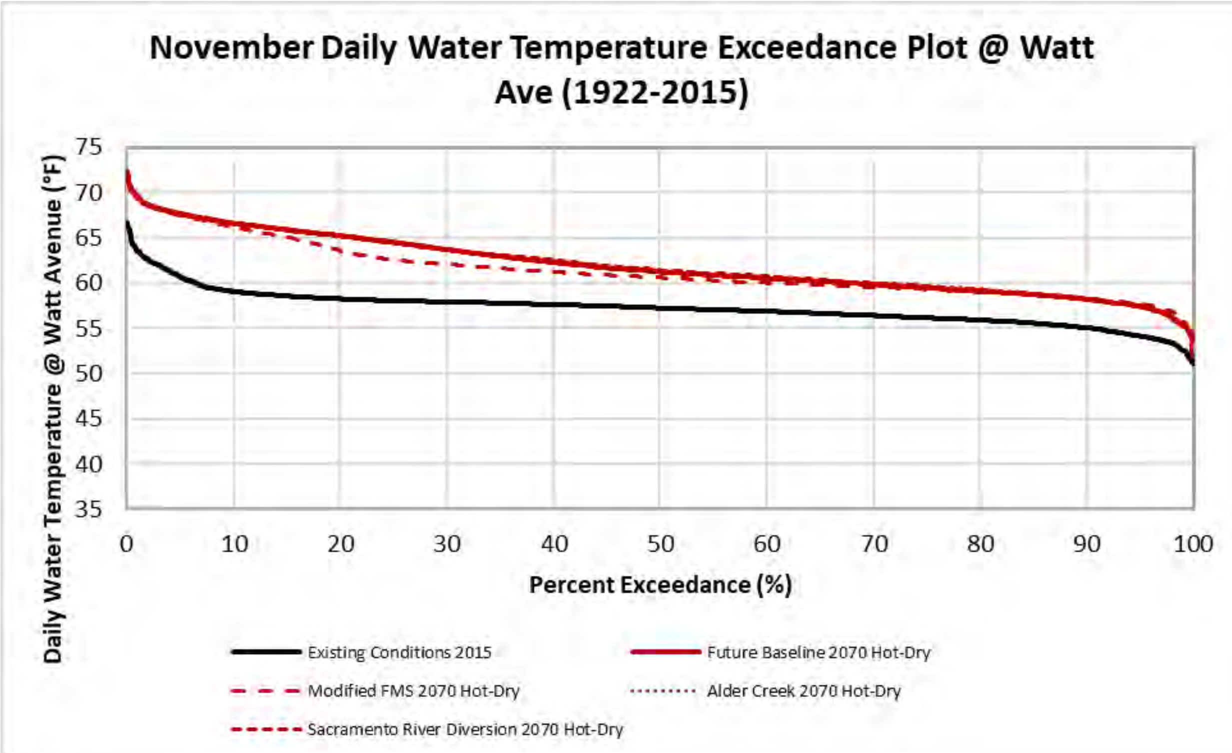

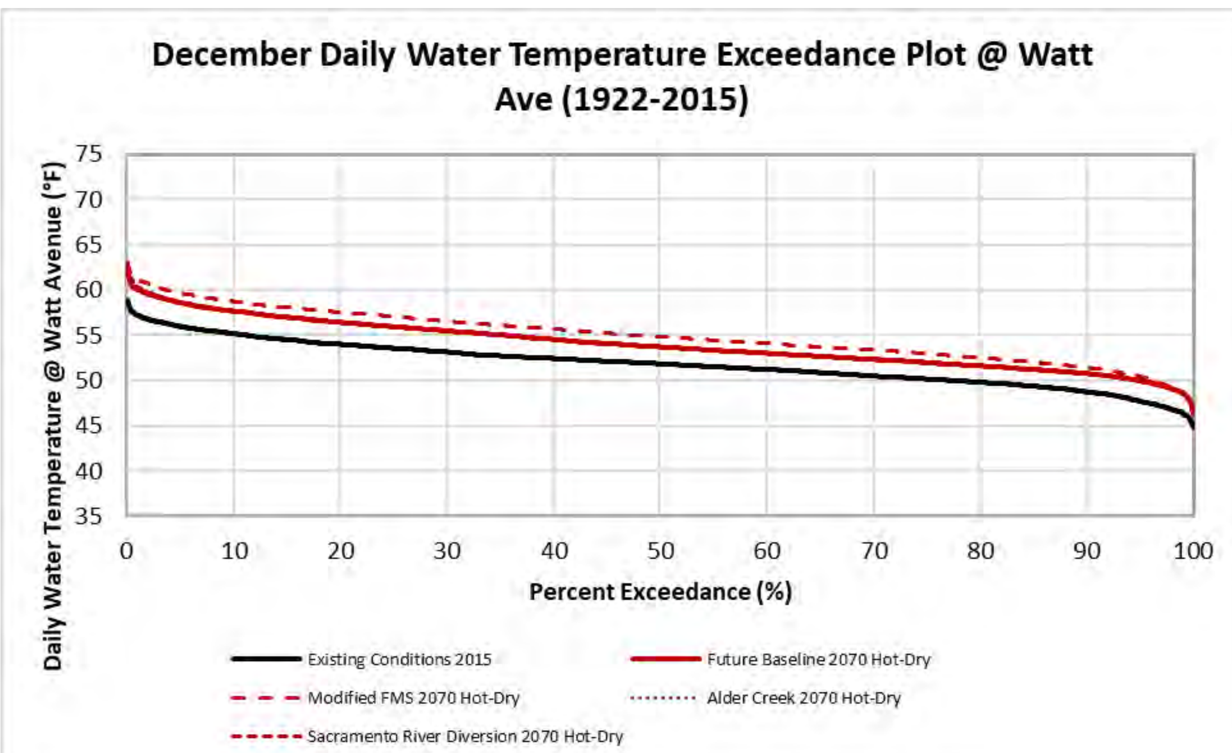

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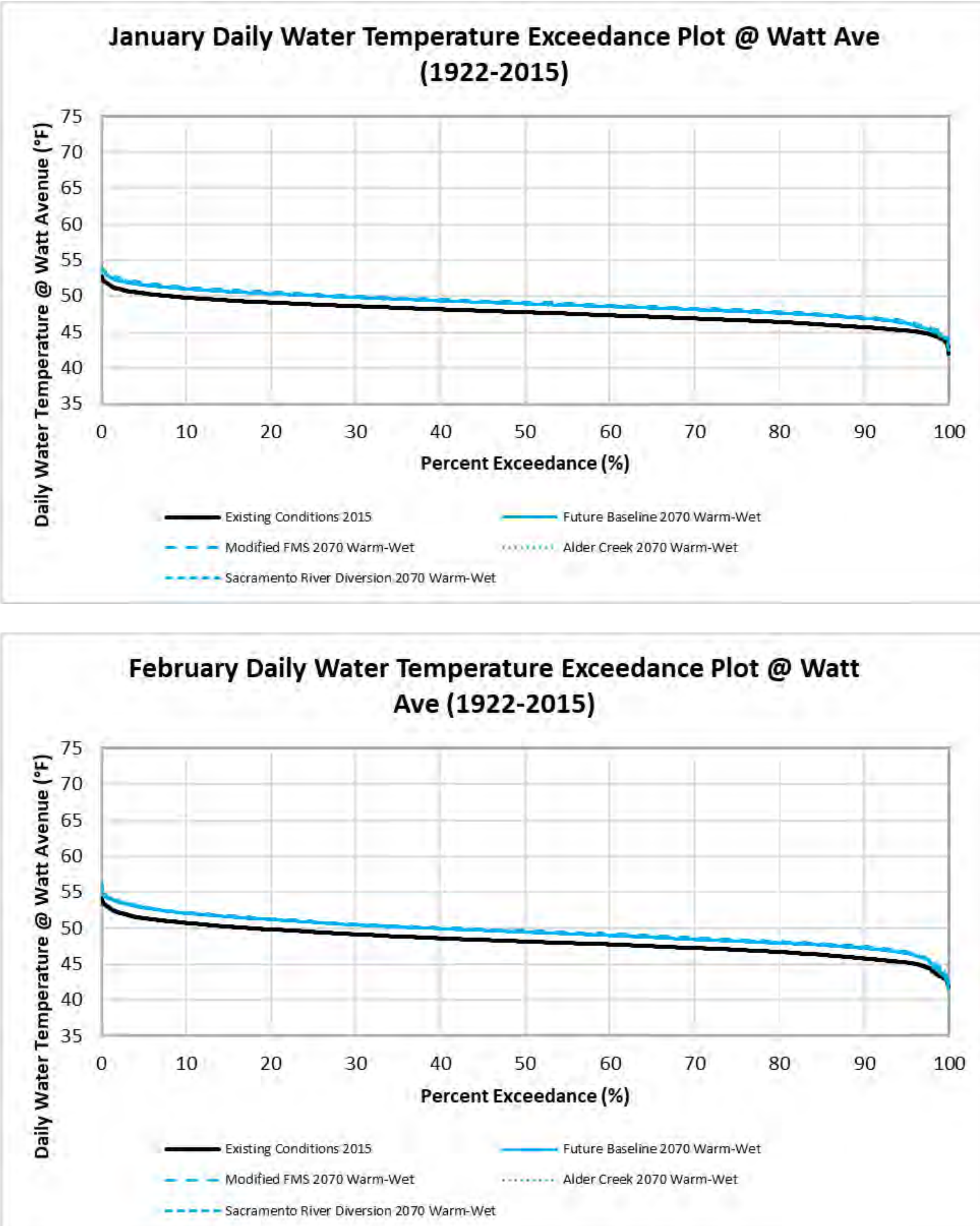
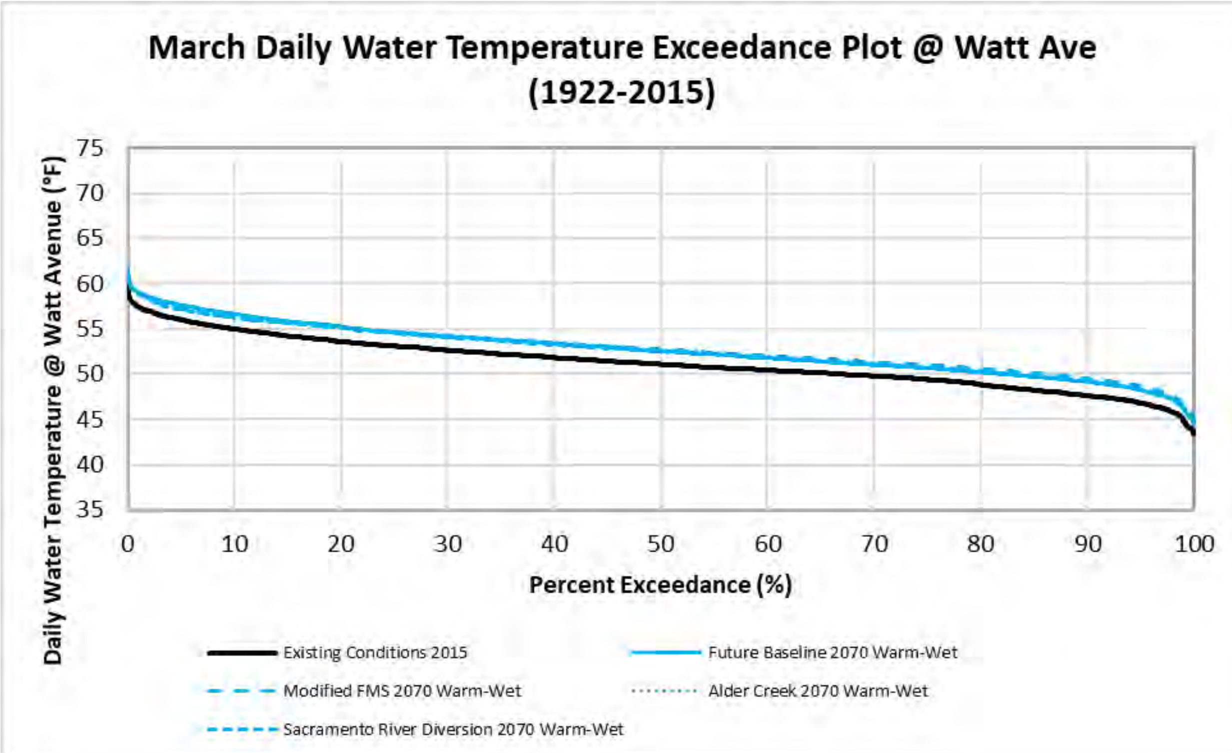
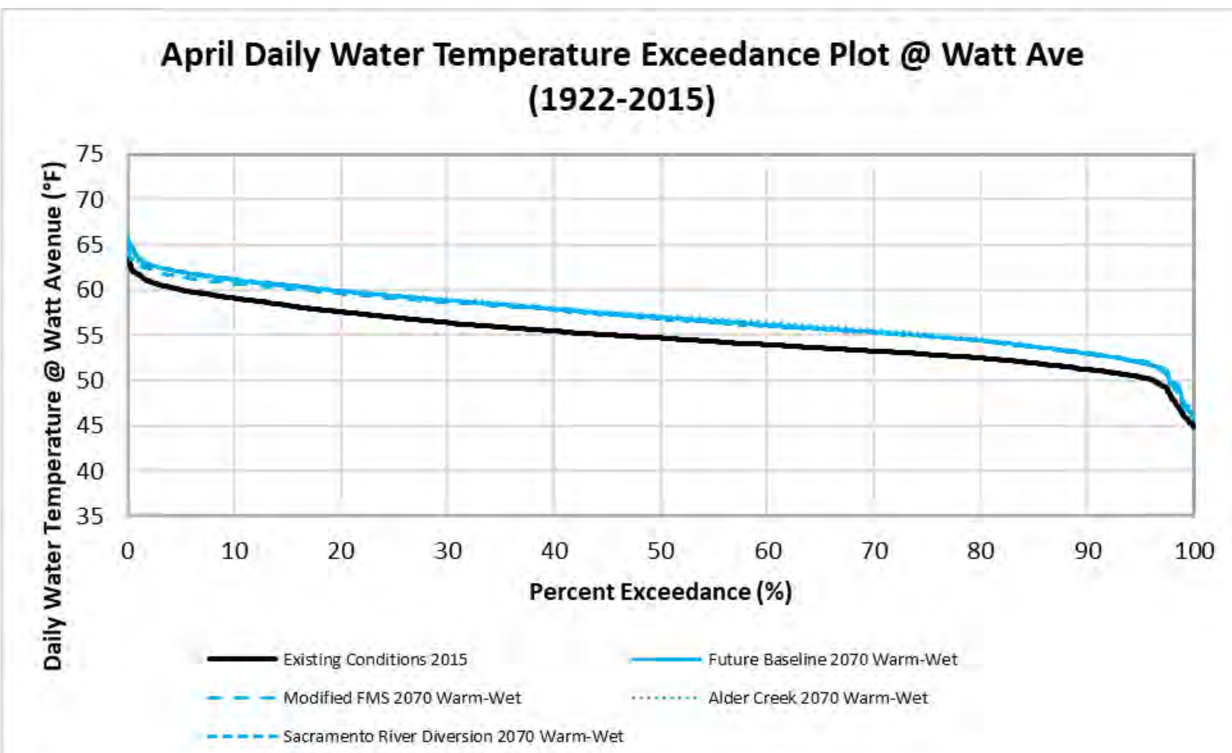


Figure 8. Monthly Exceedance Plots of Daily Water Temperature at Watt Avenue – Warm-Wet Climate Change Scenarios





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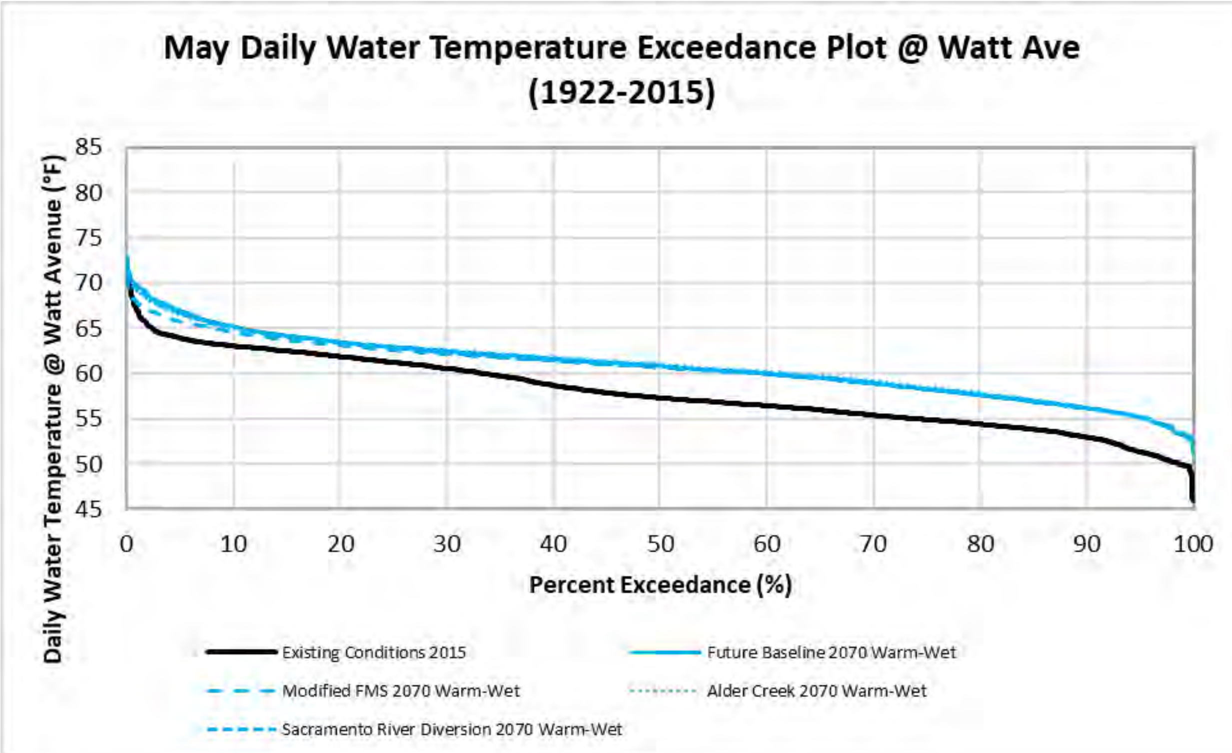

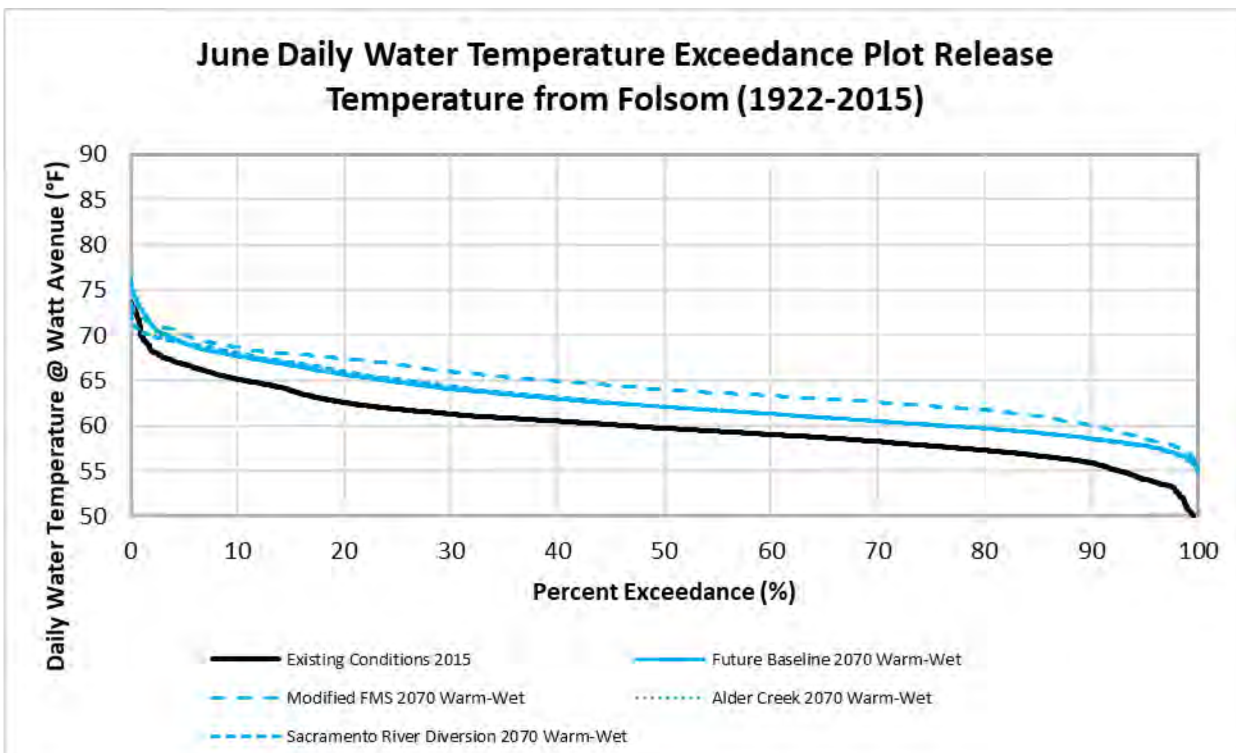

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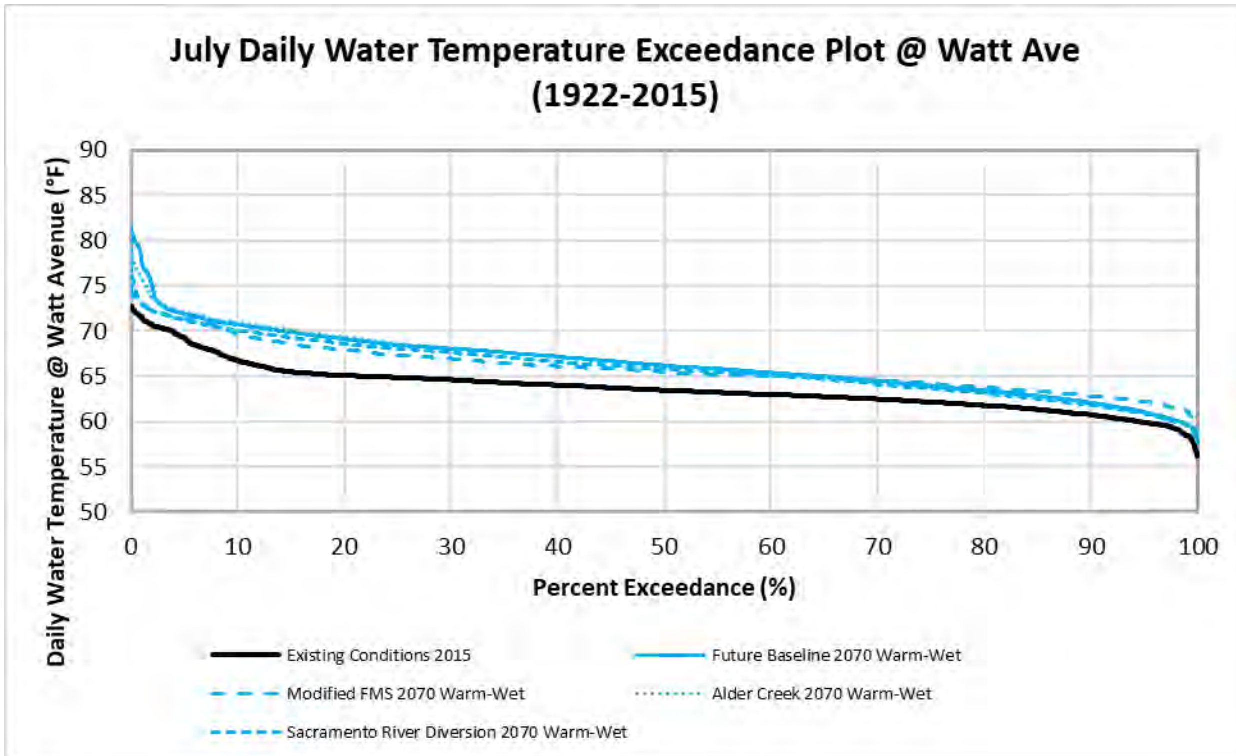

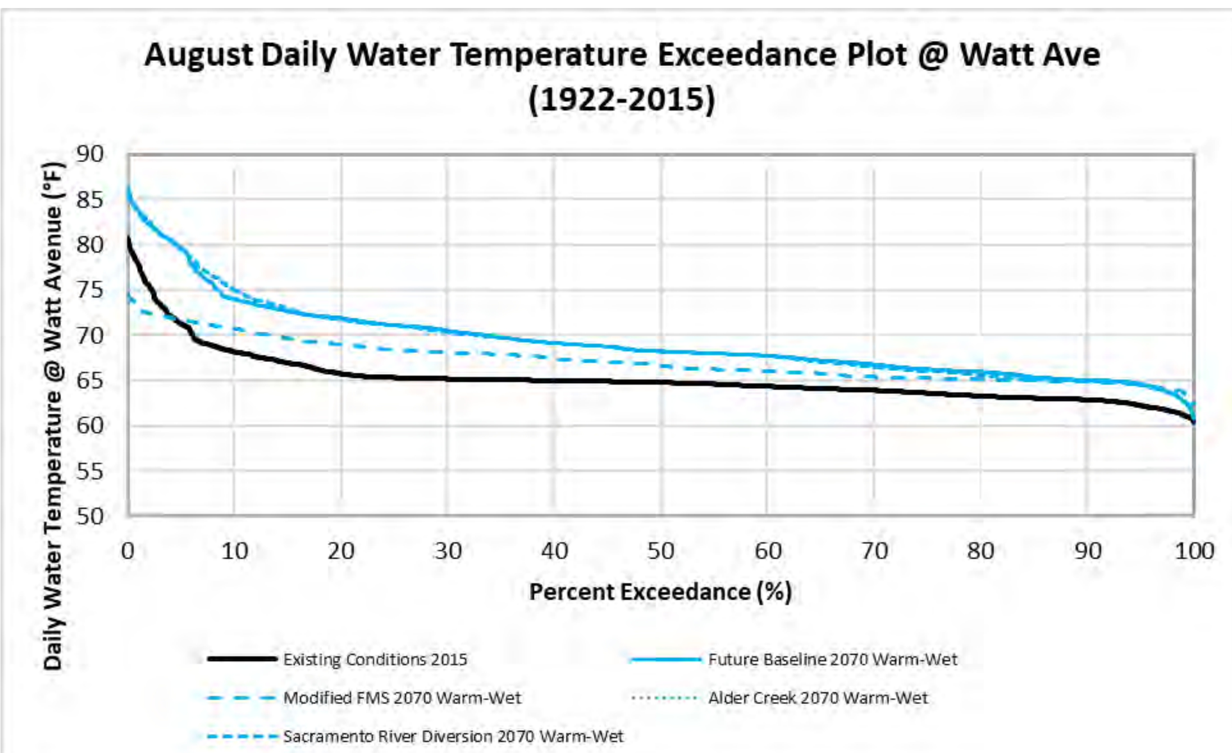

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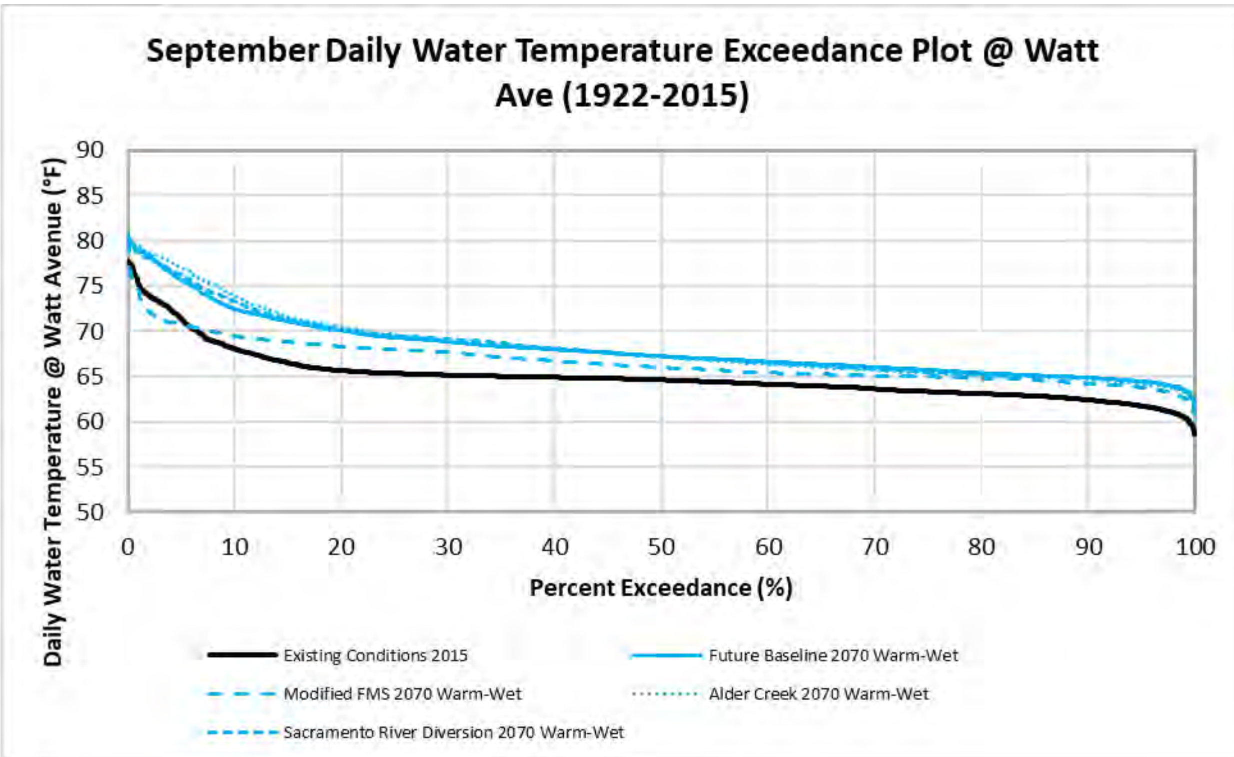

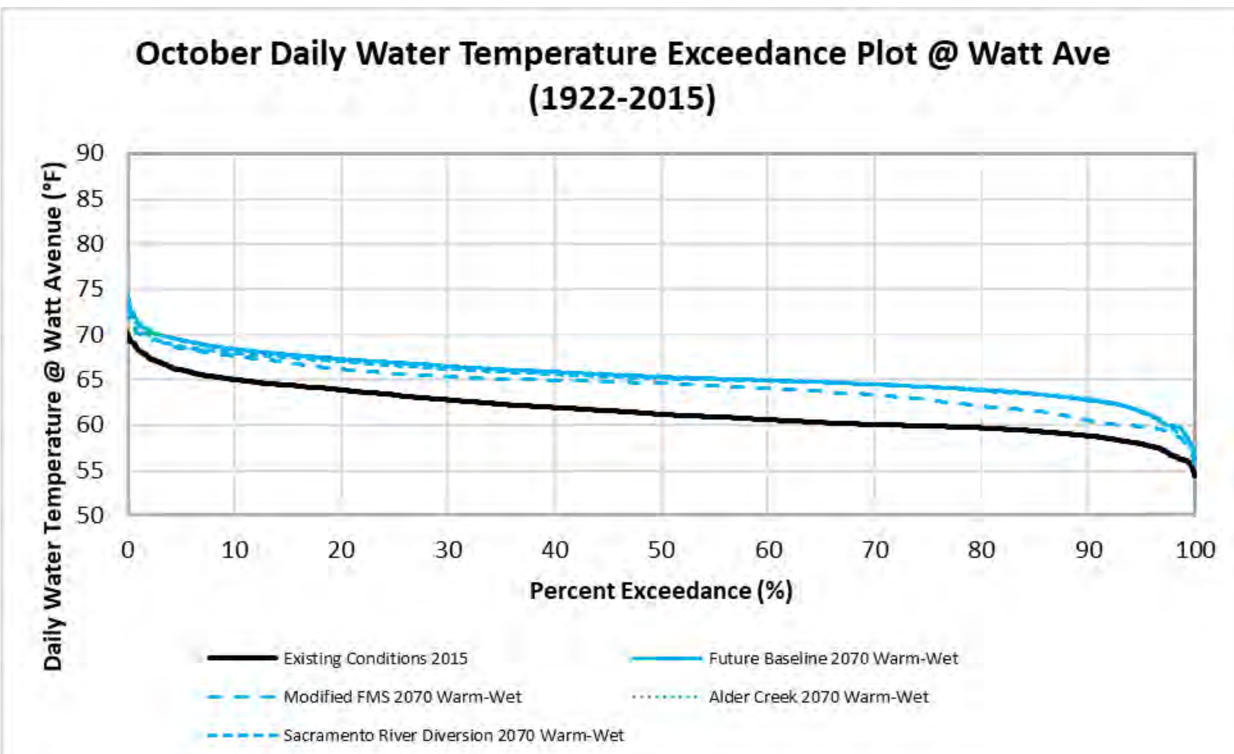

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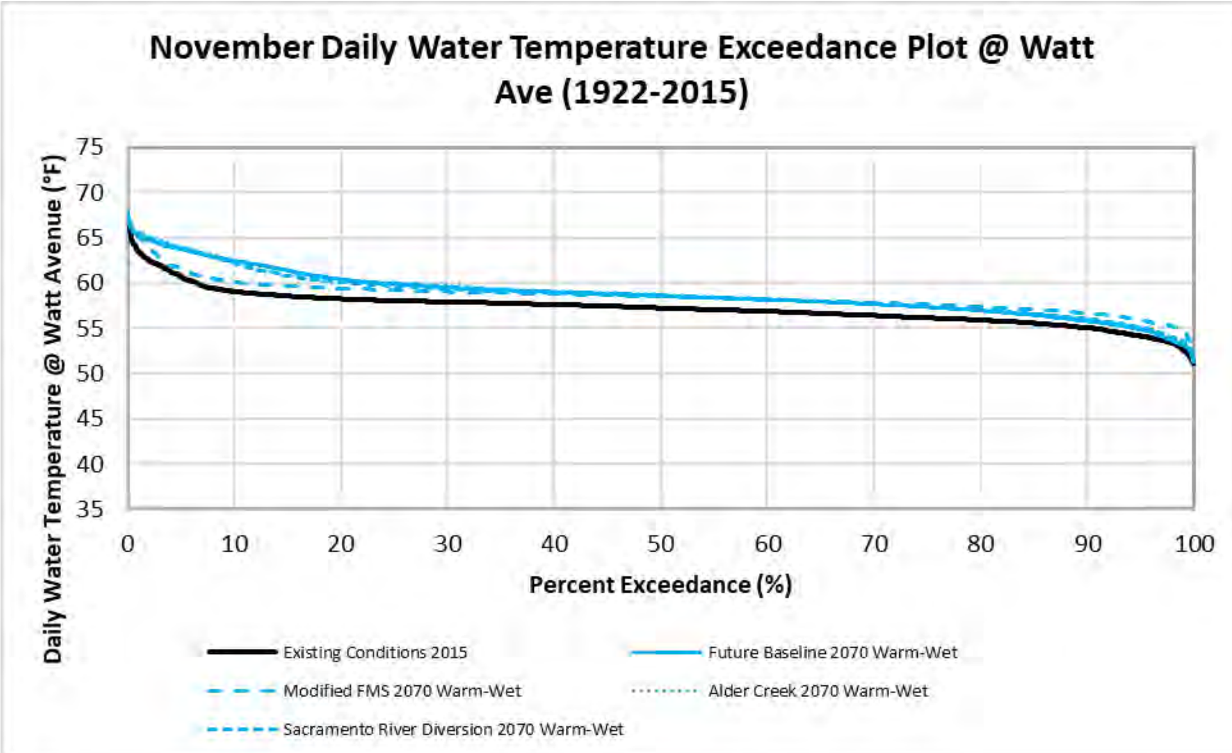

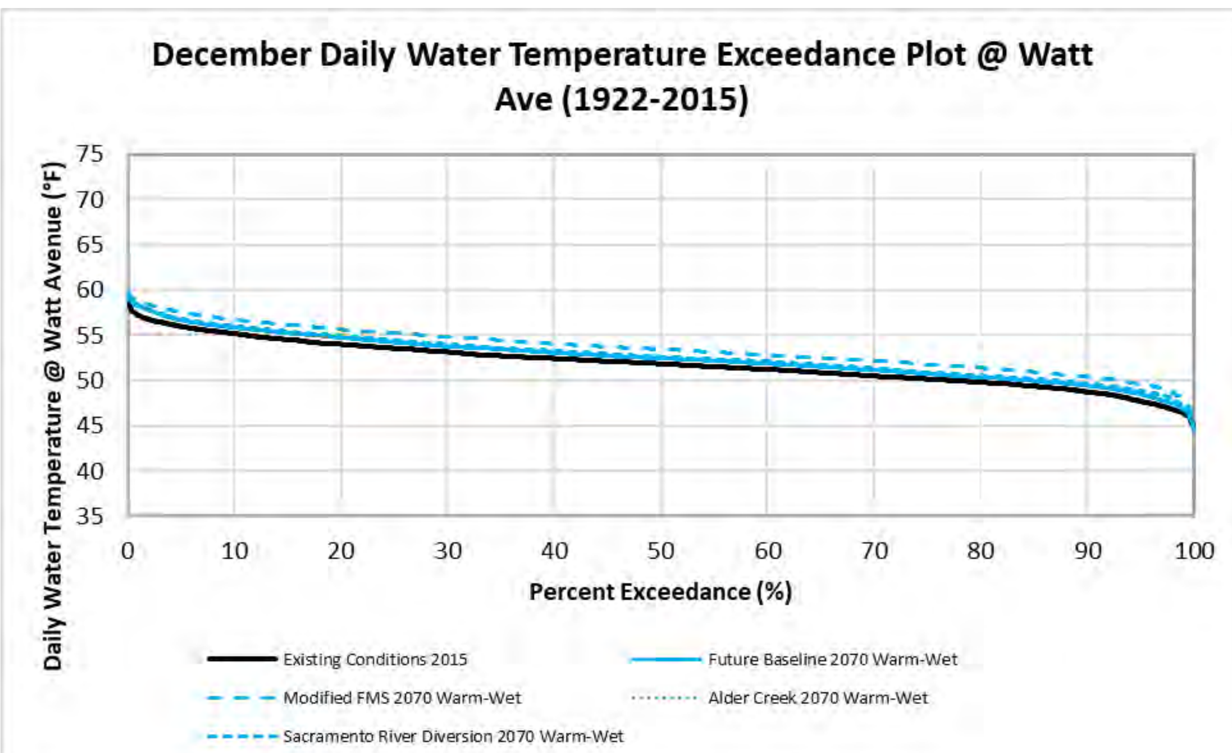

Figure 8 (continued). Monthly Exceedance Plots of Daily Water Temperature at Watt Avenue – Warm-Wet Climate Change Scenarios

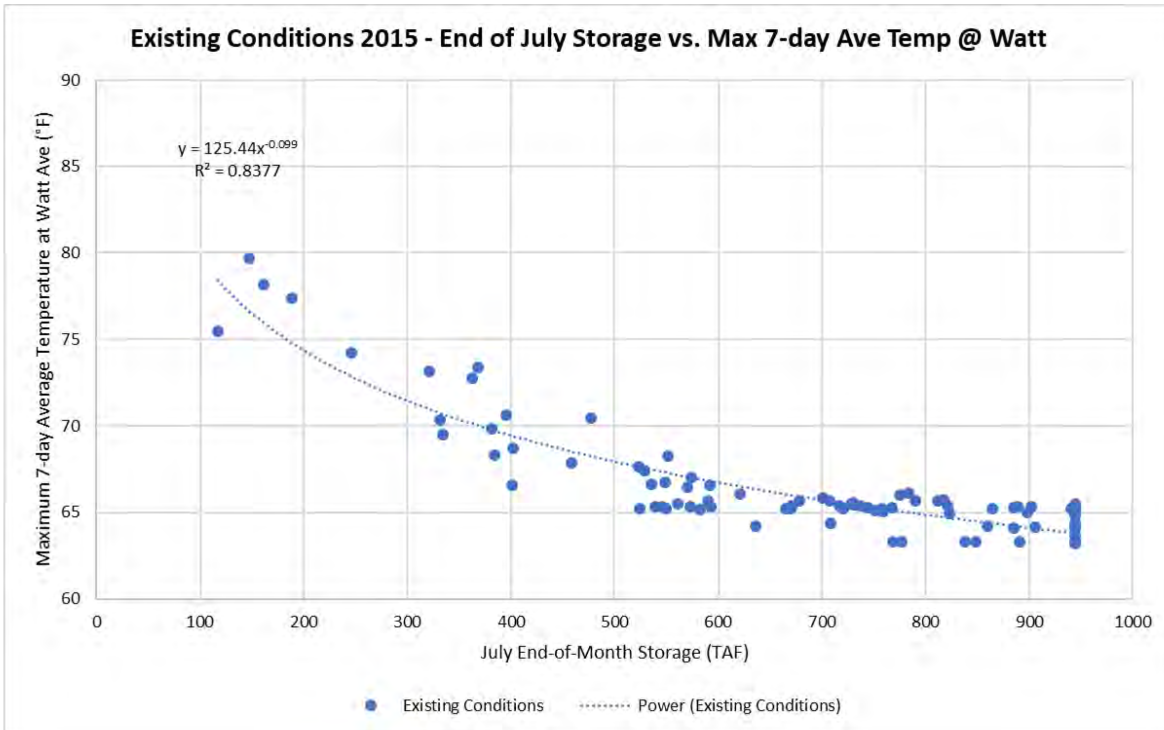

Figure 9. Existing Conditions 2015 July Storage vs. Maximum 7-day Average Temperature at Watt Avenue

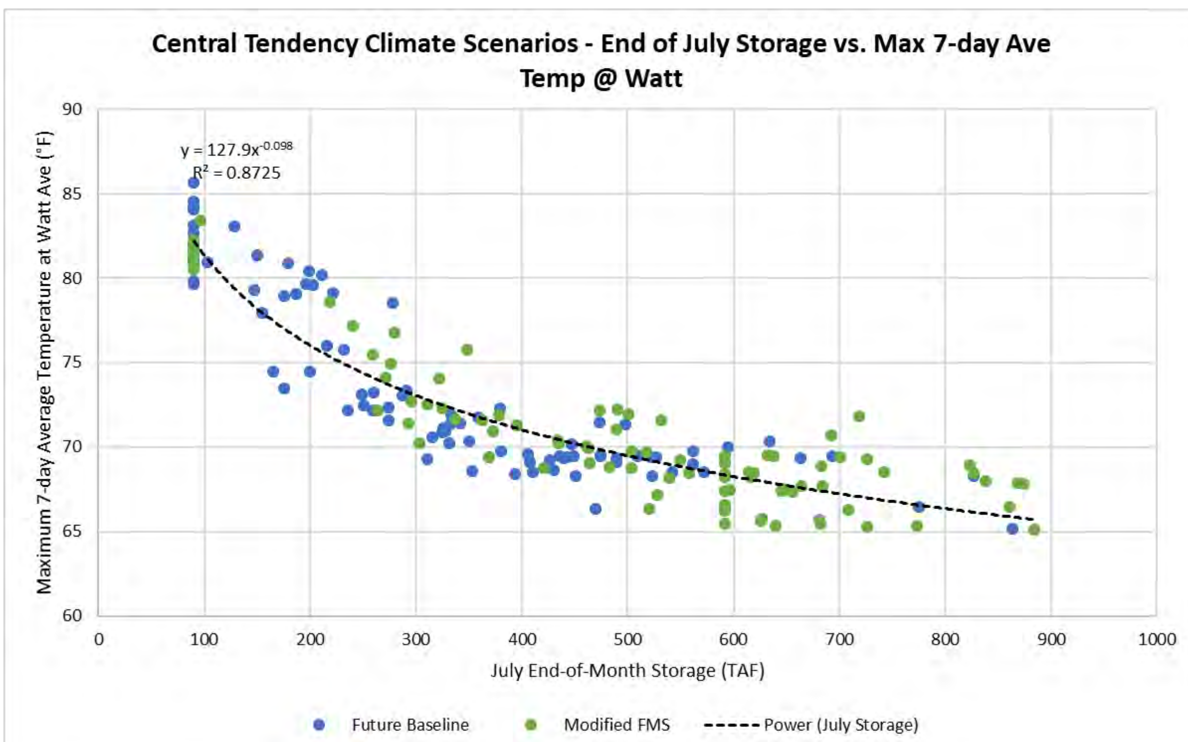

Figure 10. Future Baseline and Modified FMS July Storage vs. Maximum 7-day Average Temperature at Watt Avenue – 2070 Central Tendency Climate Change Scenarios

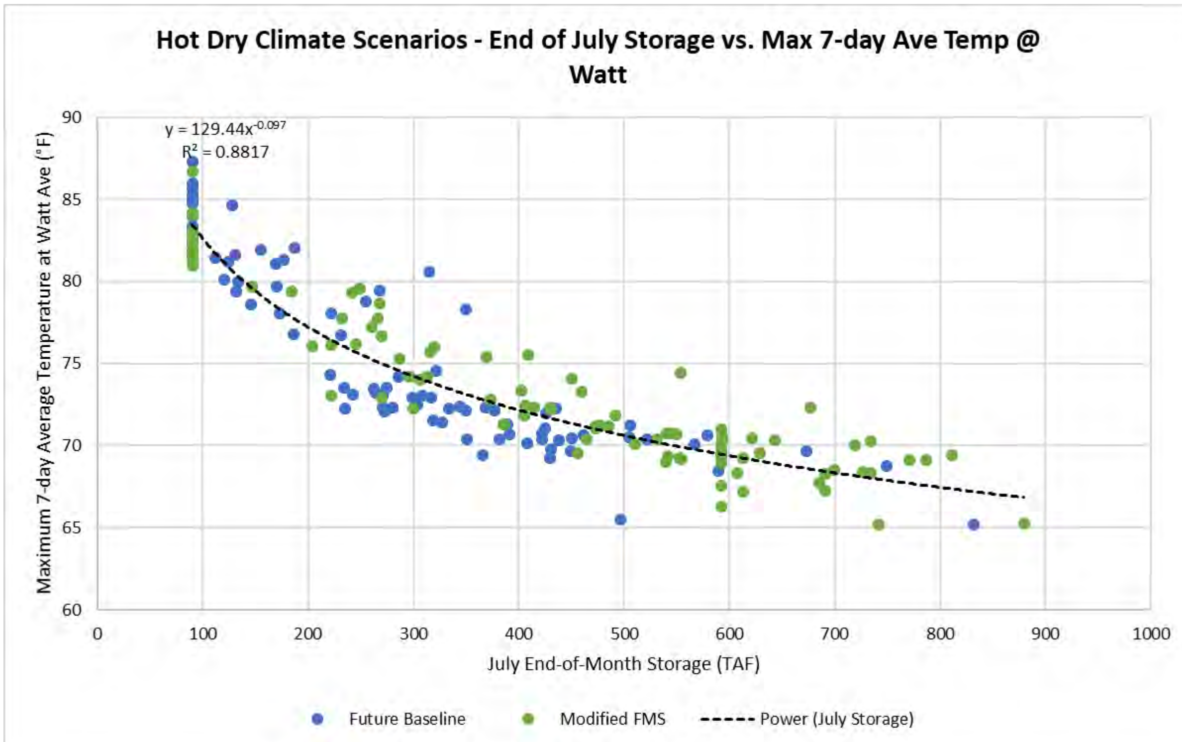

Figure 11. Future Baseline and Modified FMS July Storage vs. Maximum 7-day Average Temperature at Watt Avenue – 2070 Hot-Dry Climate Change Scenarios

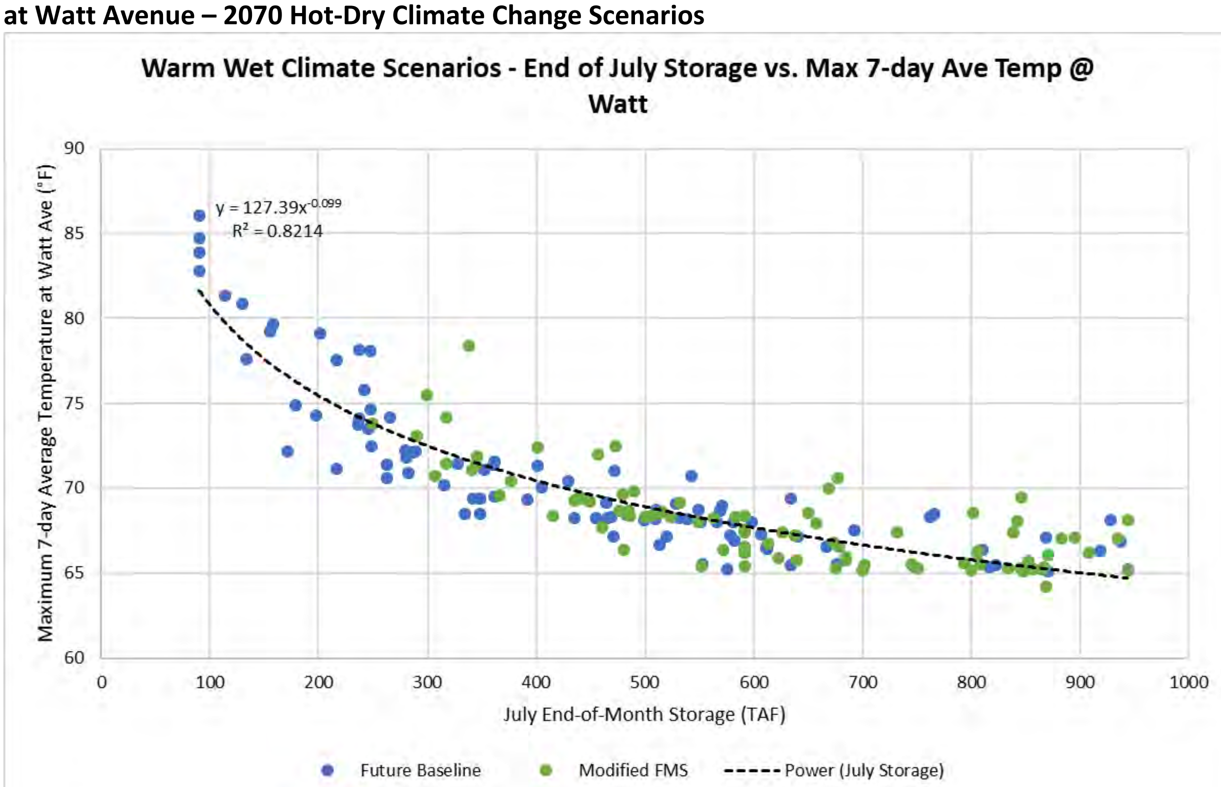

Figure 12. Future Baseline and Modified FMS July Storage vs. Maximum 7-day Average Temperature at Watt Avenue – 2070 Warm-Wet Climate Change Scenarios