

# Appendix

## for the Development of a Mono Lake Water Level Model and Projections across the 21<sup>st</sup> Century



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## A. Appendix A (Supplement to Section 2 of Main Report)

**Section 2** provides a general overview of the ERA5-WRF data used to represent observed atmospheric and hydrologic conditions across the Mono Basin and a general overview of the Mono Lake Water Budget (MLWB). In **Appendix A**, additional technical modeling details are provided for readers interested in further information associated with the development of the ERA5-WRF dataset and the MLWB. This information is primarily intended for a technical audience. The different subsections are described below:

**Appendix A.1** outlines how the ERA5-WRF precipitation data and natural flow data were adjusted to observed station data in the Mono Basin

**Appendix A.2** provides technical details relevant to the MLWB, including, but not limited to, additional information associated with the representation of regulated flow, how the average historical value for evaporation and ungauged runoff were determined, and how the error term is represented.

**Appendix A.3** describes changes made for representing present-day conditions. This reflects the set-up used for all assessments (e.g. wrapped runs, climate projections) other than the model validation against observed Mono Lake water level.

**Appendix A.4** provides an evaluation of how Mono Lake water level estimates vary under unique modeling assumptions that could have been made in the set-up of the water budget model.

**Appendix A.5** provides a description of the wrapped run methodology. This is described here since it depends on the ERA5-WRF dataset described in **Section 2.1** and used throughout this Appendix for validation purposes of the ERA5-WRF data and development of the MLWB.

### A.1 Adjustment of ERA5-WRF to Observed Station Data in the Mono Basin

When the ERA5-WRF dataset was developed, it was designed to capture conditions over the entire state of California. While ERA5-WRF was bias corrected after downscaling using observed station data throughout California, as described in Pierce et al. 2023, the dataset was not fine-tuned to specific regions that may contain additional, local data. In this study, to better represent conditions specifically across the Mono Basin, an additional mean-state adjustment was applied to ERA5-WRF variables that are relevant to the MLWB. This additional mean-state adjustment was needed since the observed data collected across the Mono Basin at the beginning of this study was not available at the time ERA5-WRF was developed as a part of California's 5<sup>th</sup> Climate Assessment (CA5). In this

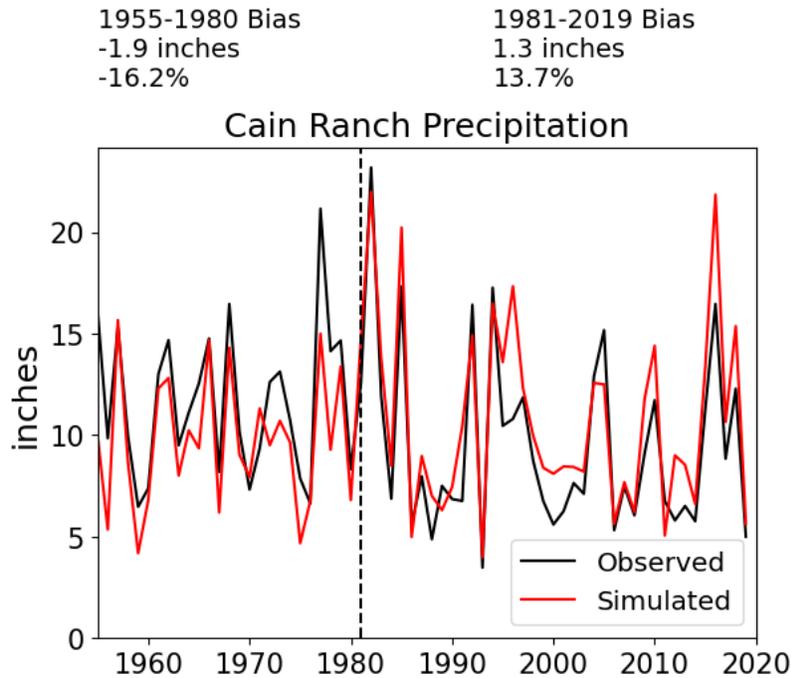
section, the mean-state adjustment that was applied to precipitation and the four-creek runoff (Lee Vining, Walker, Parker, and Rush Creeks) is outlined.

At the start of this project, discussions with Los Angeles Department of Water and Power (LADWP) and the Mono Lake Committee (MLC) identified the Cain Ranch station as the most reliable and long-term source of precipitation data near Mono Lake, a key component of the lake's water budget. Because there is no direct precipitation gauge located on Mono Lake, and Cain Ranch is the closest dependable station (~4.5 miles away), it serves as the best available reference for precipitation on Mono Lake. As such, the CA5 ERA5-WRF data product was adjusted for the MLWB based on the simulated ERA5-WRF bias compared to observed precipitation at Cain Ranch.

Similarly, natural flow associated with the Lee Vining, Walker, Parker, and Rush Creeks were obtained from LADWP after the hydrology simulations were performed for CA5. Aside from serving as the primary source of runoff into Mono Lake, these streams are also important for determining streamflow requirements. As such, a mean-state adjustment, based on comparisons to observed natural flow, was applied to the simulated flow associated with these creeks.

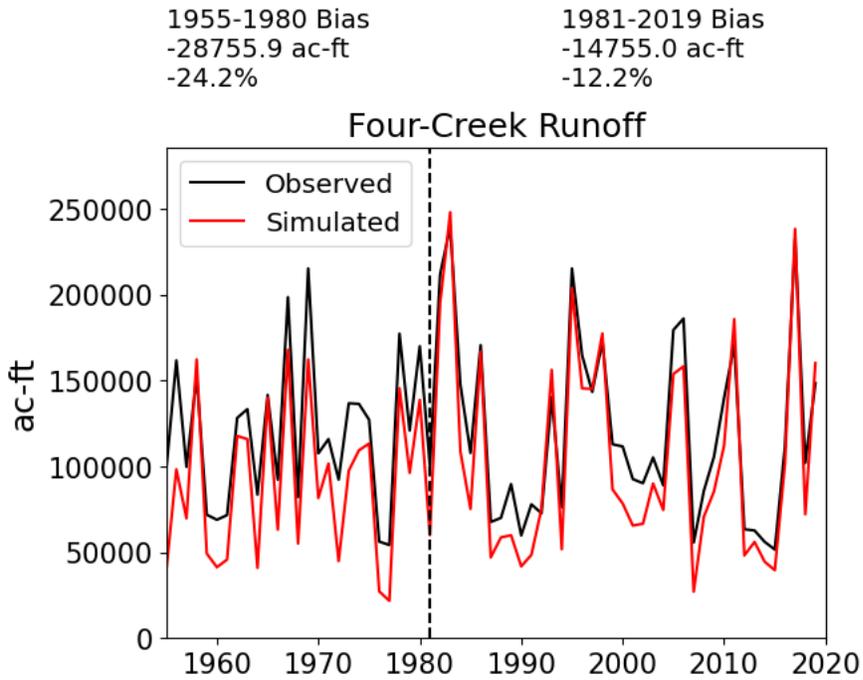
**Figure A-1** shows how the simulated ERA5-WRF precipitation at Cain Ranch from CA5 (prior to the mean-state bias adjustment) compares against the observed station data, and **Figure A-2** shows how the simulated ERA5-WRF natural runoff from CA5 (prior to the mean-state bias adjustment) compares to the four-creek, station-derived natural runoff. The ERA5-WRF data spans the period from January 1<sup>st</sup>, 1951, to December 31<sup>st</sup>, 2020 for atmospheric variables. While precipitation data exists from 1950 to 1955, the first 5-years of the hydrology data was removed to allow for adequate time for the hydrology model to spin-up. As a result, all analysis focuses on the time period from 1955 onward.

To adjust the mean state of the ERA5-WRF data, the periods before and after 1980 were treated separately due to differences in data quality. Specifically, ERA5-WRF data from 1950 to 1979 is known to be less reliable because of the limited availability of satellite observations, which are typically used in ERA5 reanalysis. As a result, each period was individually assessed and adjusted relative to observed data.

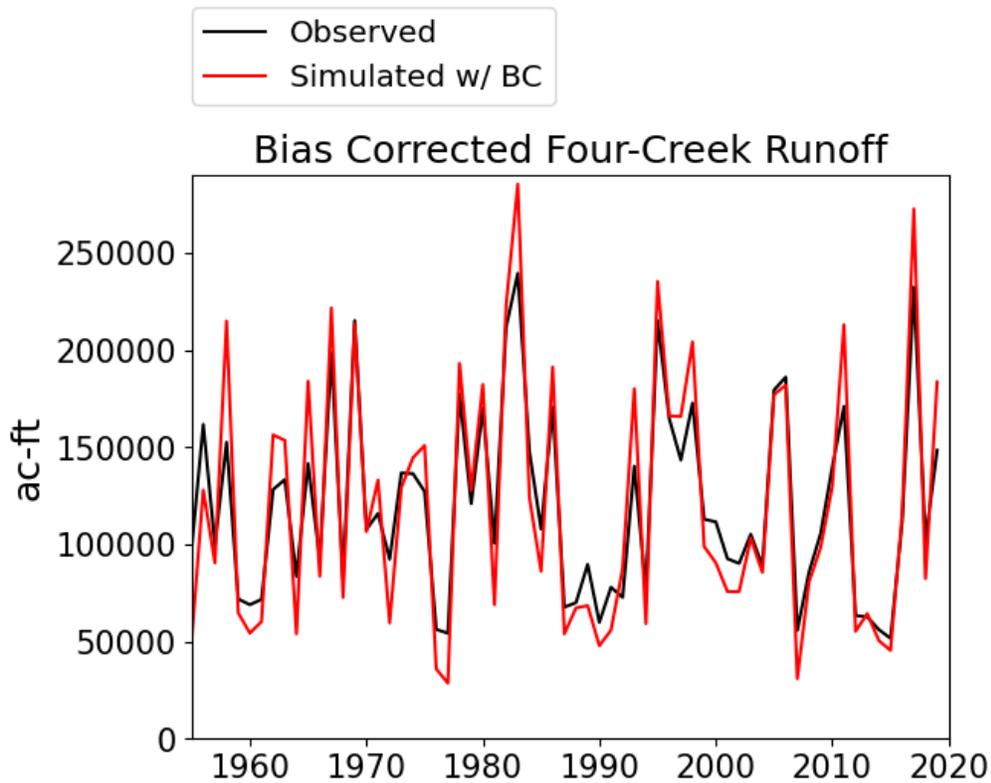


*Figure A-1. Simulated ERA5-WRF (without additional Mono Basin adjustment) precipitation (red) compared against observed station data precipitation (black). Bias for the 1955-1980 and 1981-2019 time-periods displayed as text at the top of the plot. The mean-adjusted modeled observation of precipitation at Cain Ranch precipitation shown in the main report (Figure 2-4).*

Note, while the bias for the total four-creek runoff is shown in **Figure A-2**, the bias for each creek was determined and used as shown in **Table A-1**. The resulting adjustment to the ERA5-WRF hydrology is shown in the main report for each of the four creeks (**Figure 2-7**), while the adjusted total four-creek runoff is shown here in **Figure A-3**.



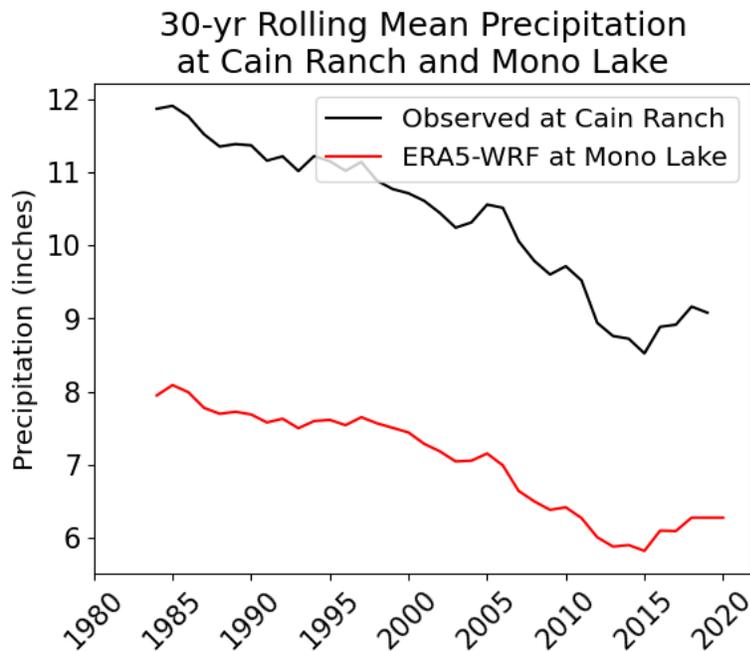
*Figure A-2. Simulated (without additional Mono Basin adjustment) four-creek runoff (red) compared to observed station data (black). Bias for the 1955-1980 and 1981-2019 time-periods displayed as text at the top of the plot.*



**Figure A-3.** Modeled observation (ERA5-WRF, red line) of four-creek runoff compared to station data (black line). Modeled observations include the additional mean-state adjustment of ERA5-WRF data in the Mono Basin. Results for each of the four creeks is provided in **Figure 2-7** of the main report.

While a distinct and larger bias exists for the 1955 to 1980 time-period owing to less satellite data availability for this time, the variability in precipitation and runoff is still captured during this earlier time period. Using the mean bias in the 1955 to 1980 and 1981 to 2019 time-periods, a mean-state adjustment was performed to the modeled observations of precipitation and runoff for these two distinct time-periods. The mean-state bias is based on the ratio of the average modeled value over the observed average value for each distinct time-period, which is then multiplied by the modeled data for that time-period. **Table A-1** outlines the adjustment ratio applied for each time-period for runoff, precipitation, and other variables relevant to the MLWB. The GCMs are mean-state adjusted to the adjusted ERA5-WRF data. However, the adjustment is applied for a single, historical time-period for the GCMs since they are not influenced by observational limitations that vary over time like the ERA5 reanalysis data.

For Mono Lake precipitation, we simply apply the same bias found between simulated and observed precipitation at the Cain Ranch station as this is the closest reliable station next to Mono Lake. This ensures the ERA5-WRF modeled bias at Mono Lake is accounted for while preserving the expected difference in precipitation magnitude at Cain Ranch and Mono Lake (**Figure A-4**). Meanwhile, the natural runoff for Lee Vining, Walker, Parker, and Rush creek was adjusted based on the natural flow data available from LADWP for these creeks.



**Figure A-4.** Comparison of ERA5-WRF (adjusted) Mono Lake precipitation to observed data at Cain Ranch. As expected, Mono Lake precipitation is roughly 3 to 4 in less than Cain Ranch. The lower

precipitation at Mono Lake is due to its lower elevation and easterly position relative to Cain Ranch. The trend in the modeled observations reflect the observed Cain Ranch trend. This negative trend does not occur in the majority of the GCMs and thus is likely due to internal variability associated with a wet time-period in the early 1980s followed by drying conditions driven by a cooling Pacific Decadal Oscillation (Bass et al., 2022; Lehner et al. 2018).

**Table A-1.** Overview of mean-state adjustment applied to the ERA5-WRF dataset. Note, the bias in Cain Ranch precipitation is used to represent the precipitation bias at Mono Lake. This is performed by multiplying the bias as a ratio shown in the table by the Mono Lake precipitation (inches) represented by ERA5-WRF.

	Rush	Lee Vining	Walker	Parker	Mono Lake Precipitation	Mono Lake Evaporation
<b>1955-1980: Obs Mean / Sim Mean</b>	1.47	1.19	0.98	1.40	1.19	1.92
<b>1981-2019: Obs Mean / Sim Mean</b>	1.23	1.08	0.84	1.25	0.88	1.90

Evaporation at Mono Lake was calculated using the Penman equation:

$$PET = \frac{(\Delta * R_n) + (\rho * c_p * \frac{VPD}{r_a})}{\lambda_v * (\Delta + \gamma)} \quad \text{Equation 3}$$

Where PET equals potential evapotranspiration from Mono Lake.  $\Delta$  represents the slope of the saturation vapor pressure curve,  $R_n$  represents the net radiation,  $\rho$  is the density of air,  $c_p$  is the specific heat capacity of air, VPD is the vapor pressure deficit,  $r_a$  is the aerodynamic resistance,  $\lambda_v$  is the latent heat of vaporization, and  $\gamma$  is the psychrometric constant. The terms in the PET calculation were obtained from the historical atmospheric and hydrologic CA5 datasets, with the average PET based on several model grid cells that fall within Mono Lake. This calculation leads to an average evaporation of 24.6 in from 1955 to 1980, and an average evaporation of 24.9 in from 1981 to 2019. It is worth noting, unlike precipitation and temperature, some of the terms used in the PET calculation are poorly constrained by observations (wind, incoming shortwave radiation, specific humidity) or lack observed data to bias correct against (e.g. incoming longwave radiation, surface pressure). The lack of observational terms to bias correct against during the development of ERA5-WRF likely lead to low estimates of potential evaporation across Mono Lake. For the MLWB set-up, it was found that an average evaporation of 47.25 led to the most accurate representation of Mono Lake's water level (discussed in **Appendix A.2.3**). As such, a mean-state, multiplicative adjustment of roughly 1.9 was applied to the ERA5-WRF evaporation, which adjusts the historical average bias while maintaining the year-to-year variability from the original ERA5-WRF simulations. As discussed in **Appendix A.2.3**, this evaporation value leads to a 0.58 mean-state adjustment of the ungauged runoff. While this is a large adjustment to the original ERA5-WRF estimate of evaporation, the resulting average evaporation roughly aligns with the magnitude of evaporation used in the Vorster model (45 in) (Vorster, 1985). All of the downscaled GCMs are bias-corrected to ensure their historical average is equal to 47.25 inches. This is completed by

comparing the bias of the GCMs to ERA5-WRF during the historical period (1955 to 2019). This bias (as a ratio) is then multiplied by the Mono Lake evaporation from 1955 to 2100. From this correction, the historical Mono Lake evaporation for the GCMs will equal 47.25 inches, but future changes or trends in evaporation are still captured. This correction ensures the historical influence of evaporation on Mono Lake’s water budget is accurately represented, and future changes in evaporation are represented as well.

## A.2 Technical Details Relevant to the MLWB

In this section, additional technical details are provided that relate to the development of the MLWB. While this information is important for a comprehensive understanding of the MLWB, it is not essential for all readers.

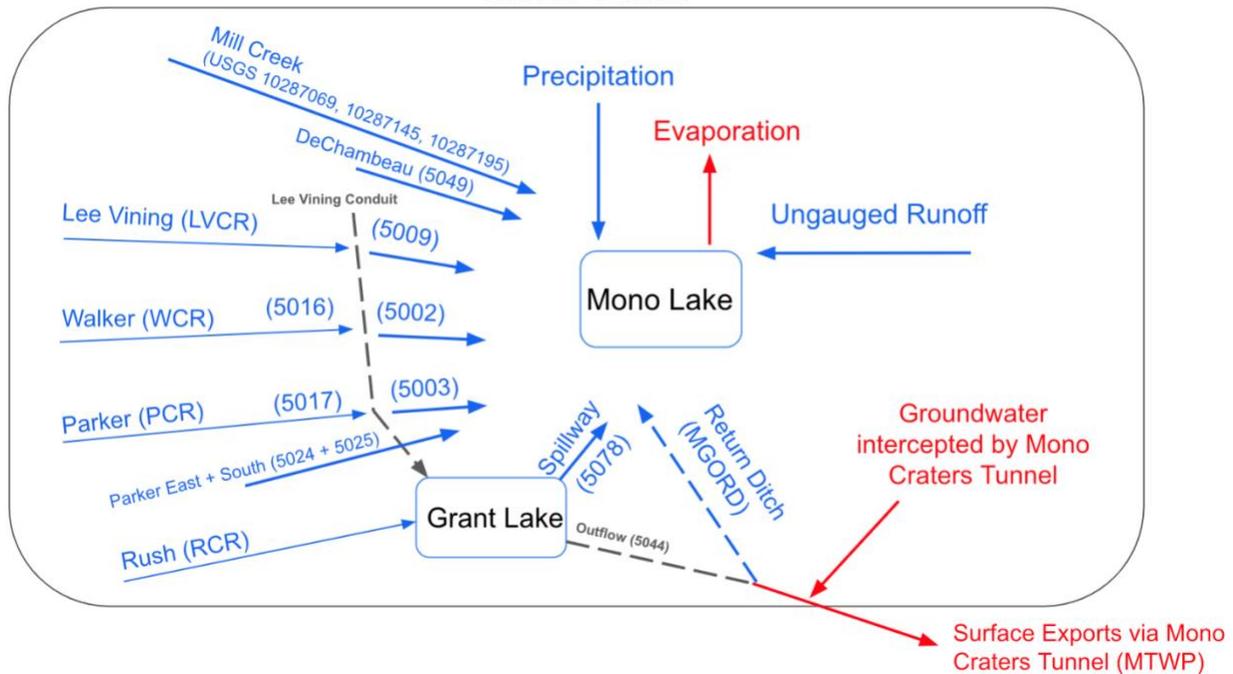
### A.2.1 Description of Regulated Flow and Station Data

In this section, an overview of LADWP water management in the Mono Basin is provided. Details regarding the stations used to represent regulated flow are also outlined. This provides context for how natural flow is modified throughout the Mono Basin.

Mono Lake is a terminal lake in the middle of the Mono Basin, where runoff throughout the Mono Basin naturally flows from the mountainous regions towards the lake. There is, however, human infrastructure within the Mono Basin that modifies natural flow conditions. This infrastructure includes modifications to flow for hydropower purposes, extraction of water for irrigation, and diversions of water through LADWP’s Lee Vining Conduit and out of the basin via the Mono Craters Tunnel.

**Figure A-5** provides a schematic of flow throughout the Mono Basin, including diversions associated with LADWP infrastructure. LADWP diversions can occur from Lee Vining, Walker, and Parker Creek into the Lee Vining Conduit, which flows into Grant Lake Reservoir. Rush Creek flows directly into Grant Lake Reservoir. At Grant Lake Reservoir, water can either be released downstream directly into Rush Creek via a spillway or released via Grant Lake’s outflow. Water released from Grant Lake’s outflow is either exported out of the Mono Basin via the Mono Craters Tunnel or returned to Rush Creek via the Mono Gate Return Ditch (MGORD). Decisions regarding whether flow is diverted or released to any of these four creeks depend on export criteria and can depend on instream flow requirements (outlined in **Appendix A.3.2**). The MLWB accounts for the previously described conditions by relating natural flow for a given subbasin upstream of Lee Vining Conduit, to the regulated flow after diversions from Lee Vining Conduit. The stations used to represent regulated flow from each creek are outlined in parenthesis in **Figure A-5**. Additional creeks such as Mill Creek, Parker East and South (Parker E+S), and DeChambeau are not diverted out-of-basin by LADWP, but can experience modifications to flow due to hydropower and irrigation practices. For the MLWB, the streams that are not modified by LADWP were grouped together, and their total natural flow was related to their total regulated flow into Mono Lake.

## Mono Basin



**Figure A-5.** Schematic of flow throughout the Mono Basin and components that make up the UCLA-MLM water budget. Terms in blue represent volumes of water into Mono Lake, while terms in red represent volumes of water removed from Mono Lake, or from entering the lake. Dashed grey lines/arrows represent LADWP infrastructure that modifies the natural flow patterns in the Mono Basin. Mono Craters Tunnel is shown as a red arrow leading to flow out of the Mono Basin but also represents LADWP infrastructure that modifies natural flow patterns. Water that is diverted out of the Mono Basin via the Mono Craters Tunnel is exported into the Owens River which eventually flows into the Los Angeles Aqueduct. Note, the terms in parentheses represent the station names for observed measurements (also outlined in **Table A-2**).

For LADWP-regulated creeks, regulated flow was derived from the following:

- Lee Vining Creek ( $Q_{Lee\ Vining}$ ): Represented by flow measured below Lee Vining Conduit (Station 5009).
- Walker and Parker Creeks ( $Q_{Walker\ \&\ Parker}$ ): Represented by Stations 5002 and 5003, respectively, which are just below Lee Vining Conduit
- Rush Creek ( $Q_{Grant\ Lake\ Release}$ ): Includes combined flows from Grant Lake Reservoir Spillway (Station 5078) and Mono Gate Return Ditch (Station MGORD), which returns water to Rush Creek.

Water not returned to Rush Creek via MGORD is diverted through the Mono Craters Tunnel (MTWP) and exported to the Owens River Basin, ultimately flowing into the Los Angeles Aqueduct.

- Creeks not modified by LADWP: Additional inflows to Mono Lake include Mill Creek ( $Q_{Mill}$ ), DeChambeau Creek ( $Q_{DeChambeau}$ ), and Parker Creek East and South tributaries ( $Q_{Parker\ E+S}$ ).

Regulated flow for these creeks were obtained from their corresponding stations listed in **Table A-2**. All flow measurements are sourced from LADWP, except for Mill Creek, which is available from United States Geological Survey (USGS) stations.

**Table A-2.** Overview of station data referenced to represent regulated flow into Mono Lake. For the evaluation of MLWB performance, Walker and Parker stations 5002 and 5003 were used; however, the final MLWB that accounts for current land use and export criteria conditions uses Stations 5016 and 5017. The water budget model validated against observed water levels includes irrigation; however, the water budget model used for all other assessments accounts for irrigation withdrawals from Lee Vining and Parker (discussed in Section A.3.1). Note, flow into Mono Lake from Rush Creek is based on Grant Lake Spillway (5078) plus MGORD, where MGORD is equal to Grant Lake Outflow minus surface water Exports.

Station	Name	Source	Daily Start	Monthly Start
10287069, 10287145 & 10287195	Mill	USGS	1988-10-01	1988-10-01
5049	DeChambeau	DWP	1990-04-01	1936-04-30
5024+5025	Parker E+S	DWP	1990-04-25	1935-04-30
5009	Lee Vining	DWP	1990-04-01	1942-04-01
5002	Walker	DWP	1990-04-01	1964-04-01
5003	Parker	DWP	1990-04-01	1964-04-01
5078	Grant Lake Spillway	DWP	1940-12-01	1941-04-30
5044	Grant Lake Outflow	DWP	1992-02-01	2018-04-30
5007	MGORD	DWP	1941-01-01	1941-04-30
MTWP	Exports	DWP	1940-12-01	1941-04-30
5016	Walker Above Conduit	DWP	1990-04-01	1964-04-01
5017	Parker Above Conduit	DWP	1990-04-01	1964-04-01

### Grant Lake Reservoir Releases

For Lee Vining, Walker, and Parker Creeks and the subbasins not modified by LADWP (e.g. Mill Creek), natural and regulated flows were found to have a direct linear relationship (**Section 2.2.2, Figure 2-11**). In contrast, regulated outflows from Grant Lake Reservoir required a more complex estimation approach due to the reservoir’s operational practices and storage variability.

A multiple linear regression was used to estimate total outflow from Grant Lake Reservoir, incorporating four independent variables:

- Current year natural flow (Lee Vining and Rush Creek combined)
- Previous year natural flow (Lee Vining and Rush Creek combined)
- Annual precipitation at Grant Lake
- Stream Restoration Flows (SRF) as defined in Order-98-05

The model equation is:

*Equation A-1*

*Grant Lake Reservoir*

$$= \beta_0 + \beta_1 * 2 - Cr Flow_i + \beta_2 * 2 - Cr Flow_{i-1} + \beta_3 * Grant Lake P_i + \beta_4 * SRF_i$$

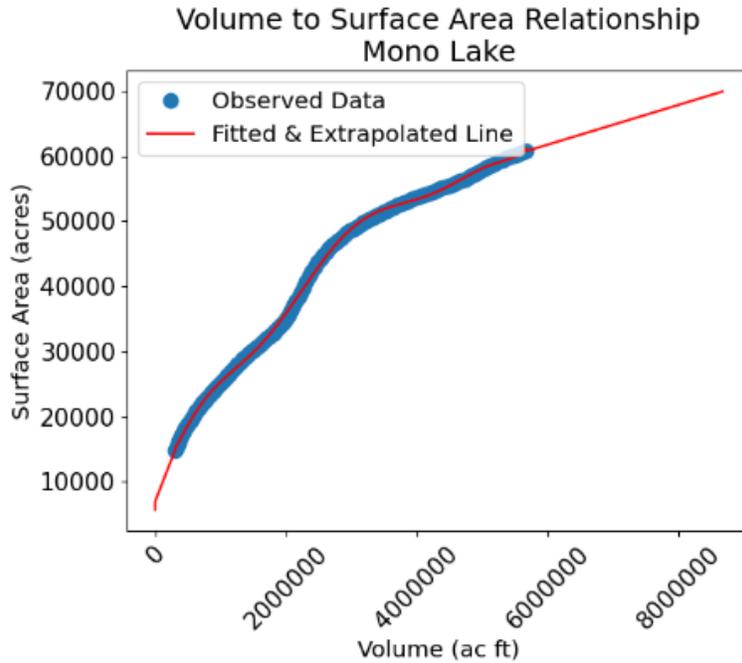
Where:

- $i$  = runoff year
- 2-Cr Flow = simulated natural flow from Lee Vining and Rush Creek
- $P$  = precipitation at Grant Lake from ERA5-WRF
- $SRF$  = instream flow requirement for Rush Creek (downstream of Grant Lake Reservoir)

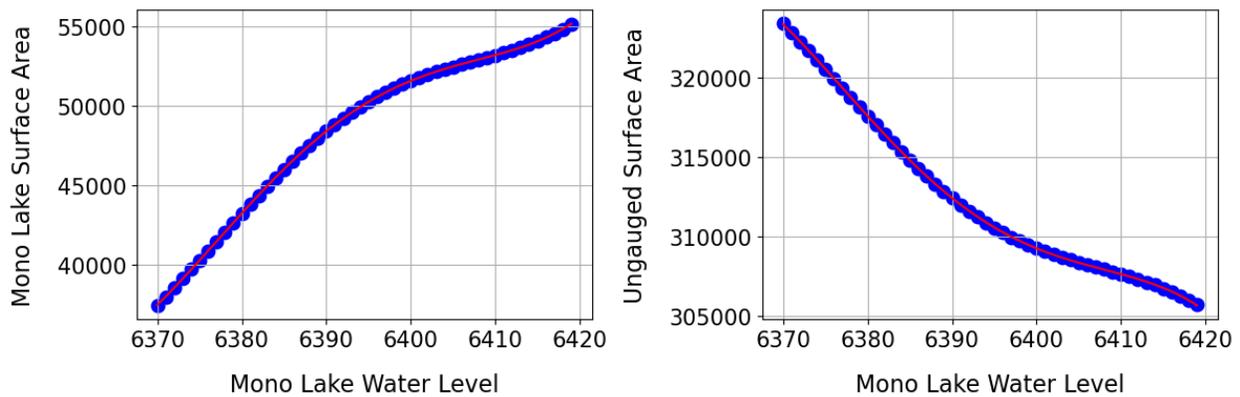
All variables were obtained from the ERA5-WRF data. This regression for Grant Lake releases approximates the storage conditions in Grant Lake Reservoir and subsequent releases. The SRF variable serves as a critical control on outflow volumes as well, as this determines the minimum flow requirement for Rush Creek, the creek downstream of Grant Lake. As was outlined in **Figures 2-11** and **2-12**, this regression is able to capture 94% of the variance in Grant Lake’s releases via its spillway and outflow.

### A.2.2 Representation of Mono Lake Surface Area

In the main report, the relationship between storage volume and the water level in Mono Lake was shown in **Figure 2-10**. The relationship between volume and water level is necessary to represent Mono Lake’s water level; however, the surface area is also essential for the MLWB. Here, the relationship between volume and surface area is shown in **Figure A-6**. Mono Lake’s surface area directly affects three key components of its water balance: precipitation over the lake, evaporation from the lake, and runoff from ungauged areas. The depth (in feet) of precipitation and evaporation are directly multiplied by Mono Lake’s surface area (in acres) to obtain the ac-ft or volume of water associated with these terms. The ungauged drainage area adjusts dynamically based on Mono Lake’s fluctuating water level. For example, an increase in Mono Lake’s water level increases Mono Lake’s surface area which decreases the ungauged runoff drainage area (**Figure A-7**).



*Figure A-6. The MLWB estimates changes in Mono Lake storage. The relationship shown here is used to convert Mono Lake storage to its surface area, which is necessary for calculating a volume of precipitation, evaporation, and ungauged runoff.*



*Figure A-7. Demonstration of how Ungauged Surface Area changes with respect to Mono Lake Water Level.*

The relationships between Mono Lake’s volume and its water level and surface area, were obtained from MLC (Raumann et al. 2002), who provided smoothed curves derived from observations at Mono Lake. To integrate these relationships into the MLWB, polynomial functions were fitted to the smoothed relationships for both storage-to-water level and storage-to-surface area. These polynomial fits allow for continuous mathematical representation of how Mono Lake’s water level and surface change with variations in stored water volume. Additionally, to account for conditions beyond observed values, linear extrapolation was applied at both ends of the dataset. Specifically, the slope between the smallest two data points and the largest two data points were extended to estimate surface area and water level under extremely low or high

storage conditions. This extrapolation ensures that the MLWB remains functional even if Mono Lake experiences storage and surface area conditions outside the observed range.

While this extrapolation is generally not required for observational validation and is rarely needed for climate projections, it becomes essential when evaluating hypothetical extreme conditions – such as severe droughts or major inflows – where Mono Lake’s storage may significantly deviate from past observations.

Lastly, using only the lake’s surface area at the start of the year can give a misleading picture of conditions throughout the entire year. The MLWB uses the average surface area for the year based on the average surface area value from the beginning and end of the year. Since surface area influences precipitation, evaporation, and ungauged runoff volumes, and those in turn affect the surface area, this calculation is repeated a few times until the surface area values stop changing significantly. This iterative approach leads to less than 1-2% difference from the initial surface area estimate, but more accurately reflects the average surface area and thus the change in Mono Lake volume for each year.

### A.2.3 Determining Average Evaporation and Ungauged Runoff

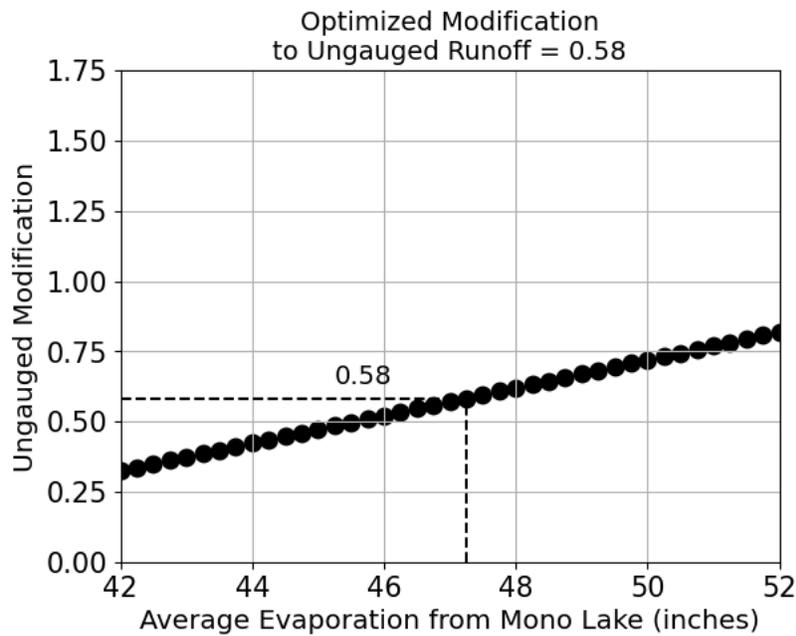
This section outlines how the historical average evaporation and ungauged runoff were determined for the MLWB. As outlined previously, Mono Lake’s historical average precipitation was adjusted using the Cain Ranch gauge and the natural flow for LADWP-regulated creeks was adjusted to observations of natural flow since the total runoff from these four creeks influences LADWP operations (later discussed in **Section A.3.2**). Non-biased representations of regulated flow were also obtained for all creeks based on observed measurements of regulated flow via the regression approach outlined in **Section A.2.1**.

However, no direct observational data are available for evaporation from Mono Lake or ungauged runoff. While ERA5-WRF accurately reflects spatial patterns and year-to-year variability, mean-state biases were shown to exist for precipitation and runoff, suggesting a mean-state bias likely exists for evaporation and ungauged runoff. Therefore, the MLWB performance was assessed under a range of evaporation and ungauged runoff conditions to determine the most appropriate corrections for these components.

A sensitivity analysis was conducted by varying average annual evaporation from 42 to 52 in/yr in 0.25-in increments (**Figure A-8**). This range was selected because it constrained MLWB error in Mono Lake water level to within  $\pm 0.5$  ft, a threshold considered acceptable for model accuracy. Also, these evaporation values are consistent with historical estimates from previous studies and reflect a range of values that encompass the average evaporation used by the Vorster model (Vorster, 1985).

While the variability in evaporation from the ERA5-WRF climate dataset was retained, the long-term average (originally 24.9 in/yr) was adjusted to improve the MLWB accuracy. For each evaporation value tested, the historical average of ungauged runoff was optimized to minimize the mean error in the MLWB representation of the Mono Lake water level. The optimal

performance occurred with an adjusted average evaporation of 47.25 in/yr (~1.9 mean-state bias correction to the ERA5-WRF 24.9 in/yr) and an ungauged runoff bias correction of 0.58. Other combinations of evaporation and ungauged runoff values produced greater errors in Mono Lake’s simulated water level compared to the observed water level, indicating that this final combination represents the most accurate estimate under current modeling constraints. These values result in a mean water level error of 0.01 ft and mean absolute error of 0.48 ft for the 1994 to 2020 validation period (**Figure 2-13**).



*Figure A-8. Shows the ungauged runoff mean-state adjustment selected via optimization to reduce the MLWB water level error for each historical average evaporation value that was assessed. Ultimately, the 47.25 in/yr average Mono Lake evaporation and a 0.58 mean-state adjustment to ungauged runoff were chosen given their ability to reduce the 1994 to 2020 mean water level error.*

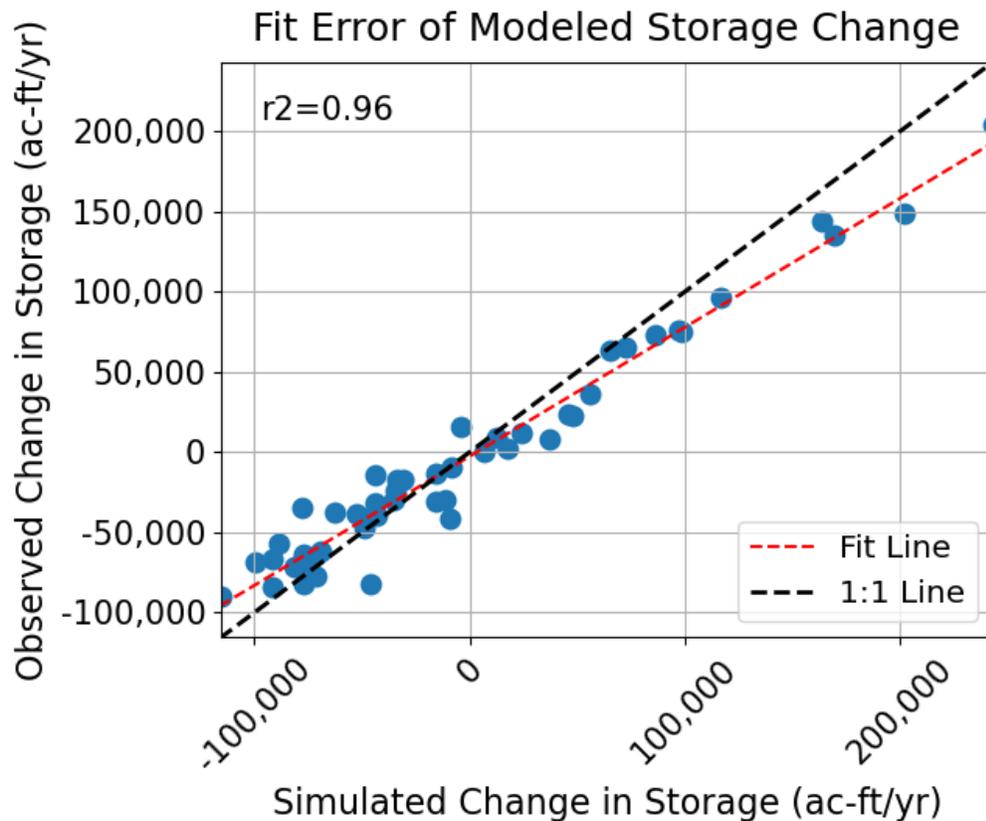
Although this correction requires nearly doubling the average simulated evaporation from ERA5-WRF, evaporation over Mono Lake depends on variables that lack direct observational data and are difficult to constrain such as Mono Lake’s humidity, wind speed, and net radiation. Despite this adjustment, using the adjusted ERA5-WRF evaporation in the MLWB yields more accurate results than relying on proxy measurements, such as pan evaporation data from the Long Valley station, located approximately 28 miles from Mono Lake. This suggests that with the mean-state adjustment, the ERA5-WRF data provides a reliable representation of historical evaporation conditions.

#### A.2.4 Error Term

Although the MLWB captures all major natural processes in the Mono Basin, it may still include some systematic errors. These are mainly due to small flow disturbances that aren’t fully captured, or limitations in ERA5-WRF. For example, the MLWB does not fully account for minor processes

such as occasional overflows from the Lee Vining Conduit, potential inaccuracies in regulated flow data as described in Los Angeles Department of Water and Power (2022), or the complexity of groundwater loss via the Mono Craters Tunnel, which is simplified in the MLWB as a constant annual loss of 5,500 ac-ft.

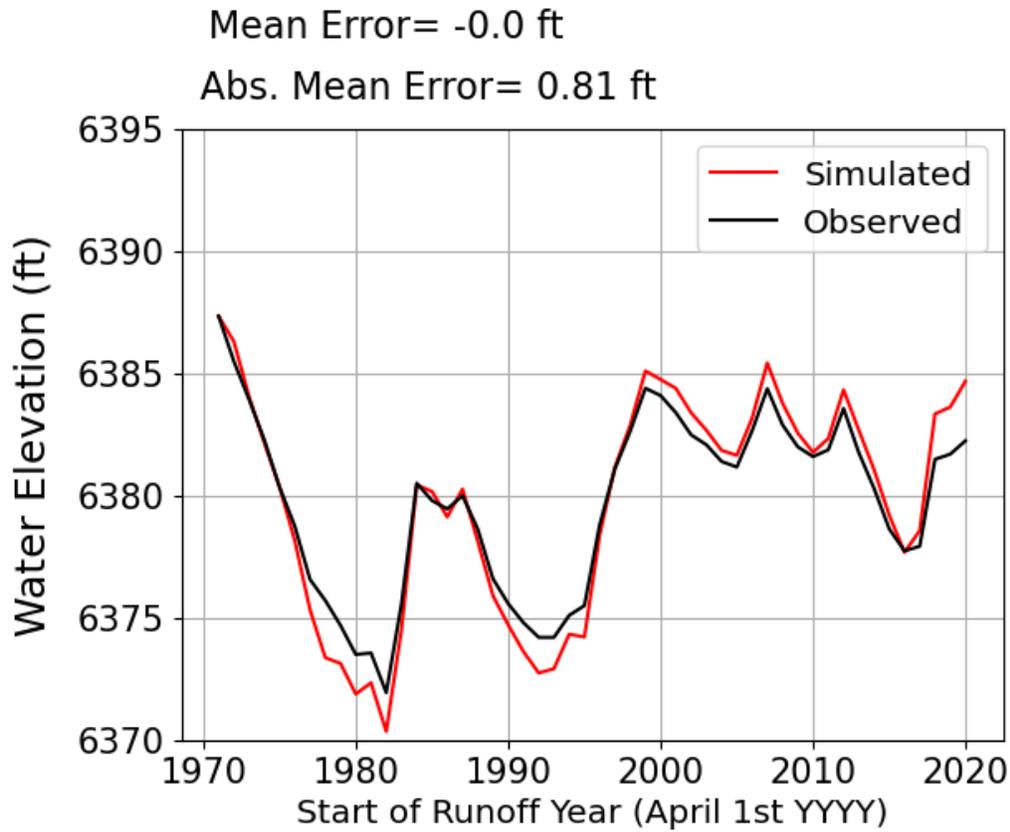
To minimize these errors, the Error Term in the MLWB **Equation 4** was obtained by fitting a linear regression between the annual change in storage estimated by the MLWB and the observed annual change in storage (**Figure A-9**). This correction is then applied as a linear adjustment to the simulated annual storage change. For example, a simulated change of 200,000 ac-ft is corrected to approximately 150,000 ac-ft based on the fit line in **Figure A-9**.



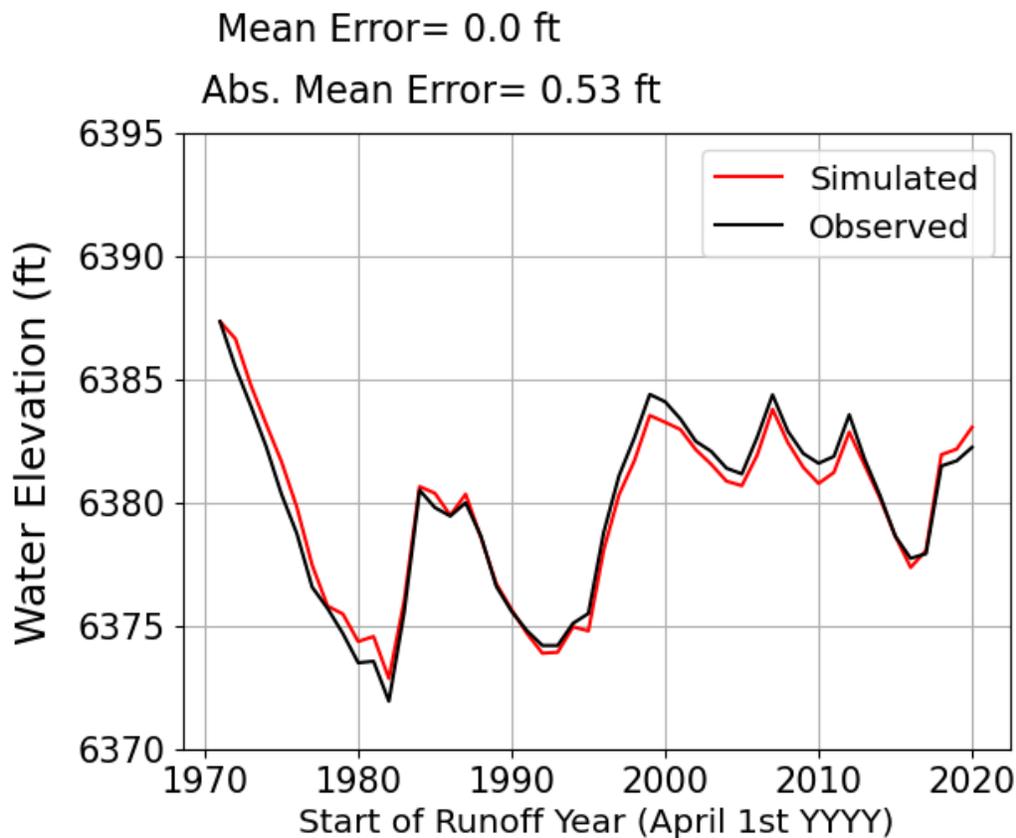
*Figure A-9. Storage error term used to adjust the water budget estimates of annual change in storage. The fit line shows how simulated changes in storage were adjusted based on its relationship to observed changes in storage. For example, a simulated change of 200,000 ac-ft/yr is converted to roughly 150,000 ac-ft/year based on the fit line.*

While smaller and negative changes in storage are well represented by the MLWB, the wettest changes in storage are overestimated by the MLWB. The MLWB error term helps account for limitations that can cause consistent (systematic) biases. **Figure A-10** shows the simulated lake level without the error term, which results in an absolute mean error of 0.81 ft. When the error term is incorporated, the absolute mean error is reduced to 0.53 ft. Because the bias captured in

the error term is systematic rather than random, the error term can reliably be used when applying the MLWB to different climate scenarios or export criteria.



*Figure A-10. Water budget model performance when using observed flow into Mono Lake along with ERA5-WRF simulated precipitation, evaporation, and ungauged runoff. Initial assessment without storage error term.*



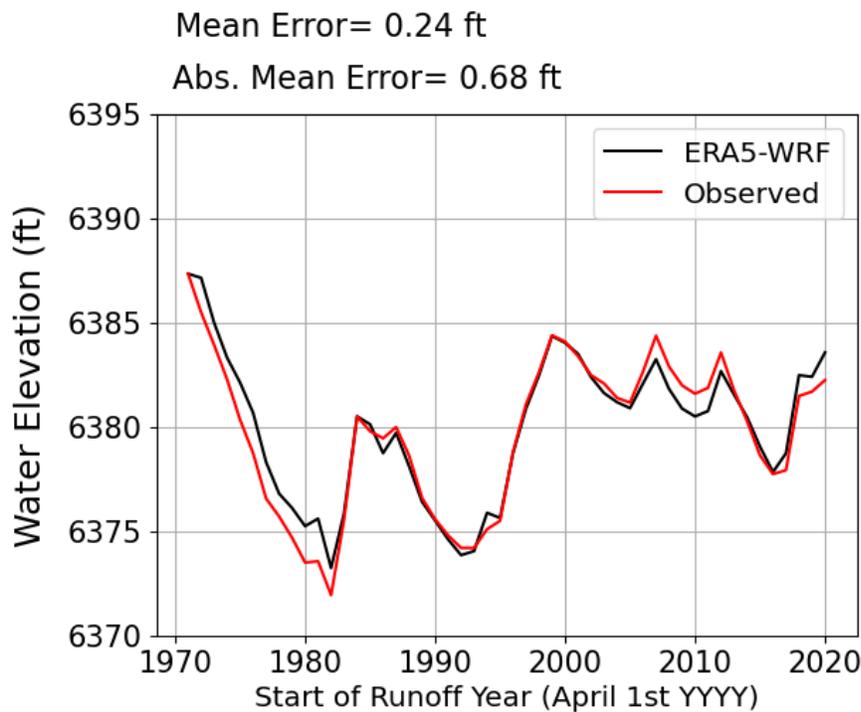
*Figure A-11. Water budget performance from 1971 to 2020 when the storage error term is incorporated into the MLWB. Note, for these years the measured flow into Mono Lake was used, while non-measured terms (Mono Lake precipitation, Mono Lake evaporation, and ungauged runoff) are from the modeled observations (ERA5-WRF).*

#### A.2.5 Assessment of MLWB from 1971 to 2020

To assess long-term performance, the MLWB was assessed over the 1971 to 2020 period using simulated natural flows and the derived statistical relationships for regulated flow (**Figure A-12**). Rather than using the measured flow, as done to produce the results in **Figure A-11**, for **Figure A-12** the simulated natural flow and its conversion to regulated flow was used as input to the MLWB. This evaluation showed a slight increase in mean absolute error to 0.68 ft, compared to 0.53 ft when using measured regulated flow. The increased error likely reflects unmodeled changes in land use and infrastructure operations prior to the 1990s, such as more extensive diversions through the Lee Vining Conduit and a lack of flow requirements.

Nonetheless, the water budget captures Mono Lake water level fluctuations well over this extended period. The results suggest that surface water exports via the Mono Craters Tunnel were the dominant control on lake level variability before the implementation of modern export criteria, as opposed to other land use conditions such as that associated with irrigation and hydropower. The MLWB's ability to represent inflow conditions under changing land use and water

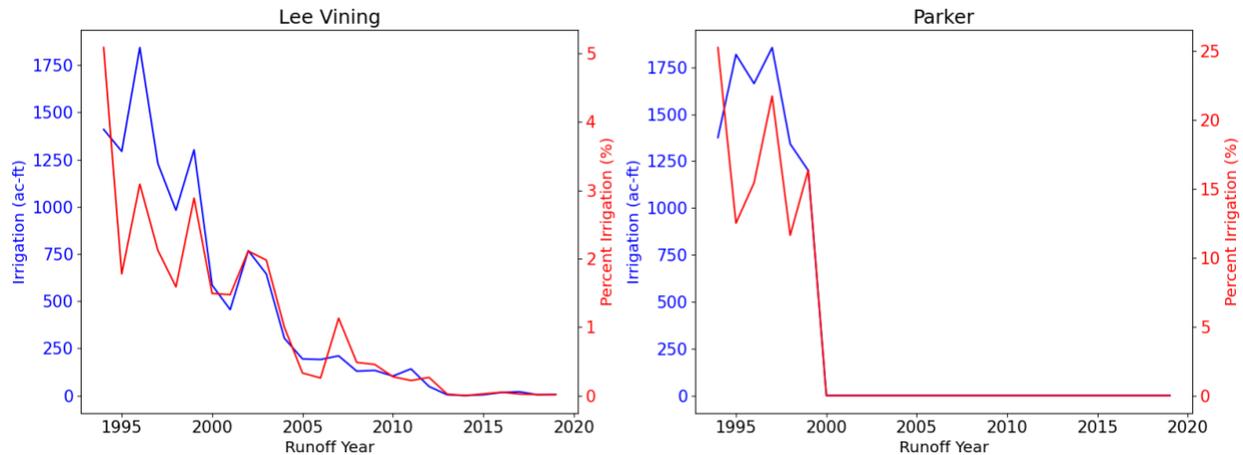
management conditions supports its application for long-term water balance analysis in the Mono Basin.



*Figure A-12. UCLA-MLM performance when compared against observations for the 1971-2020 time-period. Note, this is not reflective of the model error since it cannot simulate shifts in land use (e.g. irrigation, hydropower) prior to the 1990s.*

### A.3 MLWB Changes for Present-Day Conditions and its use for General Assessments

When comparing MLWB output to observations, observed irrigation levels and instream flow requirements should be used. However, aside from validating the MLWB, general uses of the MLWB should reflect current conditions. For example, Lee Vining and Parker Creek's irrigation should generally be set to zero in MLWB runs. This is because although Lee Vining and Parker Creek's irrigation diversions were substantially higher in the early 1990s, they are effectively zero today (**Figure A-13**, data obtained from MLC based on LADWP stations).



**Figure A-13.** Irrigation during the validation period (1994-2019) for Lee Vining Creek and Parker Creek. Blue line represents the ac-ft/year used for irrigation from each creek, and the red line represents the percent of the total creek’s flow extracted for irrigation.

In other words, present-day land use conditions should be used in all applications of the UCLA-MLM except when evaluating its ability to replicate observed water levels. Two well-documented changes occurred between 1994 and 2020: reductions in irrigation (as noted above) and modifications to instream flow requirements. In this section, a description is provided regarding how changes in these two conditions were incorporated into the version of the MLWB intended for assessments of Mono Lake under unique export criteria and climate scenarios – rather than for validation or comparisons to observed water level.

### A.3.1 Irrigation Adjustments

Changes in irrigation are well documented and notable decreases in irrigation have occurred from 1994 to 2019 for Lee Vining Creek and Parker Creek. Irrigation volumes are relatively small for Lee Vining Creek (0 to 5% of Lee Vining flow), and greater than 10% during 1994 to 2000 for Parker Creek (**Figure A-13**). From 2015 onward, irrigation withdrawals are nearly zero for Lee Vining, and from 2000 onward irrigation withdrawals are nearly zero for Parker. To account for these changes in irrigation, the observed irrigation volumes from each creek can be added back to their regulated flow into Mono Lake for each respective year. This adjustment requires re-derivation of the linear regression between natural flow and regulated flow for these creeks to ensure regulated flow accurately reflects current conditions, which exclude irrigation withdrawals. As noted previously, this is performed for general assessments with the MLWB, but not performed when the MLWB accuracy is being assessed against observed water level.

### A.3.2 Instream Flow Requirements

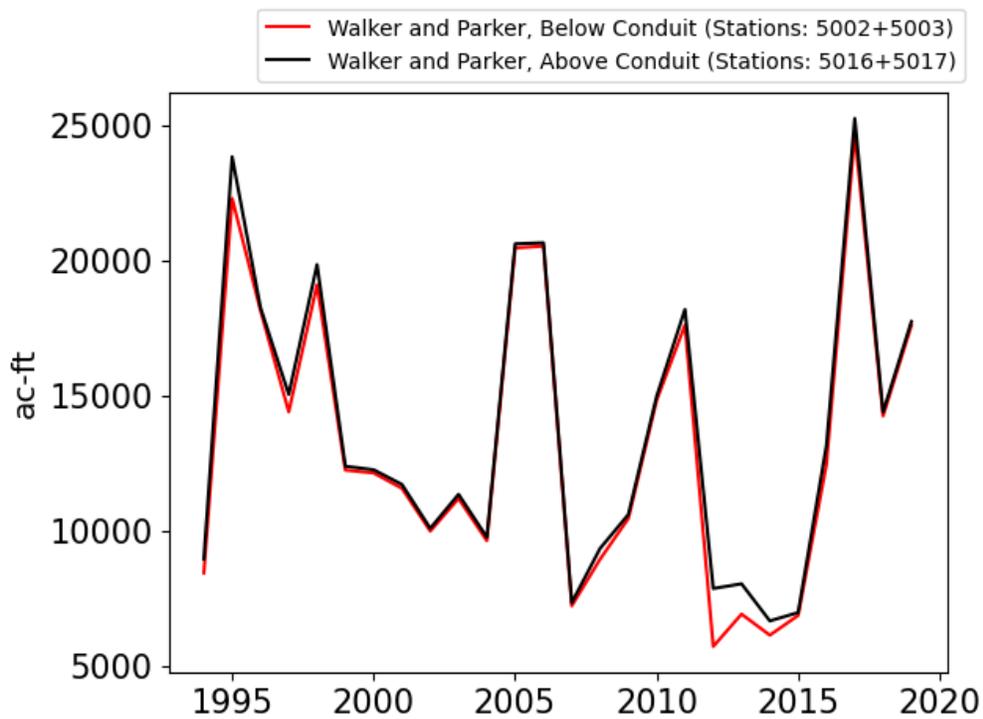
Instream flow requirements (IFRs) represent the volume of water that must flow throughout the runoff year in the Mono Basin’s major creeks. IFRs exist for Lee Vining, Walker, Parker and Rush Creek. Historically, from 1998 to 2020, Stream Restoration Flows (SRFs) determined the IFR for each stream. However, the SRFs were replaced by Stream Ecosystem Flows (SEFs) in 2021, as

defined in the current Amended Licenses issued by the SWRCB (California State Water Resources Control Board, 2021).

Stream Restoration Flows (SRFs) were used during the validation period (1994-2020) in order to assess the MLWB’s ability to represent observed water level. However, for general assessments, current instream flow requirements should be used. As such, the MLWB was modified to reflect Stream Ecosystem Flows (SEFs) for general assessments. SEFs were incorporated for Walker, Parker, and Rush Creeks for general uses of the UCLA-MLM. The SEFs for these creeks are described below.

### A.3.2.1 Walker and Parker

Under SEF requirements, diversions into the Lee Vining conduit from Walker and Parker Creeks were no longer permitted (California State Water Resources Control Board, 2021). Although observed diversions were relatively small (**Figure A-14**), regression equations were re-derived to relate natural flow to regulated flow above the Lee Vining Conduit. By regressing to regulated flow above Lee Vining Conduit, diversions from Walker and Parker are excluded per the SEF requirements. To represent SEF requirements, streamflow stations 5016 (Walker) and 5017 (Parker) were used to represent regulated flow, replacing previously used downstream stations 5002 and 5003.



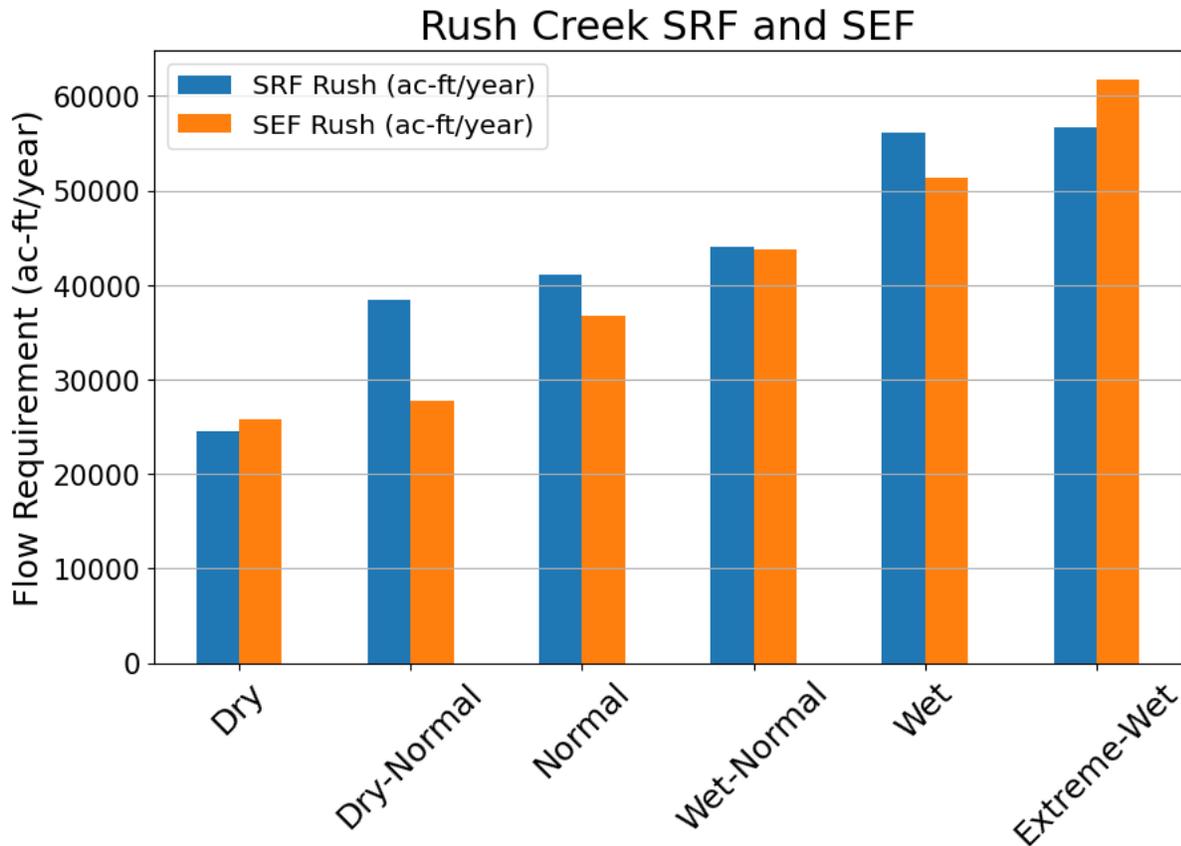
**Figure A-14.** Comparison of combined flow from Walker and Parker above (black) and below (red) the Lee Vining Conduit based on measured observations. Flows above the conduit reflect regulated flow conditions for SEFs, while flow below the conduit was used for validation purposes and reflects when SRFs were in place. Differences are minor.

The combined incorporation of existing irrigation practices and instream flow requirements, yield coefficients of determination ( $R^2$ ) comparable to previous results. For Lee Vining Creek,  $R^2$  changes from 0.91 to 0.90. For Walker and Parker Creeks,  $R^2$  increases from 0.90 to 0.92. No changes in regulated flow were required for the streams not modified by LADWP, including Mill Creek, DeChambeau Creek, and Parker East and South tributaries.

#### *A.3.2.2 Grant Lake Reservoir Considerations*

Rush Creek, downstream of Grant Lake, also has SEFs that are unique from the historical SRFs. To account for the change from SRFs to SEFs in general assessments with the MLWB, SEF volumes were substituted for SRFs in **Equation A-1**. Also, exports from Grant Lake can only begin after satisfying downstream Rush Creek SEF obligations.

Rush Creek's annual SRFs were derived from Table 2-3 from the *Synthesis of Instream Flow Recommendations* (McBain & Trush, Inc. and Ross Taylor and Associates, 2010). Rush Creek's SEFs were calculated using guidance from the *Mono Basin Operations Plan* (MBOP) appendix (Los Angeles Department of Water and Power, 2022). Both sets of flows include seasonal variation and ramping protocols that were considered when computing the annual Rush Creek SRF and SEF volume. As shown in **Figure A-15**, the volume of water for the SRFs and SEFs vary depending on the runoff year type (RYT). The derivation of the RYT is described in **Section A.3.2.4**. However, due to similar annual volumes, Dry-Normal I and Dry-Normal II runoff year types (RYTs) were combined into a single "Dry-Normal" category (**Figure A-15**).



**Figure A-15.** Annual SRF and SEF flow requirements for Rush Creek. X-axis includes unique year types, and the y-axis represents the volume of water required to flow in Rush Creek downstream of Grant Lake Reservoir. The volume of water required (SRF and SEF) varies depending on the year-type.

#### A.3.2.3 Lee Vining SEF Representation

Although SEFs apply to Lee Vining Creek, its flow into Mono Lake is represented using the observed (1994 to 2019) regression between natural and regulated flows. This approach is adopted due to the complexity of Lee Vining’s daily operational requirements, which are not explicitly represented. The observed regression is expected to meet annual SEF volumes on average.

#### A.3.2.4 Runoff Year Type (RYT) Classification

The Runoff Year Type (RYT) reflects the overall natural hydrologic conditions in the Mono Basin, which can range from dry to extreme wet. The RYT is computed based on natural flow, which then influences LADWP surface water diversions. Importantly for the MLWB, the RYT defines the SRF and SEF requirements for Rush Creek, and alternative export criteria can depend on the RYT (later discussed).

RYTs were classified in a manner consistent with LADWP Mono Basin practices (Los Angeles Department of Water and Power, 2022). This entailed using natural flow from the 1971 to 2020

runoff years which reflects a recent 50-year climatological period. Because ERA5-WRF data ends at 3/31/2020, conditions for the 2020 runoff year (covering 4/1/2020 to 3/31/2021) was estimated using 1990 as an analog year. This year was selected due to its similarity in observed four-creek runoff and observed Cain Ranch precipitation.

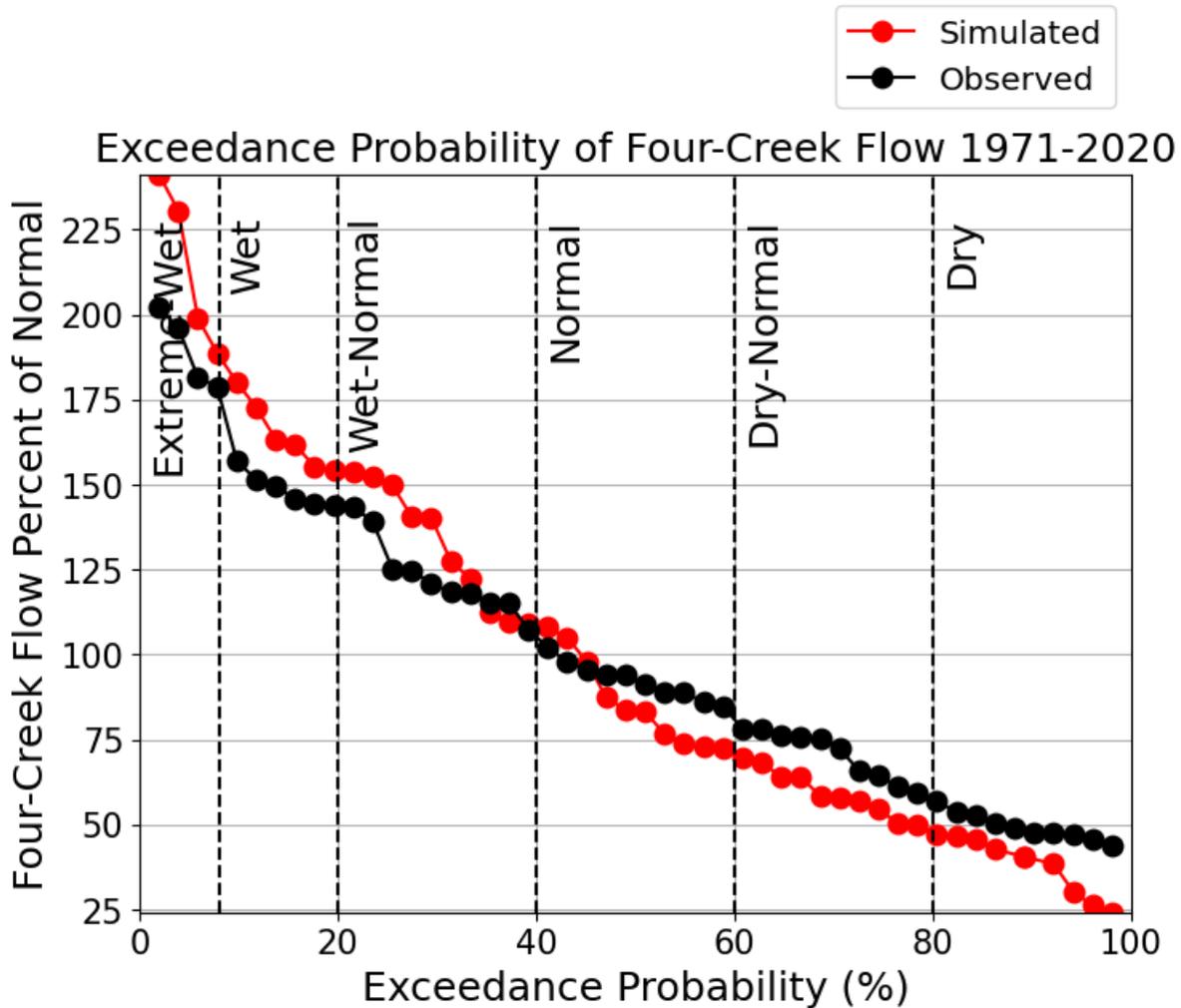
As outlined in **Table A-3** and the Amended Licenses, the exceedance probability of a year’s four-creek natural flow (from Lee Vining, Walker, Parker, and Rush Creeks) determines its RYT. The exceedance probability represents the likelihood a given four-creek flow value will be exceeded in a given year. For example, a low (high) four-creek flow relative to average conditions will have a higher (lower) exceedance probability. Consistent with LADWP (2022), the Weibull plotting formula was used to determine the exceedance probability of the four-creek natural flow from 1971 to 2020:

$$\text{Exceedance Probability} = 100 * \left(1 - \frac{i}{n+1}\right) \quad \text{Equation 7}$$

where *i* is the rank order and *n* = 50 (number of years). **Figure A-16** shows the exceedance probability on the x-axis, and the corresponding flow on the y-axis. Also consistent with LADWP (2022), the flow data is divided by the 50-year average to show the percent of normal flow rather than the actual flow values.

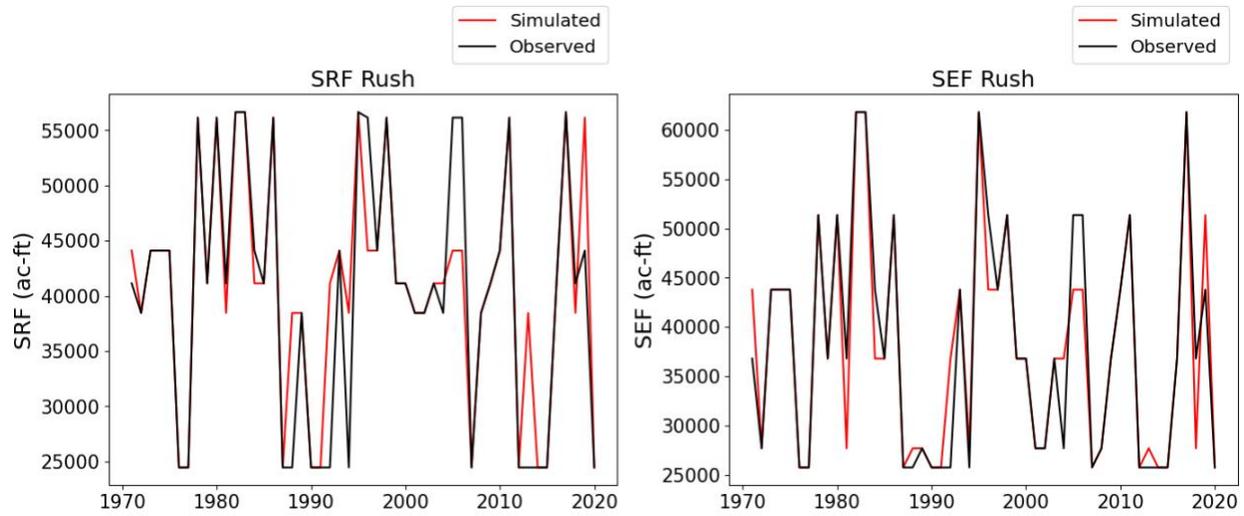
**Table A-3.** Exceedance probability associated with each runoff year type (RYT). For example, for a Dry RYT, the four-creek flow associated with the dry RYT is exceeded 80% to 100% of the time.

RYT	Exceedance Probability (%)
Dry	80-100
Dry-Normal	60-80
Normal	40-60
Wet-Normal	20-40
Wet	0-8



*Figure A-16. Four-creek flow percent of normal values (y-axis) that correspond to each RYT (separated by black vertical lines that correspond to different exceedance probabilities). Percent of normal shown based on observed data for the four-creek flow (black) and the modeled observations of four-creek flow (red).*

**Figure A-16** includes the flow values (percent of normal flow) that correspond to each exceedance probability. This is shown for measured natural flow and the ERA5-WRF hydrology. Although median flows from the ERA5-WRF hydrology align with measured natural flow, the dataset shows bias at both tails of distribution. Therefore, percent-of-normal thresholds used to assign RYTs were based on simulated flow to account for bias in the ERA5-WRF dataset. Using this approach, the SRF and SEF requirements are reasonably captured when compared to observed data (**Figure A-17**).



**Figure A-17.** Resulting Rush Creek SRF (left plot) and SEF (right plot) based on simulated (red) and observed (black) data.

## A.4 Sensitivity Tests of the MLWB

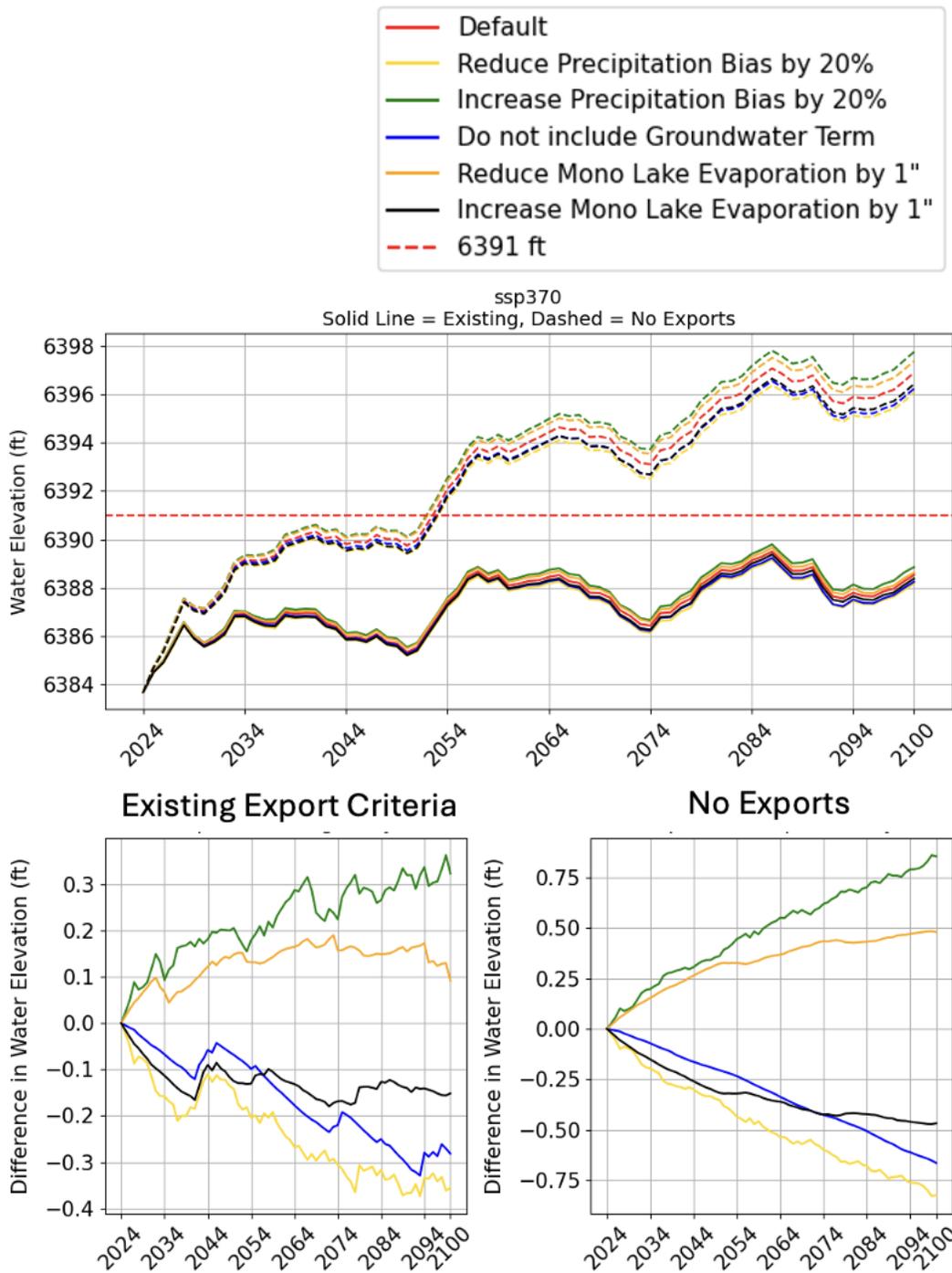
The MLWB was developed using what is believed to be the best available data, and assumptions which were required due to limitations in observed data. For this section, this final MLWB is referred to as the Default model. Here, we test how differences in our main assumptions impact estimates of Mono Lake water level. The different sensitivity tests that were performed to evaluate reasonable modifications to our assumptions are outlined in **Table A-4**. The first row in this table represents the default (or final) Mono Lake water budget model, which includes a groundwater export term, a precipitation mean-state bias correction based on the simulated bias at Cain Ranch (which is the closest location with observed data with a distance of roughly 4.5 miles from Mono Lake), and the evaporation and ungauged bias correction values which were optimized based on historical average values that lead to the lowest mean error in water level estimates compared to observations. The second and third row represent a modification where we test the impact if the bias at Cain Ranch is 20% too high and 20% too low (relative to our simulated bias at Mono Lake which we assume in our default model to be the same as the Cain Ranch simulated bias). The fourth row includes a water budget model without a groundwater export term which is set to 5,500 ac-ft/year in the Default model. Finally, the last two rows include an assumed historical average evaporation rate that is reduced by 1.0 inch (46.25 in) and increased by 1.0 inch (48.25 in) rather than the default of 47.25 in. In all of these tests, the historical average evaporation is optimized (unless it is set to a specific value like the last two tests), and the ungauged runoff mean-state bias correction is optimized. As done previously, the ungauged runoff and evaporation optimization is assessed by evaluating the combination of these two values that reduce the error of the simulated water levels compared to observed water levels. Most of the tests show negligible mean errors (0+/0.01 ft); however, modifying the evaporation value by 1-inch leads to a slight increase in the mean error (+/-0.12 ft).

**Table A-4.** Different tests that were performed to assess assumptions in the development of the MLWB that had to be made due to limited observational data.

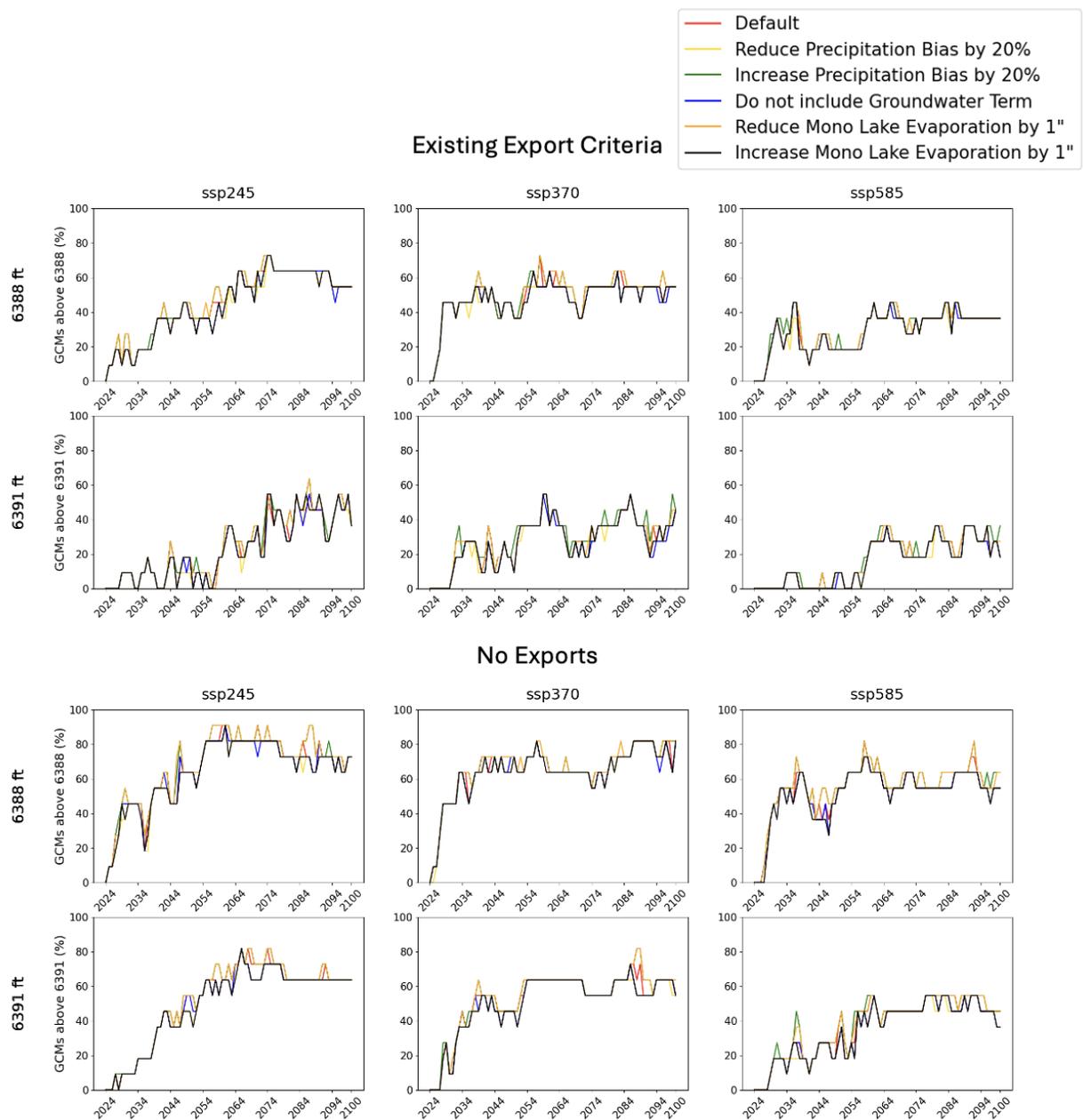
Description of Model	Mono Lake Evaporation (in/yr)	Ungauged Adjustment	1994-2020 Mean Error (ft)	1994-2020 Abs. Mean Error (ft)
<b>Default</b>	47.25	0.58	0.01	0.48
<b>Reduce Precipitation Bias by 20%</b>	46.75	0.64	0.00	0.47
<b>Increase Precipitation Bias by 20%</b>	47.75	0.53	0.00	0.51
<b>Do not include Groundwater Term</b>	48.75	0.57	-0.00	0.48
<b>Specify Mono Lake Evaporation of 46.25</b>	46.25	0.53	0.12	0.50
<b>Specify Mono Lake Evaporation of 48.25</b>	48.25	0.63	-0.11	0.48

To test the impact of the different water budget model assumptions outlined in **Table A-4**, we evaluate how the models differ in their representation of Mono Lake water level for the hydroclimate projections from the Global Climate Models (GCMs), which are outlined in Section 3 and Section 4. In **Figure A-18**, we show the mean water level projections for the 11 GCMs for the intermediate emission scenario (SSP3-7.0) for two book-end export criteria (existing export criteria with post-transition rules, and no exports in the transition and post-transition period). We found

relatively small impacts on the water level projections, with a difference between the different sensitivity tests being less than 0.4 ft for existing export criteria (D-1631, including post-transition export criteria), and roughly +/- 0.77 ft for no exports. We also show the percentage of GCMs with water levels above 6,388 ft and 6,391 ft in **Figure A-19**. Importantly, the likelihood of being at or above critical water levels (in **Figure A-19**), demonstrates that the results provided throughout the report are relatively insensitive to potential alternative assumptions that could have been made in the water budget model set-up. Finally, we note that while the magnitude of values for different export criteria can slightly differ for different modeling assumptions, differences between export criteria will be similar for different model set-ups. For the report, we use a Default model set-up that is based on what we believe to be the best assumptions given situations where observed data is lacking.



**Figure A-18.** Top figure shows the mean water level projections for emission scenario SSP3-7.0 for existing transition and post-transition export criteria (solid line) and no exports in the transition and post-transition period (dashed line) for the sensitivity tests performed when modifications are made to the Default set-up of the water budget model. Bottom row shows the difference in the mean water level projection caused by each modification to the water budget model relative to the Default set-up for existing transition and post-transition export criteria (bottom left figure) and no exports in the transition and post-transition period (bottom right figure).



**Figure A-19.** Likelihood of water level above 6,388 ft and 6,391 ft for existing export criteria with post-transition rules (top figure) and no exports in the transition and post-transition period (bottom figure). Small differences occur in the likelihood of being above or below the default water budget model for the alternative water budget model tests. 6,391 ft is relevant to the D-1631 water level objectives, while 6,388 ft is additionally compared against to assess the sensitivity to a water level that is higher relative to April 1<sup>st</sup>, 2024 conditions and that can provide benefits such as reduced air quality issues and decreased predatory land bridges.

## A.5 Adding Wrapped Run Capability

The UCLA-MLM was primarily set-up to assess the ability of Mono Lake water level under unique export criteria and climate change scenarios. However, a method, called the “wrapped run” approach, which is based on observed conditions, is commonly used by stakeholders such as LADWP and MLC (Mono Lake Technical Group, 2024). The “wrapped run” approach was included as a part of the UCLA-MLM to allow for comparisons of the approach to assessments that consider climate change. Also, the Mono Lake Technical Working Group (MLTWG) requested that the UCLA-MLM include an option to simulate lake level using the wrapped run approach to allow for comparisons of the UCLA water budget results to *eSTREAM* and Vorster model results.

This section provides an overview of the wrapped run approach, which is discussed here because it is based on the ERA5-WRF dataset described in detail in **Section 2.1** and this Appendix.

In the wrapped run approach, LADWP and MLTWG evaluated a recent 50-year time period. Here, the years 1971 to 2020 were used, since the ERA5-WRF data is not available beyond 2020, and since recent assessments of Mono Lake use this time period (Mono Lake Technical Group, 2024). The wrapped run approach is based on sequences. The number of sequences developed depends on the number of years used (50-years in this case). Each sequence is based on observed weather and hydrology, but the timing of observed weather and hydrology are shifted. When referring to observed conditions, models like *eSTREAM* use actual measurements of observed conditions. Each sequence is made-up of the same set of 50 years of observed conditions, but the starting year is unique for each sequence. For example, the first sequence covers 1971-2020 (only sequence that represents what actually occurred); the second shifts the start year to 1972 and ends with 1971, and so on. Example sequences are further outlined in **Table A-5**. Note, while *eSTREAMs* uses actual observations in the wrapped run method, the UCLA-MLM uses modeled observations from ERA5-WRF.

Each wrapped sequence begins with the same initial Mono Lake water level, but variations in the order of annual weather and hydrology conditions produce differing lake level outcomes. The method captures a range of possible outcomes resulting from possible shifts in the order of weather. This approximates internal variability, or random shifts in weather, but since it samples only from the observed record, it likely does not represent the full range of internal variability. The wrapped run method does not include future climate change projections. Even though trends such as increases in evaporation and decreases in precipitation may exist in observed conditions, such changes can be influenced by internal variability and may not reflect climate change.

*Table A-5. Example of the sequences included in a 50-year wrapped run from 1971 to 2020.*

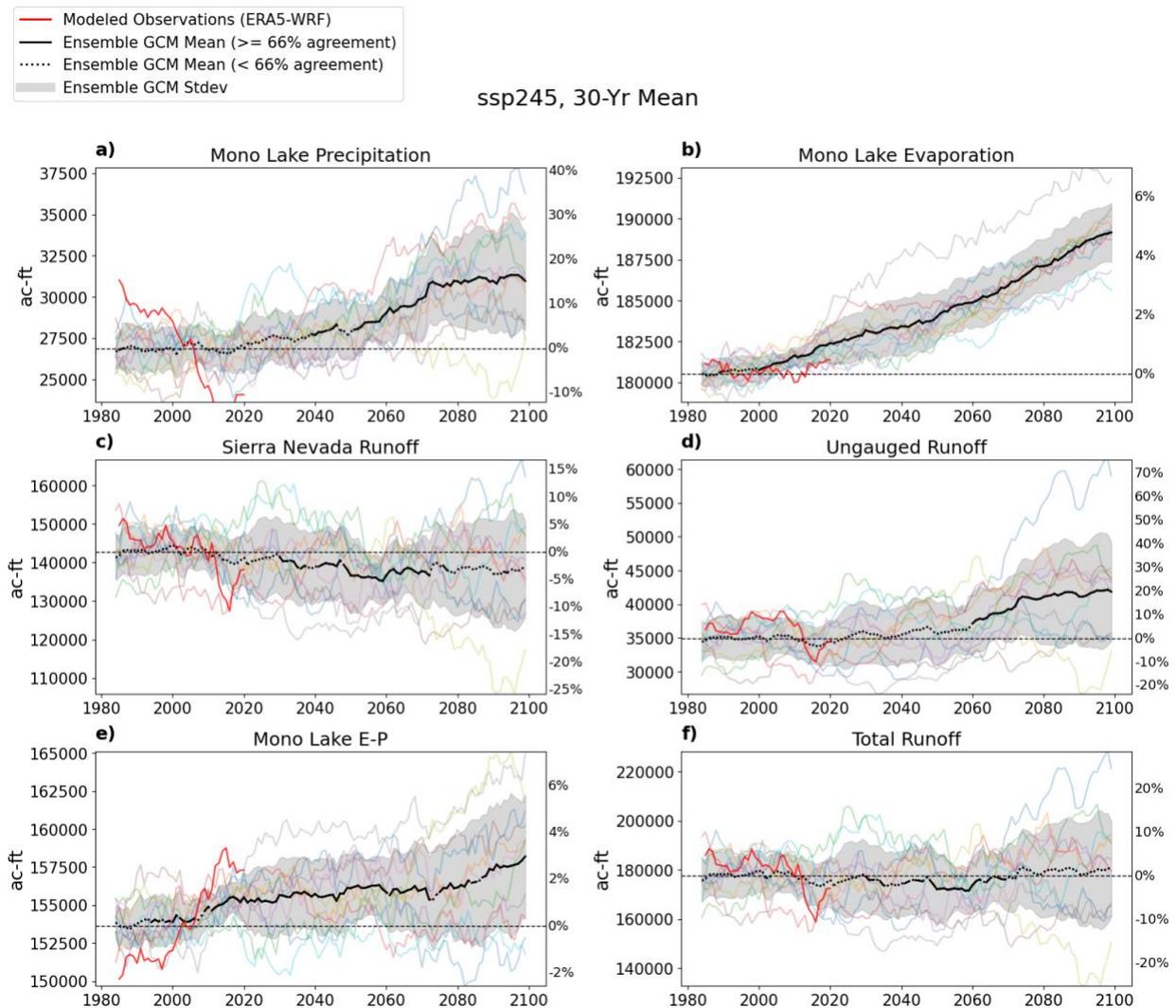
Sequence Start Year	Time-Series (50 runoff years)
1971	1971-2020
1972	1972-2020, 1971
1973	1973-2020, 1971-1972
...	...
1983	1983-2020, 1971-1982
...	...
2019	2019-2020, 1971-2018
2020	2020, 1971-2019

The UCLA-MLM supports wrapped run simulations to enable more direct comparisons with other models, such as LADWP’s eSTREAM and MLC’s Vorster models, which use the same method. However, the primary advantage of the UCLA-MLM lies in its ability to simulate both historical and future climate conditions from 1955 to 2100, using multiple hydroclimate sequences derived from global climate models (GCMs).

Unlike wrapped runs, GCM-based sequences incorporate both internal variability and externally forced climate change. When multiple GCM hydroclimate sequences show consistent trends, these signals can be attributed to climate change rather than internal variability. The use of GCMs also enables evaluation of both historical climate change (under observed emissions through 2014) and future projections under alternative emission scenarios (2015 until 2100).

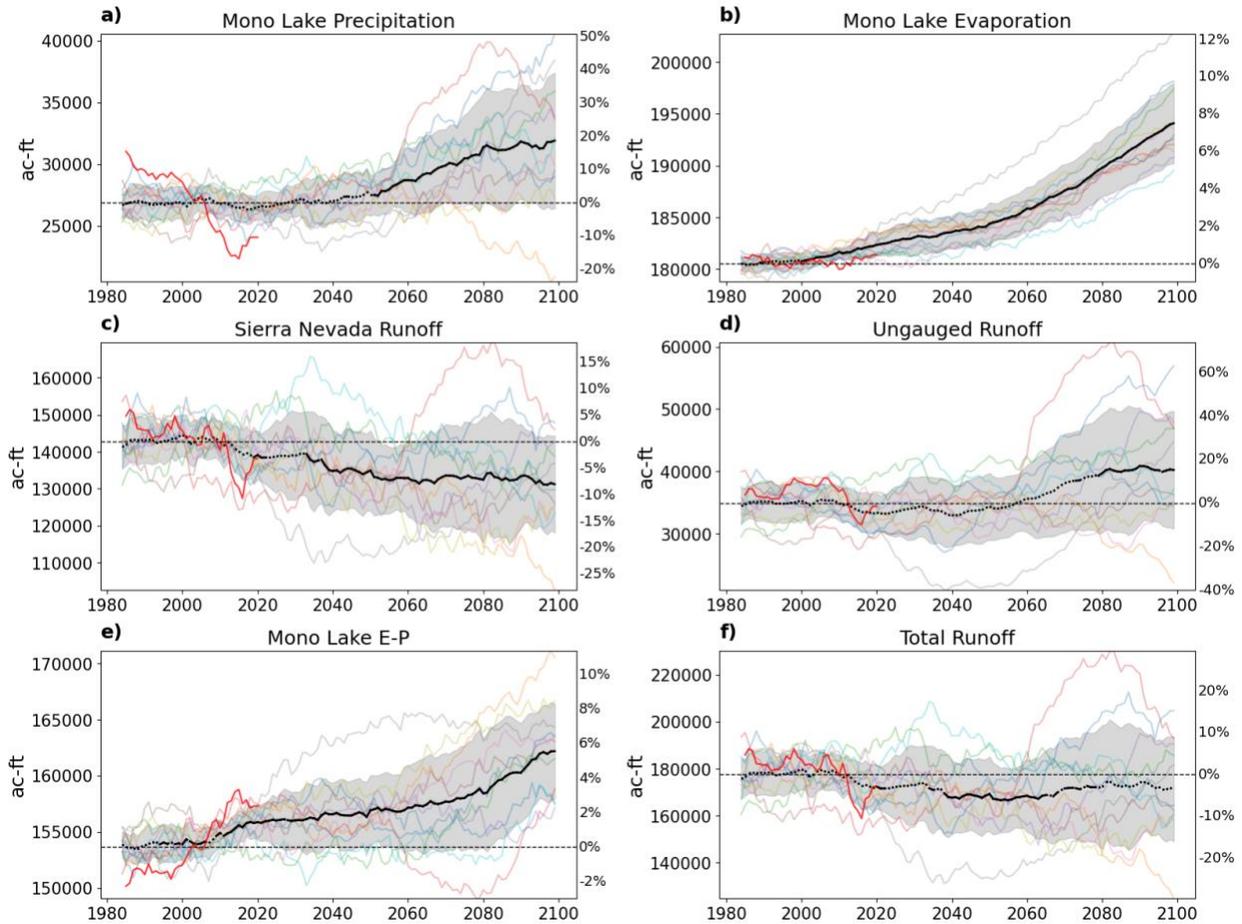
## B. Appendix B (Supplement to Section 3.5 of Main Report)

This appendix includes supplementary figures for **Section 3.5** of the report, which outlines projected climate change conditions across the Mono Basin. Descriptions of the supplemental figures are provided in the figure captions. All figures aside from **Figure B-1**, evaluate changes in Mono Lake storage based on simulations with the MLWB using an initial water level of 6383.7 ft (April 1<sup>st</sup>, 2024 water level) and not allowing any exports.

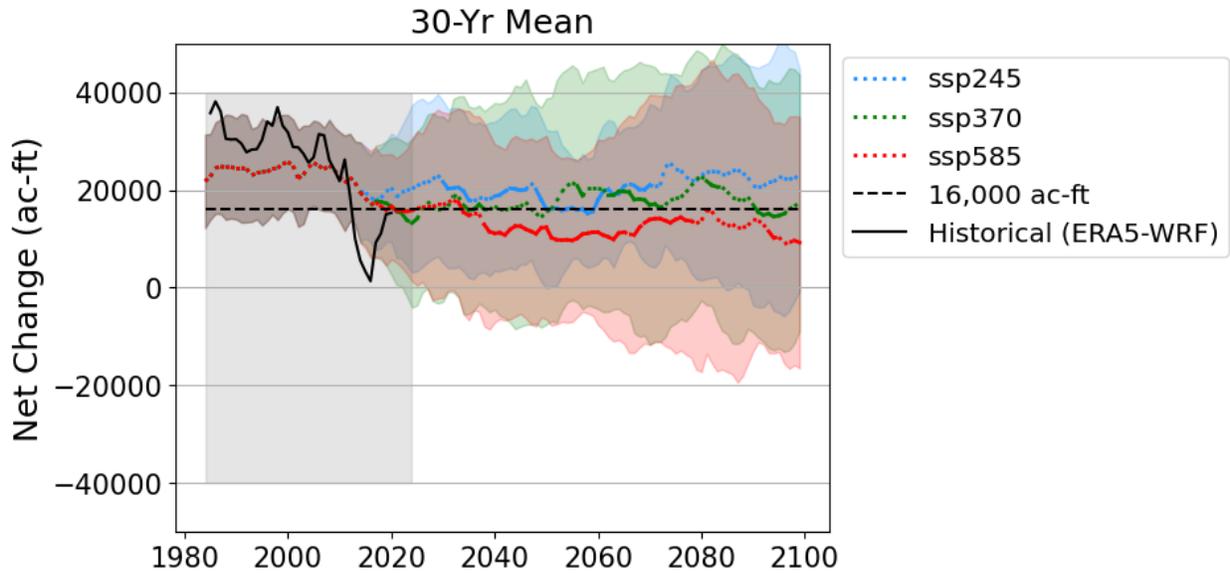




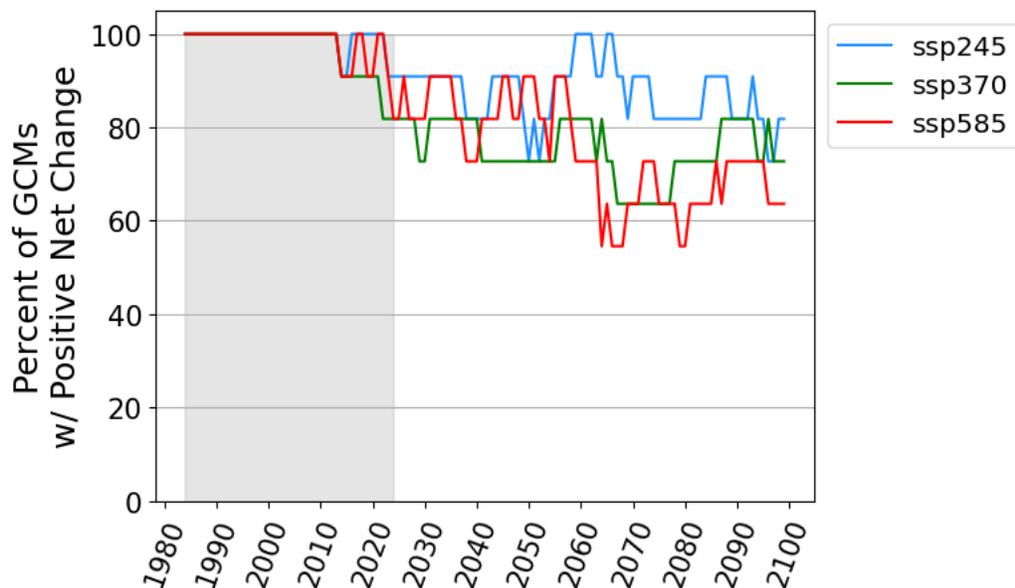
ssp585, 30-Yr Mean



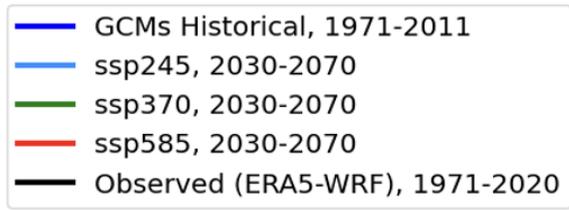
**Figure B-1.** Changes in major components of Mono Lake’s water budget for SSP2-4.5 and SSP5-8.5 (Figure 3-2 shows results for SSP3-7.0). Different colored lines represent unique GCMs. Black line represents the GCM ensemble mean, with solid indicating 2/3rds agreement on the direction of change (positive or negative) for a given time in the future compared to historical conditions (average from 1955 to 1990 for this plot). Grey shading represents 1 standard deviation. Red line represents what happened based on our modeled observations (ERA5-WRF).



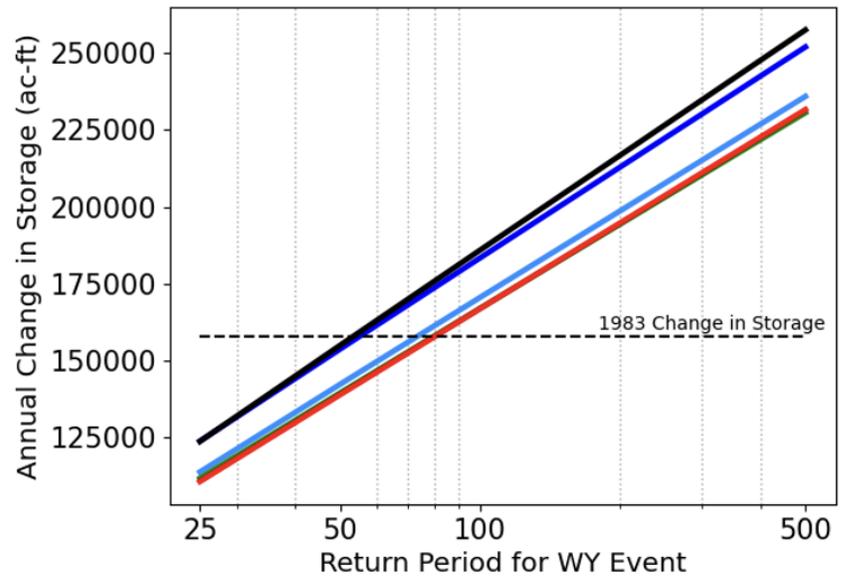
**Figure B-2.** Net change in Mono Lake storage based on the ensemble mean and standard deviation across GCMs (shading), assuming zero exports. A 30-year rolling average is used to reduce internal variability. 2/3rds GCM agreement on direction of signal is indicated when line is solid (lack of agreement indicated by dashed line). The black solid line illustrates modeled observations (ERA5-WRF) and represents what changes in storage would have been if there had been no exports. A line at 16,000 ac-ft is included for reference since this is the surface water export amount allowed by D-1631 when Mono Lake water level range from 6,380 to 6,391 ft.

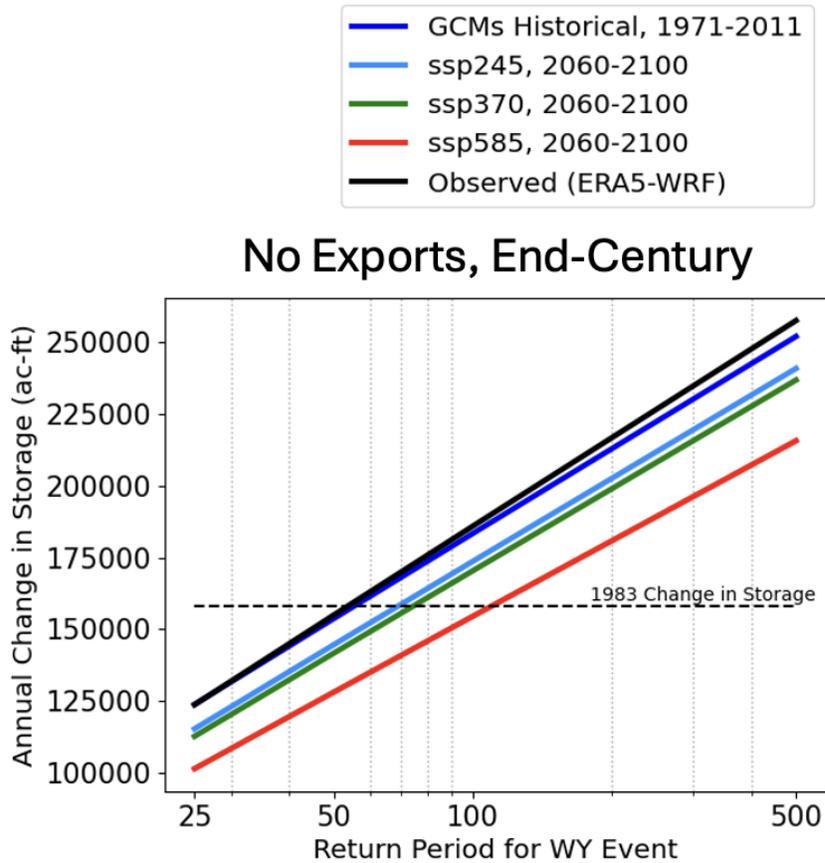


**Figure B-3.** Percent of GCMs with a positive change in storage (an annual increase in storage greater than zero which results in an increase in Mono Lake's water level), using all components that make up the Mono Lake water budget model but no exports.



### No Exports, Mid-Century

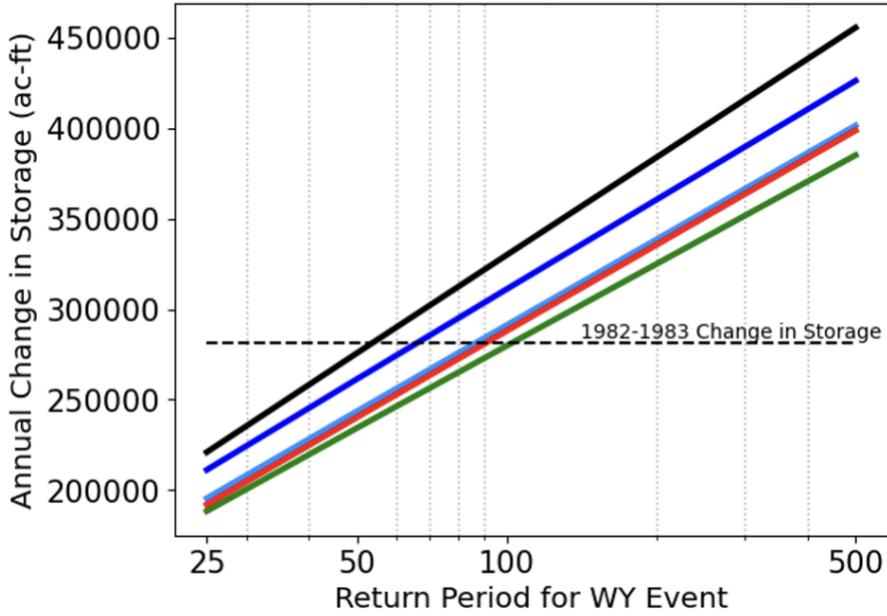


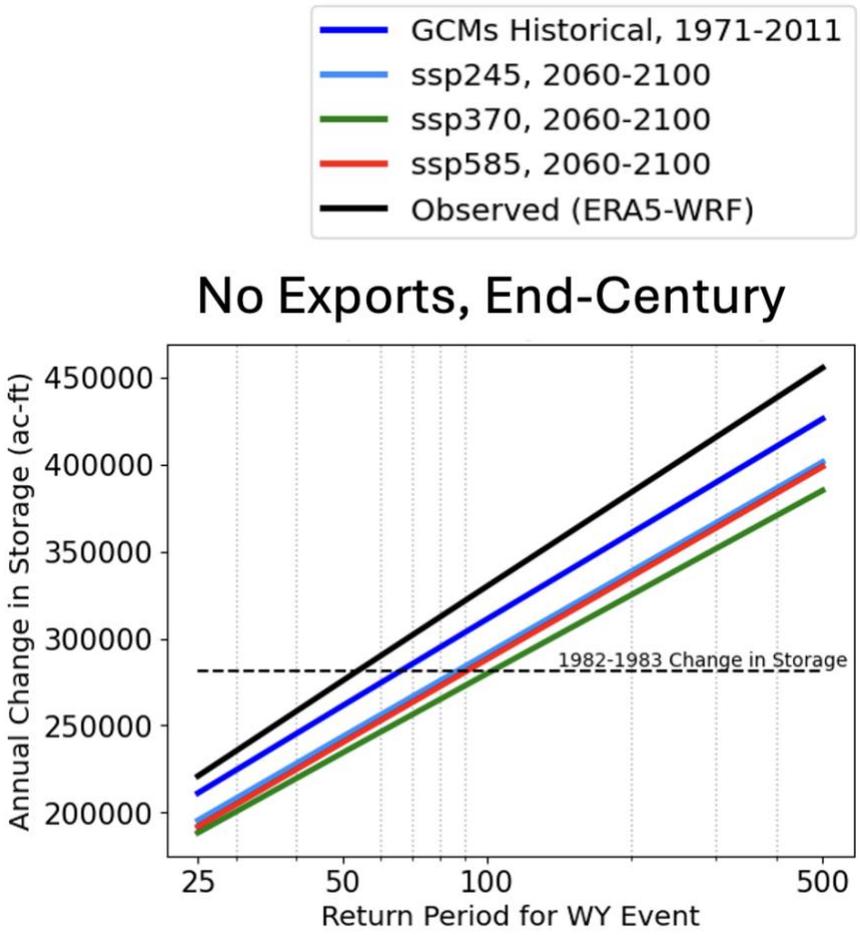


**Figure B-4.** Conditions that led to the largest observed annual change in storage occurred in 1983, which is shown as a dashed line based on our ERA5-WRF data. Here, we evaluate the return period, which is the average amount of time between occurrences of this type of event, based on ERA5-WRF compared to GCM data across the historical and future period. This evaluation is performed under an assumption of no exports in the transition and post-transition period. We use a Type 1 Generalized Extreme Value Distribution (Gumbel, right skewed) fit to the annual maximum storage data, for the years shown in the legend, to derive the return period values. This was performed using the 11 GCMs for each SSP, providing 451 years of data for a given return period assessment (11 GCMs \* 41 years for each SSP). Generally, the likelihood for such an event decreases by 2050 (top figure) and 2080 (bottom figure) compared to historical conditions (1990). Under historical conditions, such an event roughly has a 55-year likelihood, and for SSP2-4.5 and SSP3-7.0 such an event has roughly a 70 to 75-year likelihood for mid-century and end-of-century conditions.

- GCMs Historical, 1971-2011
- ssp245, 2030-2070
- ssp370, 2030-2070
- ssp585, 2030-2070
- Observed (ERA5-WRF), 1971-2020

### No Exports, Mid-Century





*Figure B-5. Same methods were applied as Figure B-4 to evaluate the return period for the two-wettest years in a row observed in the historical period. Here, we show that the likelihood of the two wettest years that occurred in the observed data is sampled as a 50-year event in the wrapped run approach, while the GCMs, which provide more samples of internal variability, suggest the two-wettest years that occurred has roughly a 70-year likelihood.*

## C. Appendix C (Supplement to Section 4.1 of Main Report)

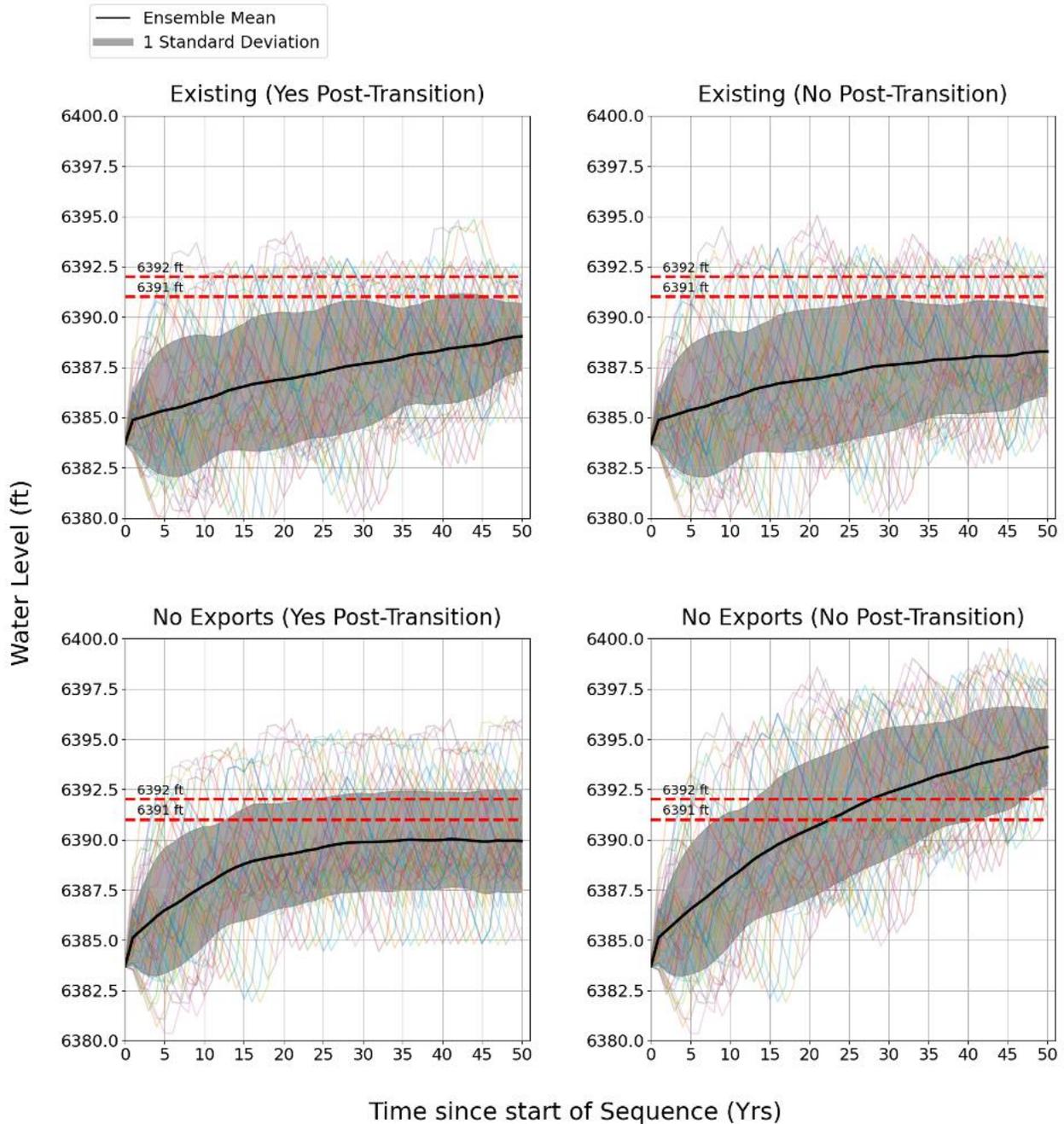
This appendix includes supplementary figures for **Section 4.1** of the report. This includes additional Mono Lake water level estimates based on a variety of simulations using the wrapped run method (**Appendix C.1**), climate change simulations using the lower and upper bound of expected exports (**Appendix C.2**), and additional figures from the assessment of climate change impacts on Mono Lake water level (**Appendix C.3**). Descriptions of the lower and upper bound of exports considered here is outlined in **Table 4-2** of the main report. Note, unlike the main report, the appendix figures include a label of (Yes Post-Transition) after Existing Exports and a label of (No Post-Transition) after No Exports.

### C.1 Results from Wrapped Runs

**Appendix C.1** includes results from the wrapped run method.

In **Figure C-1**, we show Mono Lake water levels resulting from the wrapped run approach, which consist of 50 hydroclimate sequences used as a forcing which were derived from the 1971 to 2020 ERA5-WRF time-period. In the figure, we include the individual wrapped runs as unique colors. Since these can be difficult to interpret on their own, we also include the ensemble mean and standard deviation from the wrapped runs. From the mean results, No Exports (bottom right part of figure) is the only export criteria that leads to water levels above the 6,391 ft transition level and the 6,392 ft water level target outlined in D-1631. No Exports (Yes Post-Transition) in the bottom left part of figure, clearly dampens the ability of Mono Lake to maintain a water level at roughly 6,392 ft with the wrapped runs. Based on the ensemble mean, the existing transition export criteria, with or without post-transition rules, generally lead to water levels below the 6,391 ft transition level.

### Wrapped Runs Using ERA5-WRF (1971-2020)



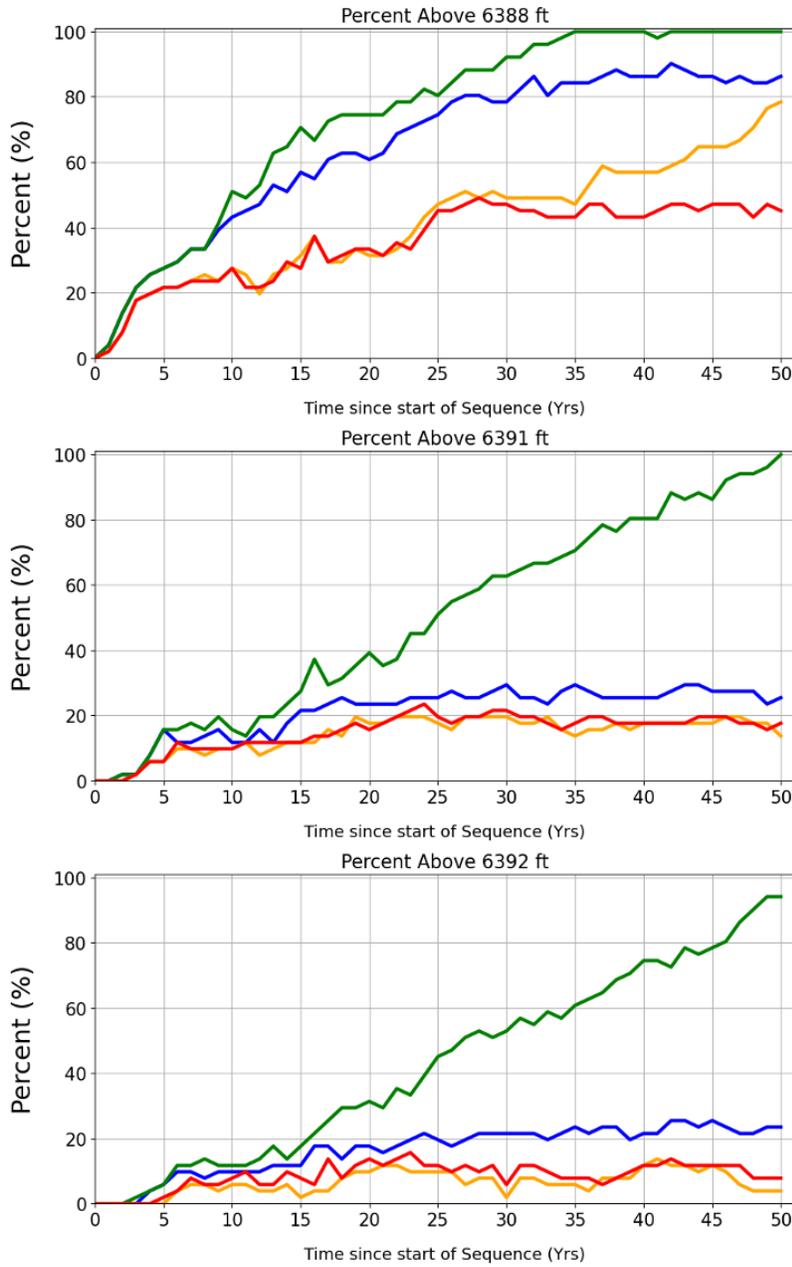
**Figure C-1.** Mono Lake water level resulting from the wrapped run approach derived from ERA5-WRF for the years 1971 to 2020. Unique colors represent individual results from the 50 wrapped runs, and the black solid line represents the ensemble mean from the wrapped runs. The grey shading represents the variability in water level (1 standard deviation) based on the range of results from 50 wrapped runs for each year in the sequence.

To more robustly interpret the results from **Figure C-1**, we show the percent of wrapped runs that lead to Mono Lake water level at or above different water level thresholds in **Figure C-2**. This

provides a more probabilistic interpretation of the wrapped runs by considering the results from every individual sequence. This figure demonstrates that of the book-end export criteria assessed, No Exports is the only export criteria that may roughly meet the goals of D-1631, which is to reach a transition water level of 6,391 ft and then maintain a target average water level of 6,392 ft. Specifically, by the end of the 50-year sequence, the criteria with No Exports is the only export criteria (of the four book-end export criteria considered here) that leads to 100% (95%) of the sequences being at or above 6,391 ft (6,392 ft). However, the other book-end export criteria, including Existing Exports (No Post-Transition) and No Exports (Yes Post-Transition), demonstrate less than a 30% likelihood of being above 6,391 ft after 50-years, and about a 25% likelihood of being above 6,392 ft after 50 years. This suggests that the existing transition and post-transition export criteria allow for exports that substantially reduce the likelihood of reaching and maintaining Mono Lake water level above 6,391 ft. Notably, these results are based on historical climatology from 1971 to 2020, which may fail to represent present-day climate conditions and how climate may change in the future.

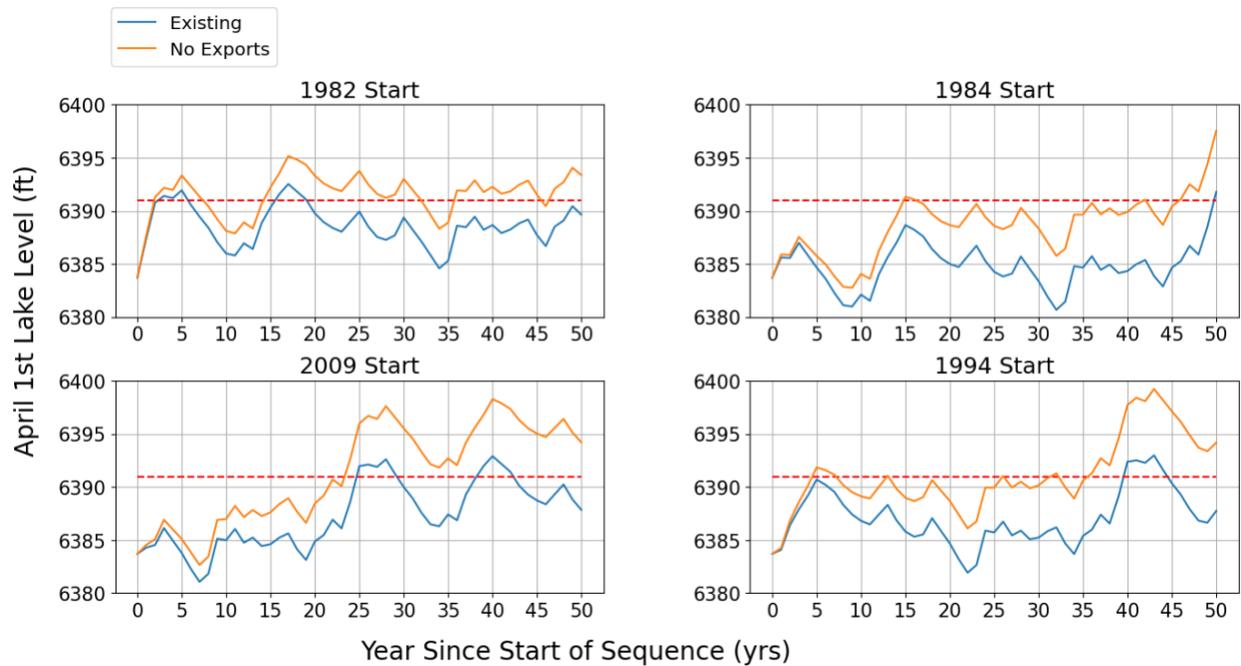


Percentage of Sequences above Water Level  
Thresholds for Book-End Export Criteria



*Figure C-2. Percent of wrapped run sequences resulting in Mono Lake water level at or above 6,388 ft (top figure), 6,391 ft (middle figure), 6,392 ft (bottom figure). Shown for Mono Lake water level response to unique book-end export criteria as outlined in the legend at the top of the figure.*

Below, we provide additional figures from the wrapped runs. We consider these figures useful; however, they are not necessary to describe the main findings from the wrapped run method.

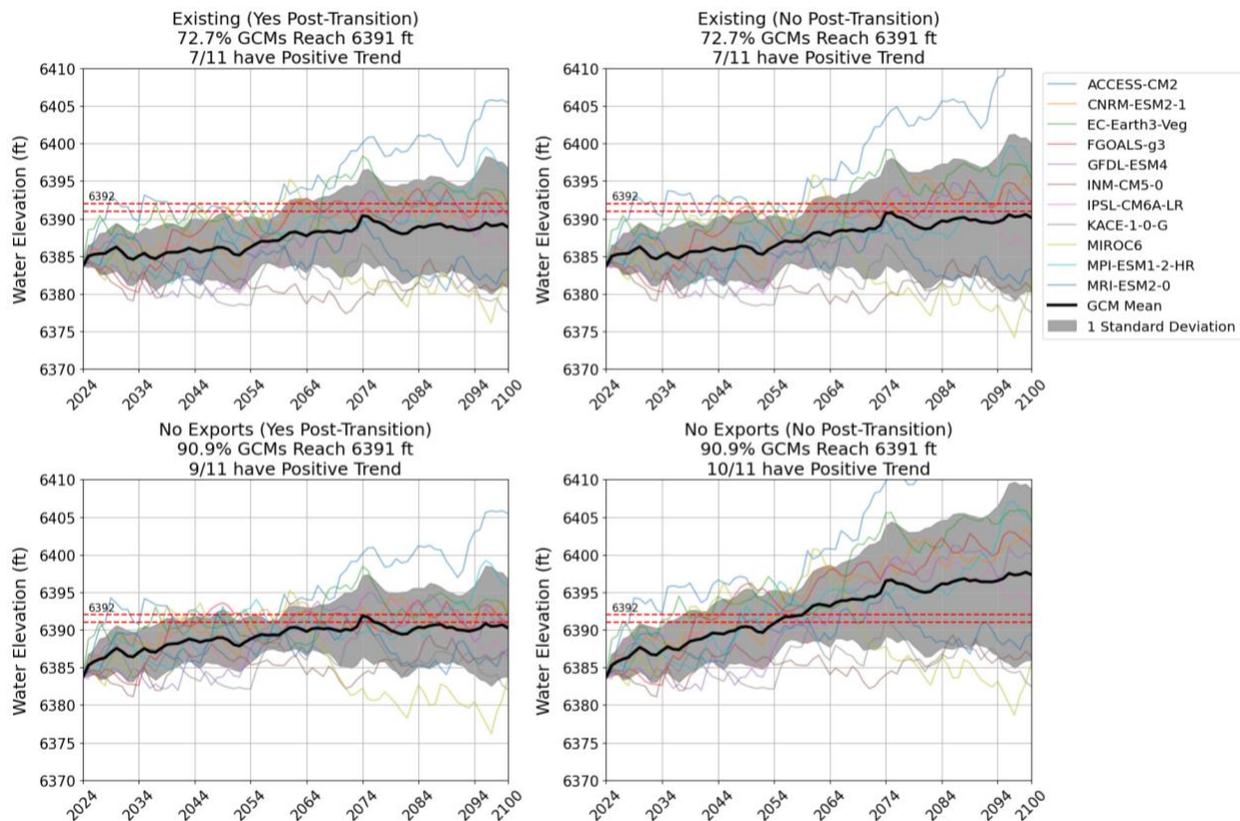


**Figure C-3.** Time-series of four sequences from the 1971 to 2020 wrapped runs for existing export criteria with post-transition rules (blue) and no exports with no post-transition exports (orange). The example start years shown here were chosen to demonstrate how Mono Lake water level responds to unique hydroclimate sequences and to allow for comparison to eSTREAM results (Mono Lake Technical Working Group, 2024).

## C.2 Additional Figures from Water Level Projections for Book-End Export Criteria

Appendix C.2 includes supplementary figures for Section 4.1.4 of the report.

### Water Level Projections for Different Export Criteria under SSP2-4.5



**Figure C-6a.** Same as **Figure 4-4** in the main report but shown for SSP2-4.5. Mono Lake water level projections for SSP2-4.5 in response to unique book-end export criteria. Individual lines in the plot with unique colors represent unique GCMs (reference legend), black solid line represents the ensemble mean (average water level from the 11 GCMs), and the grey shading represents 1 standard deviation in the water level projections. In the title of each book-end export criteria, we indicate the percent of GCMs that allow Mono Lake to reach 6,391 ft, and the number of GCMs that lead to a positive Mono Lake water level trend from 2024 to 2100.

## Water Level Projections for Different Export Criteria under SSP5-8.5

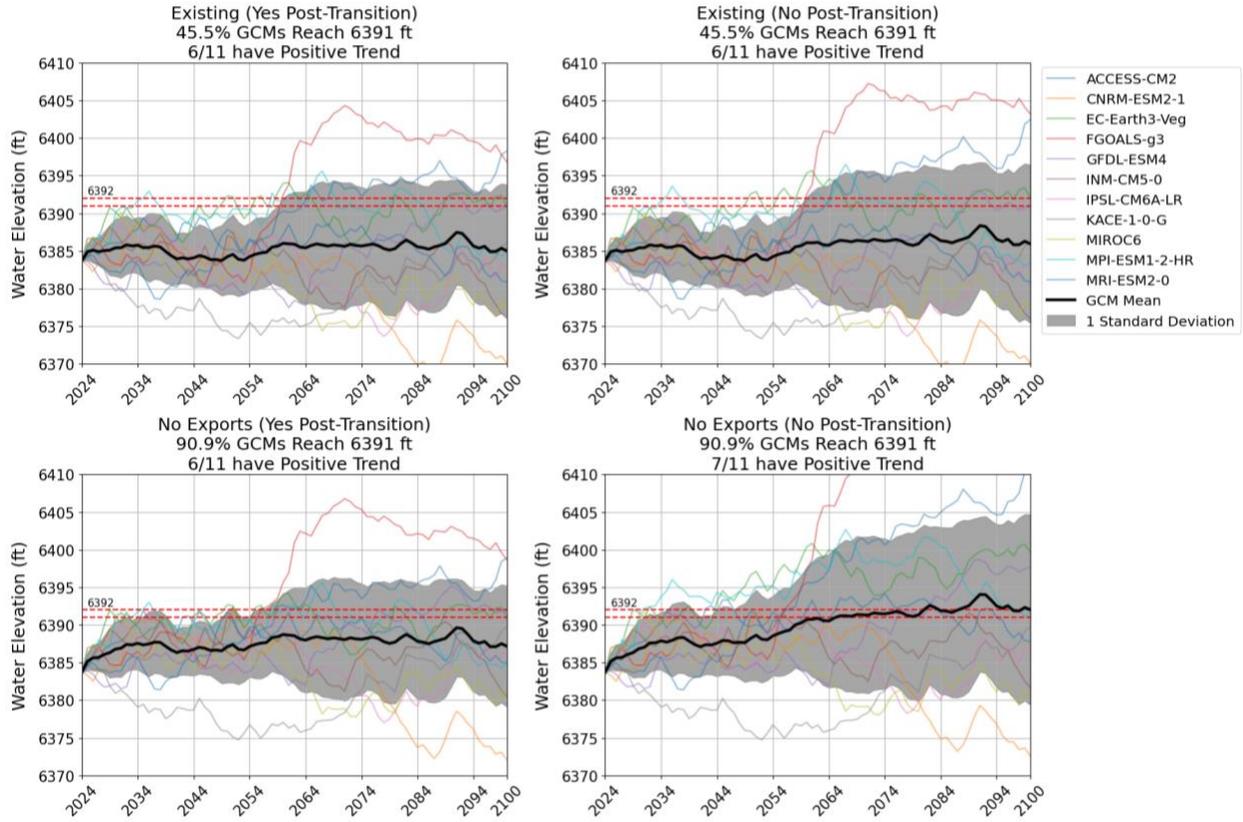
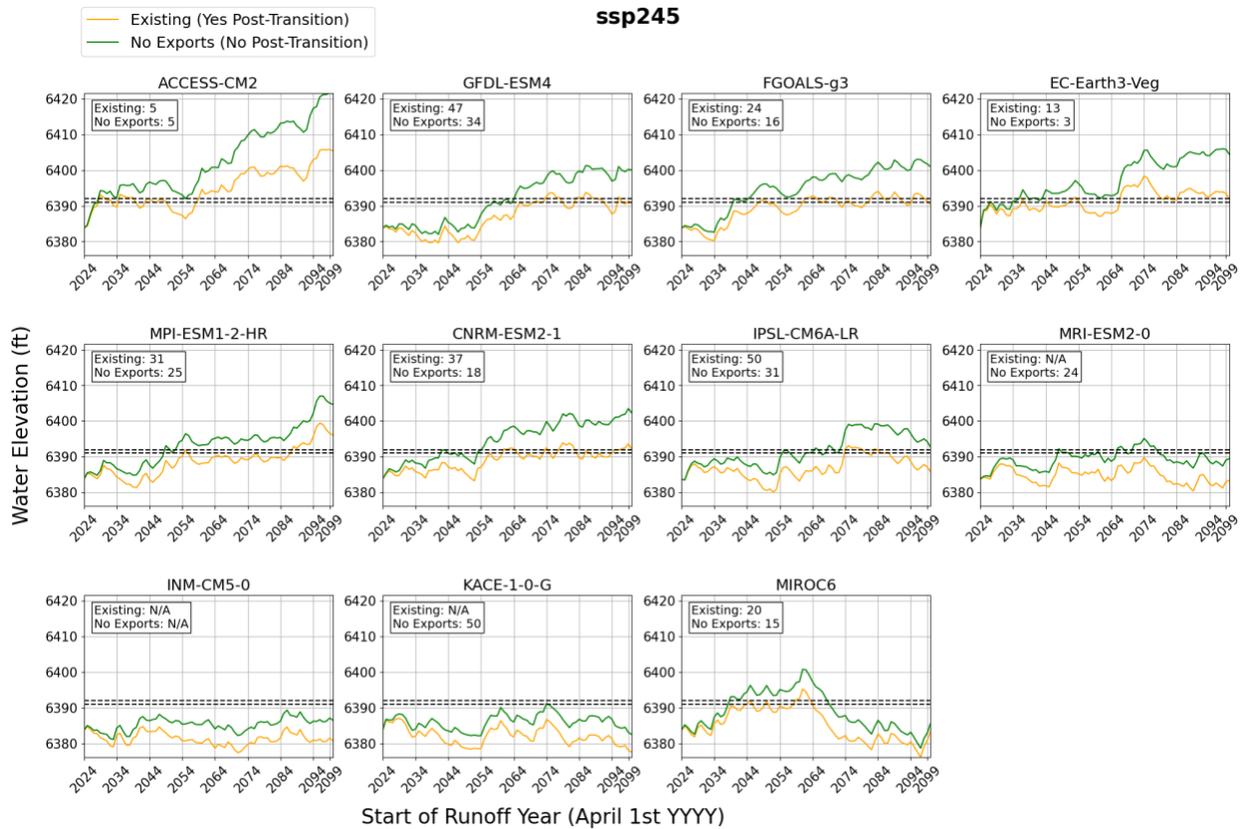


Figure C-6b. Same as Figure C-6a, but shown for SSP5-8.5.



*Figure C-7a. Mono Lake water level for the 11 GCMs under SSP2-4.5. Water levels are included for no exports with no post-transition rules (green line) and existing export criteria with post-transition rules (orange line). In the top left box of each GCM, the years to reach 6,391 ft is indicated (N/A if not reached).*

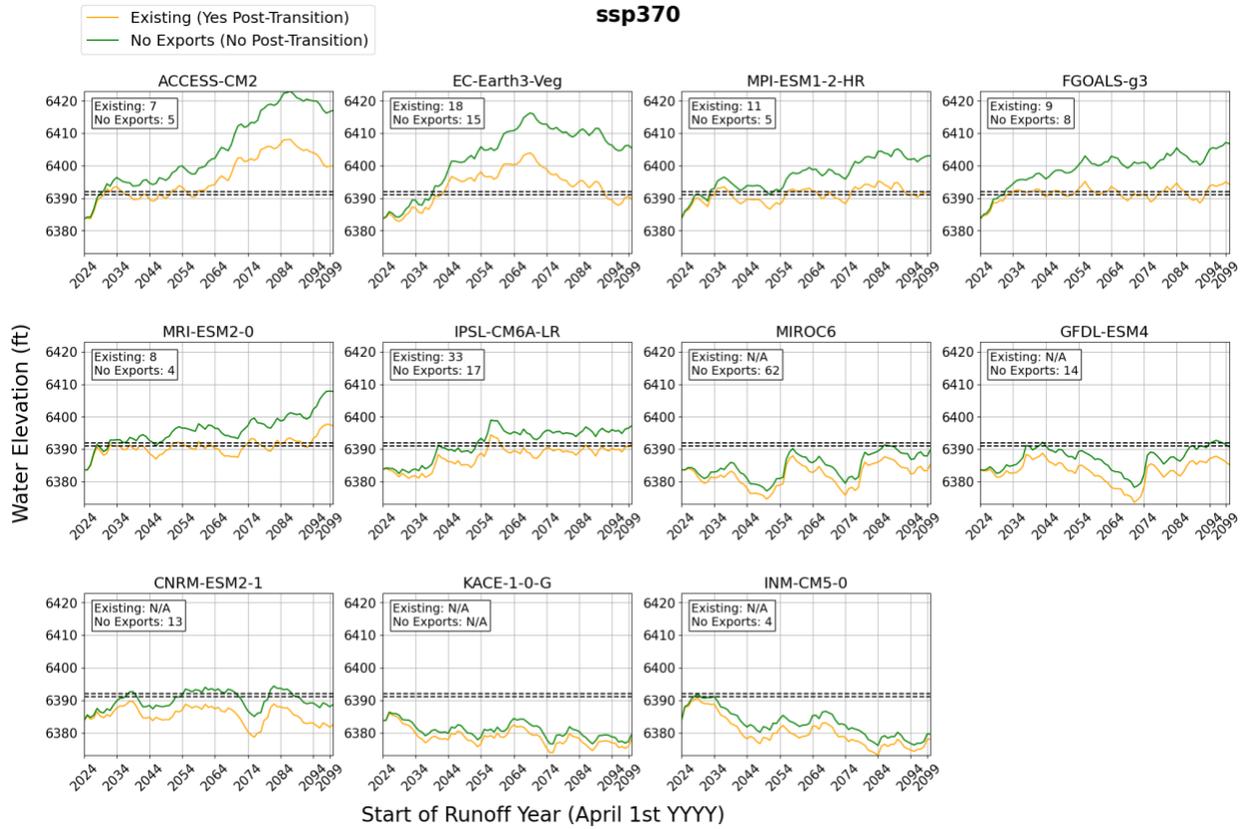


Figure C-7b. Same as Figure C-7a, but shown for SSP3-7.0.

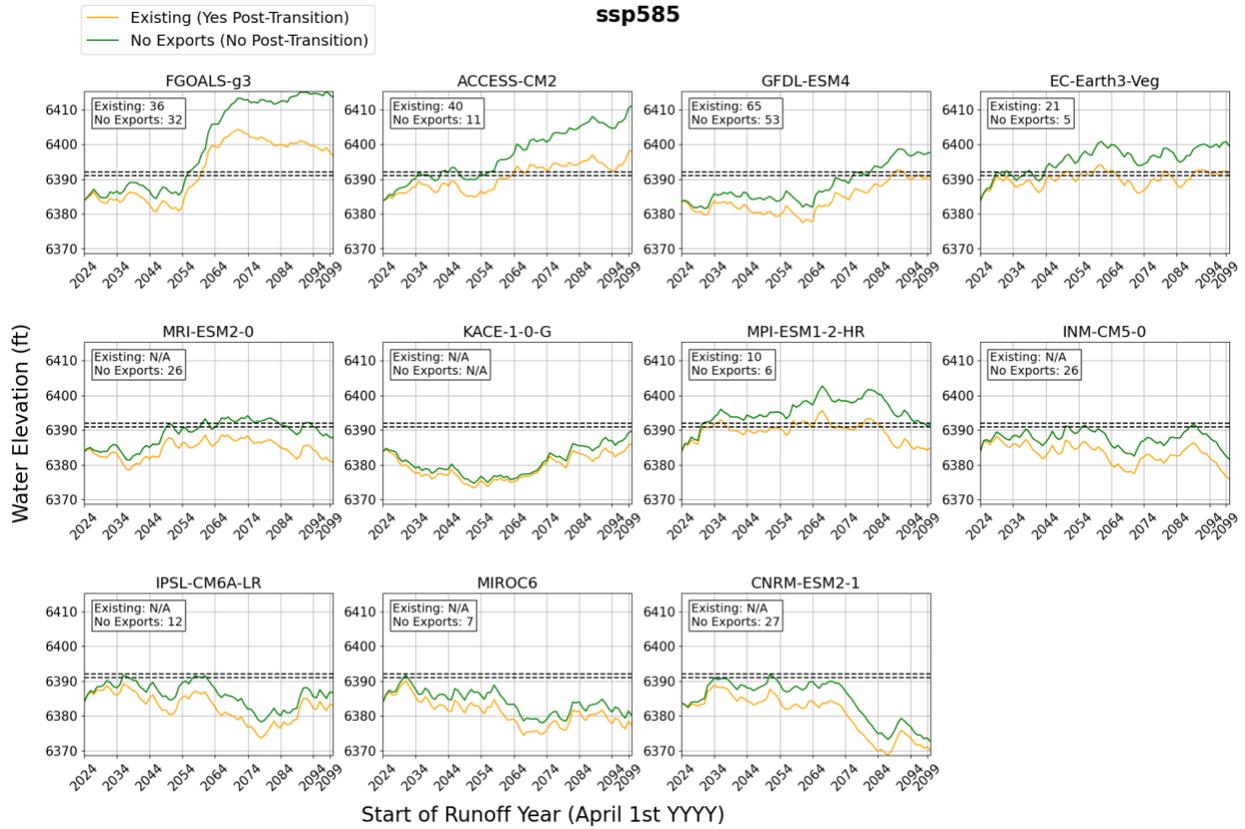
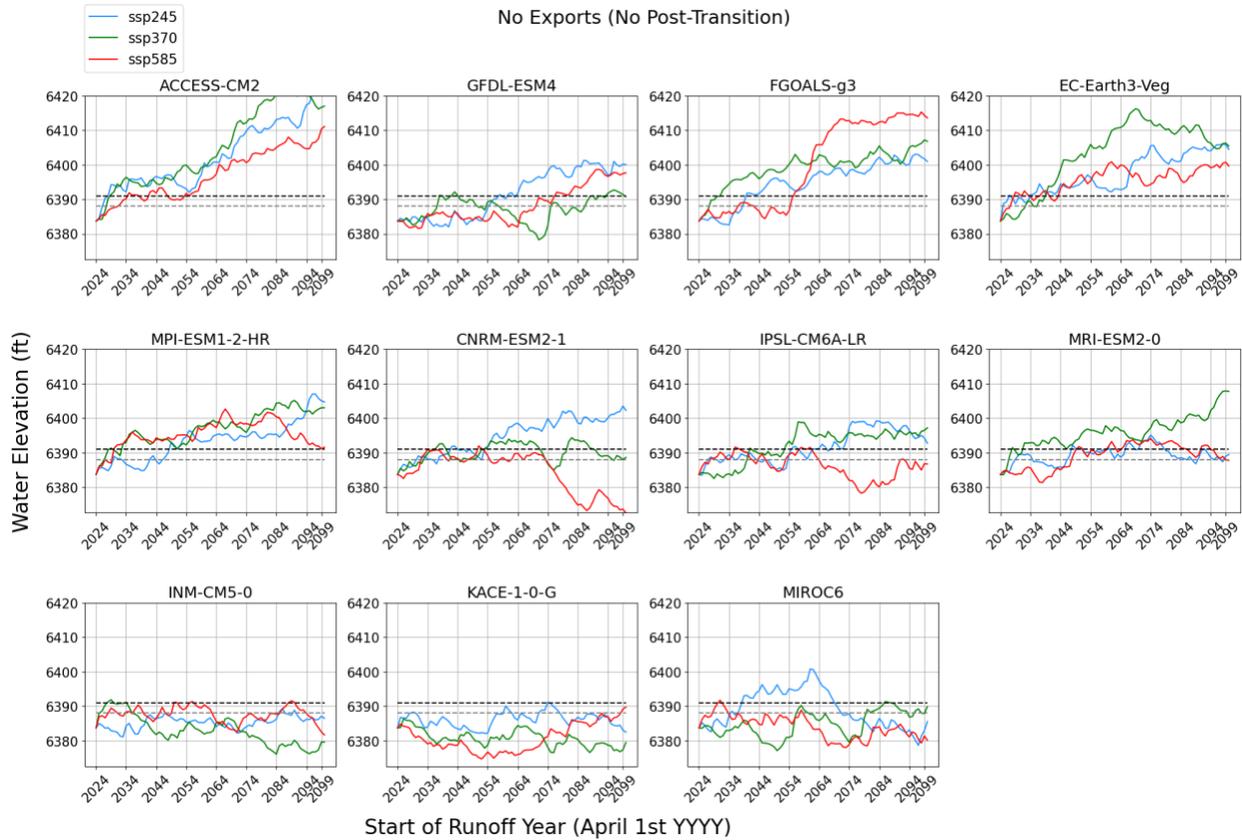


Figure C-7c. Same as Figure C-7a, but shown for SSP5-8.5.



**Figure C-8.** Comparison of the GCM ensemble mean water level projections (average from 11 GCMs) for the three unique emission scenarios (SSP2-4.5 in blue, SSP3-7.0 in green, and SSP5-8.5 in red). We show results for roughly “natural conditions” based on no exports with no post-transition rules. Generally, the highest emission scenario (SSP5-8.5) leads to lower water levels; however, this same emission scenario may show greater wetting for a few GCMs due to increases in precipitation that can occur with warmer atmospheric conditions potentially outweighing increases in evaporation.

### Likelihood of Mono Lake Above 6,391 ft Under No Exports (No Post-Transition)

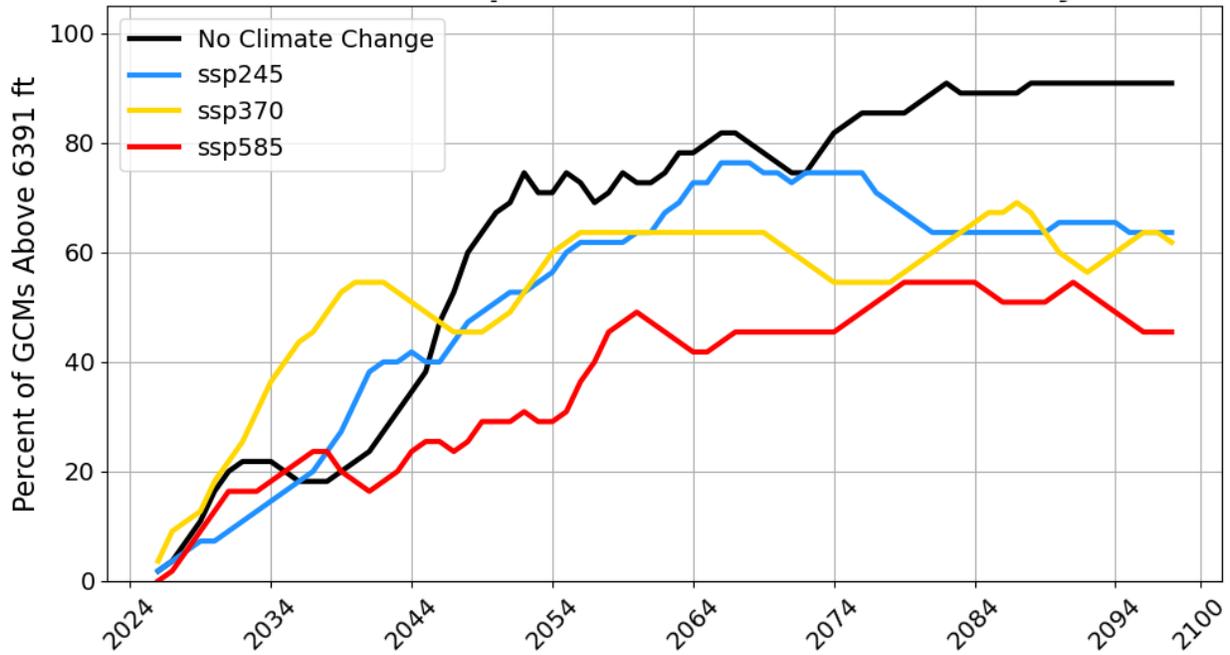


Figure C-9. Percent of GCMs that lead to Mono Lake water level at or above 6,391 ft, for No Exports (in transition and post-transition) from 2024 onward. Results are based on a 5-year centered rolling window to strengthen interpretation from climate change rather than internal variability. Black line represents simulation without climate change, while other lines represent water level response to unique emission scenarios.

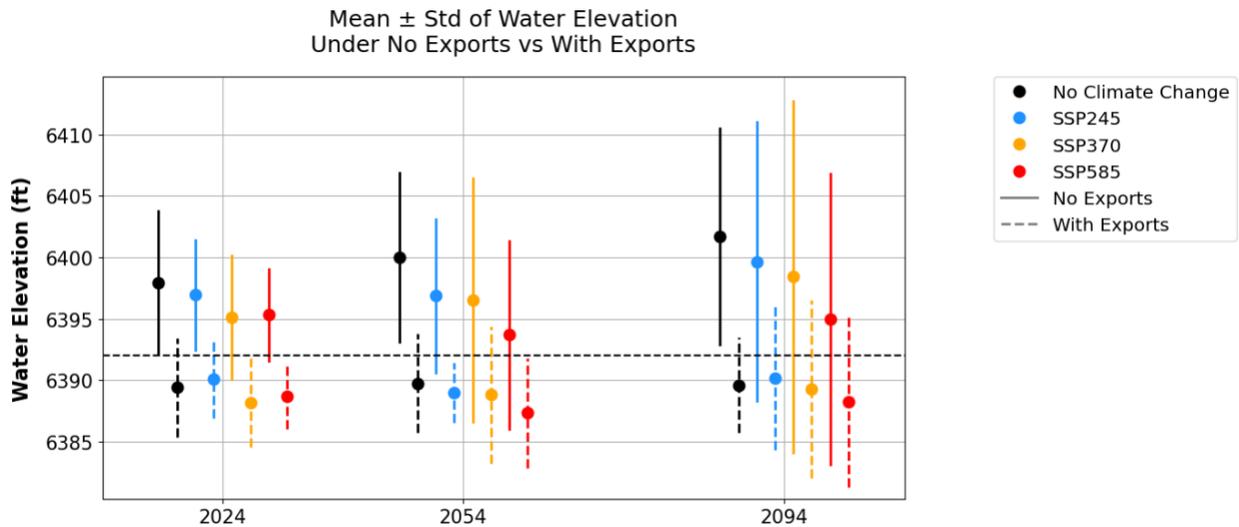
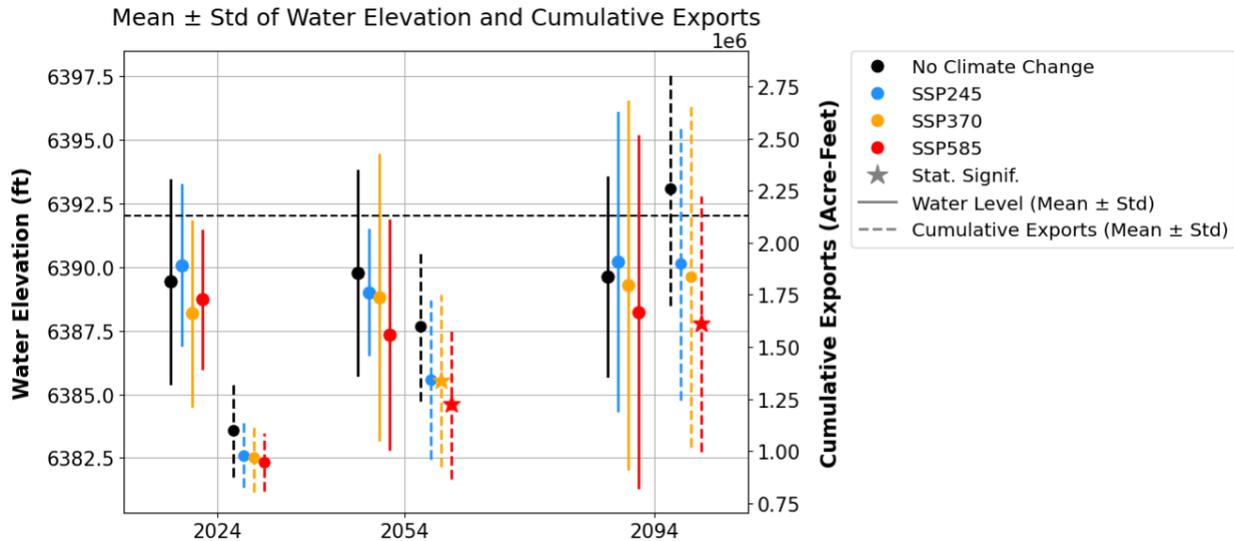


Figure C-10. Water levels resulting from emission scenarios and the simulation without climate change. Experiments start in 1955 to allow for an interpretation of overall climate change impacts and allow for assessment of present-day differences. Experiments performed for no exports (solid line) to allow for interpretation of climate change signals and the existing export

criteria (dashed lines) which modifies the climate change signal in terms of the water level. For a given year, average water level from the 10 surrounding years (e.g. for 2025 represents 2015 to 2024) are used for each GCM and experiment. Statistically significant differences occur for existing exports compared to no exports for comparisons between each scenario; however, statistically significant differences do not occur between no climate change and the SSPs. An initial water level of 6,383.7 ft was used. Horizontal dashed line is 6,392 ft.



**Figure C-11.** Water levels (solid lines) and cumulative exports (dashed) resulting from emission scenarios and the simulation without climate change. Simulation performed for the existing export criteria outlined in D-1631. Note, the effects of climate change for the existing export criteria are more apparent in terms of the impact on exports (larger reductions in the SSP water levels relative to the simulation for no climate change) relative to the water levels. Statistically significant difference indicated by star marker for the mean. Experiments start in 1955 to allow for an interpretation of overall climate change impacts and allow for assessment of present-day differences. For a given year, average water level from the 10 surrounding years (e.g. for 2025 represents 2015 to 2024) are used for each GCM and experiment. An initial water level of 6,383.7 ft was used.

## Likelihood of Mono Lake Above Different Water Levels under Various Export Criteria and Emission Scenarios

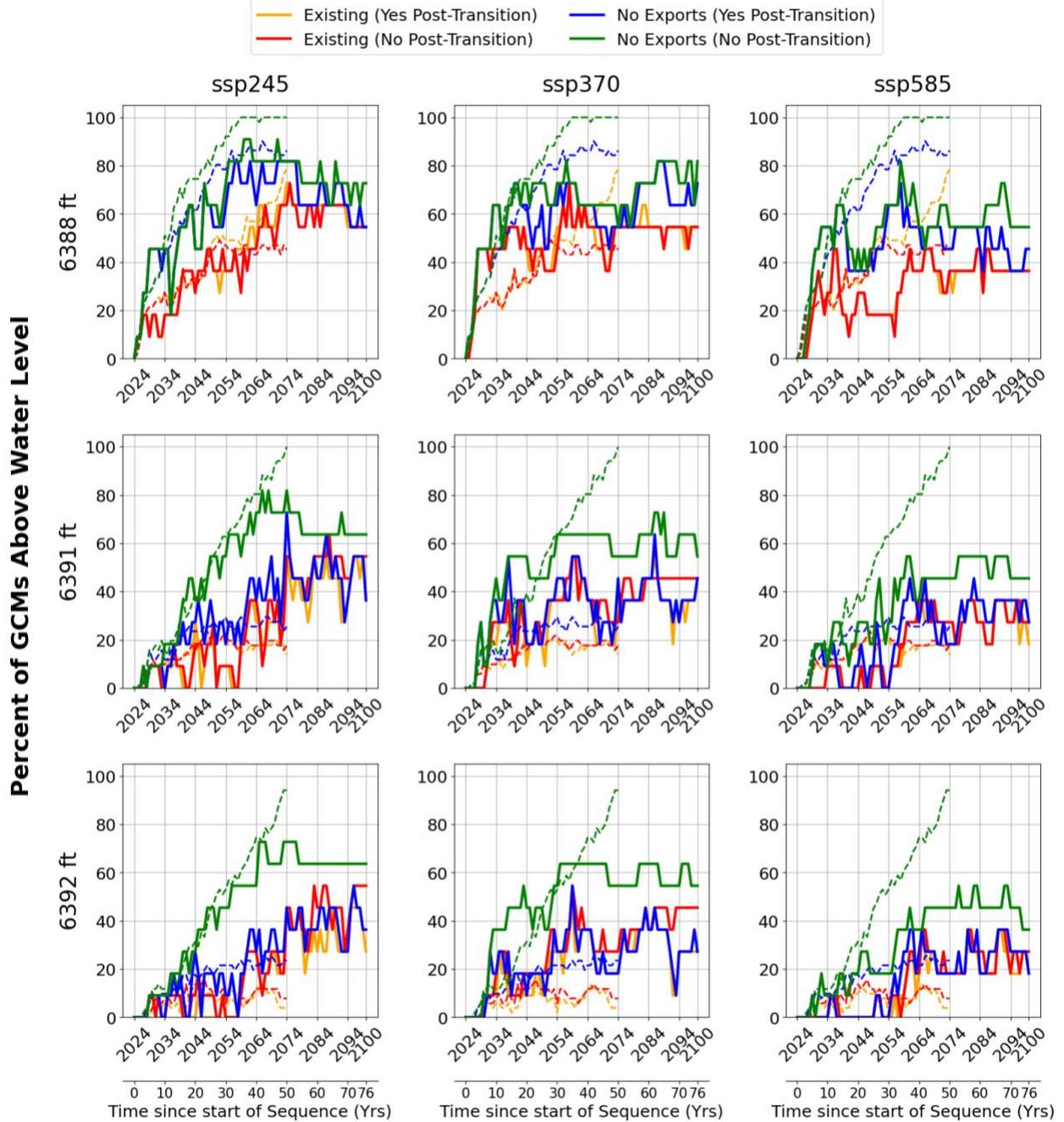
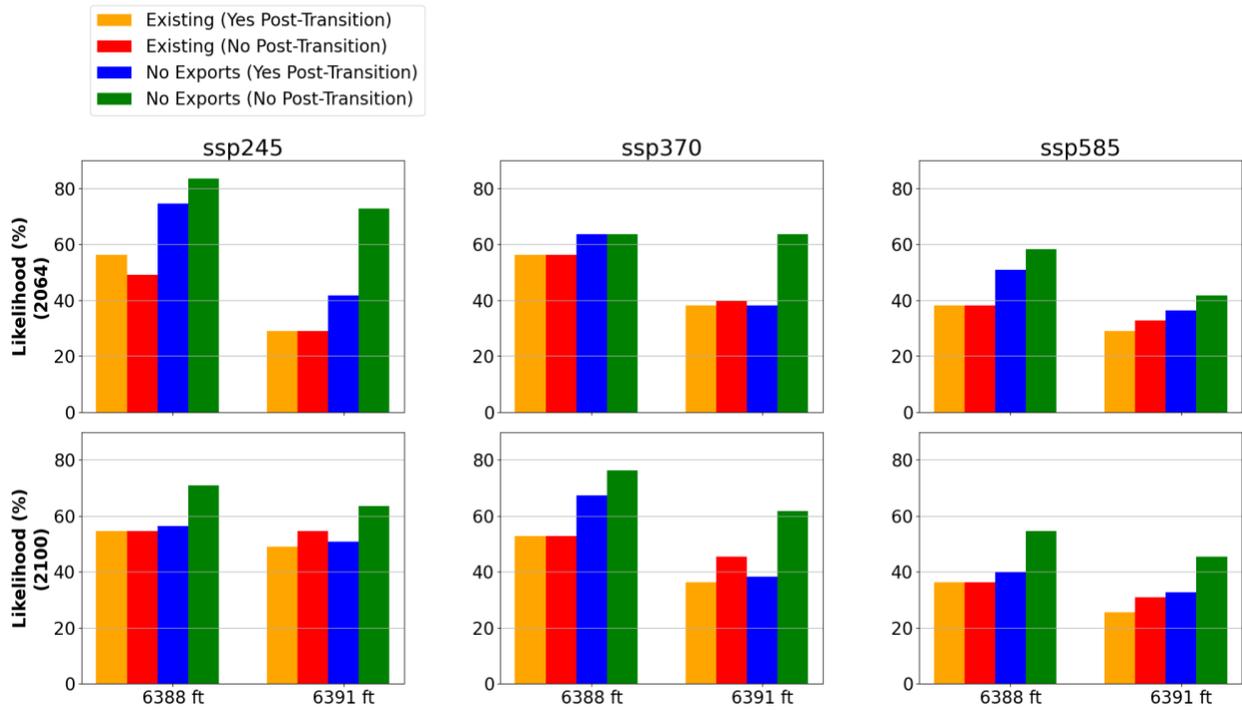
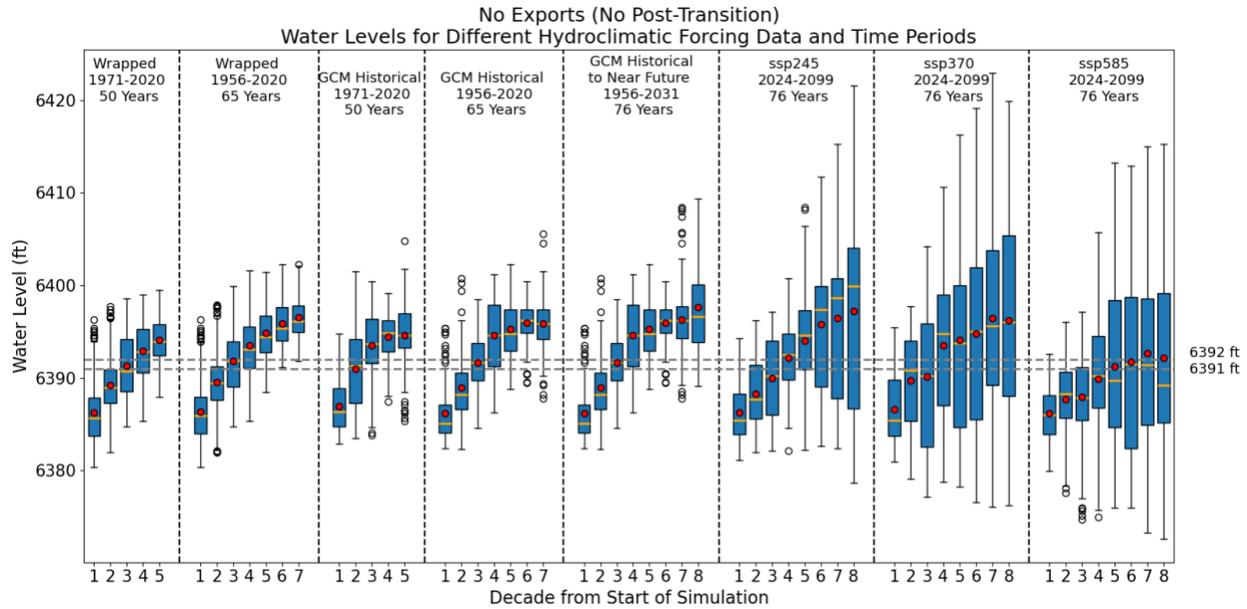


Figure C-12. Same as Figure 4-5 in the main report but shown for annual likelihoods without taking a 5-year rolling mean.

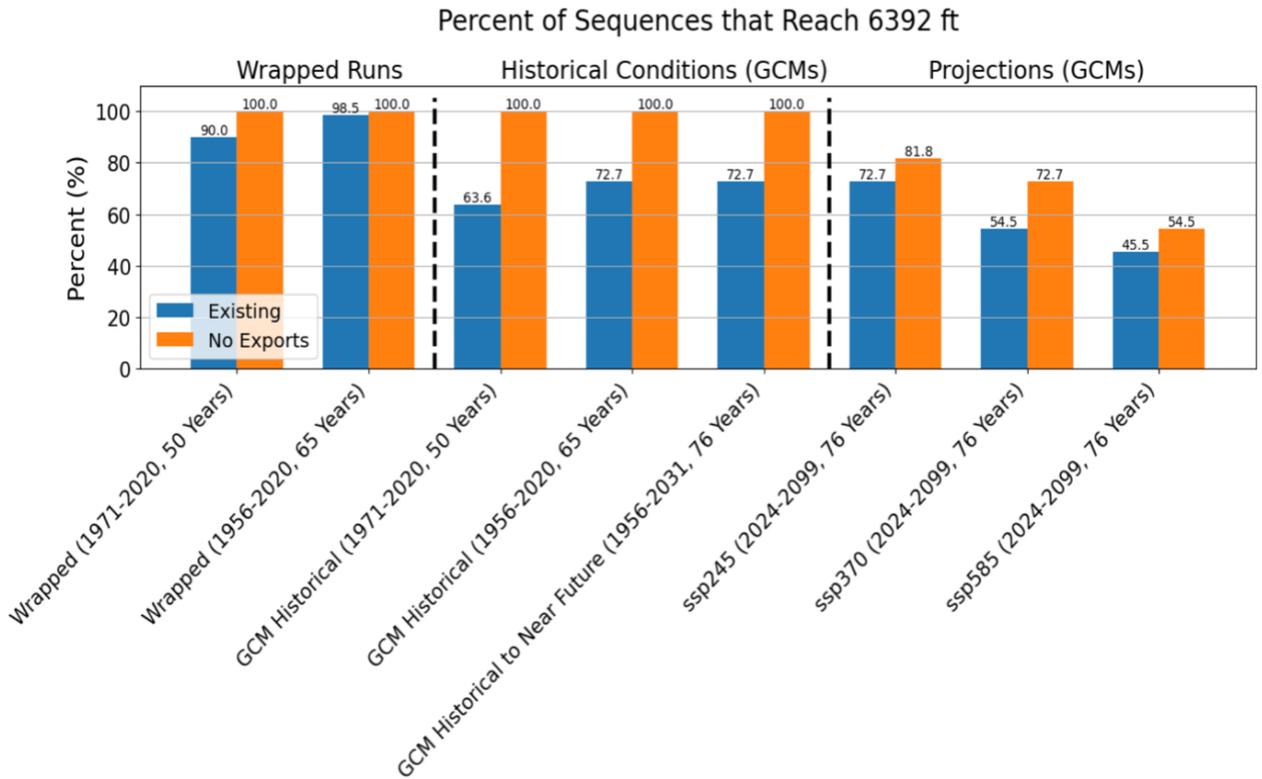
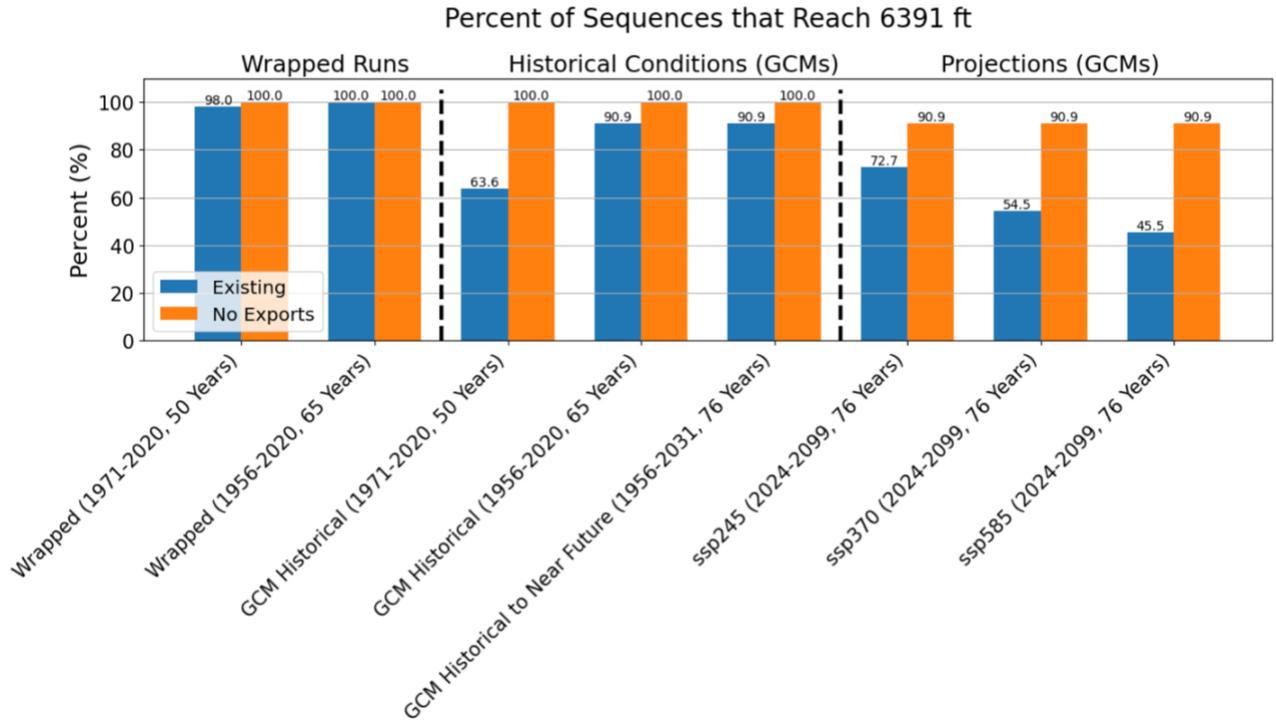
### Likelihood of being at or above Selected Water Levels in 2064 and 2100



*Figure C-13. Likelihood of Mono Lake being at or above selected water levels by 2064 (40 years from now) in top row, and by 2100 in bottom row. Analysis performed for the four existing export combinations. This is an accompanying figure for **Table 4-4** in the main report. Based on 5-year rolling mean.*



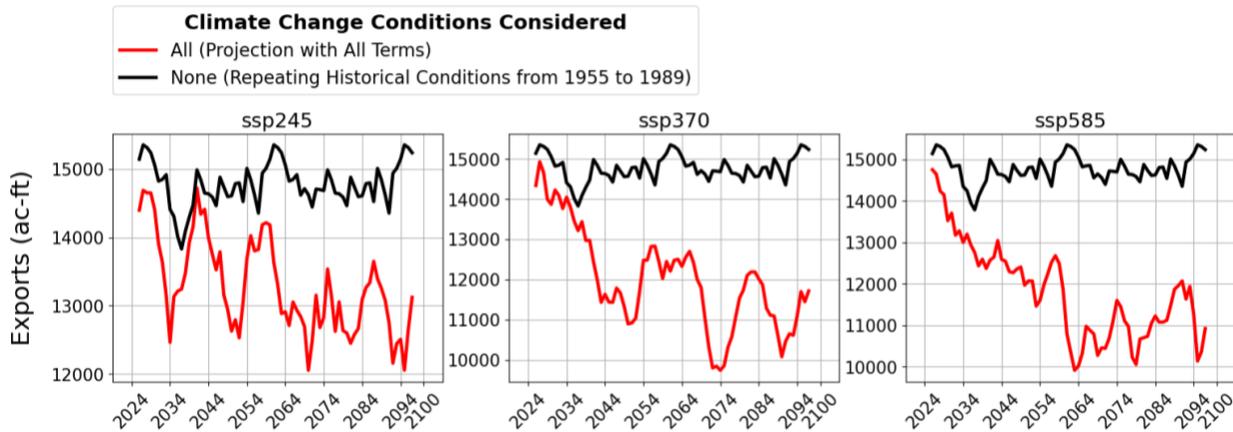
**Figure C-14.** Comparison of decadal water levels resulting from unique hydroclimate forcing datasets for the water budget model under the no exports, no post-transition export criteria. The red dot denotes the mean and orange line denotes the median. Decade 1 is the first decade and includes water levels for the first 10 years from every wrapped run or every GCM (not including the initial water level). Edges of boxplots represent the 25th and 75th percentile values, whiskers represent 1.5 times the interquartile range (IQR), and dots represent water levels that are outliers since they fall outside the 1.5 x IQR range. SSP2-4.5 can lead to a similar or even higher median and mean water level in some of the decades compared to historical conditions; however, the 25th percentile of the boxplot for this and the other SSPs have noticeably lower water levels compared to all of the historical datasets. This indicates that at least 25% of the GCMs in each SSP are consistently projecting drier future conditions with water levels below 6,391 ft.



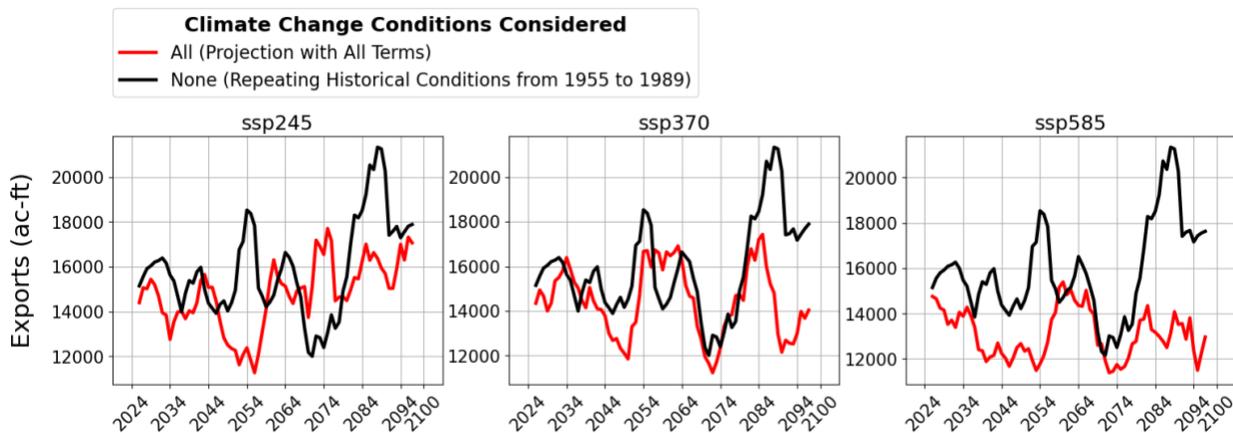
*Figure C-15. Comparison of the percent of hydroclimate sequences from the wrapped runs and percent of GCMs that reach 6,391 ft and 6,392 ft (which is an assessment of the transition water level objective). Blue represents existing export criteria with post-transition rules, and orange*

represents no exports with no post-transition rules. Generally, wrapped runs lead to a more optimistic result compared to the historical GCM assessments. For future conditions (2024 to 2100), the percentage of sequences that reach 6,391 ft or 6,392 ft is reduced for all conditions except for the existing export criteria with SSP2-4.5.

### Ensemble Mean Exports with and without Climate Change Existing Exports (No Post-Transition)



### Ensemble Mean Exports with and without Climate Change Existing Exports (Yes Post-Transition)



**Figure C-16.** Ensemble mean export volumes taken from the 11 GCM projections for each emission scenario (each column). Shown for the simulation with (red line) and without (black line) climate change. Evaluation was performed for existing export criteria (no post-transition), where transition export criteria continue to apply in the post-transition period with 16,000 ac-ft allowed above 6,391 ft (top figure). Also, shown for a simulation with Existing Exports, which includes the existing (D-1631) post-transition export criteria (bottom figure). The 5-year rolling mean in exports is shown to emphasize the overall export amounts rather than the year-to-year variability. As shown in the figure, higher exports typically occur for the No Climate Change scenario.

**Further Discussion for no post-transition rule results:** The export criteria are designed to respond to changes in lake level, creating a feedback loop that dampens the impact climate change has on

the water level. When climate change lowers the water level, exports are reduced, while the No Climate Change scenario results in higher water level, allowing for increased exports. This dampens the contrast in water level between scenarios including climate change and the No Climate Change scenario, obscuring the true climate signal.

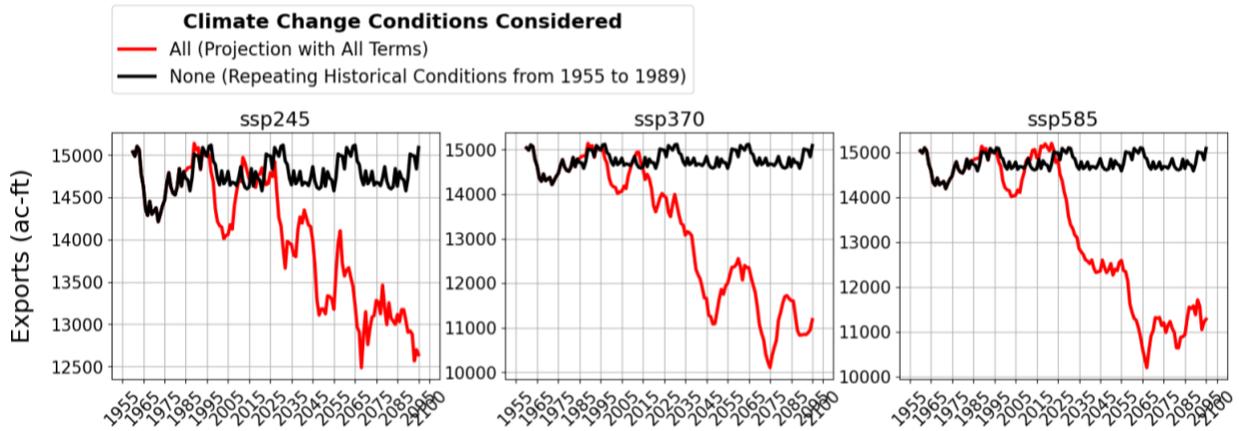
Without climate change, exports remain stable at around 15,000 ac-ft/yr. However, under climate change, exports decline steadily through the century, dropping to approximately 12,500 ac-ft/yr under SSP2-4.5, around 11,000 ac-ft under SSP3-7.0, and as low as 10,500 ac-ft under SSP5-8.5 by 2100. This steady decline reflects how reduced water availability, driven by increased evaporation, restricts exports.

The difference in export amounts between the simulation with and without climate change demonstrates that when export criteria are considered, the climate change signal is distributed between impacts on Mono Lake water level and export amounts. Criteria that allow for higher exports, like existing transition exports, can effectively balance out the water level differences between the simulation with and without climate change – hence, why the influence of climate change on Mono Lake water level was assessed for a No Export criteria in **Section 4.1.3** (e.g. **Figure 4-3**).

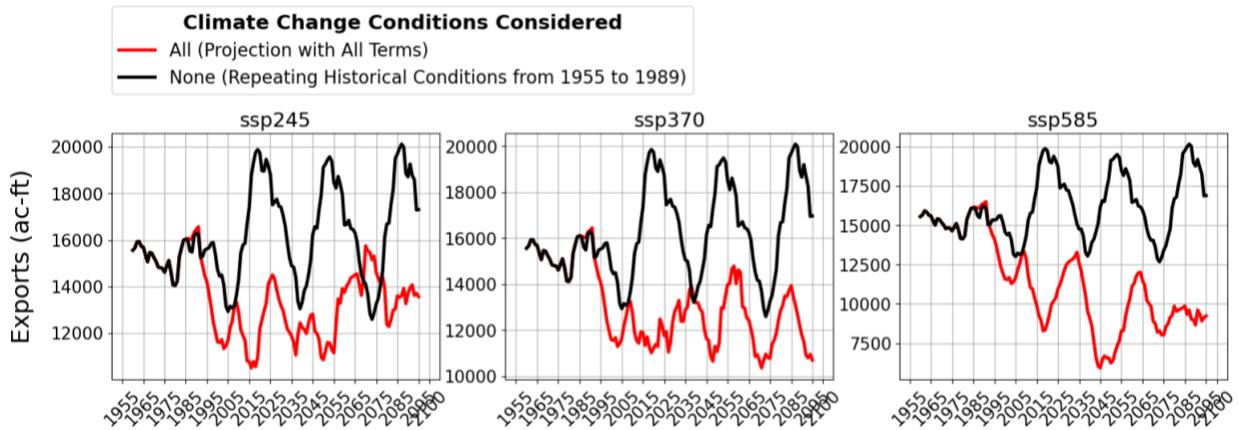
**Discussion for simulation with post-transition exports:** When post-transition criteria are in place, climate change still leads to a reduction in exports across all emission scenarios (SSP2-4.5, SSP3-7.0, SSP5-8.5), although the magnitude of this reduction is more moderate compared to an evaluation without a transition to the post-transition export criteria.

With the existing post-transition export criteria, exports with climate change (red lines) fluctuate between approximately 12,000 and 16,000 ac-ft/yr, while exports without climate change (black lines) rise over time, reaching as high as 19,000 to 20,000 ac-ft/yr by the end of the century. Greater fluctuations in the ensemble mean occur since some of the GCMs reach the post-transition period while others do not. Without the post-transition criteria, export reductions are driven directly by lower lake levels resulting from increased evaporation, making them more consistent.

## Ensemble Mean Exports with and without Climate Change Existing Exports (No Post-Transition)

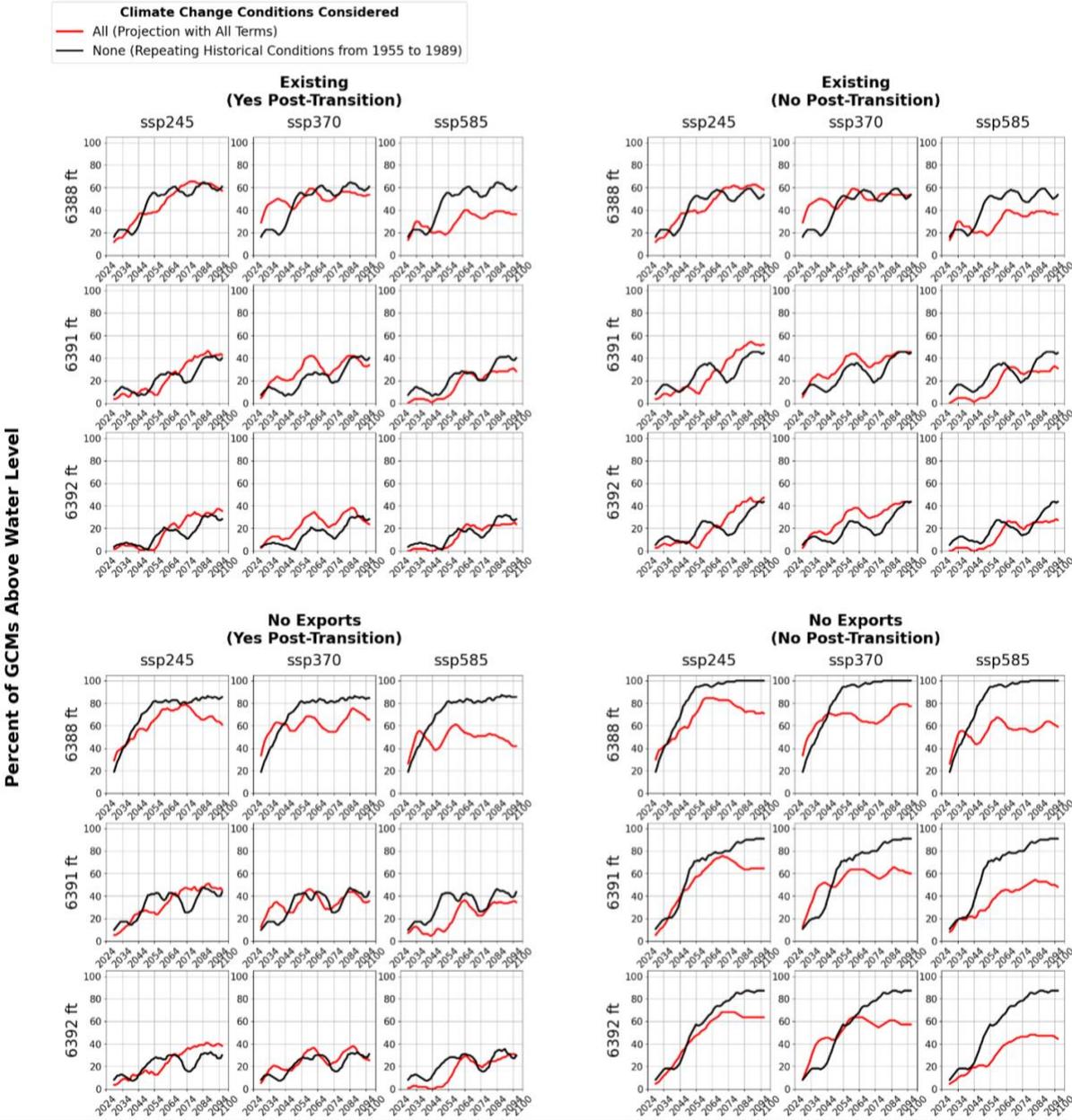


## Ensemble Mean Exports with and without Climate Change Existing Exports (Yes Post-Transition)



*Figure C-17. Same as Figure C-16 but shown for the simulation from 1955 to 2100. This demonstrates the difference in exports between a simulation with (red) and without (black) climate change for the existing transition export criteria. Top row continues existing transition export criteria even after reaching 6,391 ft, with exports of 16,000 ac-ft allowed above 6,391 ft. Bottom row includes the existing (D-1631) post-transition exports. As demonstrated, the impact of climate change can appear in exports in addition to water level differences.*

# Likelihood of Mono Lake Above Different Water Levels Under Various Export Criteria and Climate Scenarios



**Figure C-18.** Results for the simulation from 2024 to 2100 with an initial water level of 6,383.7 ft. Likelihood of Mono Lake at or above several water levels when assessed for a simulation with (red) and without (black) climate change. Each panel represents a unique book-end export criteria, with the rows of each panel representing unique water levels, and the columns representing unique SSPs. Note, only the bottom right panel, which shows results when there are no exports in the transition and post-transition period, reflects Mono Lake’s water level response to climate change in the absence of export criteria modifications to water levels. Water levels are shown as a 10-year centered rolling mean to reduce noise from inter-annual variability.

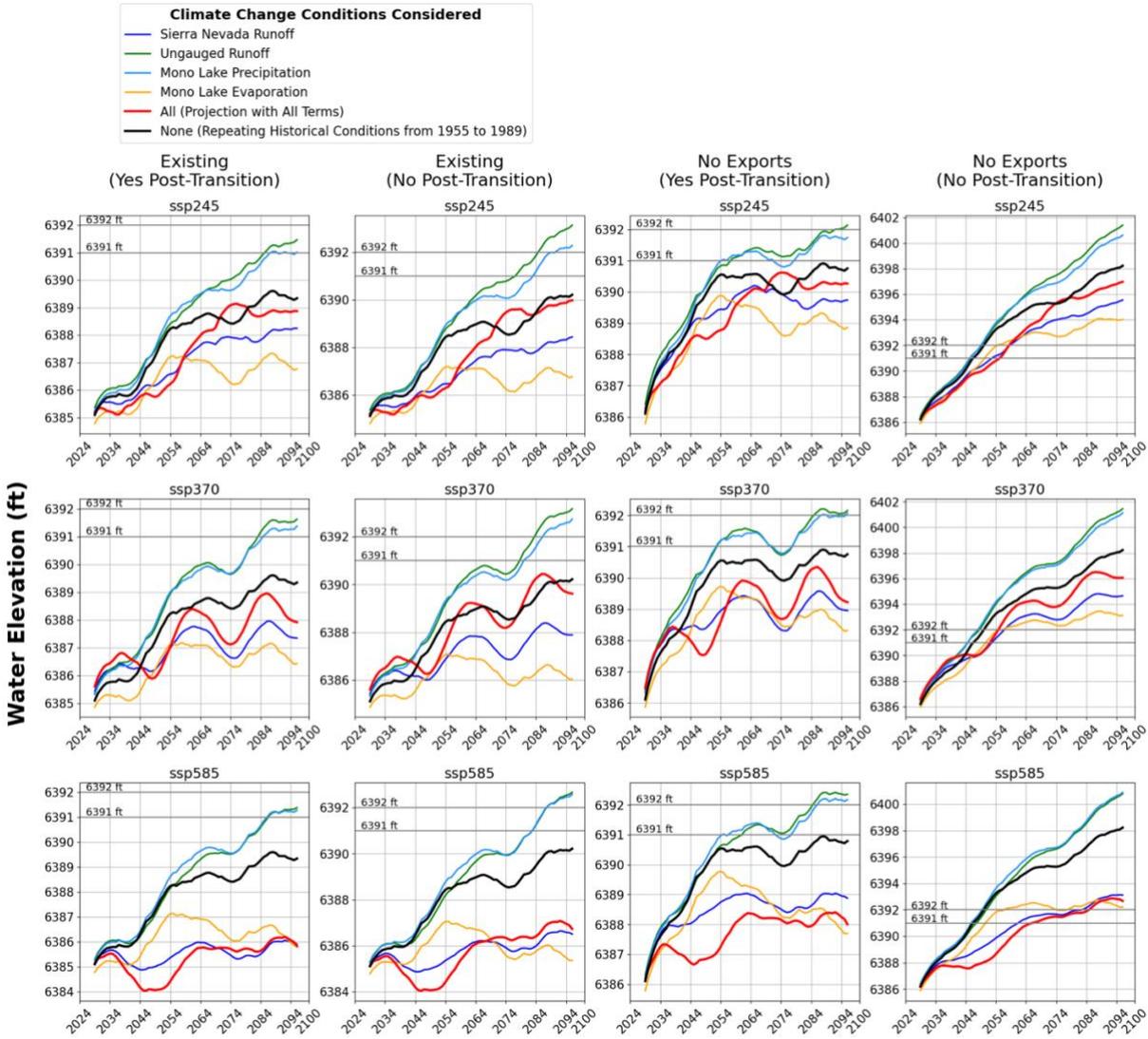
## C.3 Additional Figures for Assessment of Climate Change Impacts on Mono Lake water level

**Appendix C.3** provides additional figures and analysis that support the main findings presented in **Section 4.1.4** of the report.

To assess how climate change affects the likelihood of Mono Lake’s water level, this analysis isolates how key Mono Basin components - Sierra Nevada Runoff, Mono Lake Precipitation and Evaporation, Ungauged Runoff – affect water level projections. This builds on **Section 3.5**, which demonstrates how these components have already and may continue to change. To evaluate the influence of individual components, only one variable (e.g., Mono Lake precipitation) is allowed to change under climate projections, while all others remain fixed at their historical conditions from 1955 to 1989. For example, the 1955 to 1989 conditions are repeated from 1990 to 2024, 2025 to 2059, and so on). This period was selected as it predates clear climate change signals in the Mono Basin (see **Figure 3-2**). To simulate a no climate change simulation, all components 1955 to 1989 values are repeated in this process. The simulation with climate change follows the same procedure used throughout the report, where the GCM-simulated climate projections for every component is used.

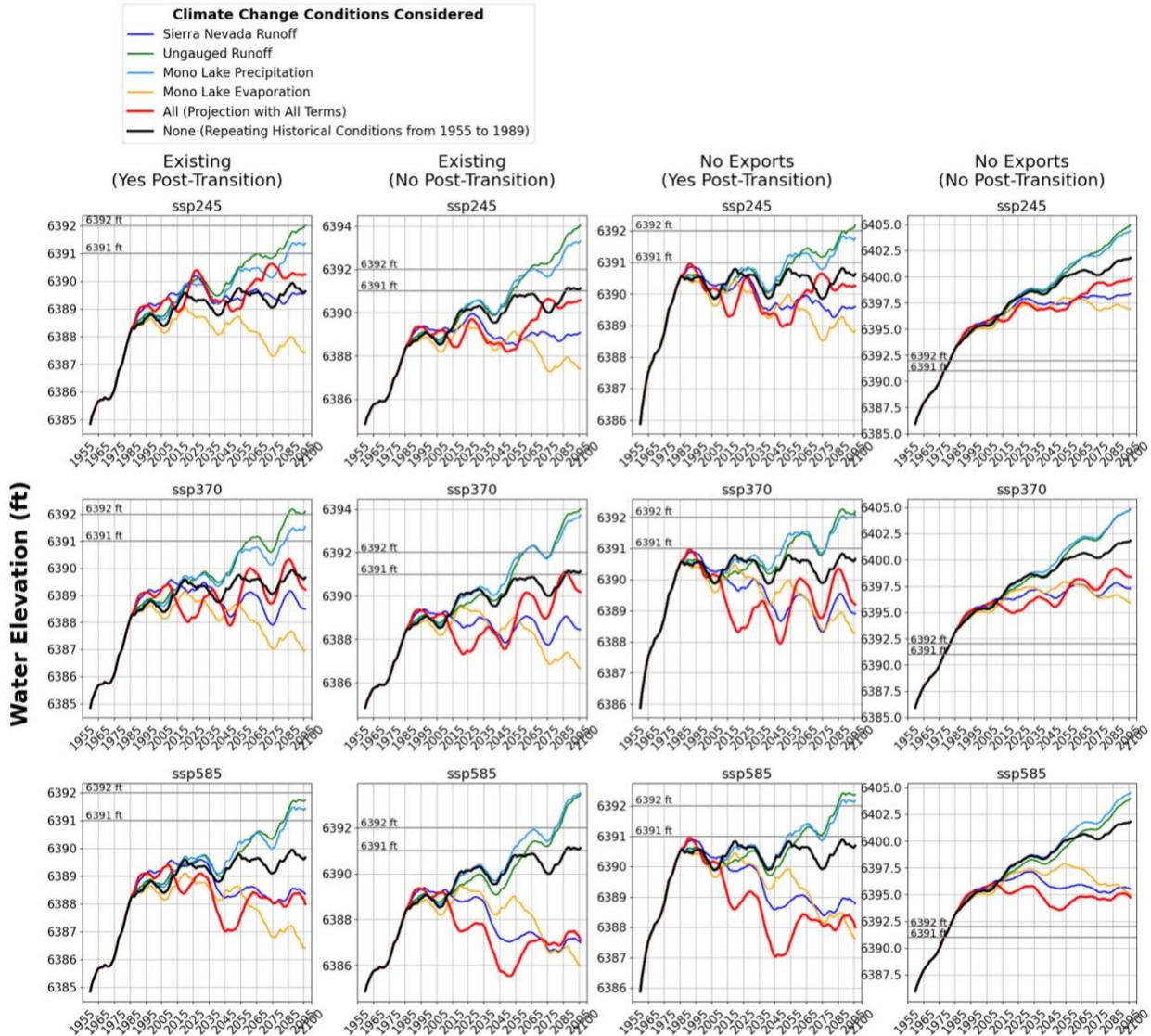
This approach clarifies the specific role of each component in shaping Mono Lake’s water level and provides deeper insight into climate change impacts on the lake’s future. This analysis is based on an initial lake water level of 6,383.7 ft (reflective of the level as of April 1, 2024) and shows the response of each of the Mono Basin components to the existing export criteria and the three emission scenarios (i.e., SSPs). While increased Sierra Nevada runoff may help mitigate losses in some cases, the overall findings suggest that climate change poses a challenge to Mono Lake’s recovery, with evaporation-driven water loss likely to outpace gains from precipitation and runoff in higher-emission futures.

## Ensemble Mean Water Level Response from 2024 to 2100 based on Projected Changes in Components of Mono Lake's Water Budget



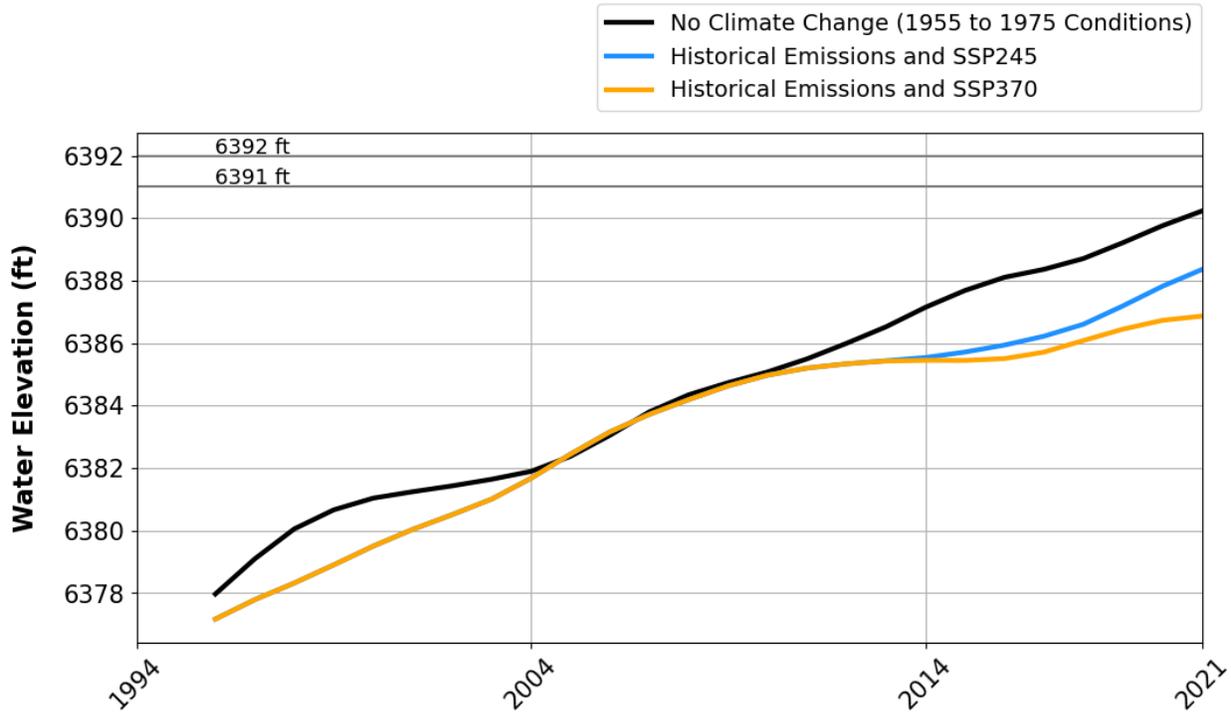
**Figure C-22.** This shows the ensemble mean water levels resulting from different experiments with (red) and without (black) climate change. Other lines represent how Mono Lake responds to changes in unique Mono Basin components (e.g. evaporation) that influence Mono Lake storage. We use a 10-year centered rolling mean (e.g. 2095 based on average from 2090 to 2099) to reduce year-to-year variability. Each row represents a different SSP, and each column represents a different book-end export criteria. Simulations were performed from 2024 to 2100 with a 6,383.7 ft initial water level.

## Ensemble Mean Water Level Response from 1955 to 2100 based on Projected Changes in Components of Mono Lake's Water Budget



*Figure C-23. Same as Figure C-22, but shown for a simulation that starts in 1955 and ends in 2100. Same initial water level as 2024 was used, but the simulation allows for an assessment of how historical climate change has possibly already had an influence on Mono Lake water level. Based on no exports and SSP2-4.5, climate change has had an estimated impact on Mono Lake water level of roughly 0.9 ft for present-day conditions. As outlined in the main report, assessments of climate change impacts on Mono Lake's water level should be conducted under a no export criteria, since allowing exports distributes the effects of climate change between water level and water exports.*

### Ensemble Mean Water Levels for Mono Lake Sensitivity to Climate Change (No Exports)



**Figure C-24.** This assessment evaluates how climate change has impacted Mono Lake’s recovery from 1994 to 2024. This was performed by comparing Mono Lake recovery with estimates of climate change that has occurred during the 1994 to 2024 time-period (orange and blue lines), and Mono Lake recovery under a climatology representing 1955 to 1975 conditions (black line). Simulations were performed with an initial water level condition representative of 1994 (6375.1 ft) and no exports. The 11 GCMs were simulated with their 1955 to 1975 conditions, and their 1994 to 2014 conditions (where SSP2-4.5 and SSP3-7.0 were used for 2014 to 2024 since historical emissions are only available until 2014, and observed trends fall roughly between these two emission scenarios). The resulting ensemble mean is shown, with a 3-year rolling window to reduce year-to-year variations from internal variability. The difference between the simulations with climate change and no climate change (reflective of 1955 to 1975 conditions) indicate that climate change reduced Mono Lake water level by roughly 2.6 ft during the 1994 to 2024 time-period; however, this estimate is associated with a standard deviation of 6.0 ft and roughly 2/3rds of the GCMs indicating climate change has led to a decline in Mono Lake’s water level, with the remainder of GCMs likely being sensitive to internal variability.

## D. Appendix D (Supplement to Section 4.2 of Main Report)

**Appendix D** contains supplementary figures for **Section 4.2** of the main report. This includes additional figures that were developed to visualize how different transition and post-transition export criteria influence Mono Lake's water level, when including climate change. Unless stated otherwise, all figures begin in 2024 with a corresponding April 1<sup>st</sup> 2024 initial water level condition.

Many of the figures presented in this appendix were developed in response to feedback provided by the Mono Lake Technical Working Group regarding additional figures of interest. Main findings are discussed in the main report. The figures provided here, which include detailed information associated with several alternatives, are intended for a technical audience.

*Table D-1. Dynamic export criteria conditions associated with U3 that are applied for the first two shifts made to the initial export criteria defined in Table 4-6. These shifts are applied every 10 years and include a 10% reduction in exports and a 1 ft shift in the water level thresholds. These modifications are made for all water levels below 6,391 ft and dynamic shifts in export criteria stop once a water level of 6,391 ft is reached.*

**Dynamic Shift Applied after First 10 Years if 6,391 ft not reached**

<b>Water Level / RYT</b>	<b>Dry</b>	<b>Dry-Normal</b>	<b>Normal</b>	<b>Wet-Normal</b>	<b>Wet</b>	<b>Extreme-Wet</b>
<b>≤6376–6377</b>	0.0	0.0	0.0	0.0	0.0	0.0
<b>6378–6380</b>	3600.0	3600.0	3600.0	0.0	0.0	0.0
<b>6381–6386</b>	5400.0	5400.0	5400.0	0.0	0.0	0.0
<b>6387–6390</b>	9000.0	9000.0	9000.0	0.0	0.0	0.0
<b>6391–6392</b>	12000.0	12000.0	12000.0	0.0	0.0	0.0
<b>6393–6394</b>	16000.0	16000.0	16000.0	8000.0	8000.0	0.0
<b>6395–6410</b>	inf	inf	inf	10000.0	10000.0	0.0

**Dynamic Shift Applied 20 Years from start of simulation if 6,391 ft not reached**

<b>Water Level / RYT</b>	<b>Dry</b>	<b>Dry-Normal</b>	<b>Normal</b>	<b>Wet-Normal</b>	<b>Wet</b>	<b>Extreme-Wet</b>
<b>≤6376–6378</b>	0.0	0.0	0.0	0.0	0.0	0.0
<b>6379–6381</b>	3240.0	3240.0	3240.0	0.0	0.0	0.0
<b>6382–6387</b>	4860.0	4860.0	4860.0	0.0	0.0	0.0
<b>6388–6390</b>	8100.0	8100.0	8100.0	0.0	0.0	0.0
<b>6391–6392</b>	12000.0	12000.0	12000.0	0.0	0.0	0.0
<b>6393–6394</b>	16000.0	16000.0	16000.0	8000.0	8000.0	0.0
<b>6395–6410</b>	inf	inf	inf	10000.0	10000.0	0.0

*Table D-2. Dynamic export criteria conditions associated with U4 that are applied for the first shift made to the initial export criteria defined in Table 4-6. Maximum of 20% reduction in exports are applied at lower water levels down to a 0% reduction at 6,391 ft every 5 years. Dynamic shifts in export criteria stop once a water level of 6,391 ft is reached. Note, export criteria for the last row continues to apply past the last water level defined (only applies if no post-transition condition is applied).*

**Dynamic Shift Applied after First 5 Years if 6,391 ft not reached**

<b>Water Level / RYT</b>	<b>Dry</b>	<b>Dry-Normal</b>	<b>Normal</b>	<b>Wet-Normal</b>	<b>Wet</b>	<b>Extreme-Wet</b>
<b>≤6376</b>	0.0	0.0	0.0	0.0	0.0	0.0
<b>6377</b>	3200.0	3200.0	3200.0	0.0	0.0	0.0
<b>6378</b>	3354.0	3354.0	3354.0	0.0	0.0	0.0
<b>6379</b>	3479.0	3479.0	3479.0	0.0	0.0	0.0
<b>6380</b>	5369.0	5369.0	5369.0	0.0	0.0	0.0
<b>6381</b>	5491.0	5491.0	5491.0	0.0	0.0	0.0
<b>6382</b>	5589.0	5589.0	5589.0	0.0	0.0	0.0
<b>6383</b>	5668.0	5668.0	5668.0	0.0	0.0	0.0
<b>6384</b>	5732.0	5732.0	5732.0	0.0	0.0	0.0
<b>6385</b>	5784.0	5784.0	5784.0	0.0	0.0	0.0
<b>6386</b>	9709.0	9709.0	9709.0	0.0	0.0	0.0
<b>6387</b>	9765.0	9765.0	9765.0	0.0	0.0	0.0
<b>6388</b>	9811.0	9811.0	9811.0	0.0	0.0	0.0
<b>6389</b>	9847.0	9847.0	9847.0	0.0	0.0	0.0
<b>6390</b>	9877.0	9877.0	9877.0	0.0	0.0	0.0
<b>6391–6392</b>	12000.0	12000.0	12000.0	0.0	0.0	0.0
<b>6393–6394</b>	16000.0	16000.0	16000.0	8000.0	8000.0	0.0
<b>6395</b>	inf	inf	inf	10000.0	10000.0	0.0

*Table D-3. The user-defined post-transition rule referred to as PT1. This allows for a gradient of increasing exports at higher water levels and greater exports for drier year types.*

<b>Water Level / RYT</b>	<b>Dry</b>	<b>Dry-Normal</b>	<b>Normal</b>	<b>Wet-Normal</b>	<b>Wet</b>	<b>Extreme-Wet</b>
<b>≤6387</b>	0.0	0.0	0.0	0.0	0.0	0.0
<b>6388–6390</b>	4500.0	4500.0	4500.0	0.0	0.0	0.0
<b>6391–6392</b>	10000.0	10000.0	10000.0	0.0	0.0	0.0
<b>6393–6394</b>	16000.0	16000.0	16000.0	4500.0	4500.0	0.0
<b>6395</b>	inf	inf	inf	16000.0	8000.0	0.0

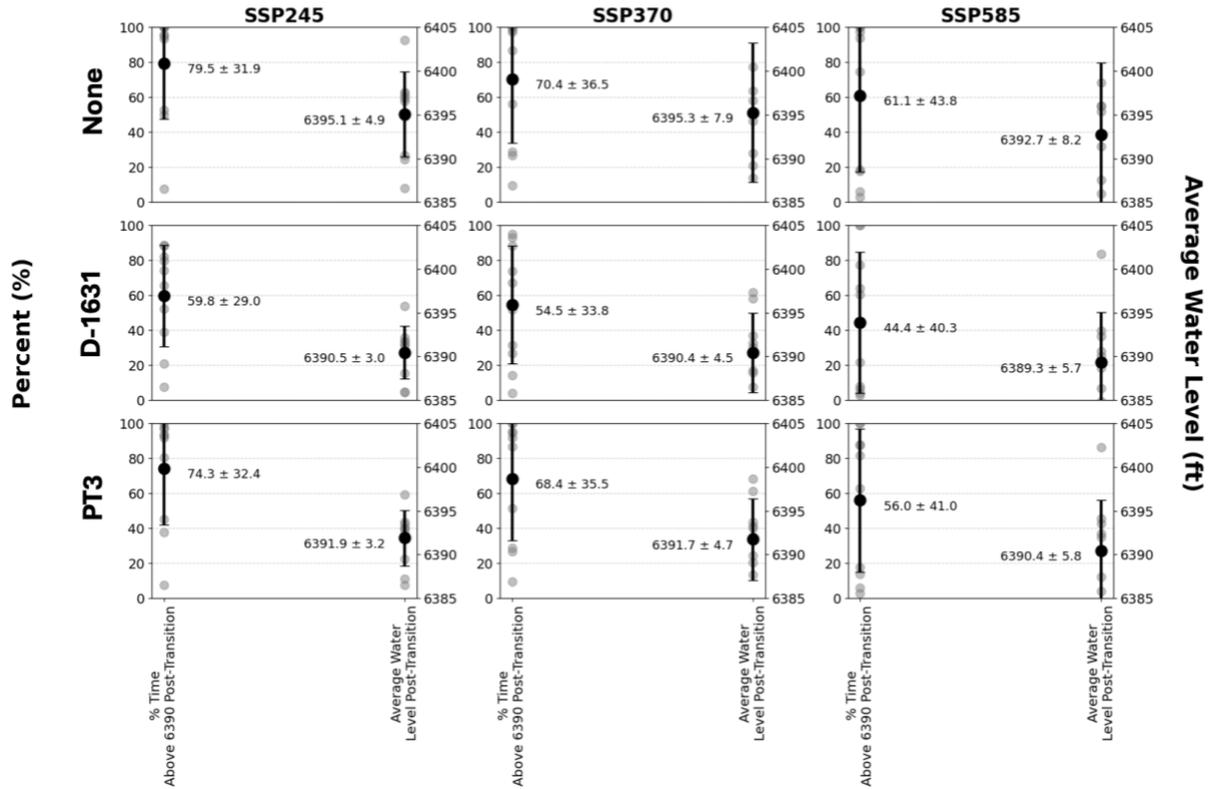
*Table D-4. The user-defined post-transition rule referred to as PT2.*

<b>Water Level / RYT</b>	<b>Dry</b>	<b>Dry-Normal</b>	<b>Normal</b>	<b>Wet-Normal</b>	<b>Wet</b>	<b>Extreme-Wet</b>
<b>≤6387–6390</b>	0.0	0.0	0.0	0.0	0.0	0.0
<b>6391–6392</b>	4500.0	4500.0	4500.0	0.0	0.0	0.0
<b>6393</b>	20000.0	20000.0	20000.0	16000.0	8000.0	4500.0

*Table D-5. The user-defined post-transition rule referred to as PT4.*

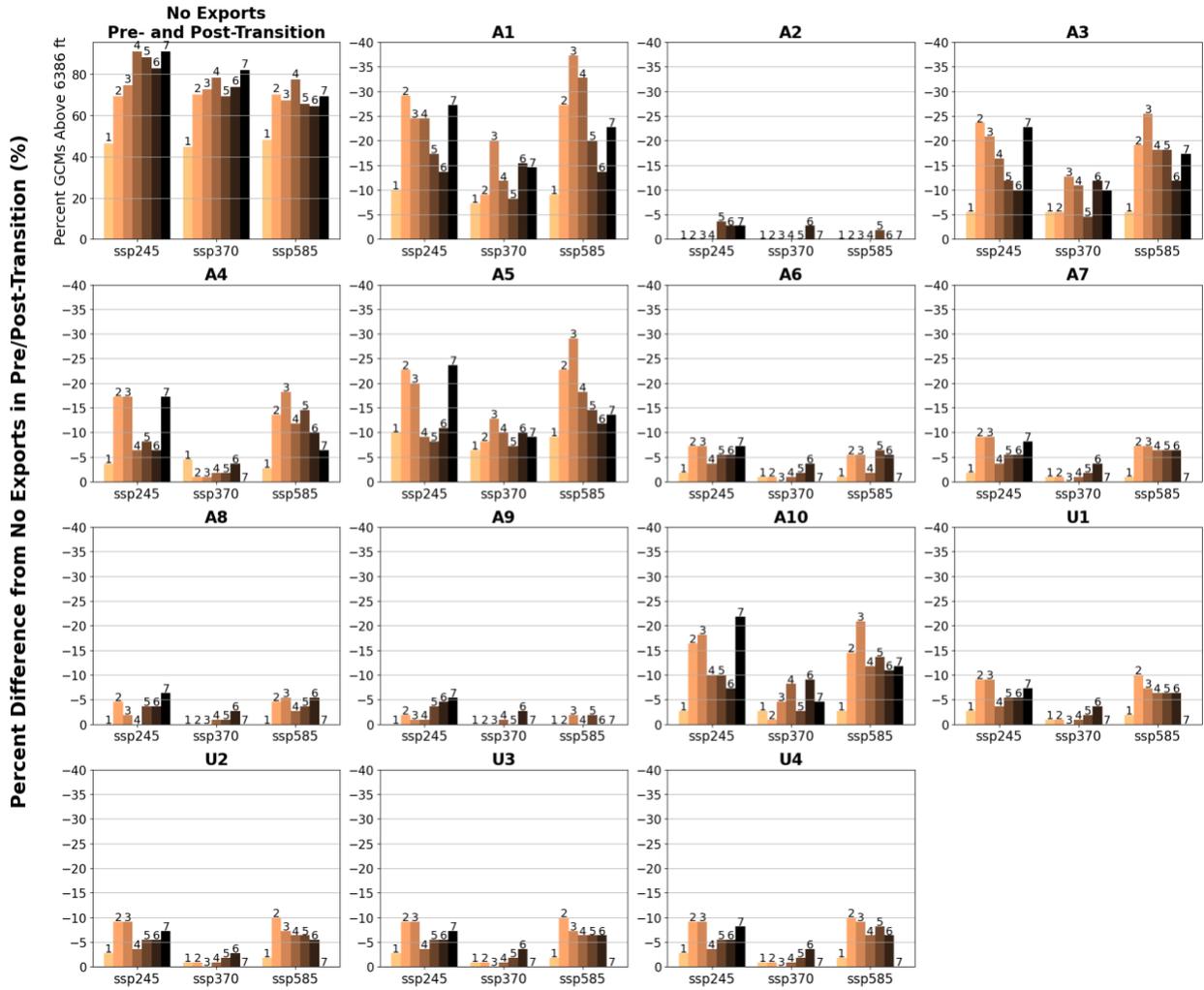
<b>Water Level / RYT</b>	<b>Dry</b>	<b>Dry-Normal</b>	<b>Normal</b>	<b>Wet-Normal</b>	<b>Wet</b>	<b>Extreme-Wet</b>
<b>≤6387–6390</b>	0.0	0.0	0.0	0.0	0.0	0.0
<b>6391</b>	4500.0	4500.0	4500.0	0.0	0.0	0.0
<b>6392</b>	inf	inf	inf	inf	inf	inf

## Post-Transition Export Criteria Performance



*Figure D-1. Post-Transition performance. Assessed using only post-transition period results after the transition with no exports (A2) reaches 6,391 ft for each GCM. Each row represents a different post-transition export criteria, and each column represents a different SSP. The main metrics evaluated for the post-transition expectation include the percentage of time water levels are above 6,390 ft in the post-transition period, and the average water level in the post-transition period which should equal the target water level of 6,392 ft. The result for each individual GCM is included along with the ensemble mean and 1 standard deviation (black circle and line).*

**Percent Difference in GCMs Above 6386 ft  
Using Post-Transition: PT3**



*Figure D-2a. Likelihood of being at or above 6,386 ft for A1-A10 & U1-U4 transition export criteria with the PT3 post-transition criteria. Shown as the difference from the highest likelihood possible which is based on no exports in the transition and post-transition period (shown in top left panel). Note, results are shown for all emission scenarios (SSPs).*

**Percent Difference in GCMs Above 6388 ft  
Using Post-Transition: PT3**

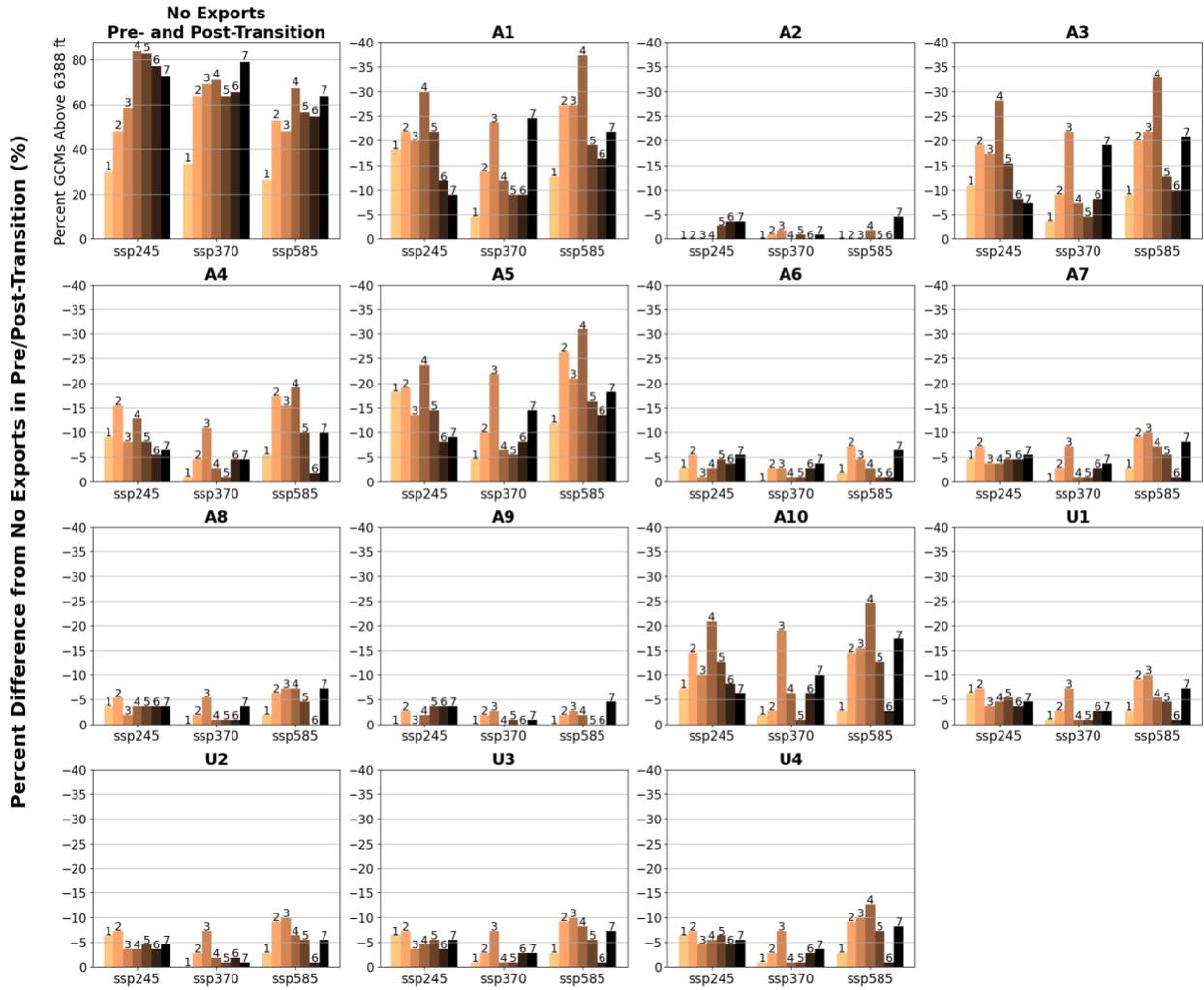


Figure D-2b. Same as Figure D-3a, but for likelihood of being at or above 6,388 ft.

**Percent Difference in GCMs Above 6391 ft  
Using Post-Transition: PT3**

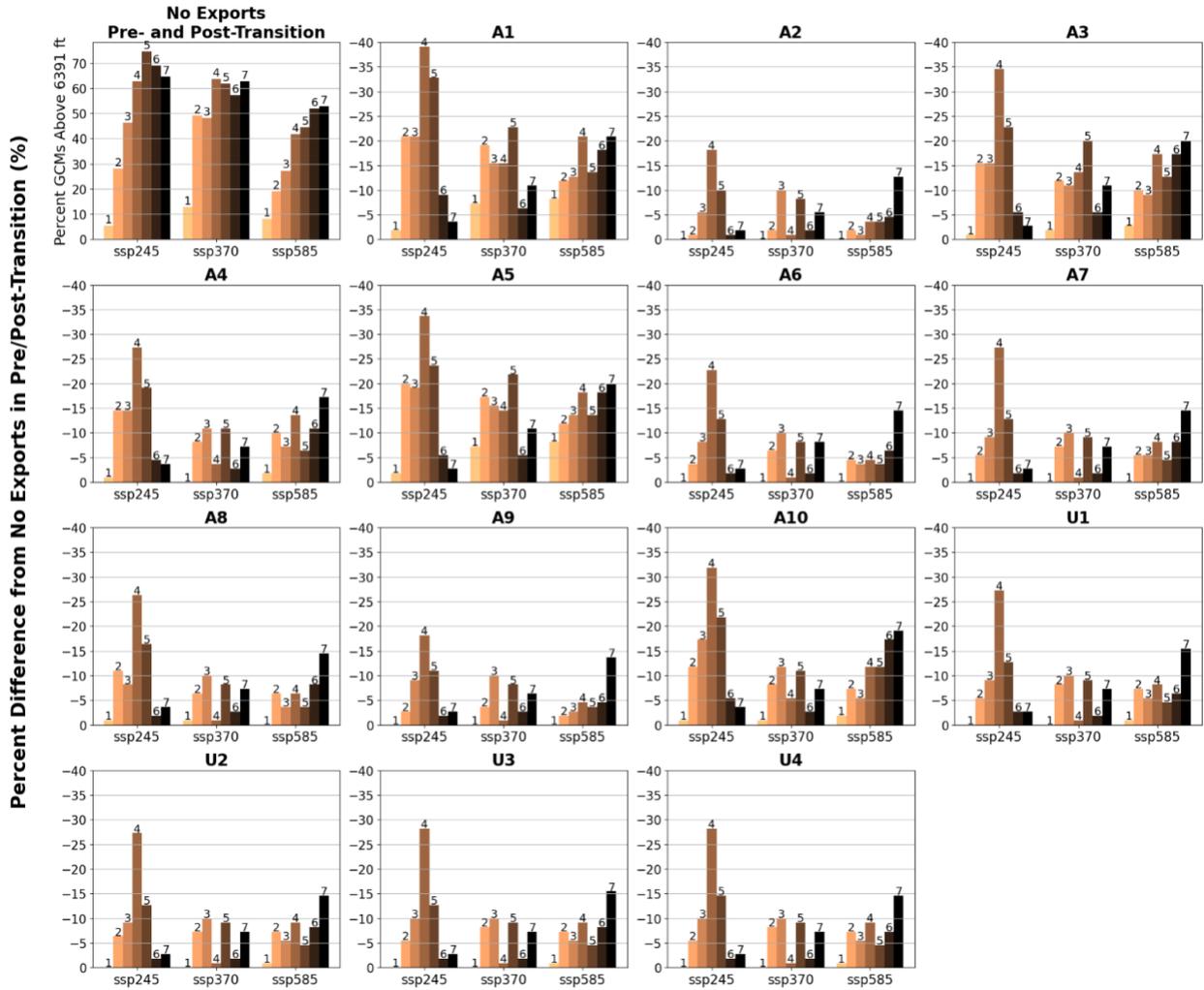


Figure D-2c. Same as Figure D-3a, but for likelihood of being at or above 6,391 ft.

**Percent Difference in GCMs Above 6392 ft  
Using Post-Transition: PT3**

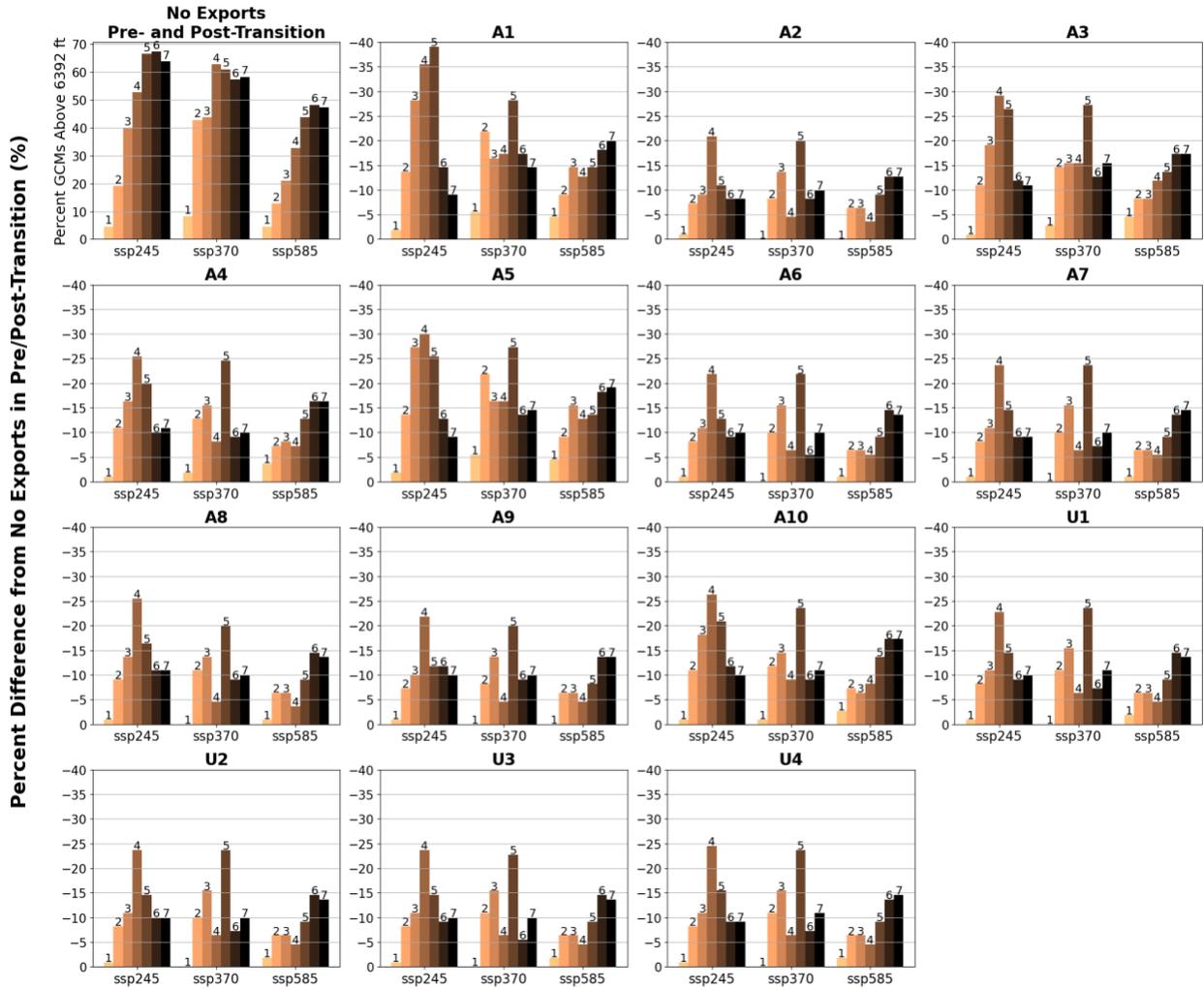
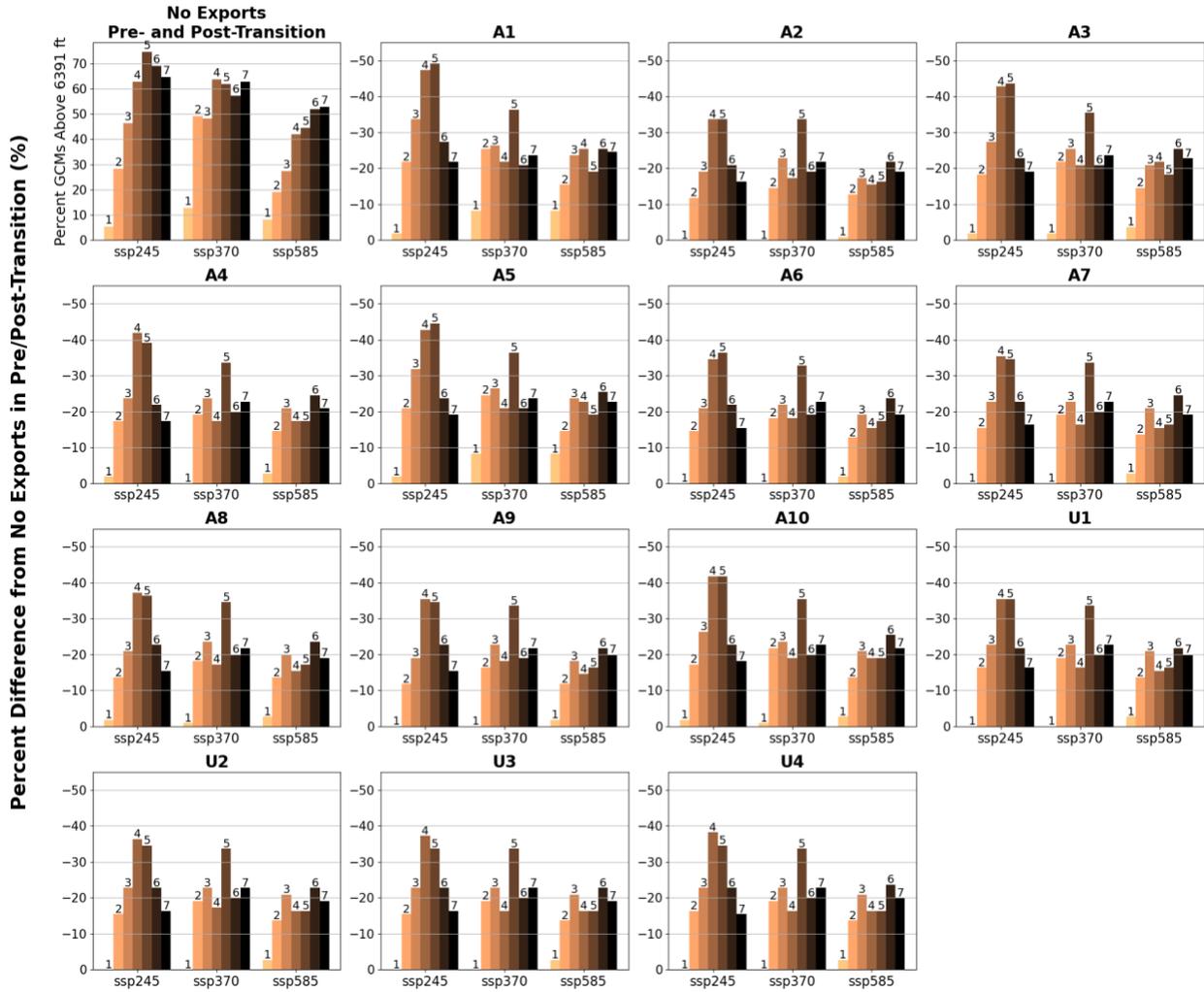


Figure D-2d. Same as Figure D-3a, but for likelihood of being at or above 6,392 ft.

**Percent Difference in GCMs Above 6391 ft  
Using Post-Transition: D\_1631**



*Figure D-3. Likelihood of being at or above 6,391 ft for A1-A10 & U1-U4 transition export criteria with the D-1631 post-transition criteria. Shown as the difference from the highest likelihood possible which is based on no exports in the transition and post-transition period (shown in top left panel). Note, results are shown for all emission scenarios (SSPs).*

**Percent Difference in GCMs Above 6391 ft  
Using Post-Transition: PT2**

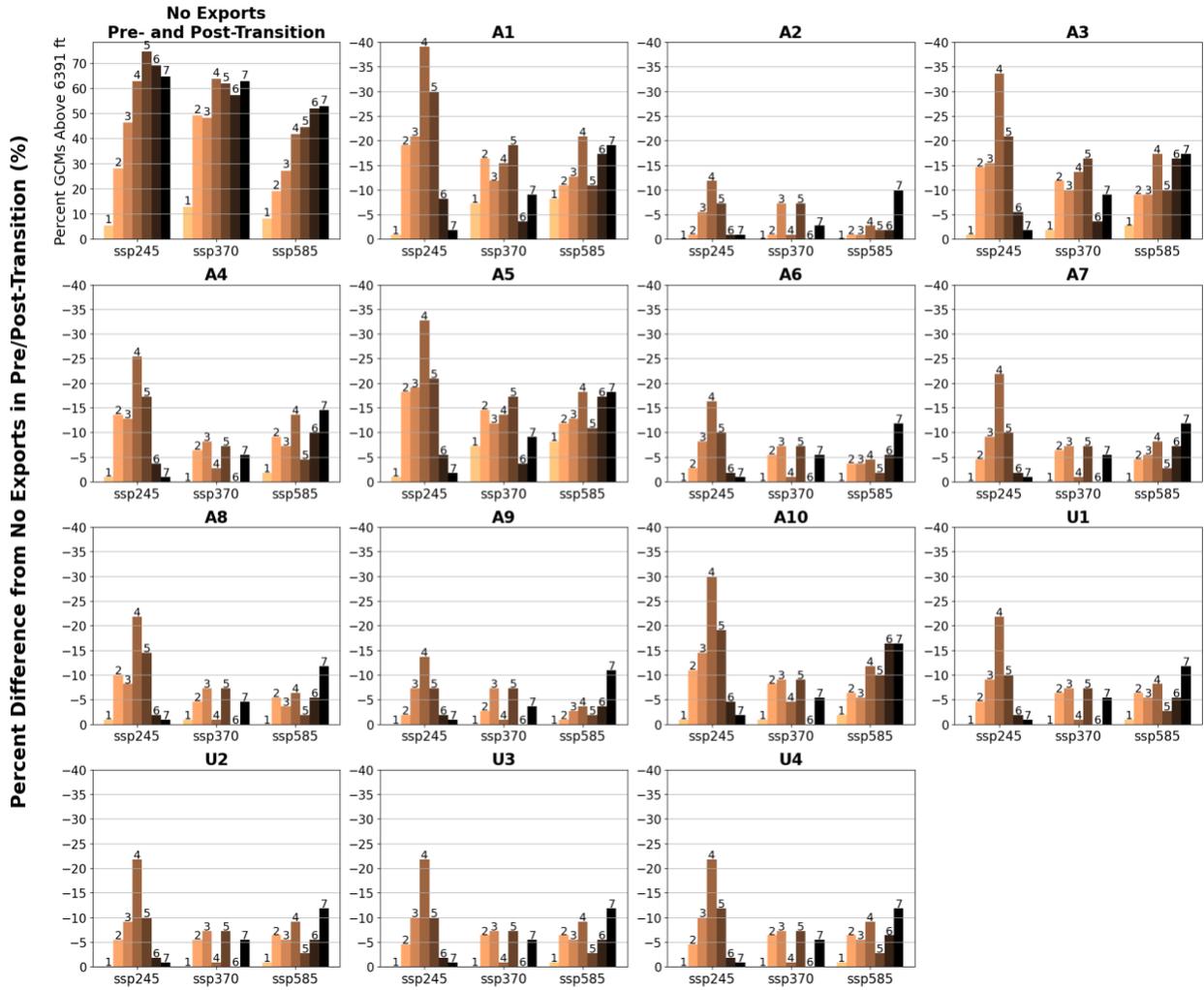


Figure D-4. Likelihood of being at or above 6,391 ft for A1-A10 & U1-U4 transition export criteria with the P2 post-transition criteria. Shown as the difference from the highest likelihood possible which is based on no exports in the pre- and post-transition period (shown in top left panel). Note, results are shown for all emission scenarios (SSPs).

## Water Level Metrics (left) and Export Metrics (right) for Several Transition Export Criteria and the PT3 Post-Transition Criteria, Under SSP2-4.5

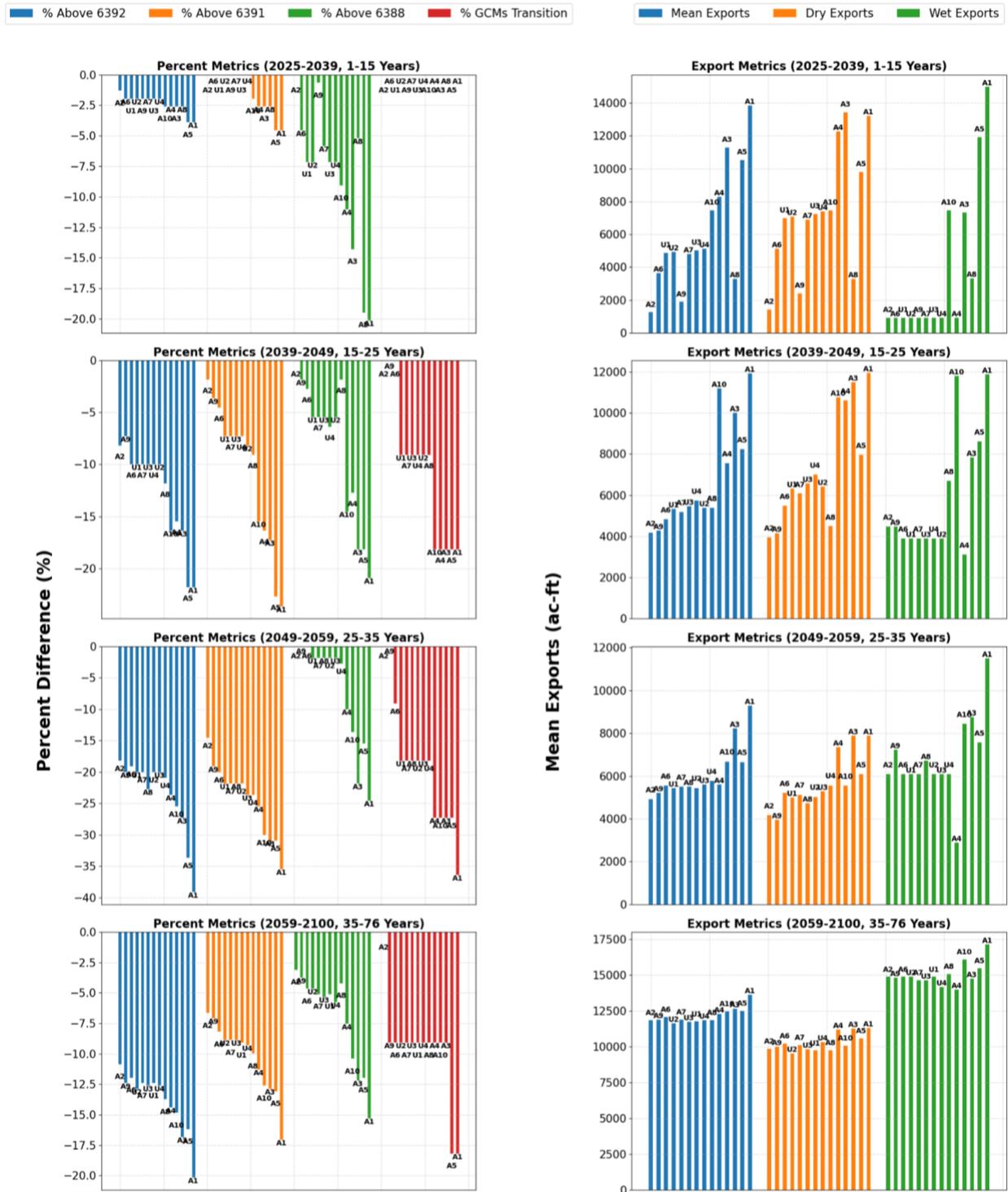


Figure D-5a. Left part of figure shows several water level metrics, which include the likelihood of being at or above 6,392 ft (blue), 6,391 ft (orange), 6,388 ft (green), and the percent of GCMs that

*transition (red). These water level metrics are assessed for several transition export criteria combined with PT3 when compared to the highest benchmark possible which occurs for No Exports (A2+None). The results, like other figures unless stated otherwise, are based on simulations starting in 2024. This figure is based on SSP2-4.5. Each row represents results for different time-slices, including 2025 to 2039 (first row), 2039 to 2045 (second row), 2049 to 2059 (third row), and 2059 to 2100 (bottom row). Negative values indicate the percent reduction in the likelihood of meeting a given water level metric relative to No Exports. For example, A2 (no transition exports) followed by a PT3 post-transition export criteria, leads to the smallest reductions in the likelihoods assessed, while A1 (existing transition exports) followed by PT3 leads to the largest reductions relative to no exports. Right part of the figure demonstrates the average amount of exports during all year types (blue), dry year types (orange), and wet year types (green). The average export amounts are based on the years considered in each figure, and the average across the 11 GCMs.*

## Water Level Metrics (left) and Export Metrics (right) for Several Transition Export Criteria and the PT3 Post-Transition Criteria, Under SSP3-7.0

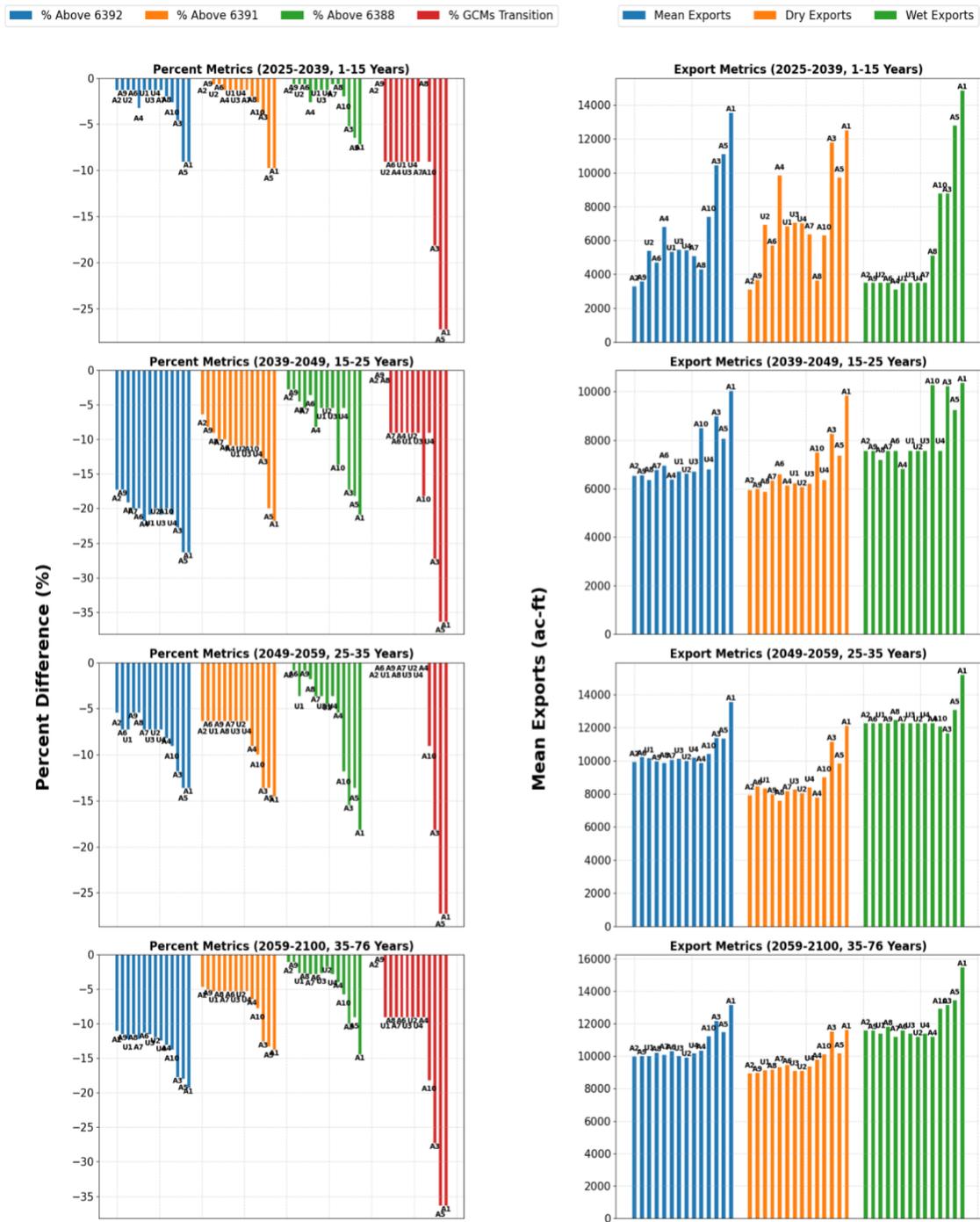


Figure D-5b. Same as Figure D-6a, but shown for SSP3-7.0.

## Water Level Metrics (left) and Export Metrics (right) for Several Transition Export Criteria and the PT3 Post-Transition Criteria, Under SSP5-8.5

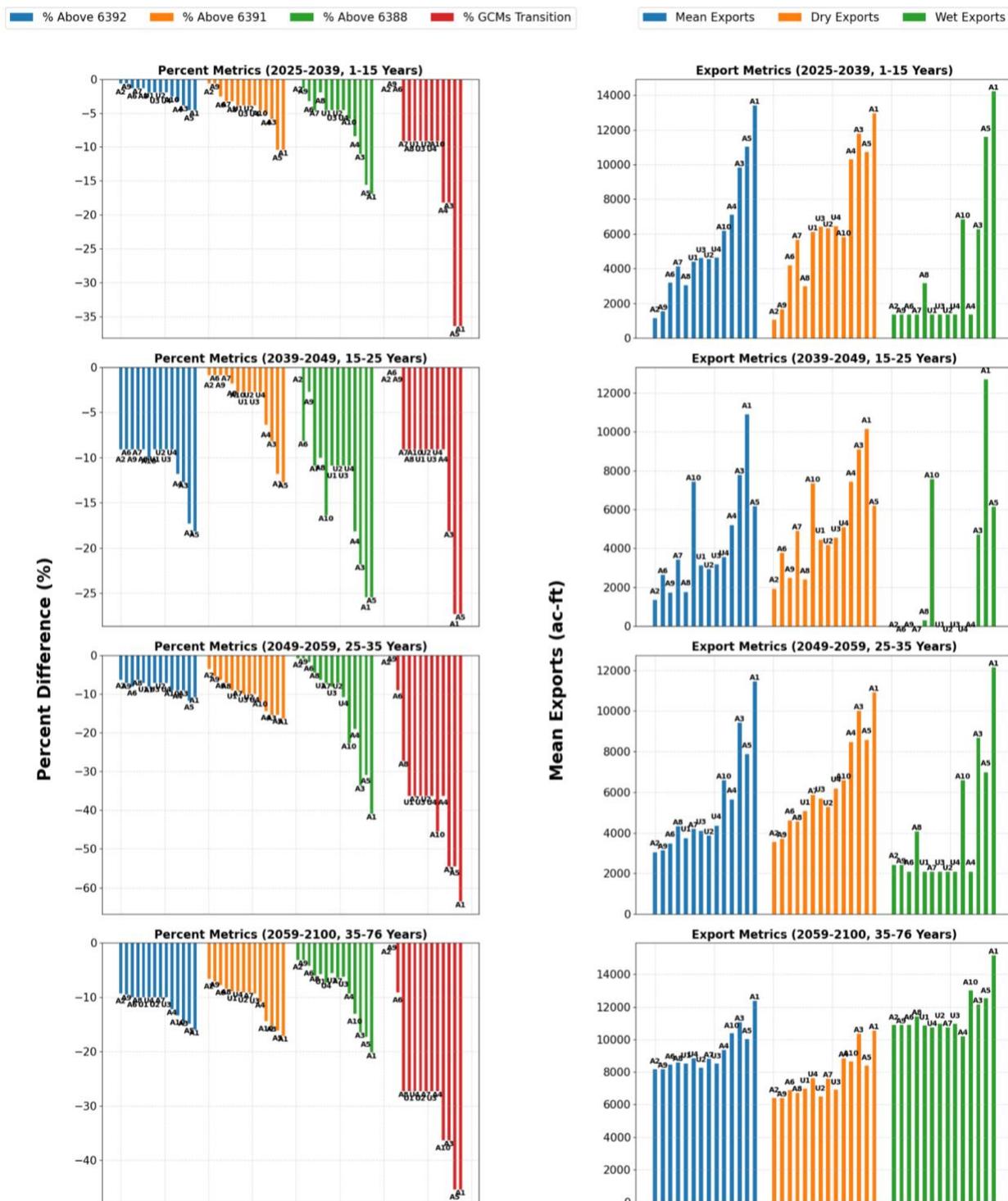
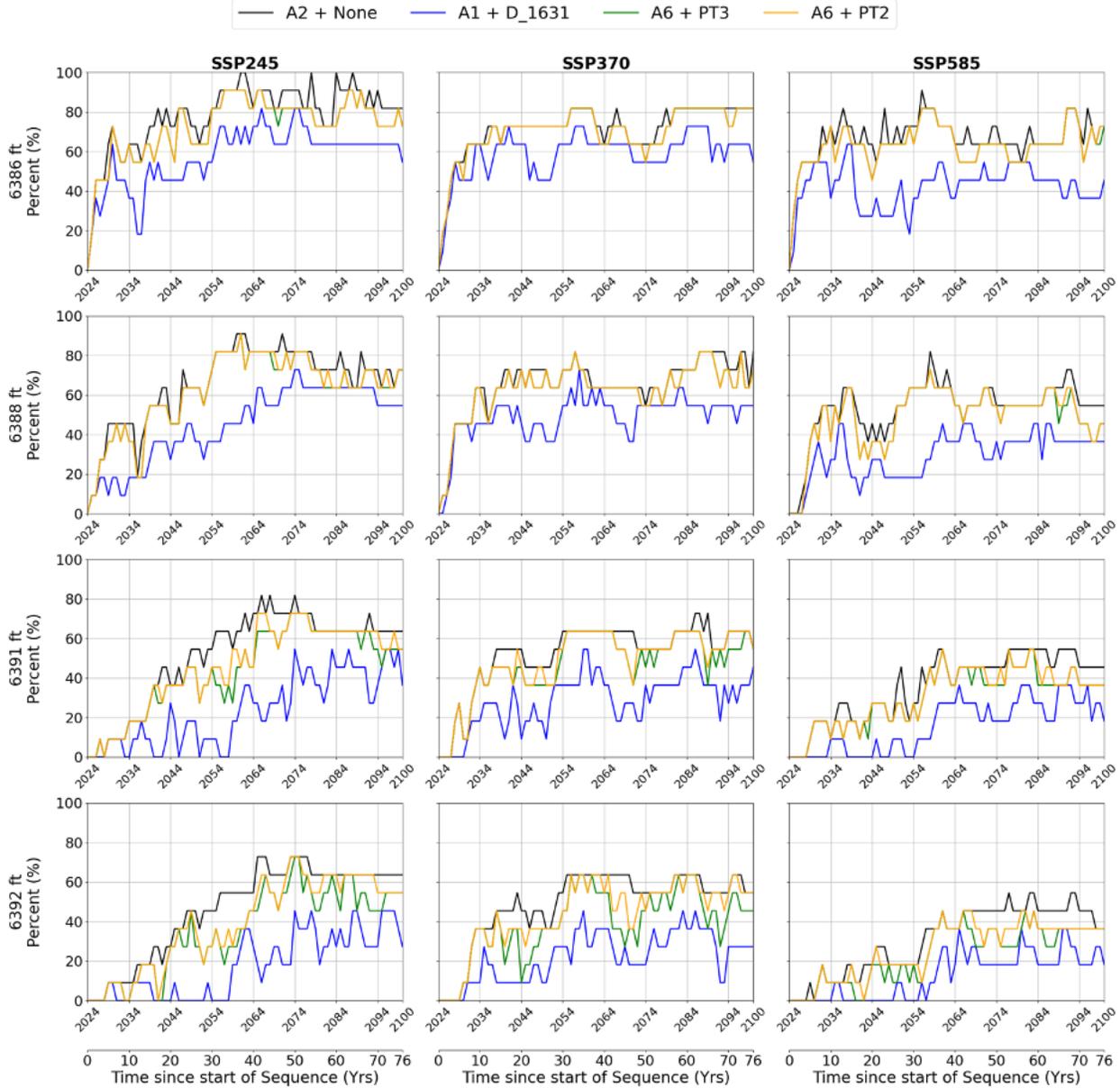


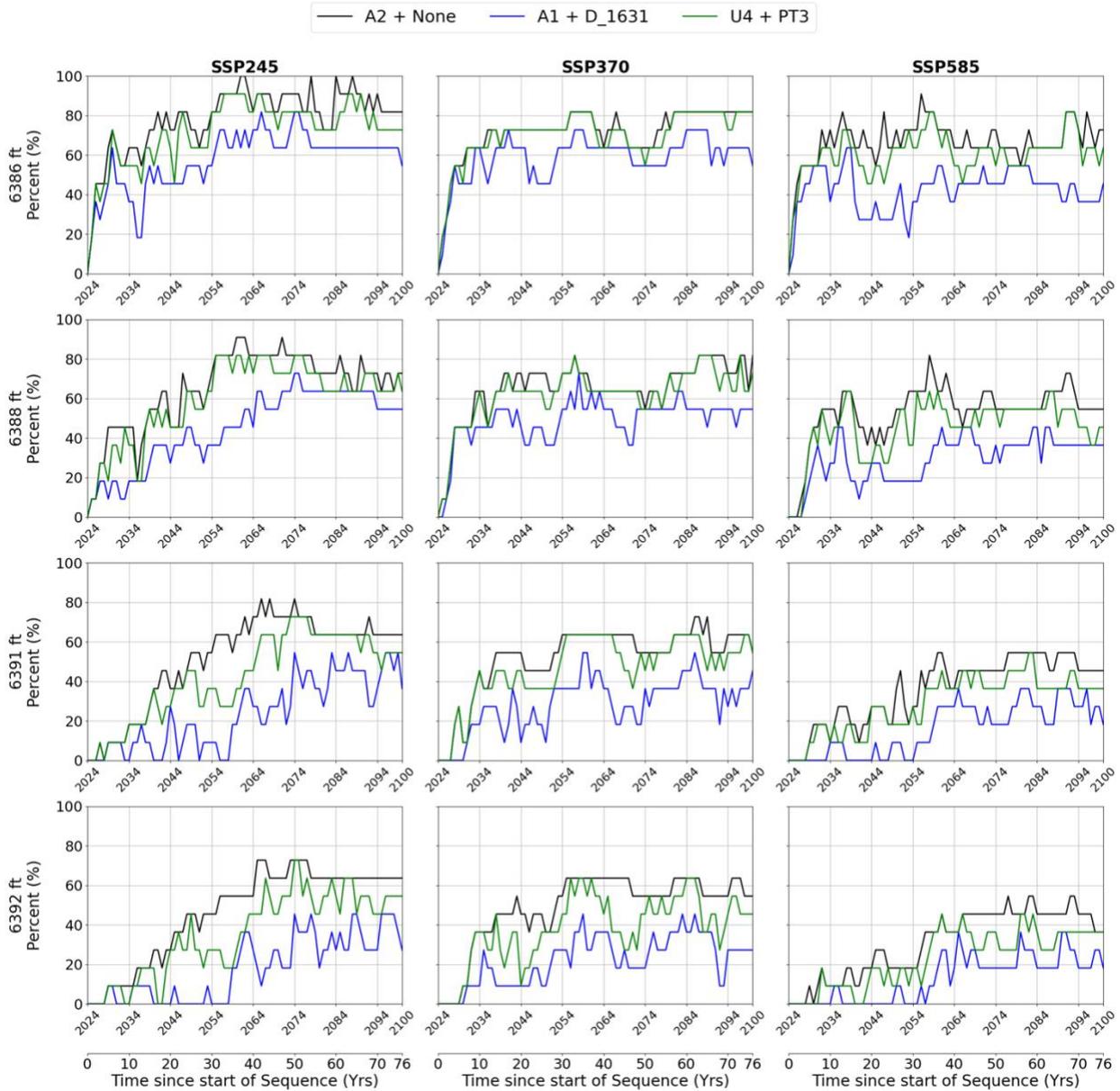
Figure D-5c. Same as Figure D-6a, but shown for SSP5-8.5.

**Percent of GCMs Above Selected Water Levels**



*Figure D-6. Likelihood for being at or above 6,386 ft (top row), 6,388 ft (second row), 6,391 ft (third row), and 6,392 ft (bottom row), for SSP2-4.5 (left column), SSP3-7.0 (middle column), and SSP5-8.5 (right column). Performance shown for A6 with the PT3 (green line) and PT2 (orange line) post-transition export criteria and the book-end export criteria, including no exports in the pre- and post-transition period (black line) and the existing pre- and post-transition export criteria (blue line).*

**Percent of GCMs Above Selected Water Levels**



**Figure D-7.** Likelihood for being at or above 6,386 ft (top row), 6,388 ft (second row), 6,391 ft (third row), and 6,392 ft (bottom row), for SSP2-4.5 (left column), SSP3-7.0 (middle column), and SSP5-8.5 (right column). Performance shown for U4 with the PT3 (green line) post-transition export criteria and the book-end export criteria, including no exports in the pre- and post-transition period (black line) and the existing pre- and post-transition export criteria (blue line).

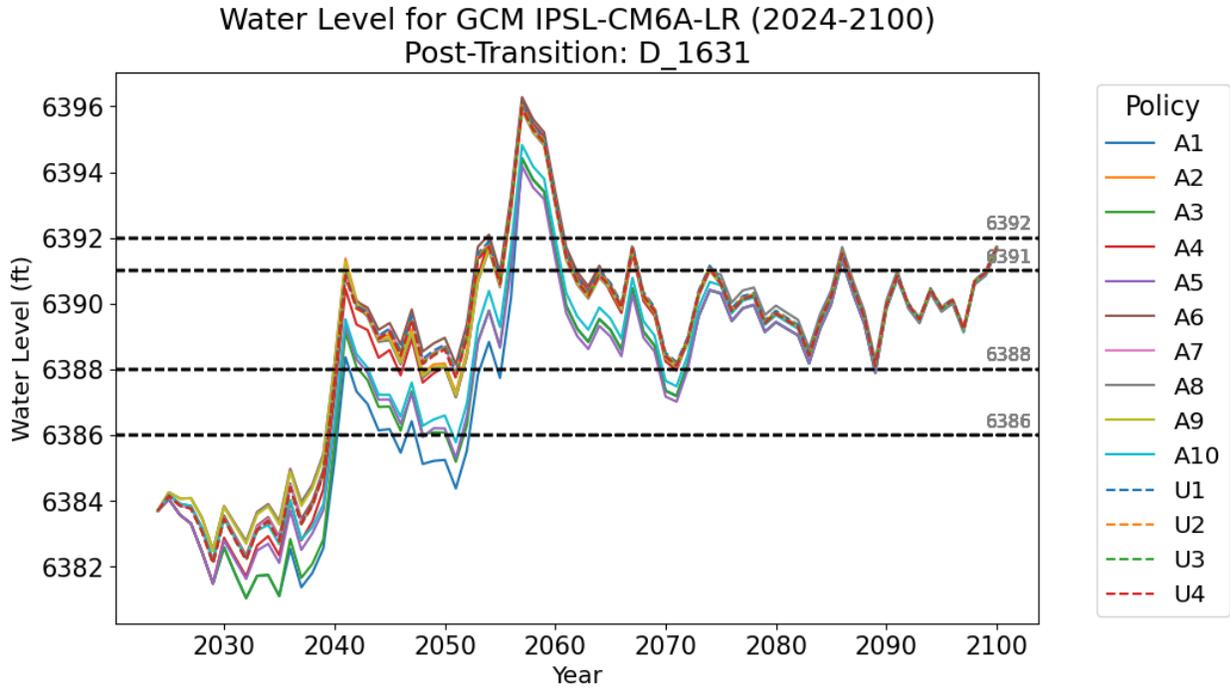


Figure D-8a. Water levels for a single GCM (IPSL chosen for demonstrative purposes) and SSP3-7.0, under a variety of transition export criteria with the existing post-transition export criteria (D-1631)

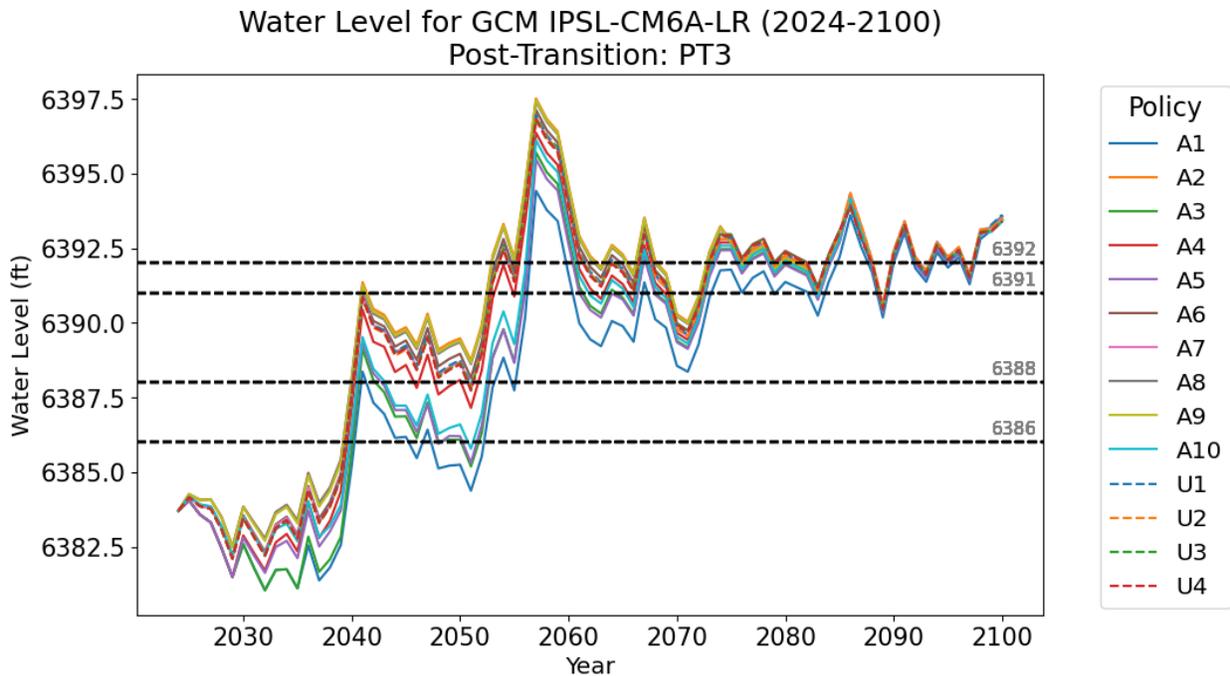
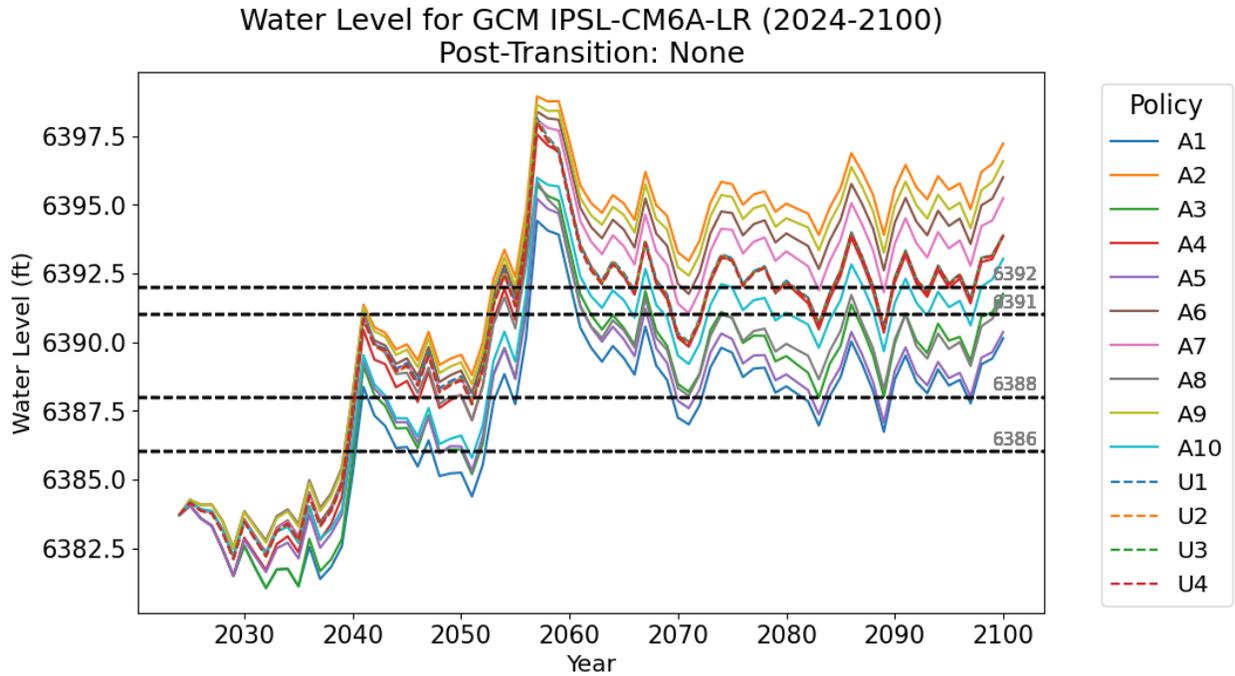


Figure D-8b. Same as Figure D-10a, but shown for the transition export criteria with the PT3 post-transition export criteria.



**Figure D-8c.** Same as Figure D-10c, but transition export criteria continue the export criteria in place at the time of reaching 6,391 ft (post-transition termed None). For example, for A1 (existing transition criteria), the exports allowed above 6,391 ft are the same as that allowed directly under 6,391 ft (continue to be 16,000 ac-ft/year).

Water Level for Different Transition Export Criteria and Post-Transition: D\_1631  
 Projections: 2024-2100

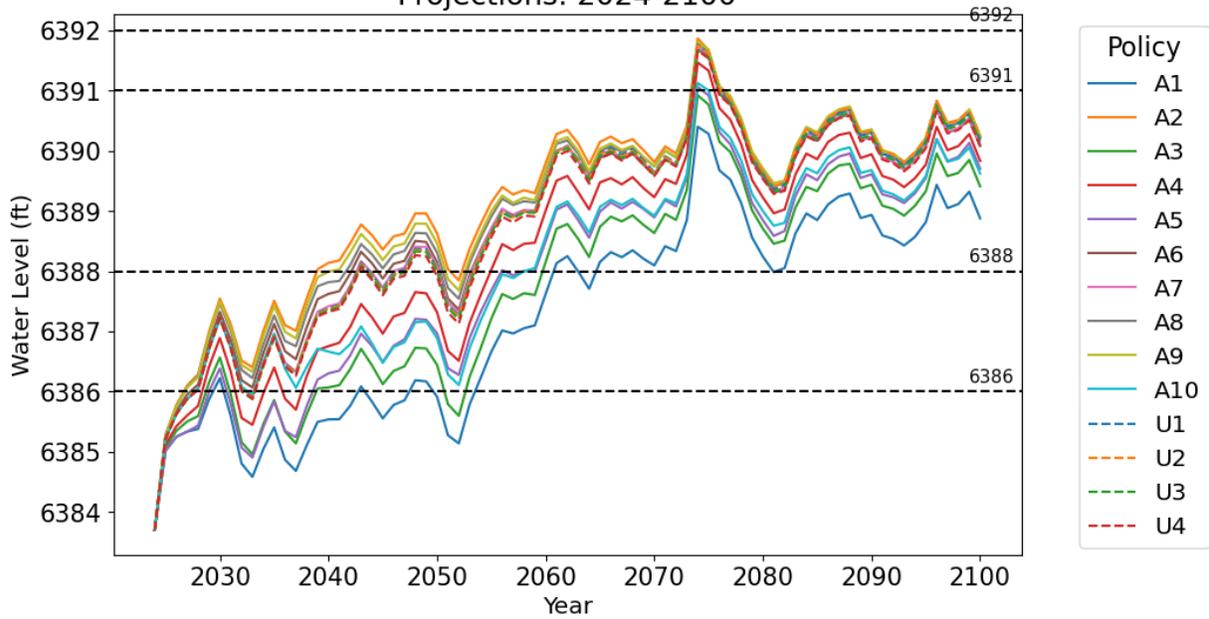


Figure D-9a. Ensemble mean water level projections for the 11 GCMs under SSP2-4.5. Shown for several transition export criteria, with the existing (D-1631) post-transition criteria.

Water Level for Different Transition Export Criteria and Post-Transition: PT3  
 Projections: 2024-2100

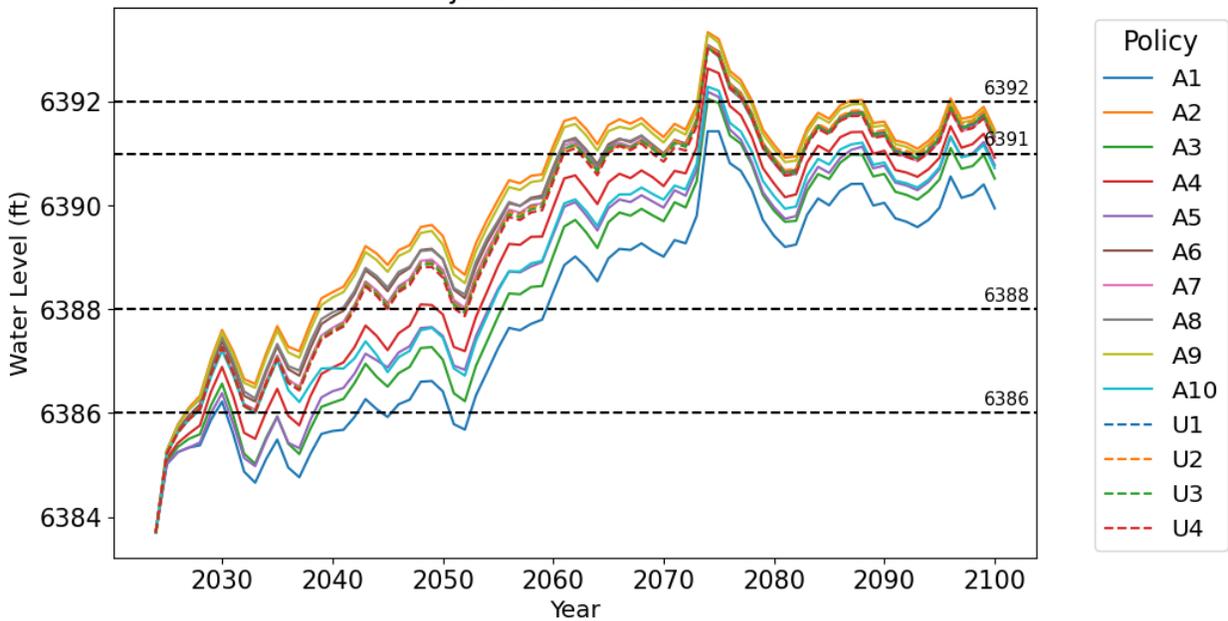


Figure D-9b. Same as Figure D-9a, but with a PT3 post-transition criteria.

Water Level for Different Transition Export Criteria and Post-Transition: None  
 Projections: 2024-2100

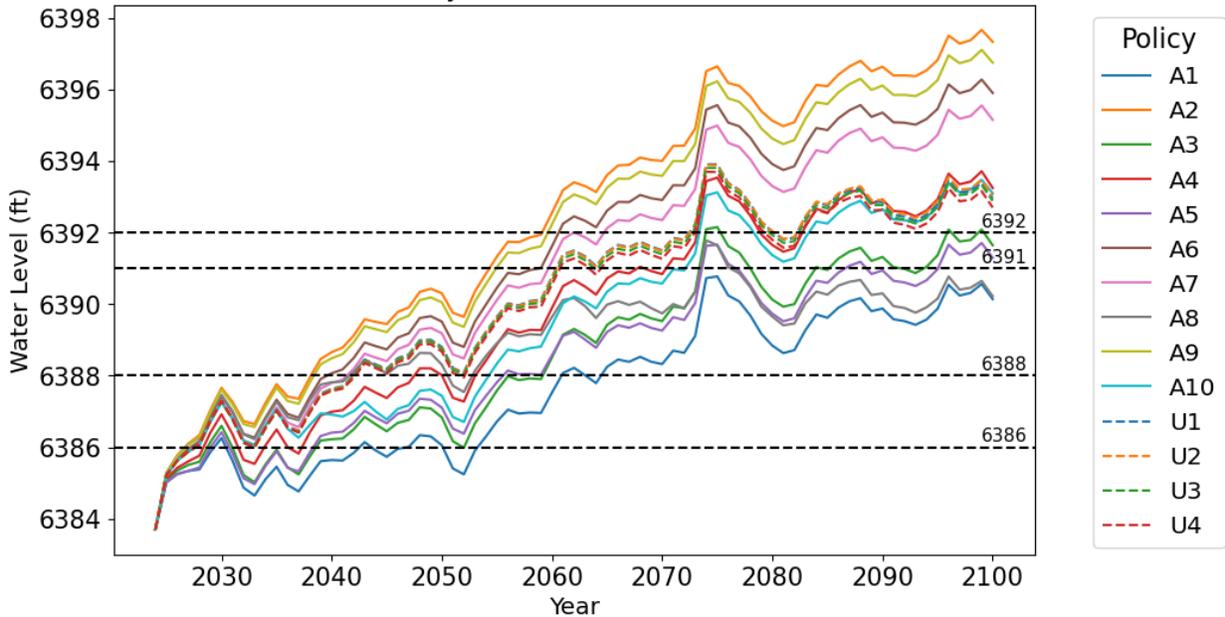


Figure D-9c. Same as Figure D-9a, but transition export criteria continue the export criteria in place at the time of reaching 6,391 ft (post-transition termed None).

Water Level for Different Transition Export Criteria and Post-Transition: D\_1631  
 Projections: 2024-2100

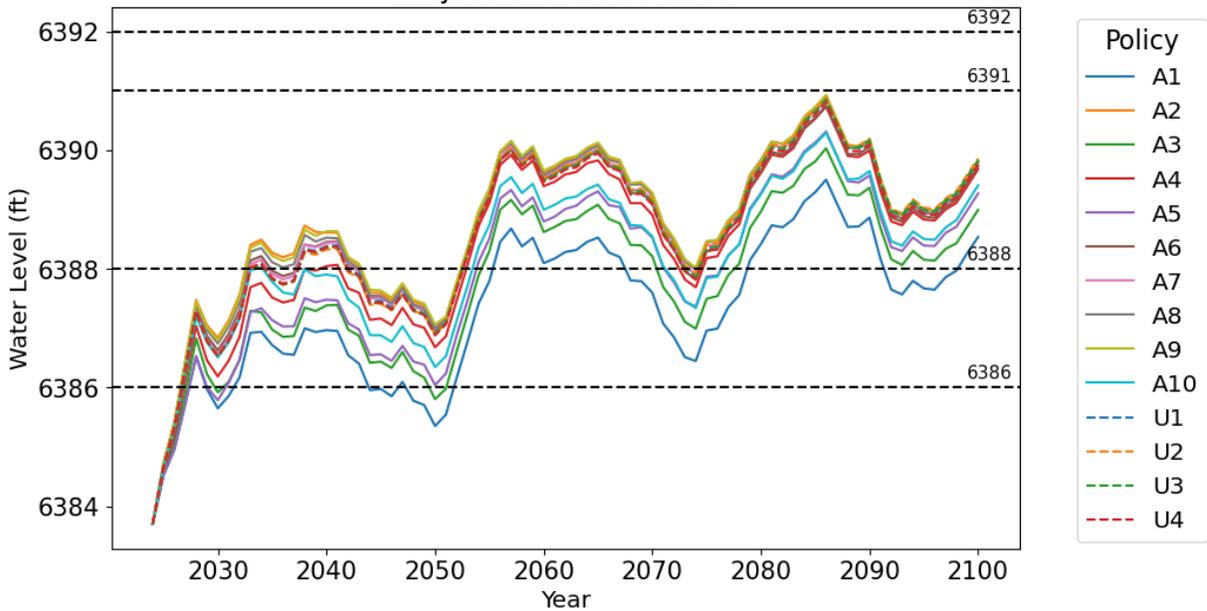


Figure D-10a. Ensemble mean water level projections for the 11 GCMs under SSP3-7.0. Shown for several transition export criteria, with the existing (D-1631) post-transition criteria.

Water Level for Different Transition Export Criteria and Post-Transition: PT3  
Projections: 2024-2100

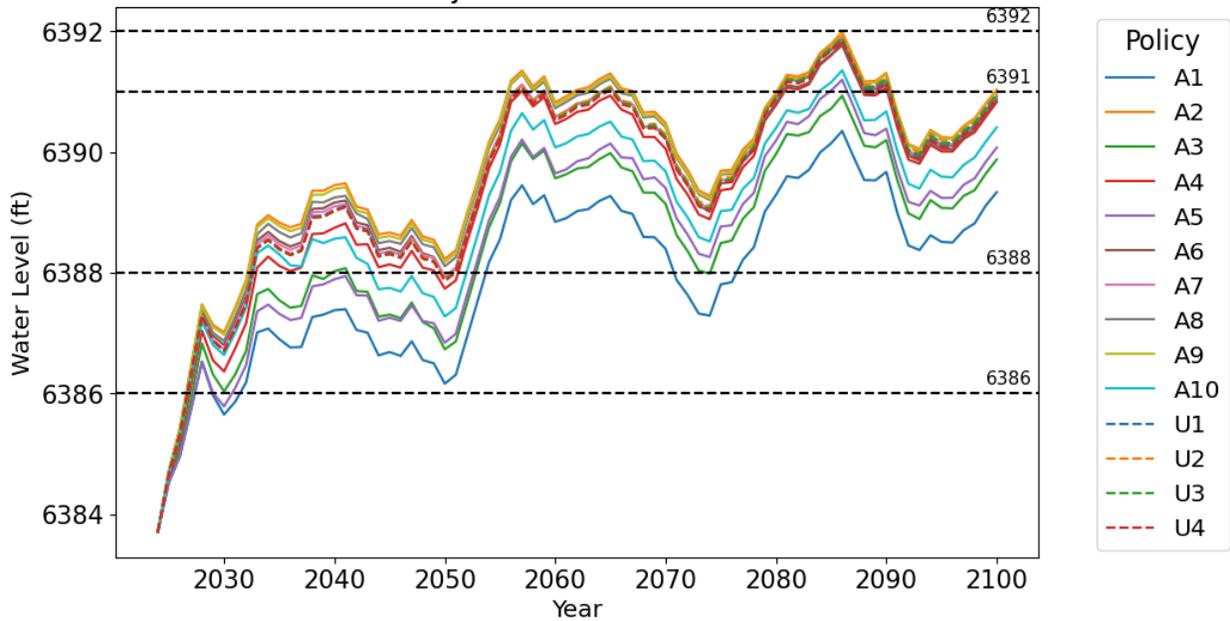


Figure D-10b. Same as Figure D-10a, but with a PT3 post-transition criteria.

Water Level for Different Transition Export Criteria and Post-Transition: None  
Projections: 2024-2100

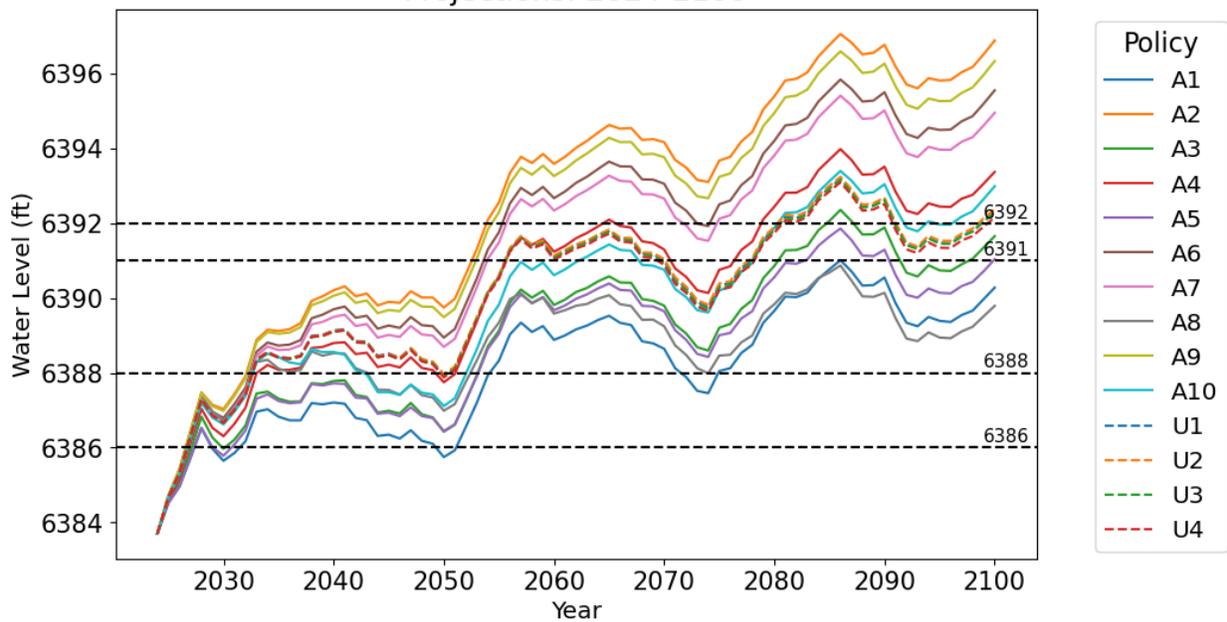
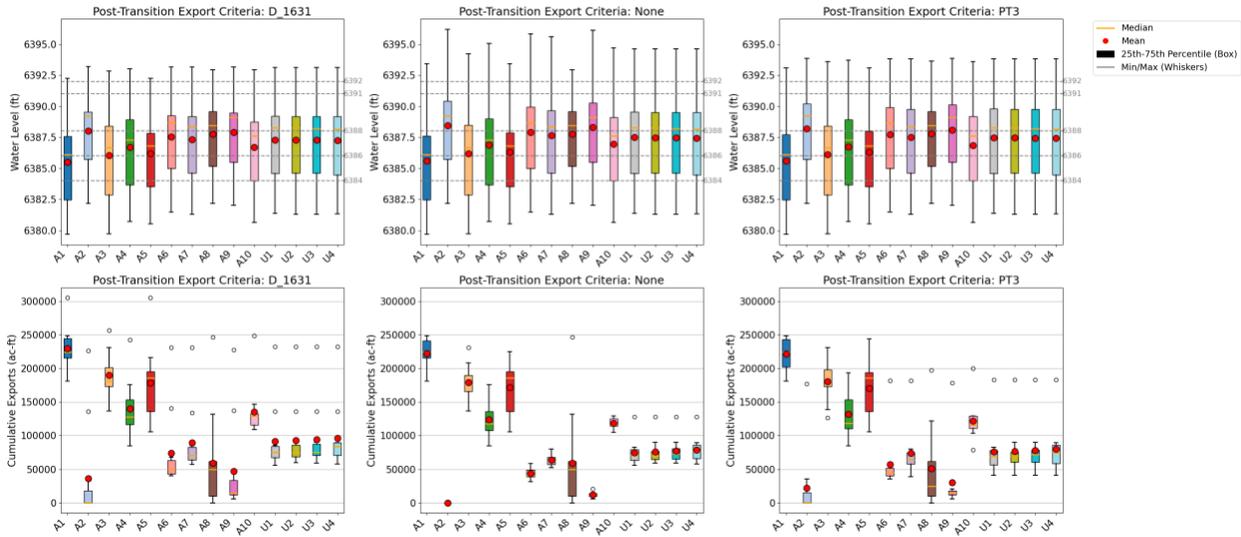
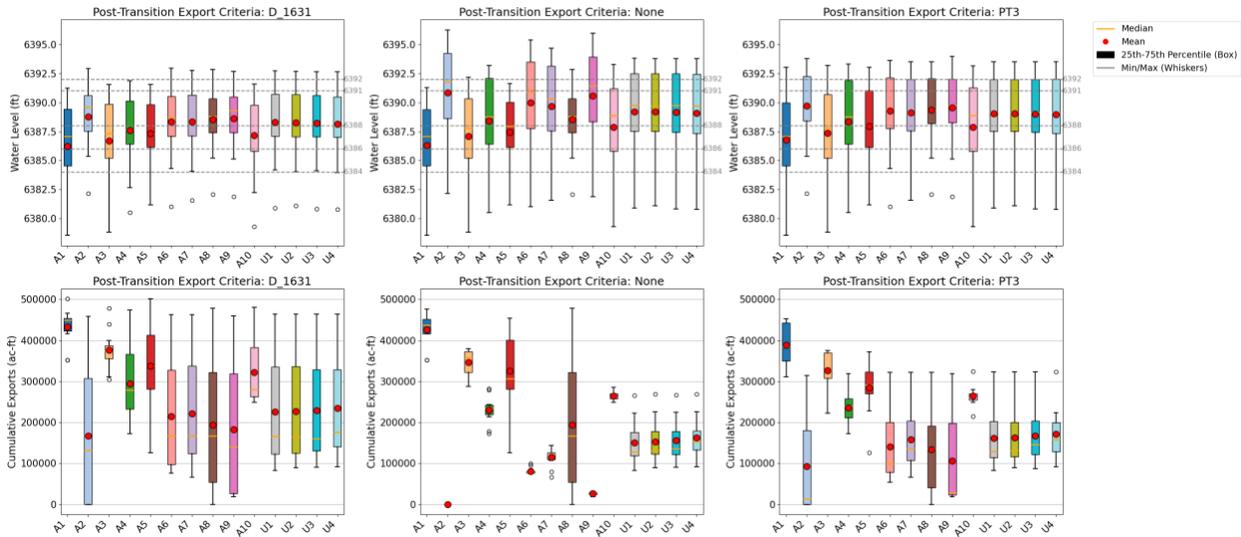


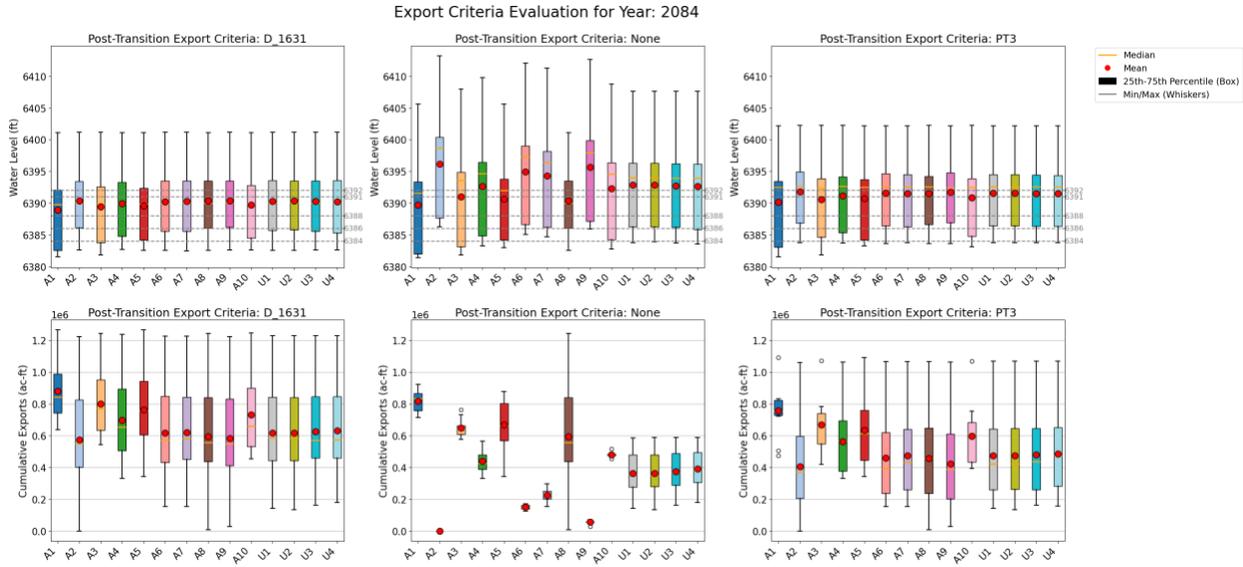
Figure D-10c. Same as Figure D-10a, but transition export criteria continue the export criteria in place at the time of reaching 6,391 ft (post-transition termed None).

Export Criteria Evaluation for Year: 2039

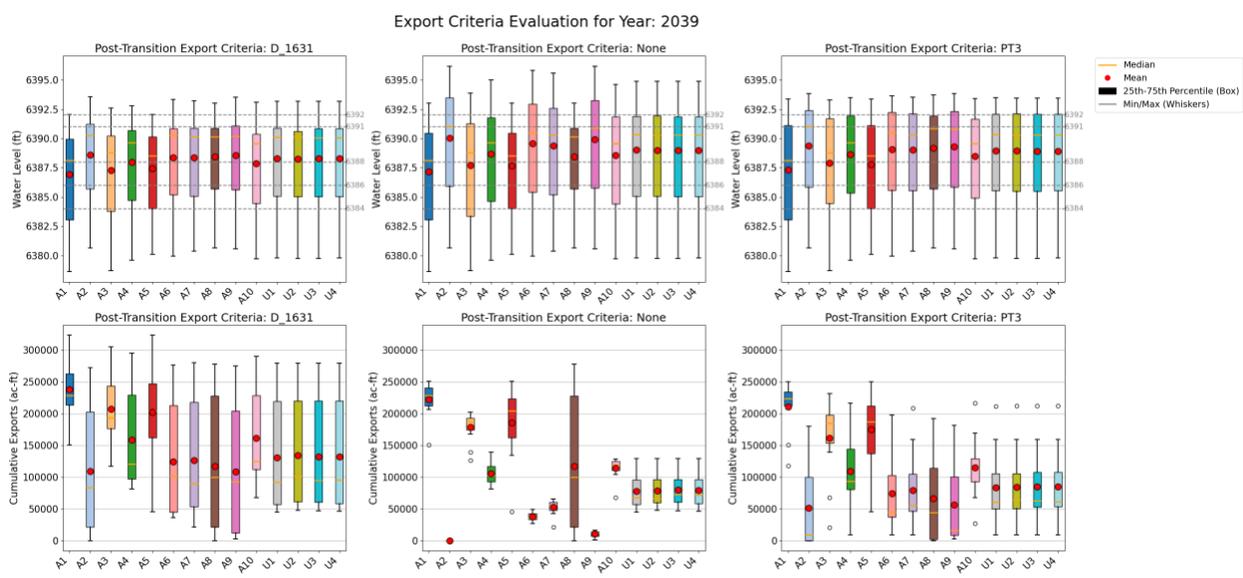


Export Criteria Evaluation for Year: 2054





**Figure D-11.** Boxplots of water levels and cumulative exports for the year 2039 (15-years from present-day), 2054, and 2084 for the 11 GCMs evaluated under SSP2-4.5. Top row includes boxplots of water levels and bottom row includes boxplots of cumulative exports from 2024 to the end year of interest. Different columns correspond to unique post-transition export criteria. Results shown for the existing post-transition export criteria (left column), no post-transition export criteria which maintains the transition export criteria when 6,391 ft is reached (middle column), and the PT3 user-defined post-transition export criteria (right column).



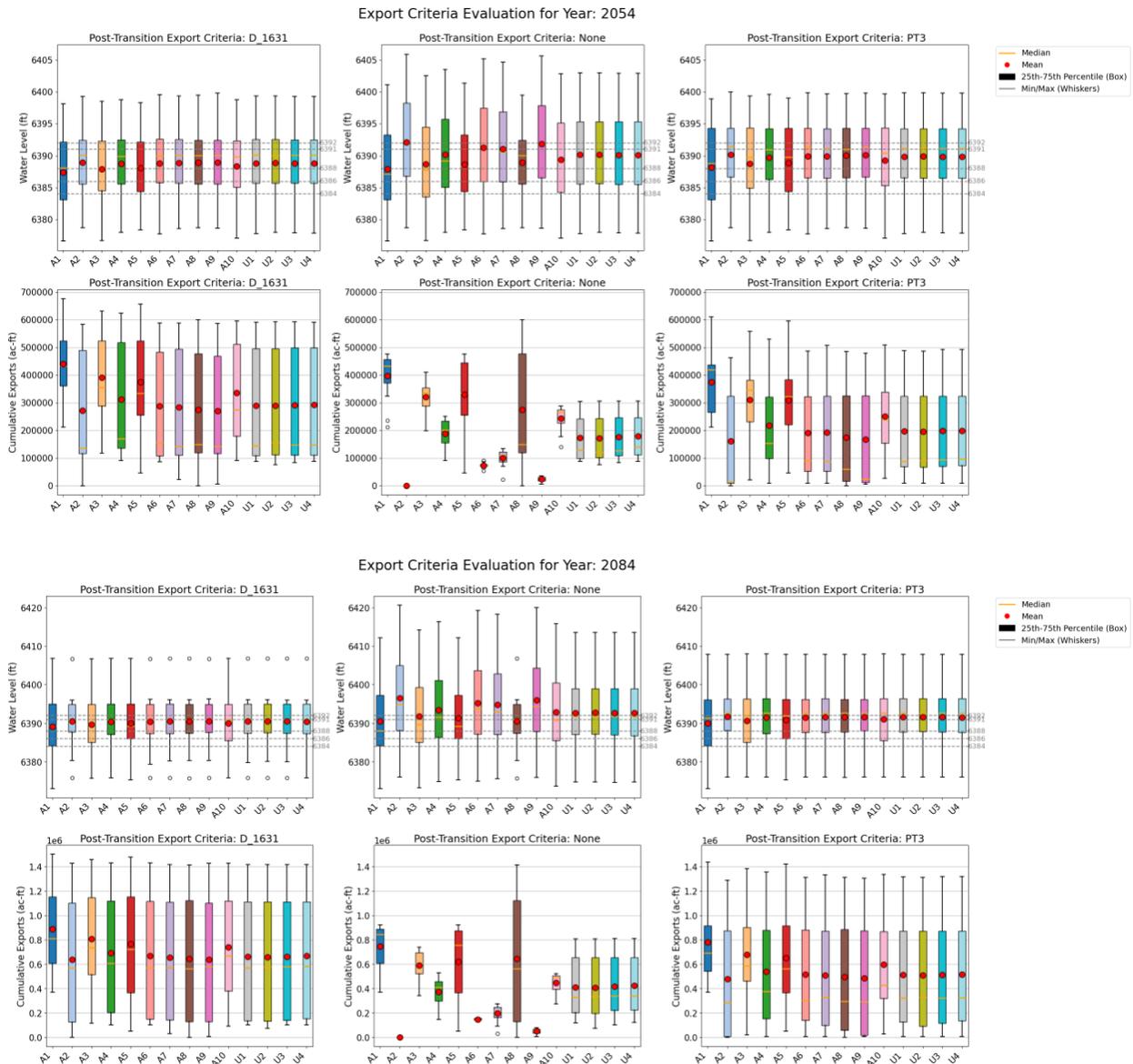
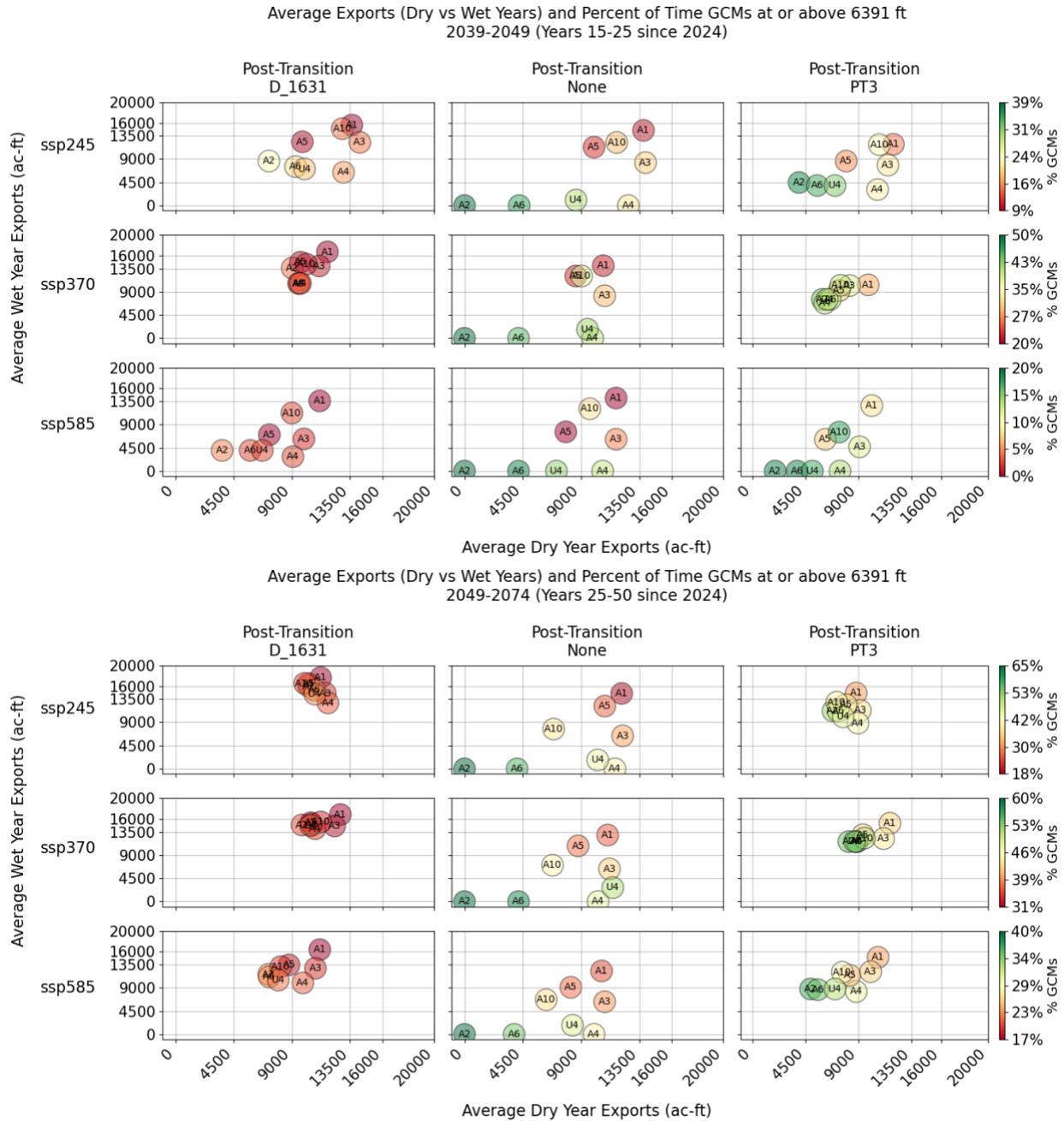
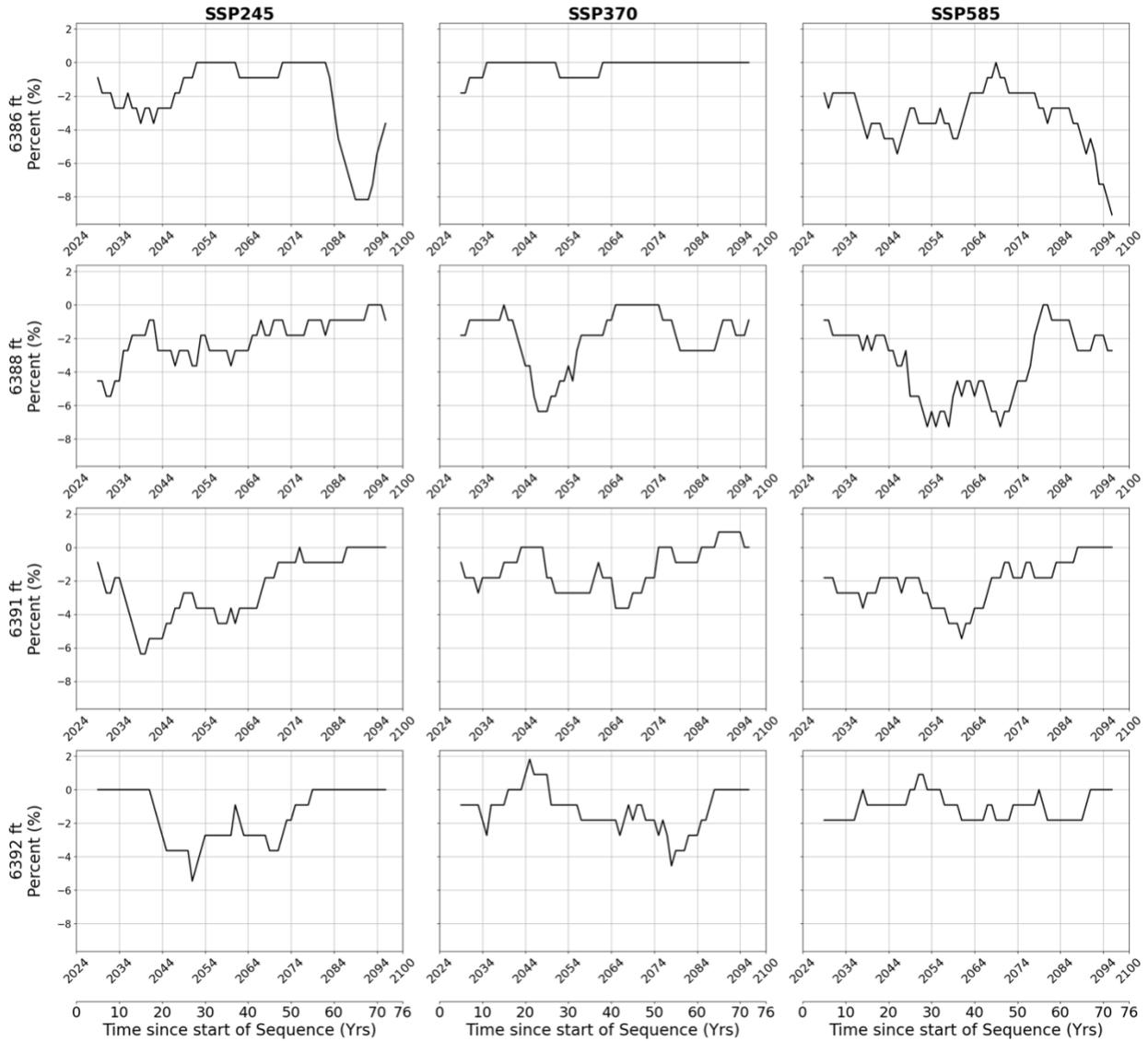


Figure D-12. Same as Figure D-11, but shown for SSP3-7.0.



**Figure D-13.** Percent of GCMs that lead to Mono Lake water level at or above 6,391 ft for a variety of transition export criteria. Evaluation shown for different SSPs (rows) and unique post-transition export criteria (columns). Only a subset of the A1-A10 and U1-U4 export criteria are included, with export criteria removed that impair visualization due to overlap. Notably, A7 nearly overlaps A6, and A9 nearly overlaps A2. Top figure shows results for 2034-2049 (10 to 25 years from now), and the bottom figure shows results from 2049 to 2074 (25 to 50 years from now). Note, the D-1631 post-transition export criteria, and less so but also for the PT3 post-transition export criteria, lead to increasingly similar results further into the future as more GCMs transition past 6,391 ft and the post-transition rules are put into place.

**Difference in Percent of GCMs Above Selected Water Levels  
Comparison between A6+PT3 and X1+PT3**

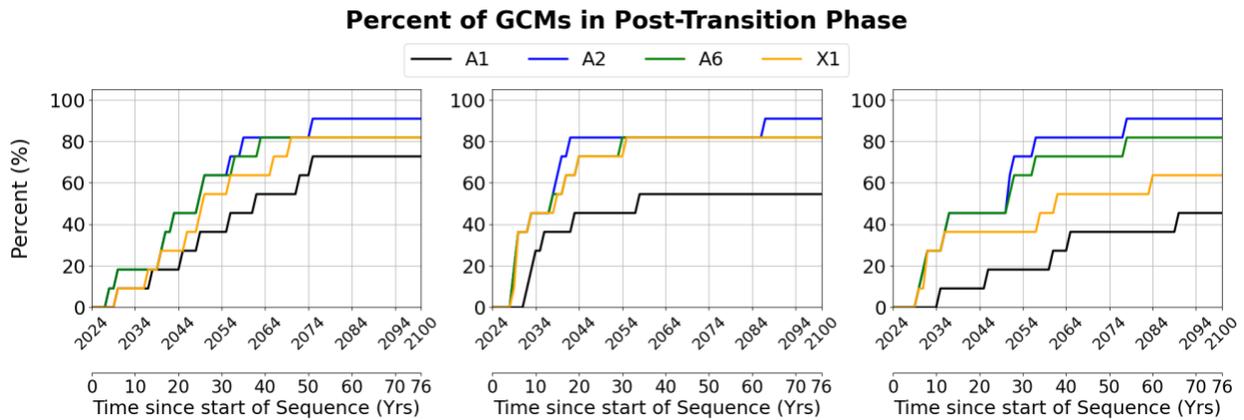


<b>Water Level / RYT</b>	<b>Dry</b>	<b>Dry-Normal</b>	<b>Normal</b>	<b>Wet-Normal</b>	<b>Wet</b>	<b>Extreme-Wet</b>
<b>≤6376</b>	0.0	0.0	0.0	0.0	0.0	0.0
<b>6377–6391</b>	4500.0	4500.0	4500.0	4500.0	4500.0	4500.0

### X1 Export Criteria

*Figure D-14.* At the bottom of this figure, we first outline the X1 export criteria, which reflects the A6 export criteria for dry year types but additionally allows for 4,500 ac-ft/yr exports during wet

year types. Above this table, we outline the likelihood for being at or above a variety of critical water levels (rows) for different SSPs (columns) based on the difference between A6+PT3 and X1+PT3. Results are based on a 10-year, centered rolling average to reduce inter-annual variability. This plot shows that there are generally reductions in likelihood for being at or above the water levels when A6 is modified to allow for wet year exports. Note, the decadal average impact of allowing wet year exports in X1 only reaches ~6% relative to A6. Also, while the overall impact of X1 is to reduce the likelihood of an increase in Mono Lake's water level, increases in likelihood can occur due to X1+PT3 delaying the transition to post-transition rules which allow for greater exports (Figure D-15).



**Figure D-15** Percent of GCMs that transition (note, X1 can delay the percent of GCMs that transition relative to A6). Left column is for SSP2-4.5, middle column is for SSP3-7.0, and right column is for SSP5-8.5

## E. Appendix E (Supplement to Section 4.4, 5.3 of Main Report)

Here, we perform a data mining exercise with the 50,000 transition export criteria outlined in **Section 4.3**. This exercise is purely academic at this point; however, we are currently working on refining such analysis to allow for more robust export criteria-decision making that makes use of quantitative analysis applied to large datasets. Please note that any reference to “policy” in the figures of this section are in fact a reference to “export criteria.”

Here, we apply a multi-objective weighting scheme to evaluate the performance of the 50,000 transition export criteria (outlined in **Section 5.3**) considered for each post-transition export criteria (D-1631, None, and PT3 which is referred to as User-Defined in this appendix). This is performed to test if a weighting scheme can be used to refine the selection of the larger set of export criteria that were evaluated. This analysis is performed for 11 to 36 years from the start of the stimulation (2035-2060). This time-frame gives each transition export criteria time to have an influence on Mono Lake water level while also representing the near-future Mono Lake water level conditions. We perform our weighting based on the objectives (metrics) and weights outlined in **Table E-1**.

*Table E-1. Example of objectives and their weights applied to select the top performing export criteria based on these criteria.*

Objective	Weight
Percent of Time Above 6,392 ft	2.0
Percent of Time Above 6,391 ft	1.0
Percent of Time Above 6,388 ft	0.5
Percent of Time Below 6,380 ft	-4.0
Percent of Time Below 6,377 ft	-2.0
Mean Exports	0.0
Mean Dry Year Exports	5.0

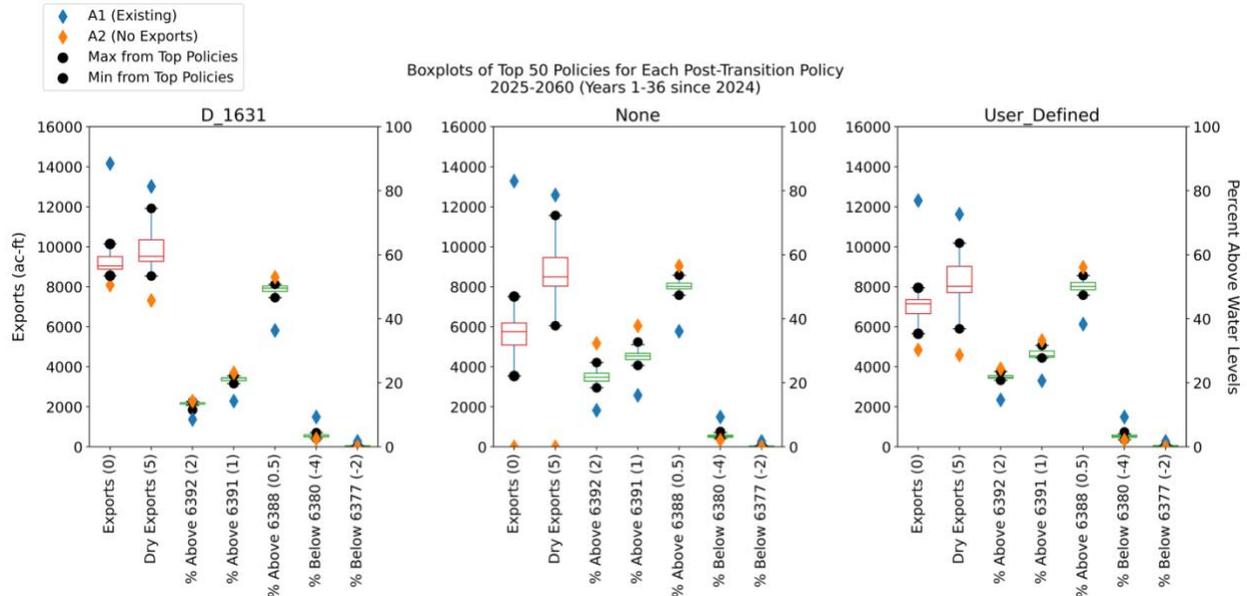
\*Note, to summarize dry and wet year type exports for this exercise, we group dry year type exports into dry, dry-normal, and normal year types, and group wet year types in normal-wet, wet, and extreme-wet year types.

Note, these objectives or metrics are subjective and can be added to and modified. For example, the exports associated with different water level ranges and the likelihood of being at or above a given water level are both flexible. Changes to the objectives and their weights can lead to a unique selection of export criteria that are determined to perform better depending on the multi-objective weighting criteria applied. We primarily apply this multi-objective weighting approach here to demonstrate how the 50,000 export criteria for each post-transition export criteria can be filtered to highlight export criteria that perform well based on user-defined criteria. However, we also chose metrics and weights that we believe lead to a successful export criteria in terms of its

ability to equally prioritize dry year type exports and Mono Lake recovery. To represent Mono Lake recovery, we selected a group of metrics that would take into account a range of potential future climate conditions. While our weighting prioritizes the ultimate goal to reach and maintain lake levels of 6,392 ft, it also attempts to facilitate better outcomes for GCMs with drier future conditions. In these GCMs, lake levels cannot reach the target level in the time frame evaluated. The weighting scheme should discourage export criteria that maintain current lake levels, as those levels remain vulnerable to further decline during drought conditions. Adding intermediate weighting thresholds would allow export criteria that preserve the status quo—but do not improve future conditions—to be weighted negatively.

From the criteria outlined in **Table E-1**, each objective is calculated for SSP2-4.5 and SSP3-7.0 for each GCM and each transition and post-transition export criteria combination. For objectives representing the amount of exports realized, we calculate the mean amount of exports across the 11 GCMs for the time-range considered (2035-2060). Similarly, for objectives representing the percentage of time above or below a given water level, the percentage of time each GCM meets a water level condition across 2035 to 2060 is calculated, and then the mean from the different GCMs is taken. We average each objective across the two SSPs that are more likely to be realized (SSP2-4.5 and SSP3-7.0). Then, the objective is min-max normalized, such that the values for each metric range from 0 to 1, where 0 represents the minimum value and 1 represents the maximum value for the given objective (considering all the export criteria for the mean across the GCMs and two SSPs). Each normalized metric is then multiplied by user-defined weights as outlined in **Table E-1**, and the weighted metrics are summed to get the overall performance of each export criteria.

We sort the export criteria from highest weight to lowest weight, and in **Figure E-1**, we outline the performance of the top 50 export criteria for each of the metrics relative to A1 (existing export criteria) and A2 (no exports). As can be seen, a variety of export criteria allow for substantial dry year type exports while also allowing Mono Lake to recover near to what would result without any exports. It is worth noting that the user-defined post-transition export criteria allows for exports similar (albeit slightly lower) to that of the D-1631 post-transition export criteria while also allowing for Mono Lake recovery similar (albeit slightly lower) to that of the no post-transition export criteria. In other words, based on **Figure E-1** we generally interpret the user-defined post-transition export criteria as leading to the highest likelihood of success in terms of dry year type exports and Mono Lake recovery (relative to the other post-transition export criteria).

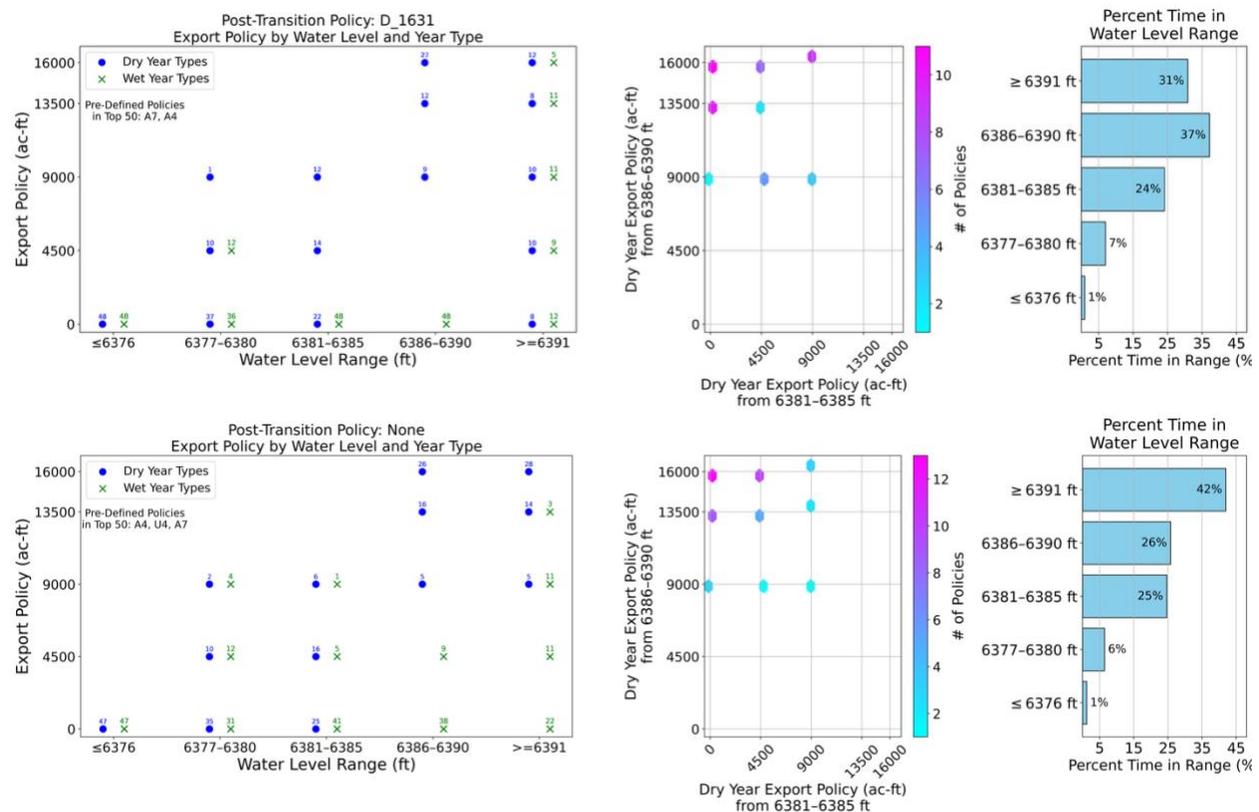


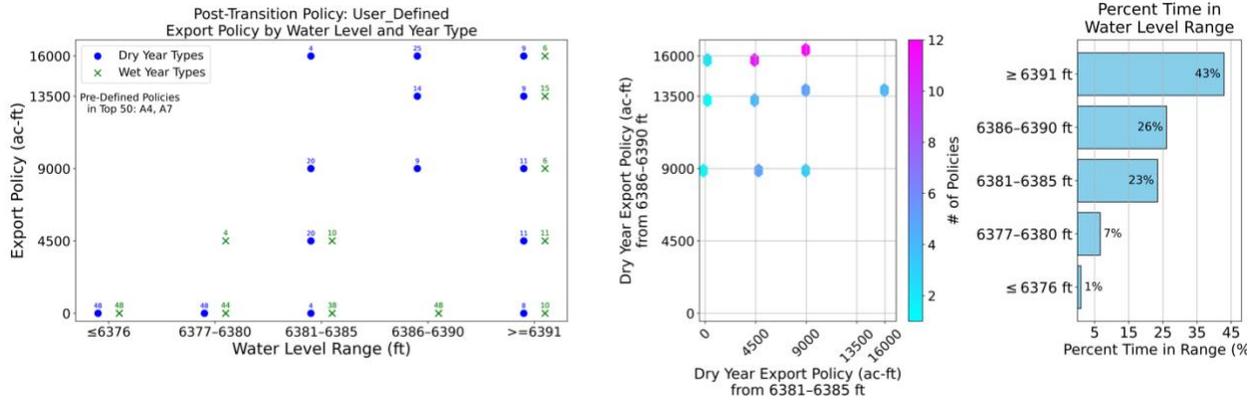
**Figure E-1.** The range of predicted outcomes for Mono Lake levels and exports under the 50 highest performing export criteria. Each column represents results for a different post-transition export criteria (D-1631, None, User-Defined). Predicted outcomes are quantified using seven different metrics which include two export related metrics (Exports and Dry Year Exports) and four lake level related metrics (% Above 6392 ft, % Above 6391 ft, % Above 6388 ft, and % Above 6377 ft). To select the 50 highest performing export criteria, each export criteria was evaluated based on those same metrics and given a score using the multi-objective weighting scheme detailed in Table E-1. The box plot shows the median performance of those 50 export criteria for each metric, with export related metrics shown in red on the left side, and lake level related metrics shown in green on the right side. The top and bottom edge of each box plot indicates the 25<sup>th</sup> and 75<sup>th</sup> percentile of the set and the upper and lower bounds are indicated by the black circles. For comparison, the predicted outcomes for each metric under the transition export criteria (A1; blue diamond) and without exports (A2; orange diamond) are also included.

For each post-transition export criteria, we display the export rules associated with the top 50 performing export criteria in **Figure E-2**. This is intended to highlight the characteristics of export criteria that perform well based on the specified criteria. As the “best” outcome, or best balance between the criteria used in our weighting, is subjective, we don’t intend to single out any specific export criteria. Instead, we intend to provide a sense for the range export criteria characteristics and possible outcomes. Generally, the highest scoring export criteria have low or zero exports at water levels below 6,385 ft, but there are top export criteria that allow up to 9000 ac-ft of exports for these lower water levels. All the top 50 export criteria allow for dry year exports of 9000 ac-ft or above for the water level range of 6,386-6,390 ft, with a large portion allowing for 16000 ac-ft of dry year exports. However, top export criteria that allow higher dry year exports between 6,386-6,390 ft tend to allow lower dry exports between 6,377-6,385 ft and vis-versa, which is demonstrated in the second column of **Figure E-2**. Finally, in the last column of **Figure E-2**, we

show the percent of time the projections are in different water level ranges that correspond to the transition export criteria considered. We include this to serve as a reference for understanding which water level ranges are actually relevant with respect to the export criteria. For example, only 6-7% of the time cumulatively for all GCMs is spent at water levels between 6,377-6,380 ft, which may result in export criteria with anomalous exports for this water level range falling within the top 50.

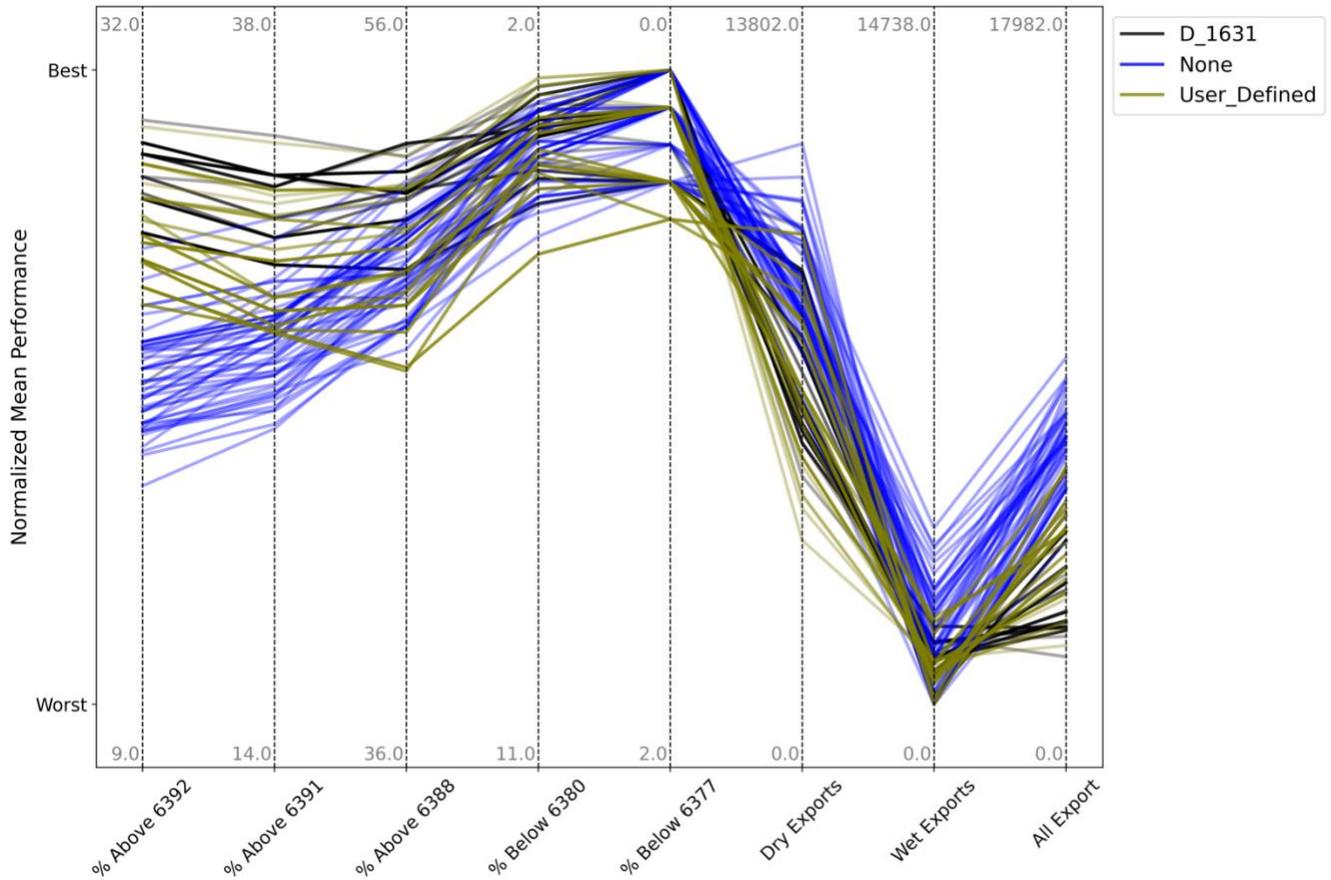
Figure E-3 shows the normalized performance for the top 50 export criteria associated with each post-transition export criteria for the criteria in Table E-1 in the form of a parallel coordinate plot. As expected, export criteria that perform better for the metrics associated with lake levels have lower exports, but there are export criteria that perform well for the lake level metrics and allow for higher dry year exports. This plot also shows that even within the top 50 export criteria based on a single metric weighting, there is a substantial range of outcomes and a variety of different ways to balance performance across the different metrics. It also appears that the User Defined post-transition export criteria presents the greatest opportunity for export criteria that perform well across all criteria. This set of top 50 export criteria includes export criteria with some of the best outcomes for lake recovery while still allowing for some exports, especially in dry years.





**Figure E-2.** Key characteristics of the 50 highest performing export criteria. Each row represents results for a different post-transition export criteria (D-1631, None, User-Defined). Export criteria are designed to limit the allowed exports for each year using a combination of the lake’s water level and recent hydrologic conditions. The export criteria framework used for this exercise, specifically, allows different amounts of exports (either 0, 4500, 9000, 13500 or 16000 ac-ft) for each combination of five water level ranges ( $\leq 6376$  ft, 6377-6380 ft, 6381-6385 ft, 6386-6390 ft, and  $\geq 6391$  ft) and two hydrologic conditions (dry year types and wet year types). The left column shows where the 50 highest performing export criteria (the same used in Figure E-1) fall within this framework. For each export criteria in this set, the markings show the amount of exports allowed (y-axis) for each water level range (x-axis) during dry year types (blue circles) and wet year types (green x’s). The number of export criteria represented by each mark is indicated above it. The second column shows how those 50 highest performing export criteria balance allowed exports across different water levels. For each export criteria, the allowed exports during dry year types for 6381-6385 ft (x-axis) and 6386-6390 ft (y-axis) are plotted against each other. The color of the mark indicates the number of export criteria it represents, with warmer colors corresponding to greater numbers. The plot in the right column shows the percent of time (x-axis) the lake is predicted to spend in each water level range (y-axis) under the 50 highest performing export criteria. This is included to provide some insight into the relative importance of different export criteria features (i.e. how often the conditions needed to trigger a certain piece of the export criteria will actually occur).

### Performance of Top 50 Export Criteria based on Multi-Objective Weighting



**Figure E-3.** Normalized performance (across all 50,000 export criteria) of the 50 highest performing export criteria. Normalized performance (y-axis) is shown for eight metrics, represented by the vertical dotted lines, with the five lake level related metrics (% Above 6392 ft, % Above 6391 ft, % Above 6388 ft, and % Above 6377 ft) on the left and the three export related metrics (Dry Exports, Wet Exports and All Export) on the right. Each of the 50 export criteria are represented by a single line, and its predicted normalized performance for each metric is indicated by where it intersects the corresponding vertical dotted line. Intersecting higher indicates better performance and intersecting lower indicates worse performance. For each metric, the best outcome across all 50,000 export criteria is written in gray at the top of the plot and the worst outcome is written in gray at the bottom of the plot. The color of the line represents results for different post-transition export criteria (black for D-1631, blue for None, and green for User-Defined).