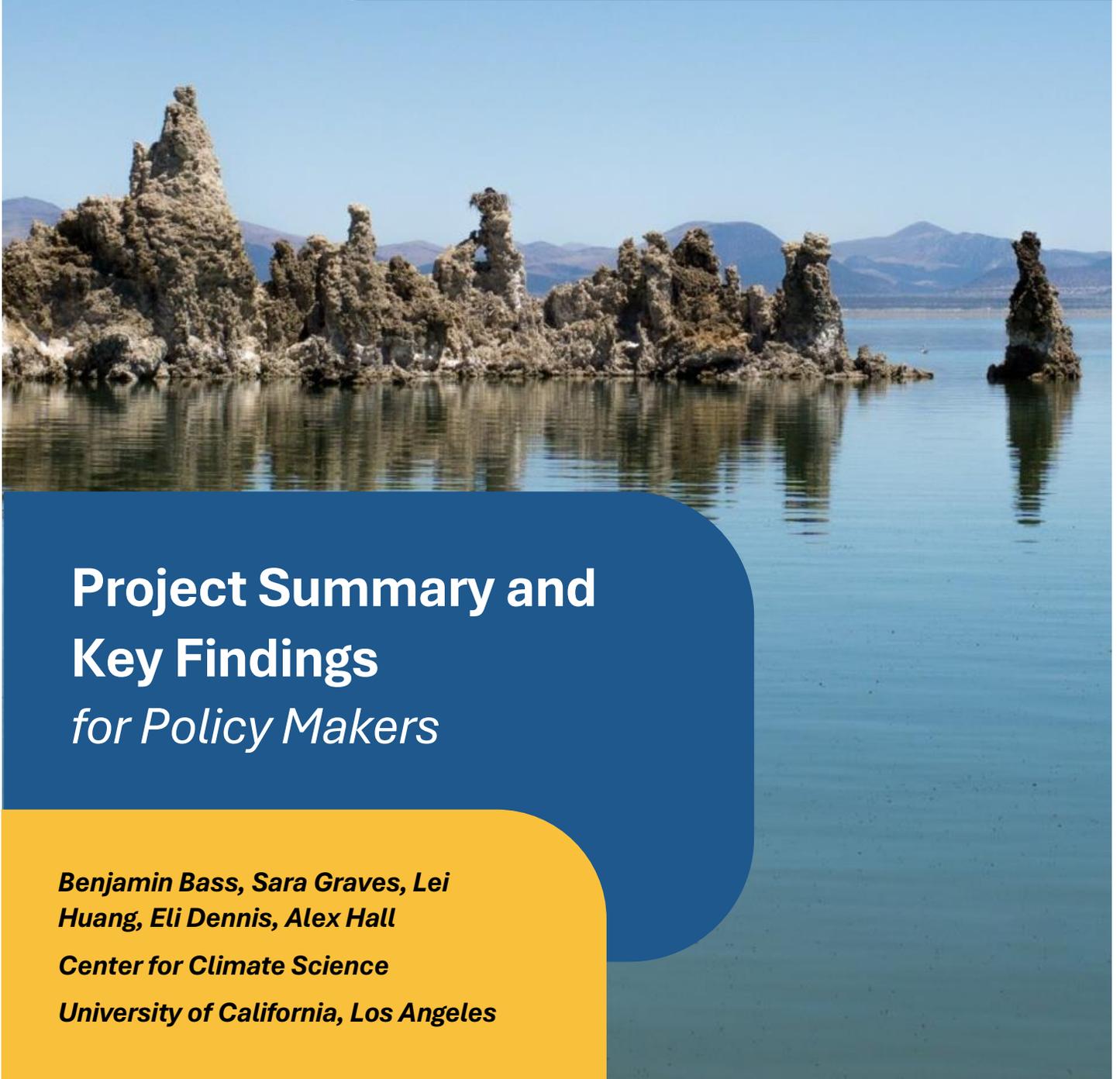


# Mono Lake in a Changing Climate



## Project Summary and Key Findings *for Policy Makers*

***Benjamin Bass, Sara Graves, Lei  
Huang, Eli Dennis, Alex Hall***

***Center for Climate Science***

***University of California, Los Angeles***

# Overview of Resources

## ***Project Summary and Key Findings for Policy Makers***

This report provides a more succinct and accessible overview of the methods and important takeaways from using the University of California, Los Angeles Mono Lake Model (UCLA-MLM) to study Mono Lake's water level for varying export and climate conditions. This is also intended to be a summary of the main report. This summary was created for policy makers, organizers, community advocates and members of the public.

## ***Main Report***

The Main Report provides a more extensive overview of the study area, the datasets and methods used to represent Mono Lake's water budget, and the impact of exports and climate change on Mono Lake's water level. The main report is roughly 100 pages long.

## ***Appendix***

The Appendix is primarily referenced throughout the main report and contains details and figures that may be of interest to technical experts but are not necessary to understand the overall workflow and findings outlined in the main report.

## ***UCLA Mono Lake Model Access***

The UCLA MLM is a complex, technical tool that incorporates climate projections and detailed hydrologic processes. It was developed for use by scientists, engineers, and water-management professionals with experience in climate and hydrologic modeling and familiarity with the broader ecological challenges facing Mono Lake. As such, the model is not intended for general public use or simplified interpretation. To support transparency and understanding, summaries and key findings are provided to explain what the model shows and how it informs management decisions.

The UCLA MLM is accessed through a User Interface, which will be made available to interested parties by request. The SWRCB may also coordinate sessions to demonstrate UCLA-MLM use and functionality.

# Definitions

**6,391 ft:** This is the transition water level that was intended to be reached approximately 20 years after D-1631, which was adopted by the SWRCB in September 1994. When this water level is reached, the post-transition export criteria go into effect.

**6,392 ft:** This is the average long-term target water level determined in D-1631 to protect public trust resources at Mono Lake.

**Amended Licenses:** The authority to divert water goes back to 1940. D-1631 provided master requirements, and the amended licenses formalized the new conditions under which LADWP could divert water from the Mono Basin, incorporating environmental protections and revised flow requirements for the streams feeding Mono Lake. State Water Board Orders WR 98-05 and 98-07 required LADWP to implement restoration, monitoring and Grant Lake Reservoir operation plans as part of a Stream Restoration and Monitoring Program. State Water Board Order WR 2021-0086 Amended Licenses 10191 and 10192 incorporated the 2013 Mono Lake Basin Restoration Settlement Agreement between LADWP and interested parties.

**Bias Correction:** Process of adjusting model outputs to remove systematic errors (bias) so that the results more accurately reflect observed or true values.

**CA5:** California Fifth Climate Assessment. A comprehensive, state-led research initiative designed to advance actionable science and strengthen understanding of local climate impacts in California. Mandated by Senate Bill 1320, it provides updated data, models, and nine regional reports to guide policies, investments, and community-led resilience actions across California. This report primarily refers to the dataset from CA5, which was used for analysis this study.

**Climate Change:** Climate change refers to statistically significant, persistent changes in the mean state and variability of the climate system over decades or longer, resulting from internal variability inherent to the climate system and/or from changes in external anthropogenic forcings (e.g., greenhouse gas emissions, aerosol emissions, and land-use and land-cover change).

**CMIP6:** The sixth phase of the Coupled Model Intercomparison Project, providing climate model simulations to study past, present, and future climate changes.

**D-1631:** The SWRCB decision adopted in 1994 required LADWP to reduce the amount of water it diverted from the Mono Basin in order to restore Mono Lake to an average elevation of 6,392 ft. D-1631 states, “This decision also amends Los Angeles’ water right licenses to

include specified water diversions criteria which are intended to gradually restore the average water elevation of Mono Lake to approximately 6,392 ft above mean sea level in order to protect public trust resources at Mono Lake.”

**Downscaling:** A method for deriving high-resolution climate data from coarse global climate models (GCMs).

**Emission Scenario:** A pathway of projected levels of greenhouse gas emissions over time, which for CMIP6 are based on socioeconomic scenario pathways (SSPs). A range of intermediate to very high emission scenarios are assessed in this report since the actual emission scenario that will occur is unknown.

**ERA5:** ERA5 is the fifth-generation global atmospheric reanalysis dataset produced by the European Centre for Medium-Range Weather Forecasts (ECMWF). It provides 31 km resolution, consistent, and comprehensive estimates of historical weather and climate variables by assimilating a vast array of observations into numerical weather prediction models. See “Reanalysis.”

**ERA5-WRF:** A 3 km version of ERA5 produced by the UCLA Center for Climate Science and UC Scripps. ERA5-WRF was developed using a numerical weather model (Weather Research Forecasting, WRF) to downscale ERA5 from its native 31 km resolution to a 3 km resolution using physics-based mass and conservation representation of the atmosphere and its land-surface interactions. This downscaling process was followed by bias corrections to precipitation, temperature, wind, shortwave solar, and humidity stations available throughout California.

**Exports:** Surface water exports are made by diverting water from tributary streams that would otherwise flow into Mono Lake. The diverted water is stored in Grant Lake Reservoir, with some of that water being diverted out of the basin via the Mono Craters Tunnel. Exports out of the basin are directed into the Owens River and then the Los Angeles Aqueduct. Exports include surface water exports and groundwater exports; however, unless otherwise stated, exports is used to refer to surface water exports.

**Export Criteria:** Export criteria determine the maximum amount of water in acre-feet that LADWP can export in a runoff year. Export amounts are determined by current D-1631 criteria. While groundwater exports can occur via the Mono Craters Tunnel, the export criteria is assumed to apply to surface water exports.

**Four-Creek Flow:** The combined flow from Lee Vining, Walker, Parker, and Rush Creek which determines the runoff year type.

**GCMs:** Global Climate Models (also referred to as General Circulation Models), which are complex mathematical models used to simulate Earth's climate system and estimate climate change.

**Hydrology Model:** Here, a physics-based hydrology model is used to simulate the processes governing the fluxes and storages of water within the hydrologic cycle across spatial and temporal scales. This model is used to represent the land surface response to meteorological forcing and to evaluate the effects of climate change on natural runoff conditions throughout the Mono Basin. This provides a critical term for the Mono Lake Water Budget Model. Human alterations are represented in the Water Budget Model, but not the hydrology model.

**Hydroclimate Projections:** This term is used throughout the report to reflect global climate model (GCM) projections of precipitation, evaporation, and runoff conditions throughout the Mono Basin, which influence Mono Lake water level.

**IFR:** Instream flow requirements, including stream restoration flows (SRF) and stream ecosystem flows (SEF). These requirements ensure that sufficient water remains in the natural system to sustain the health and function of aquatic ecosystems.

**Internal Variability:** Natural fluctuations (e.g. El Niño Southern Oscillation) in the climate system that occur without external forcings (changes in the Earth's energy budget) like greenhouse gas emissions or volcanic eruptions.

**LADWP:** The Los Angeles Department of Water and Power is the municipally owned utility of the City of Los Angeles, responsible for the generation, transmission, and distribution of electricity and the supply, treatment, and delivery of potable water. LADWP exports a portion of the water from the Mono Basin to provide a portion of the water supply for the City of Los Angeles.

**Lee Vining Conduit:** The Lee Vining Conduit, completed in 1941, diverts water from Lee Vining Creek into Grant Lake. This water then flows towards Mono Lake or out of the Mono Basin via the Mono Craters Tunnel. Historically, the Lee Vining Conduit also diverted water from Walker and Parker Creek; however, stream ecosystem flows no longer allow diversions from Walker and Parker as of 2020.

**Likelihood:** The likelihood or probability of a condition occurring is assessed by the percentage of GCMs that agree on a specific change. This metric is commonly used to evaluate the likelihood of being at or above a particular water level. Descriptions of likelihoods presented throughout the report are based on numeric ranges used by the IPCC and the National Climate Assessment (Table 3-2).

**LOCA2-Hybrid:** Statistical downscaling technique called Localized Constructed Analogs version 2 (LOCA2) that is trained on dynamically downscaled GCM data from WRF. This report uses atmospheric projections produced from this method at a 3 km resolution.

**Modeled Observations:** Representation of observed atmospheric and hydrologic conditions that occurred across the Mono Basin from 1955 to 2020 (see ERA5-WRF).

**Model Resolution:** Atmospheric data are typically produced at the global scale with coarse spatial resolution (e.g., grid spacing on the order of ~100 km). Downscaling is a method used to derive higher-resolution atmospheric information (e.g., grid spacing on the order of ~3 km) for specific regions of interest by dynamically or statistically refining coarse-resolution model outputs.

**Mono Craters Tunnel:** An 11 mile long, roughly 9 ft diameter tunnel completed in 1939. This tunnel exports water from the Mono Basin that would otherwise naturally flow into Mono Lake. The Mono Craters Tunnel also intercepts and exports roughly 5,500 acre-feet/year of groundwater sourced from the Mono Basin.

**Mono Lake Technical Working Group (MLTWG):** Meetings which included technical experts from several participating organizations, including LADWP, MLC, CDFW, and the SWRCB. Over 12 technical group meetings were held to discuss how to simulate Mono Lake, evaluate its recovery, and to develop export criteria alternatives to consider from September 2023 and April 2024.

**MLWB:** Mono Lake Water Budget Model. This is the water budget model of Mono Lake developed by UCLA CCS and described in this report.

**MBOP:** Mono Basin Operations Plan, developed and written by LADWP to provide guidelines for LADWP operations in the Mono Basin as a part of the requirement from the 2013 Mono Basin Settlement Agreement and further SWRCB Amended Licenses.

**Natural Runoff:** The flow of water that would occur in a watershed basin without human alterations, such as damming, diversions, or other infrastructure. It is an idealized measure of the water generated by natural processes, assuming no human interference. Natural runoff is approximately the same as unimpaired runoff.

**Transition Criteria:** Criteria outlining allowed LADWP surface water exports until Mono Lake reaches 6,391 ft. These criteria were set in D-1631. Once this water level is reached, the post-transition export criteria go into effect.

**Post-Transition Criteria:** Criteria outlining allowed LADWP exports once Mono Lake reaches the transition water level of 6,391 ft. These criteria were set in D-1631. The post-transition expectation is to ensure a long-term average water level of 6,392 ft.

**Reanalysis (ERA5):** Reanalysis data, such as ERA5, is created by feeding historical observations (from satellites, weather stations, and other sources) into a numerical weather model, providing detailed data on atmospheric, land, and oceanic conditions over time. Reanalysis data can provide a more comprehensive set of climate variables than observed data and is more geographically and temporally complete and consistent.

**Recovery:** An increase in Mono Lake's water level. Broadly used in the context of Mono Lake's water level being higher than the April 1<sup>st</sup>, 2024 water level of 6,383.7 ft.

**Regulated/Impaired Flow:** The flow of water includes modifications to that flow made by human structures, such as dams or reservoirs for purposes like irrigation, flood control, or hydropower.

**RY:** Runoff Year, which occurs from April 1<sup>st</sup> YYYY to March 31<sup>st</sup> YYYY+1

**RYT:** Runoff Year Type, which includes seven year types that were defined in MBOP: Dry, Dry-Normal I, Dry-Normal II, Normal, Wet-Normal, Wet, and Extreme-Wet. Runoff year types are defined based on four-creek flow conditions. In this report RYTs were simplified to six year types by combining the range of flow conditions experienced in Dry-Normal I and Dry-Normal II since their total annual flow requirements are roughly the same.

**SSP:** Shared Socioeconomic Pathways, which are scenarios used to project future climate change based on a range of potential future socio-economic choices and their impact on greenhouse gas emissions, climate change mitigation and other climate impacts.

**UCLA-MLM:** UCLA Mono Lake Model, which includes both the hydroclimate forcing data and water budget model developed to represent Mono Lake water level.

**Water Budget Model:** A modeling tool used to quantify the movement of water through a system (usually a watershed or basin) by representing each component of the system's inflow (or supply) and outflow (or demand). The basic components usually include precipitation, evaporation, natural runoff and changes in storage.

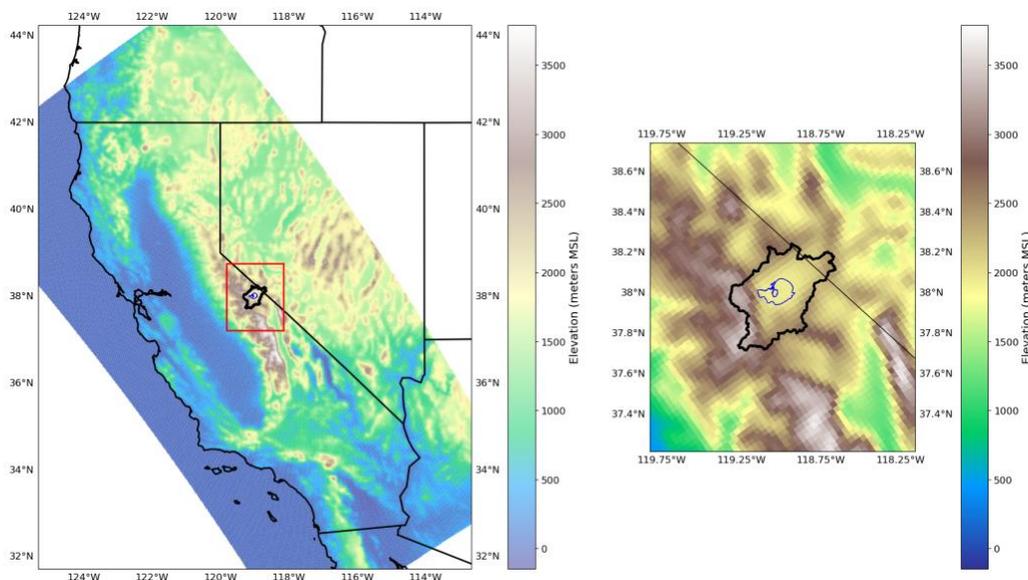
**Wrapped Runs:** Approach in which historical conditions as they were observed are reevaluated by considering how Mono Lake water level would have evolved with a different start year. For example, rather than solely evaluating 1971 to 2020 hydroclimate conditions as they actually occurred, a wrapped run will also include 1972-2020, 1971; 1973-2020, 1971-1972; etc. For a range of years like 1971 to 2020, this leads to 50 unique hydroclimate sequences. This approach shows how Mono Lake water level conditions respond to variations in weather, thus approximating the influence in internal variability.

# Introduction

Mono Lake is a terminal lake in California's Eastern Sierra Nevada that is important both ecologically and societally. It is sustained by precipitation and runoff within the Mono Basin and has no natural outlet, making evaporation its primary natural water loss mechanism. The lake is known for its striking limestone formations, called Tufa towers, and its unique ecosystem, which supports a large population of brine shrimp and alkali flies that provide food for migratory birds and nesting California gulls. The lake has long held cultural importance to the Kootzaduka'a tribe, and more recently, has become an important recreation site and tourist attraction.



Figure 1 : Map of the Mono Basin



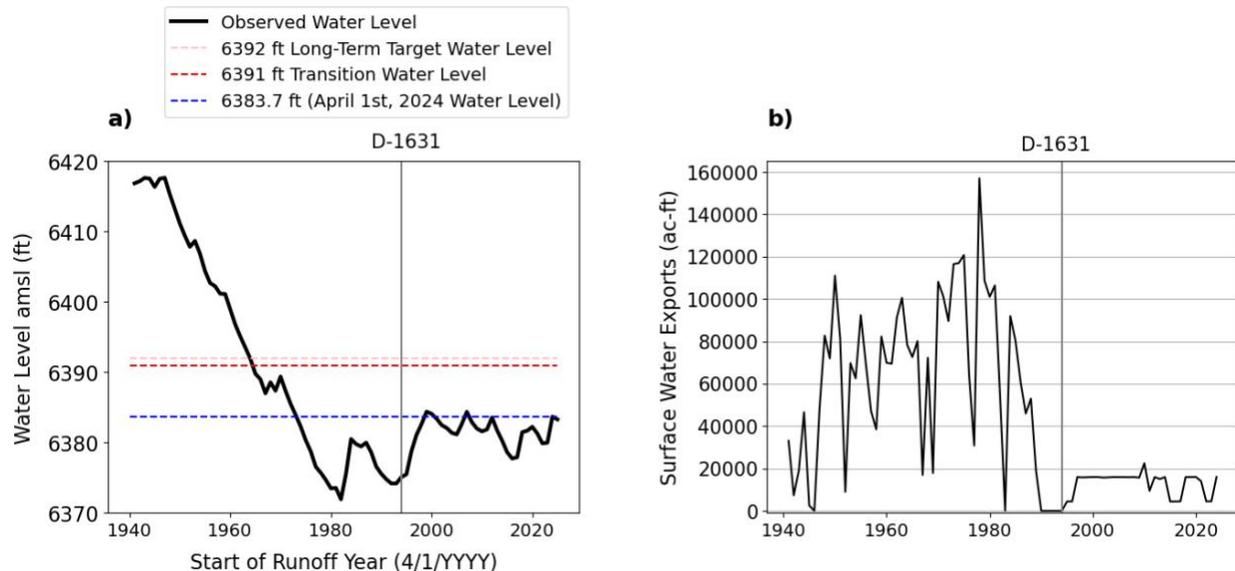
**Map of California Showing the Location of the Mono Basin and Mono Lake.** Colors represent elevation (meters). Red outline depicts the zoomed-in bounds shown in the right figure. The Mono Basin includes a mountainous high-elevation portion at its western edge that separates the Western Sierra Nevada from the Eastern Sierra Nevada mountains. The majority of runoff that flows into Mono Lake comes from the Sierra Nevada portion of the Mono Basin. The rest of the Mono Basin contains mountain terrain with a gently sloping gradient surrounding Mono Lake.

## Historical Context

In the late 1930s and early 1940s, the Los Angeles Department of Water and Power (LADWP) built a system of conduits, reservoirs, and tunnels to export water from the Mono Basin. Since 1941, LADWP has diverted varying amounts of surface water from the Mono Basin into the Owens River and subsequently into the Los Angeles Aqueduct, which delivers water to the City of Los Angeles. From 1941 to 1989, these diversions drastically reduced inflow into Mono Lake, which led to more than a 40 ft drop in the lake's water level and roughly a 50% reduction in its volume.

These reductions increased the lake's salinity and modified its shorelines, which degraded vital habitats, threatened the lakes ecosystem, and caused air quality issues stemming from exposed lakebed dust. In response, *National Audubon Society v. Superior Court* (1983) 33 Cal.3d 419 expanded the definition of California's public trust doctrine, which protects environmental resources for public benefit, to include streams flowing into navigable waterways, even if water rights were already allocated to such streams. The California Supreme Court held that the state has a duty to take the public trust into account in the planning and allocation of water resources and to protect public trust uses when feasible. Even after an appropriation has been approved, the public trust imposes a duty of continuing supervision.

**Figure 2: Observed Mono Lake Level and Exports**

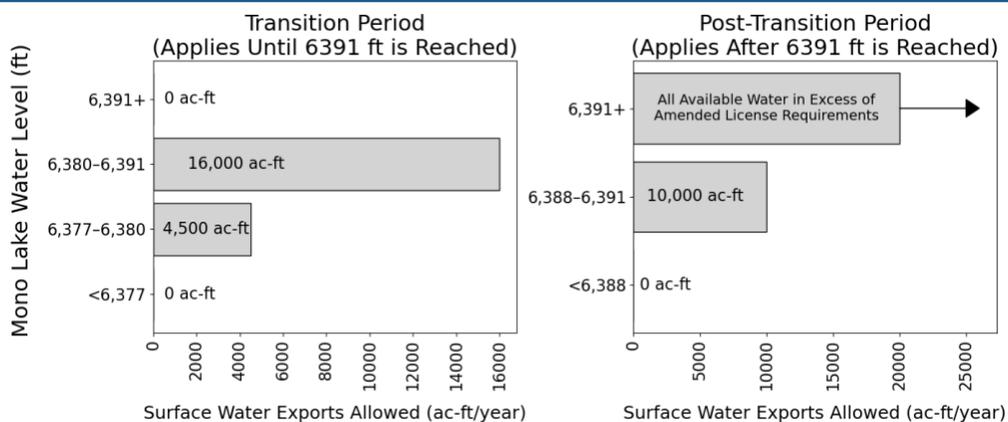


**Mono Lake Water Levels and LADWP Exports from 1940 to 2024.** Figure 2a shows changes in Mono Lake's water level since LADWP exports began, with relevant water levels included as dashed horizontal lines. Figure 2b shows LADWP surface water exports. Both figures include the year D-1631 was adopted (September 1994) as a vertical grey line.

*Decision 1631* (D-1631). A target water level for Mono Lake was established with insights from experts and community members. D-1631 ultimately concluded that maintaining Mono Lake at an elevation of 6,392 ft would adequately protect air and water quality, habitat for migratory birds, and recreational and scenic values, while still allowing for some municipal water for LADWP. At the time of the decision, the lake level was roughly 6,375 ft.

D-1631 outlined a two-part plan which established a set of criteria limiting LADWP exports from the Mono Basin, referred to as *export criteria*. During the first period, or the **Transition Period**, the objective was to gradually raise the lake level to 6,391 ft within 20 years. Once this occurred, the second period, or **Post-Transition Period**, would be initiated, with the goal of maintaining an average water level of 6,392 ft. D-1631 Transition and Post-Transition export criteria are collectively referred to as the **Existing Export Criteria**.

**Figure 3: The Existing Export Criteria Defined Under D-1631**



**Descriptions of Transition (left figure) and Post-Transition (right figure) Export Criteria.** Annual surface water exports allowed by LADWP per D-1631, established in September 1994. Note, the arrow for a water level of “6,391+” in the right figure, indicates that any amount of water can be exported when water levels are above 6,391 ft as long as the Amended Licenses requirements (e.g. instream flows) are met.

## Mono Lake Today

**More than 30 years after D-1631 was adopted, the lake has not reached the 6,391 ft transition threshold, measuring 6,383.3 ft as of April 1st, 2025.** In D-1631, it was prescribed that the failure to reach an elevation of 6,391 ft in 20-years (by September 28<sup>th</sup>, 2014) would prompt the SWRCB to hold a hearing to reconsider the condition of Mono Lake and the existing export criteria. In 2022, Mono Lake dropped to roughly 6,378.5 ft, prompting urgent requests from the Mono Lake Committee (MLC), the Mono Lake Kootzaduka'a Tribe, and the California Department for Fish and Wildlife (CDFW) for the SWRCB to take immediate action to prevent further lake declines. Although above average precipitation in water year 2022-2023 helped the lake rebound to slightly above 6,383 ft, it remains nearly nine ft below the target water level of 6,392 ft required by D-1631. Mono Lake's inability to recover, despite LADWP's adherence to the export criteria in D-1631, raises concerns about the suitability of the existing export criteria, particularly in the context of changing climate conditions.

### Project Overview

In light of the SWRCB's ongoing responsibility to protect public trust resources and support Mono Lake's recovery, the SWRCB recognized that understanding the impact of historic and future climate change on Mono Lake would be vital to evaluating Mono Lake's ability to reach the D-1631 water level objectives. To address this knowledge gap, the SWRCB contracted the University of California, Los Angeles (UCLA) Center for Climate Science (CCS). The SWRCB selected UCLA CCS for its expertise in climate and water resource modeling, particularly its ability to produce state-of-the-art climate projections and apply them to assess climate-driven changes in regional water systems. To support the work of the SWRCB, UCLA CCS was tasked with developing a model of Mono Lake capable of incorporating the impacts of climate change and export criteria scenarios.

In collaboration with the SWRCB as well as other technical experts, UCLA CCS developed the UCLA Mono Lake Model (UCLA-MLM), the first Mono Lake model specifically developed to simulate and evaluate Mono Lake levels in the context of climate change. UCLA-MLM was created to assess how climate-driven changes in precipitation, evaporation and runoff could influence Mono Lake's water level throughout the 21<sup>st</sup> century, and to serve as a tool for evaluating the ability of Mono Lake to recover under existing and alternative export criteria.

After developing UCLA-MLM, UCLA CCS carried out a quantitative evaluation of Mono Lake's ability to recover under past and projected climate conditions, with existing and alternative export criteria. This work aims to support informed decision making for the

management of Mono Lake in the context of climate change through the exploration of several central scientific questions:

<b>What factors have limited Mono Lake’s ability to meet D-1631 water level objectives?</b>	How much as climate change already impacted Mono Lake’s water level?
	How have exports under the Existing Export criteria impacted Mono Lake’s water level?
<b>How will climate change impact Mono Lake’s future water level conditions?</b>	How will components of the Mono Lake water budget be impacted by climate change?
	How do future outcomes change for different emission scenarios?
<b>How will exports impact Mono Lake’s future water level conditions?</b>	What is the likelihood of Mono Lake meeting D-1631 water level objectives with the Existing Export criteria and No Exports?
	Is there an alternative export criteria that can meet D-1631 water level objectives will also allowing for exports?

## Document Overview

**A summary of the key findings and important takeaways from the evaluation carried out by UCLA CCS is presented here.** This summary report is intended for policy makers, organizers, community advocates and members of the public who have a vested interest in Mono Lake.

The following section, **Methods Overview**, contains a brief description of methods used to conduct this research. This information is included to aid in the interpretation of the results. After this, the most significant results are presented in **Key Findings**, along with a summary of important conclusions.

# Methods Overview

UCLA-MLM simulates changes in Mono Lake’s water level on an annual timescale under past climate conditions and projected future climate conditions, outputting the predicted lake level for April 1<sup>st</sup> of each year. Unlike existing approaches that rely solely on historical data, which may no longer reflect the current or future state of the climate, this model integrates climate change projections that account for past and future human greenhouse gas emissions. In addition, UCLA-MLM simulates Mono Lake surface water exports using a flexible framework that allows for the application of various export criteria, enabling an integrated evaluation of the impacts of climate conditions and exports on Mono Lake levels.

## Climate Data

The primary natural components that impact Mono Lake’s water level are precipitation, evaporation and runoff. These components depend on atmospheric and hydrologic conditions across the Mono Basin and can be represented using climate data.

This study uses climate model datasets to evaluate both historic and future conditions affecting Mono Lake. Because the analysis spans observations, future climate conditions, and past climate conditions, it relies on three distinct types of climate model datasets: **(1) Modeled Observations**, representing past conditions as they actually occurred **(2) Future Projections**, representing future climate conditions, and **(3) Historical Simulations**, representing historic climate conditions.

### Modeled Observations

Observed conditions are simulated using the ERA5 reanalysis dataset. The term *reanalysis* refers to a scientific method for reconstructing observed climate conditions using a modeling framework. By combining observations with global weather models (like ERA5), a dataset can be produced that matches observed weather conditions, but with the uniform structure of a model dataset.

## Future Projections

In this study, future conditions for the years between 2015 and 2100 were represented using a total of 33 different climate model projections. This includes projections from 11 different Global Climate Models (GCMs) and three greenhouse gas emission scenarios. This GCM Ensemble captures a range of potential future climate conditions, which is critical to carrying out a robust climate change analysis.

## Historical Simulations

GCMs can also be used to model historical climate conditions. During these historical simulations, GCMs are simulated for the years between 1955 to 2014 using historically observed emissions. By producing multiple reconstructions of historical conditions, the use of historical simulations can provide greater insight into past climate change impacts compared to observations alone. This is particularly important when trying to distinguish long term trends associated with climate change from short term variations in the climate that occur naturally, referred to as internal variability. The same ensemble of 11 GCMs used for future projections are assessed under historical emissions. These are used to simulate historic Mono Basin conditions and assess historical climate change impacts.

## Why use an ensemble of GCMs?

The climate system is incredibly complex, meaning that a single GCM projection may be limited in its ability to represent future climate conditions. As a result, climate scientists use an ensemble that includes various GCMs and various emissions scenarios to represent future conditions. This captures a more complete range of plausible future outcomes and accounts for modeling uncertainties.

### *Multiple GCMs*

Many different GCMs are created and run by research centers around the world, and each of these models takes a slightly different approach to modeling the climate system. Using multiple GCMs is essential for robust climate change analysis, as it captures the range of possible future climate outcomes that can result from these differences. This work uses 11 different GCMs that were selected as a part of California's 5<sup>th</sup> Climate Assessment (CA5). These 11 GCMs were chosen from a broader set of GCMs based on their ability to accurately represent California's hydroclimate.

### *Multiple Emissions Scenarios*

A major source of uncertainty in projecting future climate conditions is human decision making, or how future emissions may evolve based on various societal choices and socio-economic conditions. To account for this, the Intergovernmental Panel on Climate Change (IPCC) created a set of plausible scenarios called Shared Socioeconomic Pathways (SSPs), which capture a range of future emissions. The analysis here uses climate change projections simulated under three different SSPs: an intermediate scenario (SSP2-4.5), an intermediate-high or business-as-usual scenario (SSP3-7.0), and a very high scenario (SSP5-8.5).

# Analysis of Climate Data

Performing analysis with an ensemble of future climate data can present challenges when interpreting the results. The ensemble represents a range of future conditions, which produces an implied range of different outcomes for Mono Lake. Because of this, climate scientists have devised a set of standard statistical methods that are used to assess climate-driven changes. The primary metrics used to evaluate Mono Lake conditions are described below:

**Ensemble Mean:** The mean taken across all 11 GCMs. Generally, in climate science, the ensemble mean is considered to be the most likely outcome.

**Likelihood or Chance:** The likelihood, or chance, of a condition occurring is determined based on the percentage of individual GCMs (out of 11) where that condition is met. The table below outlines the qualitative terms commonly used to describe different likelihood ranges.

Term	Likelihood or Chance (%)
Virtually certain	99 – 100%
Very likely	90 – 100%
Likely	66 – 100%
About as likely as not	33 – 66%
Unlikely	0 – 33%
Very unlikely	0 – 10%
Exceptionally unlikely	0 – 1%

For future conditions, these metrics can be presented as a single value, corresponding to a specific SSP, or as a range of values, representing variation across all three SSPs. When presented as a range, it describes the spread across the three SSPs (usually between SSP2-4.5 and SSP5-8.5).

# Water Budget

UCLA-MLM estimates Mono Lake's changes in annual storage and thus its water level using a water budget. Changes in annual storage are determined by taking the difference between the amount of water that enters the lake (**Inflows**) and the amount that leaves the lake (**Outflows**).

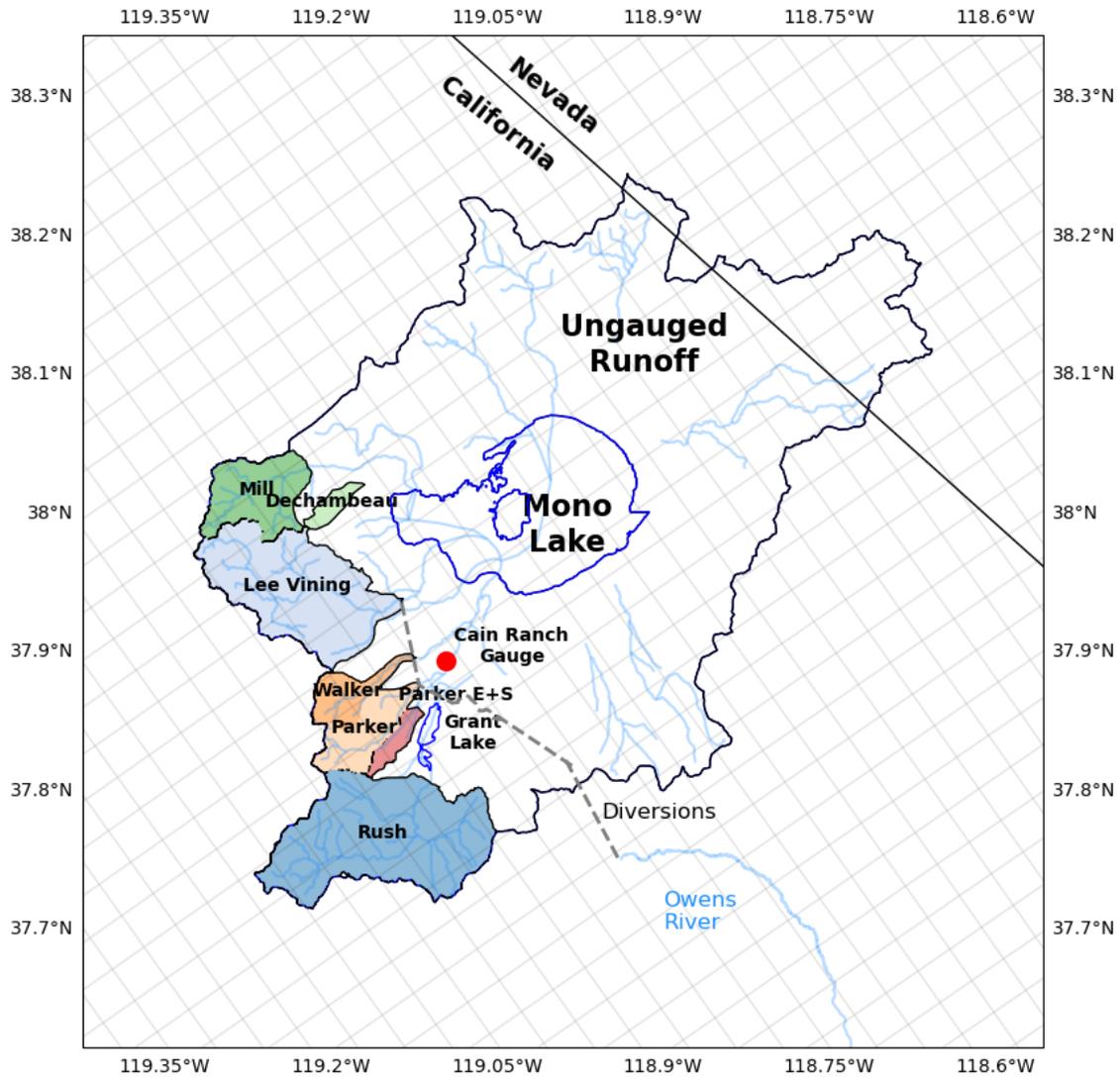
## Inflows

1. **Mono Lake Precipitation:** Precipitation that falls directly into Mono Lake.
2. **Surface Flows:** Surface water that flows into the lake from the surrounding area.
  - a. **Sierra Nevada Runoff:** The primary streams that feed into Mono Lake that originate in a set of sub-basins in the Sierra Nevada.
  - b. **Ungauged Runoff:** Runoff directly into Mono Lake from all other portions of the Mono Basin that are not part of the Sierra Nevada Runoff. The Ungauged Runoff is primarily sourced from small, ungauged sub-basins in the Sierra Nevada and from smaller mountain ranges around Mono Lake.

## Outflows

1. **Mono Lake Evaporation:** Evaporation directly from Mono Lake.
2. **LADWP Exports:** Surface water diverted from Mono Lake tributaries by LADWP. Exports are determined by Export Criteria, which are a set of regulations that dictate the maximum amount that LADWP can export in a given water year, and refer only to surface water exports unless otherwise noted.

**Figure 4: Overview of Water Budget Components and Climate Data Grid**



*The climate data grid and core Mono Basin components used to develop the UCLA-MLM. The light grey grid throughout the study region represents the resolution of the modeling data used (3 km grid cells). Basins with colors and labels represent Sierra Nevada Runoff basins with measured flow data. Diversions (grey dashed line) include approximate location of Lee Vining Conduit and the Mono Craters Tunnel. Light blue lines represent prominent rivers and their tributaries in the Mono Basin, with Owens River additionally shown for reference.*

# Export Criteria

In addition to climate conditions, Mono Lake's water level is sensitive to exports. Surface water exports from the Mono Basin depend on Export Criteria, which are described below. UCLA-MLM is able to evaluate Mono Lake's response to a range of transition and post-transition export criteria under changing climate conditions. The range of export criteria includes the **Existing Export Criteria**, or the set of criteria defined under D-1631, **No Exports** which does not allow any exports, and a proposed list of **Alternative Export Criteria** for both transition and post-transition periods.

Generally, export criteria determine the amount of water LADWP can export in a year based on two main conditions: Mono Lake level and the Mono Basin hydrologic conditions, or how dry or wet a given year is. Exports respond to lake level ranges and the Mono Basin hydrologic conditions which are categorized using six different Runoff Year Types (RYTs) which range from Dry to Extreme-Wet. Export limits are then defined for each combination of the selected lake level ranges and RYTs. As defined by D-1631, each set of export criteria has a transition and post-transition period. The transition export criteria are applied during the period before the lake reaches 6,391 ft and the post-transition export criteria are applied after the lake reaches 6,391 ft. Since the issuance of D-1631, the transition lake level of 6,391 ft has never been reached. As a result, LADWP exports have remained subject only to the transition export criteria. However, UCLA-MLM can simulate the post-transition export criteria if and when the transition lake level is reached in a future scenario.

Alternative export criteria were developed as part of the Mono Lake Technical Working Group (MLTWG) meetings, a technical collaboration including the SWRCB, UCLA CCS, MLC, LADWP, CDFW and other key parties. The alternative export criteria developed by the MLTWG include transition export criteria labeled as A1-A10, where A stands for alternative. A1 is the same as Existing Export Criteria, A2 is the same as No Exports, and A3 through A10 represent a gradient of export criteria between A1 and A2. While the Existing Export Criteria only depends on Mono Lake's water level, A3 through A10 explore export criteria that vary depending on the runoff year type (RYT) in addition to Mono Lake's water level. A few additional post-transition export criteria were additionally evaluated, which are referred to as PT which stands for post-transition.

# Key Findings

## Since D-1631, Mono Lake has faced several major challenges on its path to recovery

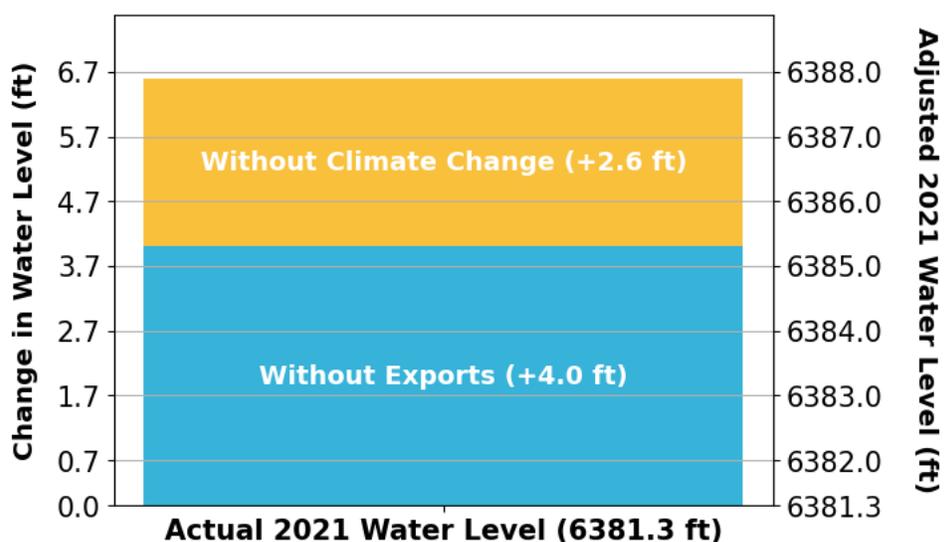
*Historically, exports and climate change have hindered efforts to increase Mono Lake's water level.*

**Exports have slowed increases in Mono Lake's water level.** As of 2021, Mono Lake's water level was still significantly below the transition level, falling roughly 9.5 ft short of 6,391 ft. Between 1994 and 2021 climate model simulations show that exports caused a 4 ft reduction in lake levels.

**Climate change has also likely contributed to Mono Lake's failure to reach the transition water level of 6,391 ft.** The ensemble mean from the 11 climate models indicate that climate change has reduced Mono Lake's water level since D-1631 went into effect. By 2021, this amounted to a loss of roughly 2.6 ft.

**Collectively, climate change and exports are responsible for an almost 6.6 ft decrease in Mono Lake water levels since 1994.** This means that, without both factors, Mono Lake would likely be much closer to the transition water level, with simulated 2021 water levels nearly 6,388 ft.

Figure 4 : Factors Impacting Historical Mono Lake Levels (1994-2021)



*This figure illustrates the impact of climate change (in yellow) and exports (in blue) on Mono Lake water levels between 1994 and 2021 by showing how much 2021 water levels would have changed in their absence. The impact of exports are determined by comparing 2021 water levels resulting from modeled observations (ERA5-WRF) with and without exports. The impact from climate change is estimated by simulating the GCMs with and without climate change. Water level values are based off the GCM ensemble mean.*

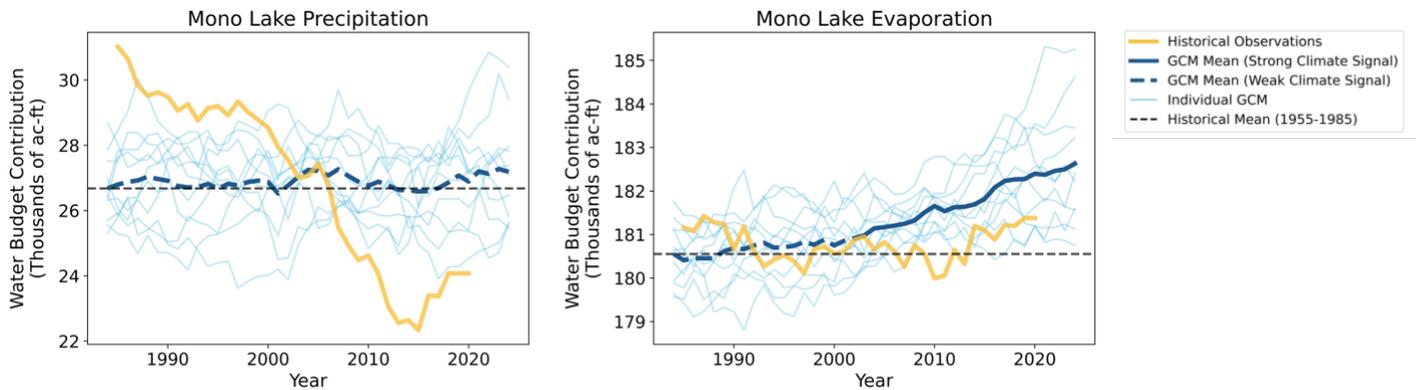
## Climate Change in the Mono Basin

### ***How has climate change impacted Mono Lake's water budget?***

Over the past few decades, climate change has altered Mono Lake's water budget, or the amount of water entering and leaving the lake. Recent observed trends show that the amount of water evaporating out of Mono Lake is increasing. Climate model simulations over these same years demonstrate similar trends, indicating that this increase in evaporation is caused by climate change. These evaporation increases appear to be the primary driver of the historic lake level reductions associated with climate change.

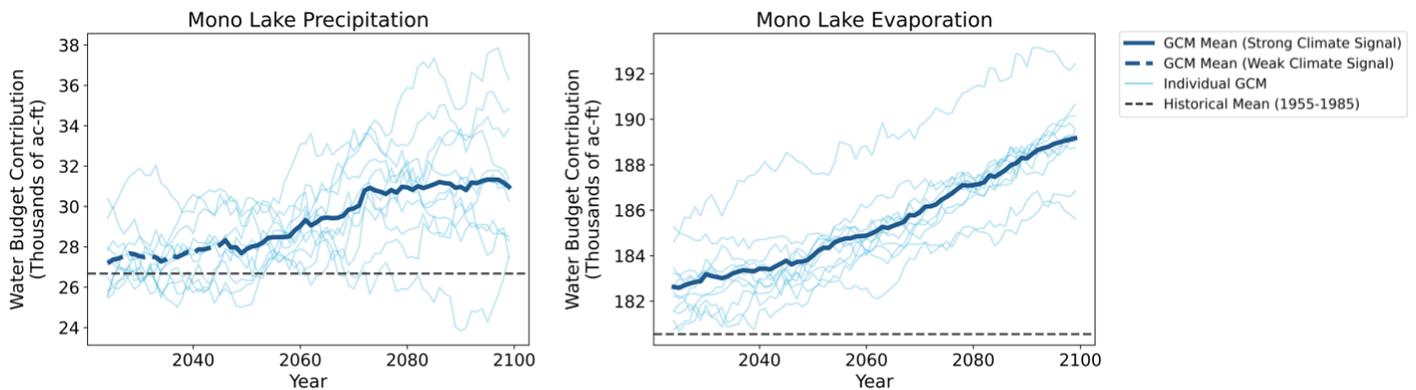
While other parts of Mono Lake's water budget also demonstrate recent observed trends, these changes do not appear to be related to climate change. For example, the amount of precipitation falling on Mono Lake in recent years has been significantly below average, however, this trend is not observable in climate models. This suggests that it is unlikely this change was caused by climate change. These dry precipitation conditions were likely caused by naturally occurring fluctuations in weather, or internal variability.

**Figure 5 : Impacts of Historical Climate Change on Mono Lake's Water Budget**



***This figure shows how different components of Mono Lake's water budget have historically been altered by climate change. Changes in Mono Lake Precipitation and Evaporation are represented for the years between 1985 and 2024 using an ensemble of GCMs simulating historical climate conditions. The light blue lines represent each individual GCM and the dark blue line represents the GCM ensemble mean, with a dotted line indicating a weak climate signal and a solid line indicating a strong climate signal based on two-thirds of the GCMs agreeing on the direction of change. The yellow line shows modeled observations for the years between 1985 and 2021.***

**Figure 6 : Impacts of Future Climate Change on Mono Lake's Water Budget**



***This figure shows how different components of Mono Lake's water budget will be altered by future climate change. Changes in Mono Lake Precipitation and Evaporation are estimated for the years between 2024 and 2100 using an ensemble of GCMs simulated under SSP2-4.5. Other emission scenarios lead to larger changes.***

# Future climate change will pose a substantial barrier to Mono Lake's recovery

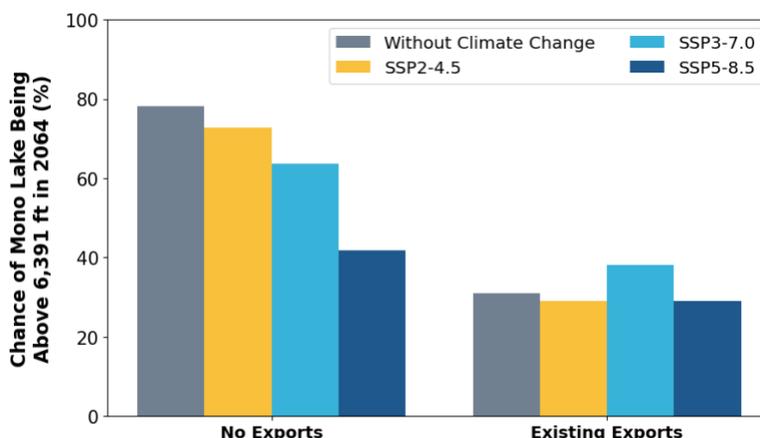
**... even without future exports.**

Climate change will continue to hinder recovery efforts as its impacts intensify over the coming decades. By the end of the century, climate change could reduce lake levels by as much as 6.5 ft, posing a challenge to Mono Lake's ability to achieve the water level objectives outlined in D-1631. Even without any future exports, there is less than a 3 in 4 chance that Mono Lake water levels will be above 6,391 ft by the middle of the century. If future climate change is more severe, the chances of being at or above 6,391 ft by the middle of the century could be as low as 1 in 2.

***If the existing export criteria continues, meeting D-1631 water level objectives will be unlikely.***

If current export criteria remain unchanged, future exports from Mono Lake will decrease the chance of being above 6,391 ft even further. Under the Existing Export criteria, the chances of Mono Lake being at or above 6,391 ft by the middle of the century are low—about 1 in 3. This suggests that if the Existing Export criteria continue, meeting the water level objectives of D-1631 will be unlikely.

**Figure 7: Chances of Mono Lake being at or above 6,391 ft**



***This figure compares the chances of Mono being at or above 6,391 ft in 2064 for No Exports (left) and with Existing Exports (right). Climate change impacts on Mono Lake's water level can only be characterized under No Exports because the existing export criteria tends to mask natural changes in lake level.***

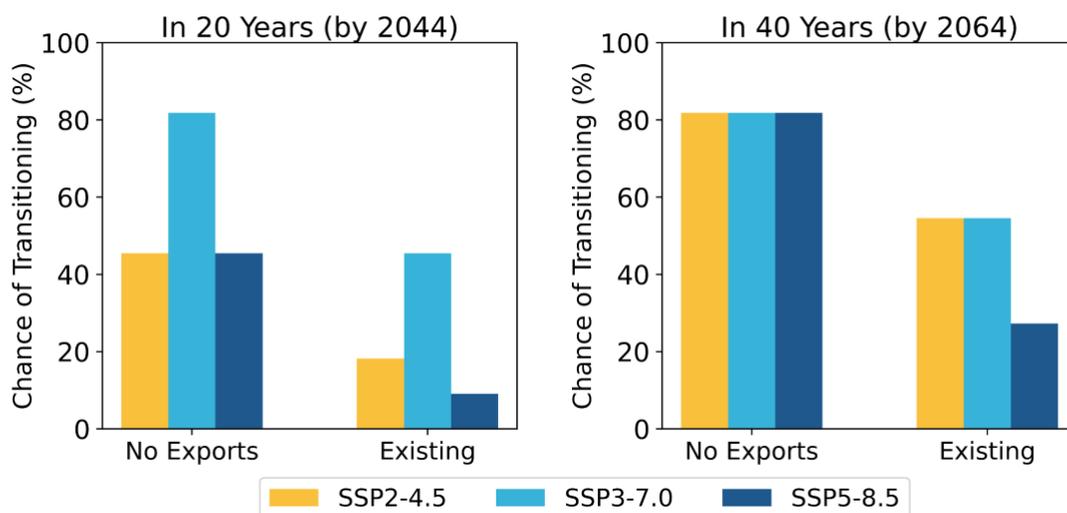
## Both the transition and post-transition export criteria pose challenges in meeting D-1631 water level objectives

To facilitate Mono Lake recovery, the export criteria consists of two periods with two different objectives. The transition export criteria was designed to allow Mono Lake's water level to rise to the transition water level of 6,391 ft. After this occurs the post-transition export criteria goes into effect, which was designed with the goal of maintaining an average lake level of 6,392 ft. Despite their intended purposes, our simulations indicate each period of the Existing Export criteria result in concerning chances of meeting their objectives.

### Transition Export Criteria

It is unlikely that Mono Lake will reach the transition level of 6,391 ft in the next 20 years under the existing transition export criteria. Even after 40 years, there is only about a 1 in 2 chance to reach 6,391 ft. Eliminating exports roughly doubles the likelihood to reach 6,391 ft in the next 20 years, suggesting that exports under the existing export criteria are a significant hindrance to achieving the transition objective.

Figure 8 : Performance of the Existing Transition Export Criteria

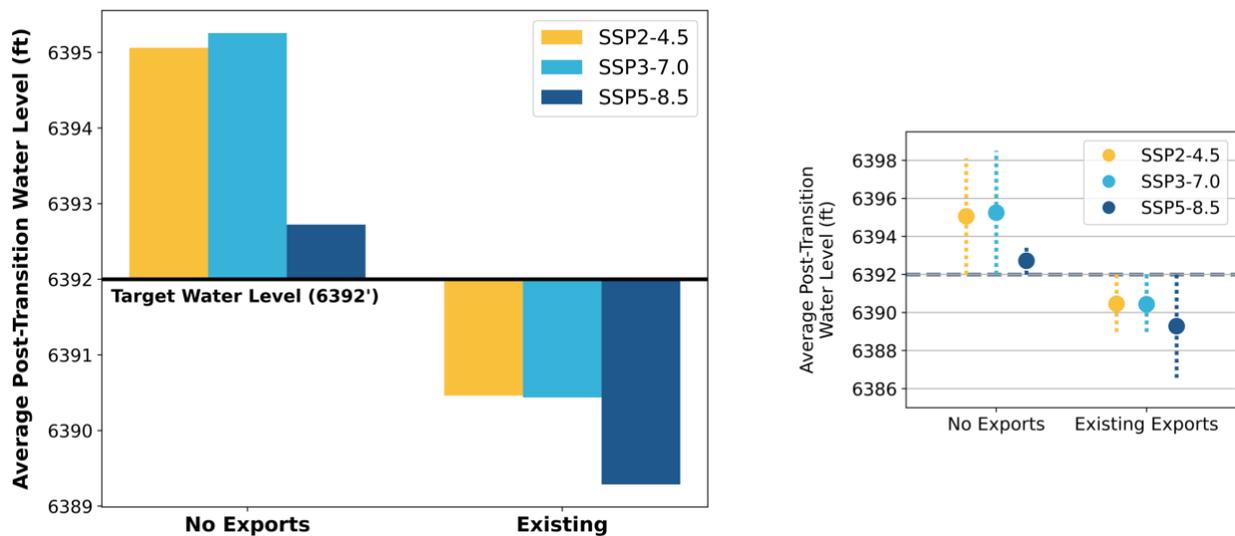


*This figure demonstrates how the existing transition export criteria perform. Performance is based on Mono Lake's chance to reach 6,391 ft at any point from 2024 to 2044 (left figure) and at any point from 2024 to 2064 (right figure). This assessment is performed under the current export criteria and no exports.*

## Post-Transition Export Criteria

Even if the lake reaches the transition level, our simulations suggest the existing post-transition export criteria falls short of achieving its objective of maintaining an average water level of 6,392 ft. Exports under the existing post-transition criteria are projected to result in an average post-transition water level that falls several feet below 6,392 ft.

**Figure 9 : Performance of the Existing Post-Transition Export Criteria**



***This figure demonstrates how the existing post-transition export criteria performs during the post-transition period of recovery. This assessment is focused on the D-1631 objective of the post-transition export criteria, which is to maintain an average water level of 6,392 ft. The ensemble mean post-transition water levels through 2100 are shown in the left figure under the current export criteria and no exports for various future climate change scenarios. Figure on the right includes the ensemble mean (circle marker) and one standard deviation as a dotted line.***

# Strategic adjustments to export criteria can improve future recovery outcomes

*There are a variety of alternative export criteria that aid recovery while still allowing for some exports.*

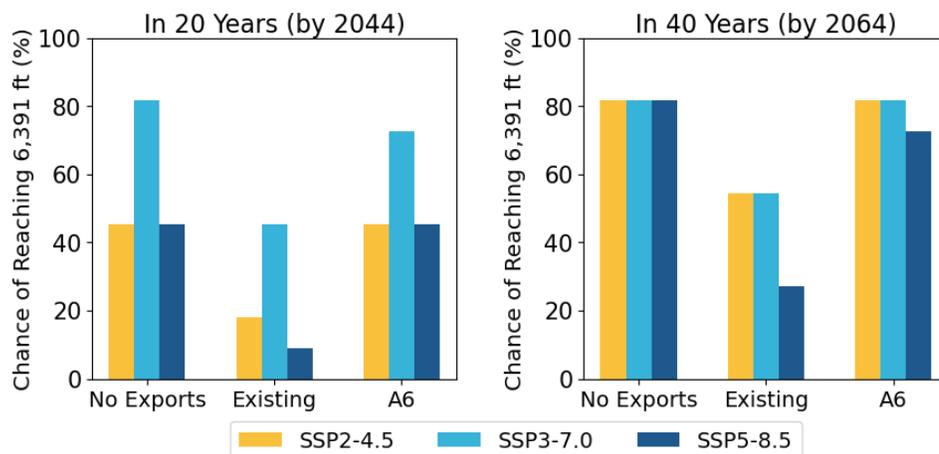
Generally, Mono Lake recovery outcomes, such as being at or above 6,391 ft, improve as exports in the transition and post-transition periods decrease. However, there is some room for compromise. By strategically restricting exports, it is possible to increase the chances of maintaining Mono Lake’s water level above 6,391 ft compared to the existing export criteria while still allowing for some exports.

Based on stakeholder feedback, a set of alternative export criteria were evaluated. Several of these alternatives are referenced below to demonstrate the potential impacts associated with different export criteria characteristics. Because these alternatives only represent a small portion of the many possible export criteria, these examples are meant to act as general guidance rather than specific recommendations.

## Transition Export Criteria

Several alternative transition export criteria improve the chances of Mono Lake to reach the transition lake level in the coming years. This is achieved by reducing exports, even as the lake level approaches 6,391 ft, and prioritizing exports during dry years when water supply is most needed. For example, under alternative export criteria A6 (described in the next section), the chance to reach the transition lake level are very similar to the chance to reach the transition lake level without exports.

**Figure 10 : Performance of Alternative Transition Export Criteria A6**



*This figure demonstrates how the alternative export criteria A6 performs during the transition period of recovery.*

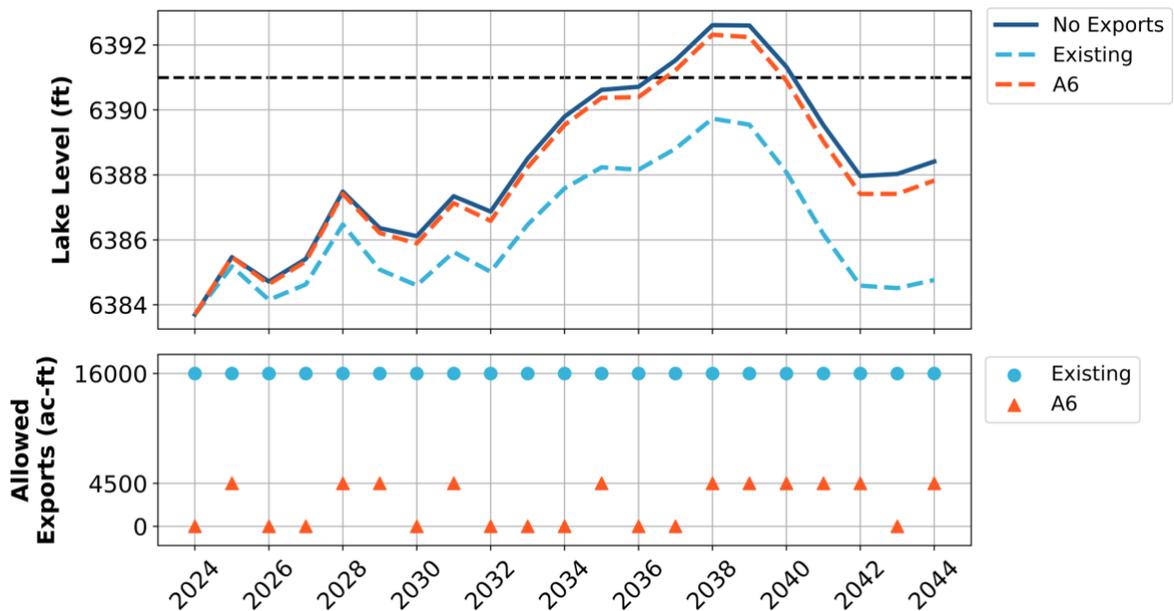
## A Closer Look at Alternative Transition Export Criteria A6

Export criteria A6 allows for exports when the water level is above 6,377 ft, but only during dry and normal years. This helps ensure that water is available for export during droughts, while maximizing recovery potential during wet years. Also, even as water levels approach the transition level, A6 limits exports significantly more than the existing export criteria (4,500 ac-ft as compared to 16,000 ac-ft). This increases the chances that the lake level will continue to rise and eventually reach 6,391 ft.

**Table 1: Description of Transition Export Criteria A6.**

	Dry	Dry-Normal	Normal	Wet-Normal	Wet	Extreme-Wet
< 6,377 ft	0 ac-ft	0 ac-ft	0 ac-ft	0 ac-ft	0 ac-ft	0 ac-ft
6,377 -6,391 ft	4,500 ac-ft	4,500 ac-ft	4,500 ac-ft	0 ac-ft	0 ac-ft	0 ac-ft

**Figure 11: Transition Example Scenario**

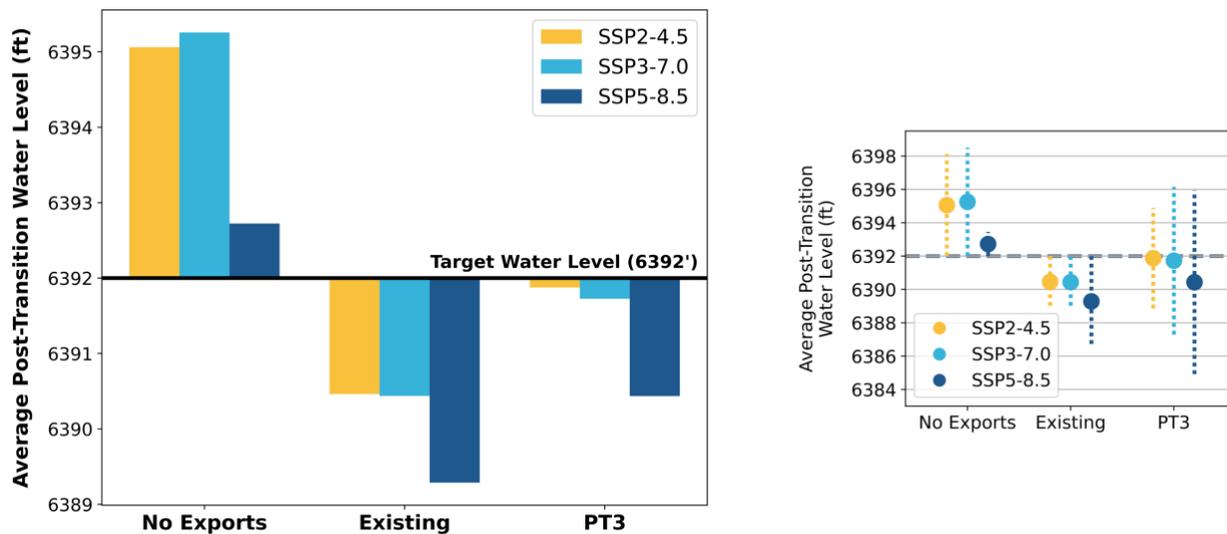


*This figure depicts how a potential future scenario could evolve under alternative export criteria A6 compared to the existing export criteria. To highlight the differences between these two export criteria, water levels and allowed exports are shown for a single GCM between 2024 and 2044. Dark blue represents no exports, light blue represents existing exports, and red represents A6.*

## Post-Transition Export Criteria

The existing post-transition export criteria results in an average post-transition water level that falls roughly 1.5 to 3 ft below 6,392 ft. A variety of alternative post-transition export criteria come closer to meeting the post-transition objective of maintaining a water level of 6,392 ft. These alternatives raise the water level cut-off for unlimited exports above the existing export criteria, while allowing only limited exports as the water level falls below this cut-off level. Implementing these adjustments, as illustrated by alternative post-transition export criteria PT3 (described in next section), can substantially improve post-transition recovery outcomes. PT3 maintains an average post-transition water level closer to 6,392 ft, improving on the existing export criteria. However, if very high emissions like SSP5-8.5 are realized, a stricter post-transition export criteria could be necessary to maintain a 6,392 ft water level.

**Figure 12: Performance of Alternative Post-Transition Export Criteria PT3**



*This figure demonstrates how alternative export criteria PT3 performs during the post-transition period of recovery.*

# A Closer Look at Alternative Post-Transition Export Criteria PT3

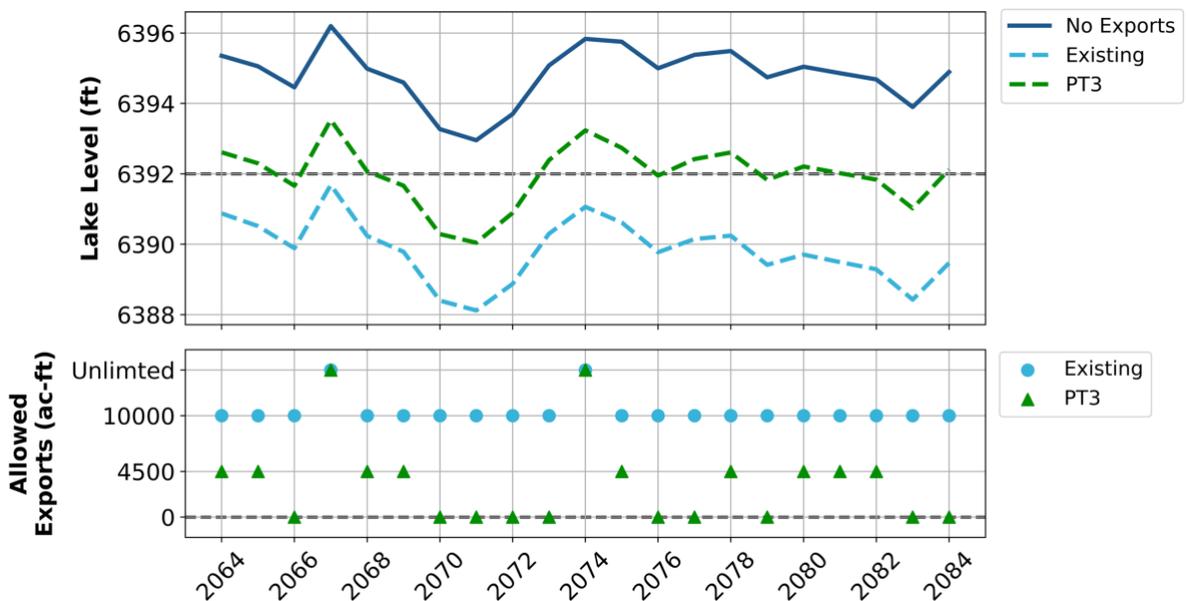
Alternative post-transition export criteria PT3 eliminates exports if the lake level drops below 6,391 ft. This prevents backtracking, preserving recovery progress made during the transition period better than the existing export criteria, which allows for 10,000 ac-ft of exports between 6,388 ft and 6,389 ft. Even at levels above 6,391 ft, PT3 limits exports considerably, only permitting unlimited exports above 6,393 ft when the lake is more securely above the target level. Projections show that, it is generally rare for lake levels to rise during conditions when unlimited exports are allowed, meaning that the cut-off water level for unlimited exports often acts as a sort of cap, establishing a maximum water level. Therefore, it is critical that this cut-off be at or above the target water level.

**Table 2: Description of Post-Transition Export Criteria PT3.**

	Dry	Dry-Normal	Normal	Wet-Normal	Wet	Extreme-Wet
< 6,391 ft	0 ac-ft	0 ac-ft	0 ac-ft	0 ac-ft	0 ac-ft	0 ac-ft
6,391-6,393 ft	4,500 ac-ft	4,500 ac-ft	4,500 ac-ft	0 ac-ft	0 ac-ft	0 ac-ft
> 6,393	Unlimited*	Unlimited*	Unlimited*	Unlimited*	Unlimited*	Unlimited*

\* All available water in excess of the Amended Licenses Requirement

**Figure 13 : Post-Transition Example Scenario**



*This figure depicts how a potential future scenario could evolve under alternative post-transition export criteria PT3 compared to the existing export criteria. Water levels and allowed exports are shown for a single GCM for the years between 2064 and 2084, representing the post-transition period. Dark blue represents no exports, light blue represents existing exports, and green represents PT3.*

# Important Takeaways

Mono Lake's recovery remains a significant challenge, especially under changing climate conditions. Climate change is projected to significantly reduce the chance of Mono Lake's water level reaching and remaining above 6,391 ft, making the path to recovery uncertain even in the absence of surface water exports. Several climate models predict drier future conditions across the Mono Basin that could hinder the ability of Mono Lake to recover. Overall, these findings highlight the potential for climate change to substantially impact Mono Lake's water level, underscoring the importance of explicitly incorporating climate change into Mono Lake management.

Strategic, adaptive planning will be essential to protect Mono Lake as a vital public resource in the decades ahead. These results demonstrate that while eliminating exports allows for the greatest increase in water level, targeted changes to the export criteria can also improve water level outcomes while still allowing for some exports. Through analysis of alternative export criteria, this study sheds light on a range of adaptive approaches that balance water supply and ecological needs. For example, export criteria that limit exports to dry years and incorporate modified post-transition export criteria are projected to achieve improved water level outcomes. As compared to the existing export criteria, these proposed alternatives increase the chance of Mono Lake to reach and maintain water levels above 6,391 ft over the coming decades. Although these alternatives improve water level outcomes compared to the existing export criteria, even the most stringent option—eliminating exports entirely—yields roughly a 3 in 4 chance of recovery by 2064 (approximately 40 years from now).

The transition and post-transition criteria evaluated for this study provide a baseline set of options, but do not represent the full range of possibilities. Ongoing analysis with the UCLA-MLM, including public access to the model, is intended to support continued collaboration, transparency, and refinement of export criteria. It is paramount that any considerations of revised export criteria be informed by how the climate has changed, and is expected to continue changing, rather than relying solely on historical conditions. Decisions made in this context will play a critical role in determining how Mono Lake can successfully be restored and preserved as a valuable ecological and public resource for generations to come.

## Additional Information - Overview of Detailed Report

In collaboration with the SWRCB, UCLA CCS produced an in-depth report, titled *UCLA Mono Lake Water Level Model: Development and 21<sup>st</sup> Century Projections*, which provides a detailed description of the work carried out by UCLA CCS as part of this project.

This report is available for those interested in additional details regarding the scientific methods and evaluation techniques used. The report describes the development and validation of the UCLA-MLM, the development and integration of regional climate data, and presents a comprehensive explanation of the analysis performed.

### Report Structure

**Section 1 (Introduction)** outlines the historical context of the Mono Basin, the development of its export criteria, and an overview of other existing models. **Section 2 (Development of the Mono Lake Water Budget)** details the development and performance of the water budget model and the forcing data used to represent observed conditions. **Section 3 (21<sup>st</sup> Century Hydroclimate Simulations)** outlines the Global Climate Model (GCM) projections used and their anticipated impacts on Mono Basin's precipitation, evaporation, and runoff. **Section 4 (Modeling Mono Lake's Water Level Under Varying Export Criteria and Climate Conditions)** examines how the lake responds to observed weather and climate change scenarios, under existing and alternative transition and post-transition export criteria. Finally, **Section 5 (Future Work)** includes information regarding the User Interface of the UCLA-MLM and ongoing research at the UCLA CCS, and **Section 6** provides **Conclusions and next steps**.

For readers interested in learning about the UCLA-MLM development **Sections 2** and **3** are relevant, while readers interested in results from the UCLA-MLM can refer to **Section 4**. Additional details not critical to the report are provided in the main report's **Appendix**.

## References

- Bass, B., Su, L., and Lettenmaier, D. (2023, November). *California Energy Commission, Climate Data and Analysis Working Group (C-DAWG)*. Retrieved from Data Adoption Justification Memo (for California's Fifth Climate Change Assessment): Hydrology Projections: [https://analytics.cal-adapt.org/data/more\\_data/](https://analytics.cal-adapt.org/data/more_data/).
- California Energy Commission (accessed 7/15/2025). Climate Data and Analysis Working Group (C-DAWG): California Climate Change Assessment Data Summaries. <https://www.energy.ca.gov/programs-and-topics/topics/research-and-development/climate-data-and-analysis-working-group-c-dawg>.
- California State Water Resources Control Board (2021). *Right to Divert and Use Water, Amended License 10191*.
- Eyring et al., V. S. (2016). Overview of the Coupled Model Intercomparison Project Phase 6 (CMIP6) Experimental Design and Organization. *Geoscientific Model Development*, 1937-1958, <https://doi.org/10.5194/gmd-9-1937-2016>.
- Hersbach, H. B. (2020). The ERA5 global reanalysis. *Quarterly Journal of the Royal Meteorological Society*, 146 (730), 1999-2049.
- Intergovernmental Panel on Climate Change (IPCC) (2014). *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*.
- IPCC. (2023). *Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*.
- LADWP. (2020). *Urban Water Management Plan*. Retrieved 1 November, 2023, from [https://www.ladwp.com/sites/default/files/documents/LADWP\\_2020\\_UWMP\\_Web.pdf](https://www.ladwp.com/sites/default/files/documents/LADWP_2020_UWMP_Web.pdf).
- Los Angeles Department of Water and Power. (2022). *Mono Basin Operations Plan*.
- McBain & Trush, Inc. and Ross Taylor and Associates. (2010). *Mono Basin Stream Restoration and Monitoring Program: Synthesis of Instream Flow Recommendations to the State Water Resources Control Board and the Los Angeles Department of Water and Power*.
- State Water Resources Control Board. (1994). *Mono Lake Basin Water Right Decision 1631*.
- Weins, J. P. (1993). Assessing ecological impact assessment: Lessons from Mono Lake, California. *Ecological Applications*, 3 (4), 595-609.