Appendix E

Watercourse Engineering

Mono Lake Elevation Studies

Technical Memorandum

October 2020

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Re: Mono Lake Elevation Studies

1. Introduction

Four studies were developed to improve the understanding of forecasting Mono Lake surface elevation. These included:

- Revisiting the Los Angeles Aqueduct Monthly Program (LAAMP) model used in developing the 1994 Environmental Impact Report (EIR) for Decision 1631 (D1631)
- Updating the regression equations used to forecast Mono Lake surface elevations in the *e*STREAM model (previously updated in 2017)
- Using *e*STREAM to update the analysis of Mono Lake elevation effects with additional export of 12,000 acre-feet as defined in the Settlement Agreement
- Assessing long term exports and Mono Lake elevations under post-transition conditions

This suite of studies addresses a range of questions regarding expectation of Mono Lake elevation and associated export. The LAAMP assessment provides insight into the time to transition estimate based on the D1631 EIR analyses given that Mono Lake is approximately halfway to the transition elevation of 6,391 ft above mean sea level (amsl) after more than 25 years. Updating the regression equations used to forecast Mono Lake surface elevations in *e*STREAM provides the latest information to use in assessments of (a) additional exports and (b) the implication of long-term exports and Mono Lake elevations under post-transition conditions. Using the latest hydrologic data and model developments and refinements provides information to decision-makers and resource managers to consider when assessing current and potential future conditions at Mono Lake.

2. LAAMP

In May of 1993 the California State Water Resources Control Board (SWRCB) released a draft Mono Lake Environmental Impact Report (J&S 1993) that described the Los Angeles Aqueduct Monthly Program (LAAMP) model (version 2.0). The original computer code for the LAAMP model was written in FORTRAN and is a "modified and enhanced" version of a Los Angeles Department of Water and Power (LADWP) aqueduct operations simulation model (Hutchison et al. 1994). The model and its application are discussed in Appendix A of the Draft Mono Lake Environmental Impact Report (DEIR). Subsequently, the LAAMP model was updated (to version 3.3) prior to the release of the Final EIR (FEIR) (J&S 1994).

The LAAMP model contains a water balance for Mono Lake in order to calculate surface elevation in response to specified hydrology and aqueduct operations. The Mono Lake water balance equation was used to estimate water surface elevation (WSE) by balancing water gains and losses to Mono Lake under historic hydrology. The equation was calibrated with measured Mono Lake WSE for this representative time period, and subsequently used to compare the effects of differing management scenarios on Mono Lake WSE.

Herein, the Mono Lake water balance equation from LAAMP (version 3.3) has been reviewed and applied using an updated hydrology that includes the last 30 years of hydrology and diversions. The Mono Lake water balance was first applied to the historic period from runoff year (RY) 1941 to RY 1989 to ensure that Mono Lake WSEs were reasonably simulated. Subsequently, the model was applied using hydrologic input data from RY1990 to RY2019. The LAAMP Mono Lake water balance equation overpredicted Mono Lake WSE by nearly five feet, suggesting a systematic bias in the equation when forecasting future conditions.

2.1. LAAMP Water Balance Equation

The LAAMP v3.3 computer code was used to build a replica water balance equation in an Excel spreadsheet. This approach used the original equations for estimating unmeasured inflows and evaporation and was verified by re-creating historic Mono Lake WSE for RY1941 to RY1989. Once verified, the replica equation was used with hydrologic data from RY1990 to RY2019 to estimate more recent Mono Lake WSE.

To apply the water balance equation, four sets of hydrologic data were developed:

- Measured Mono Basin runoff
- Measured release to Mono Lake
- Cain Ranch precipitation
- Historic Mono Lake WSE

Additionally, Mono Lake bathymetry was also needed. Mono Basin runoff is represented by flows measured at Lee Vining, Walker, and Parker Creeks above the Lee Vining Conduit (LVC) diversion points and in Rush Creek above Grant Lake (at the damsite). Measured flow to Mono Lake is represented by Grant Lake outflows (spill and releases to

Rush Creek) and flows in Lee Vining, Walker, and Parker Creeks below conduit diversions. For the original model period (RY1941-RY1989), measured flows were taken from the original model input file (INPHYD.DAT). For the more recent period (RY1990-RY2019), LADWP monitoring stations and calculated diversion flows were used to determine measured basin flows and measured flows to Mono Lake. Historic WSE is based on the USGS datum. Mono Lake bathymetry was based on surveys by Pelagos (1986) that are incorporated in the original water balance equation and are referenced in the EIR.

Several assumptions were used to estimate inflows and outflows that are not directly measured for Mono Lake. These assumptions were used to evaluate:

- Precipitation
- Evaporation
- Unmeasured inflow

Mono Lake precipitation was assumed equal to LADWP monthly recorded precipitation at Cain Ranch. Cain Ranch precipitation was multiplied by the Mono Lake surface area to determine monthly precipitation volume in acre-feet (AF) per month. Lake surface area was calculated using the Mono Lake bathymetry and the associated lake surface elevation or storage.

Evaporation was assumed to equal 48 in/year and varied by month-of-year according to a schedule determined based on the preliminary water balance estimates (Table 1). While the values vary by month, they are the same for all years (e.g., evaporation in January is assumed to be 1.8 inches regardless of the year). As with precipitation, evaporation rate is multiplied by Mono Lake surface area to determine monthly evaporation losses from Mono Lake (AF/mon). Monthly fractions of total annual evaporation in LAAMP (v3.3) are similar to, but differ slightly from, monthly fractions listed in “Table 2. Monthly Evaporation Estimates for Mono Lake” of the DEIR (Figure 1). Those values in the LAAMP computer code were employed herein.

Table 1. Monthly evaporation estimates for Mono Lake.

Month	Evaporation (inches/month)	Fraction
January	1.8	0.038
February	1.3	0.027
March	1.1	0.022
April	2.1	0.043
May	4.2	0.088
June	5.7	0.119
July	6.4	0.132
August	7.9	0.164
September	6.3	0.132
October	5.5	0.114
November	3.8	0.080
December	2.1	0.044
Total in/yr:	48.0	1.003

* Monthly evaporation is calculated as the annual evaporation multiplied by the monthly fraction. The sum of the fractions equals 1.003, and were transcribed directly from the LAAMP v3.3 model.

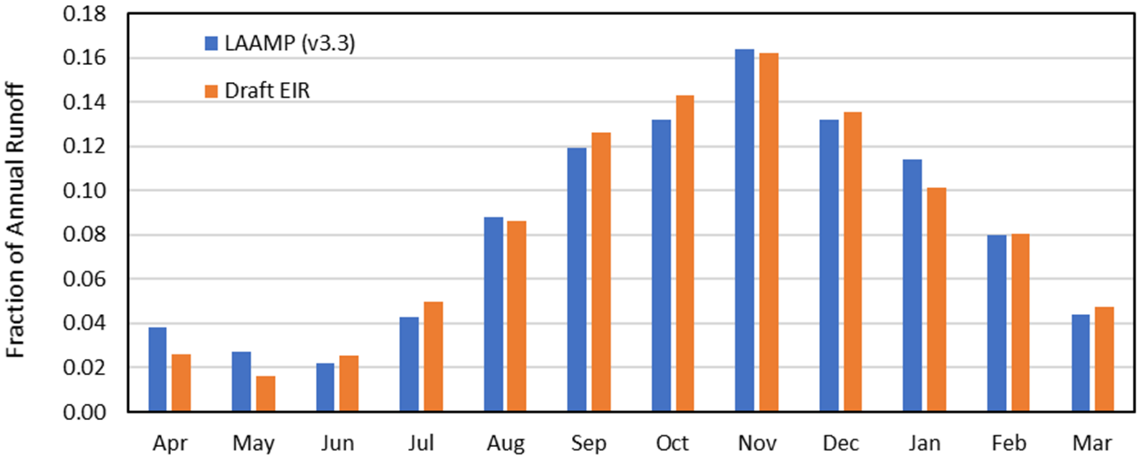

Figure 1. Estimated monthly fraction of total annual evaporation from Mono Lake.

Estimating unmeasured flow in the Mono Lake water balance equation required several assumptions. Unmeasured flow (USC) is assumed to be a linear function of measured basin runoff ($MBRO$). Slope-intercept coefficients for this linear equation were determined as linear functions of annual evaporation rate ($MLEVAP_{13}$).

$$USC_m = RIFAC(YINT + RI * MBRO_m)$$

where

$$YINT = -8651.95 + 238.897 * MLEVAP_{13}$$

$$RI = -0.206935 + 0.00905776 * MLEVAP_{13}$$

$RIFAC$ is a user specified constant, set to a value of 1.0 in the input files used for the DEIR. For an annual evaporation rate of 48 inches ($MLEVAP_{13} = 48$), the constant intercept ($YINT$) is equal to 2,815 AF/month and the slope or fraction of runoff (RI) is equal to 22.8%. These are the same values reported in the DEIR's Appendix A.

The Mono Lake storage change volume ($MLSC_m$) is a function of the measured (XSC_m) and unmeasured (USC_m) flows into Mono Lake.

$$MLSC_m = XSC_m + USC_m$$

Where

$$XSC_m = TREL_m + MLRAIN_m - MLTEV_m$$

$$MLRAIN_m = ADJRN_m + MLAREA_m$$

$$MLTEV_m = MLEVAP_m + MLAREA_m$$

The measured flows are composed of the releases into Mono Lake ($TREL_m$) from Lee Vining Creek and Rush Creek below Walker and Parker Creeks, the inflow from precipitation ($MLRAIN_m$), and the evaporative losses ($MLTEV_m$). Recall that the monthly precipitation ($ADJRN_m$) and evaporation ($MLEVAP_m$) rates are multiplied by the surface area of Mono Lake ($MLAREA$) to determine the flow rates.

Finally, the end of month storage in Mono Lake ($MLVOL_{m+1}$) is the sum of the start of month storage ($MLVOL_m$) plus the change in storage ($MLSC$).

$$MLVOL_{m+1} = MLVOL_m + MLSC_m$$

2.2. Data Sources

Mono Basin hydrologic data were compiled from several sources to test and apply the Mono Lake water balance equation. For the historic period (RY1940-RY1989), data from LAAMP model inputs were employed. For the RY1990-RY2020 period, input data were developed based on LADWP monitoring stations records. Data sources used to characterize basin runoff for model simulations from RY1941 to RY2019 are listed in Table 2.

Table 2. Data sources for Mono Basin runoff used in reconstructed water balance modeling.

Site	Runoff Period[1]	
	1941 - 1989	1990 - 2019
Lee Vining Creek Above Conduit	LAAMP Input	LADWP Station #5008 + GCDAC[2]
Walker Creek Above Conduit	LAAMP Input	LADWP Station #5016
Parker Creek Above Conduit	LAAMP Input	LADWP Station #5017+ PCDAC[3]
Rush Creek At Damsite	LAAMP Input	LADWP Station #5013
Cain Ranch Precipitation	LAAMP Input	LADWP Station #5116

[1] Runoff years span April 1 to March 31.
[2] Gibbs Creek diversion abv conduit (GCDAC) was discontinued November,1999.
[3] Parker Creek diversion above conduit (PCDAC)

2.3. Results

Simulated Mono Lake WSEs were compared to historic WSEs for the original LAAMP modeling period (RY1941-RY1989) to confirm that the equation and data sources were consistent with the DEIR. Overall, the WSEs produced using the water balance equation for Mono Lake were fairly consistent with the historic WSE for the RY1941 to RY1989 period (Figure 2). The average difference was 0.9 ft (maximum of 2.1 ft and minimum of 0.8 ft). The difference in WSE at the end of the simulation (March 31, 1990) was 0.5 feet. Minor differences are attributed to uncertainty about exact equation formulations and the data used to develop the regression equations (e.g., Figure 1, above).

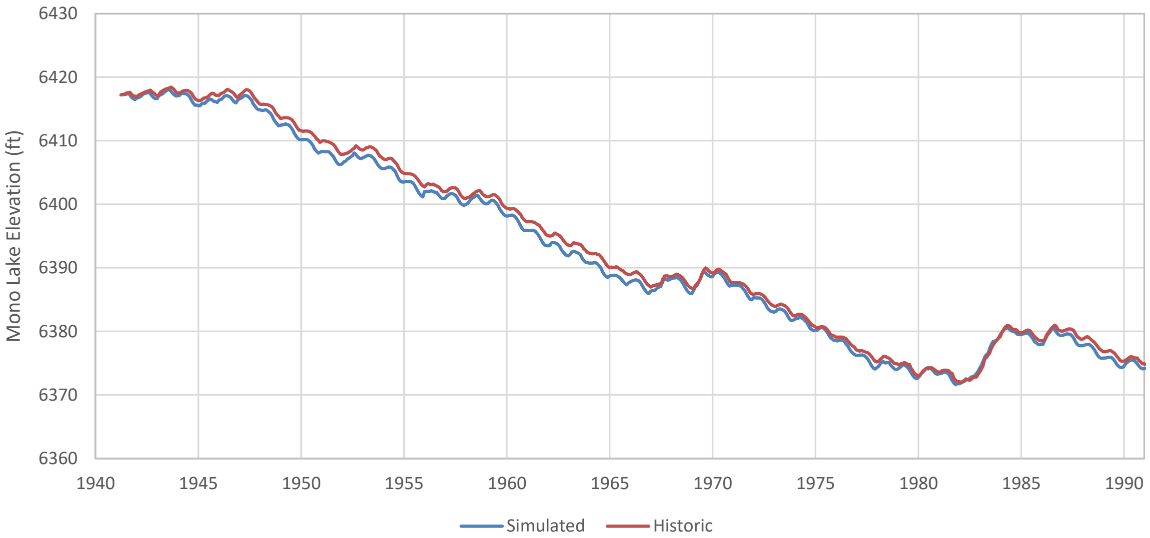

Figure 2. Simulated (blue) and historic (red) Mono Lake WSEs (RY1941 to RY1989).

When the original model was applied using more recent hydrology, simulated WSE varied significantly from historic WSE (Figure 3). The difference in WSE at the end of the simulation (March 31, 2020) was 4.6 feet, which translates to approximately 210,000 acre-feet of storage. Recall that RY1941 to RY1989 were used to develop the ungaged inflow term in the Mono Lake water balance equation. During this time Mono Lake declined from an elevation of approximately 6,418 ft msl to approximately 6,375 ft msl – a decline of 42 feet. During RY1990 to RY2019, lake elevations experienced periods of increases and declines, indicating that general basin conditions may no longer be consistent with the RY1941 to RY1989 period.

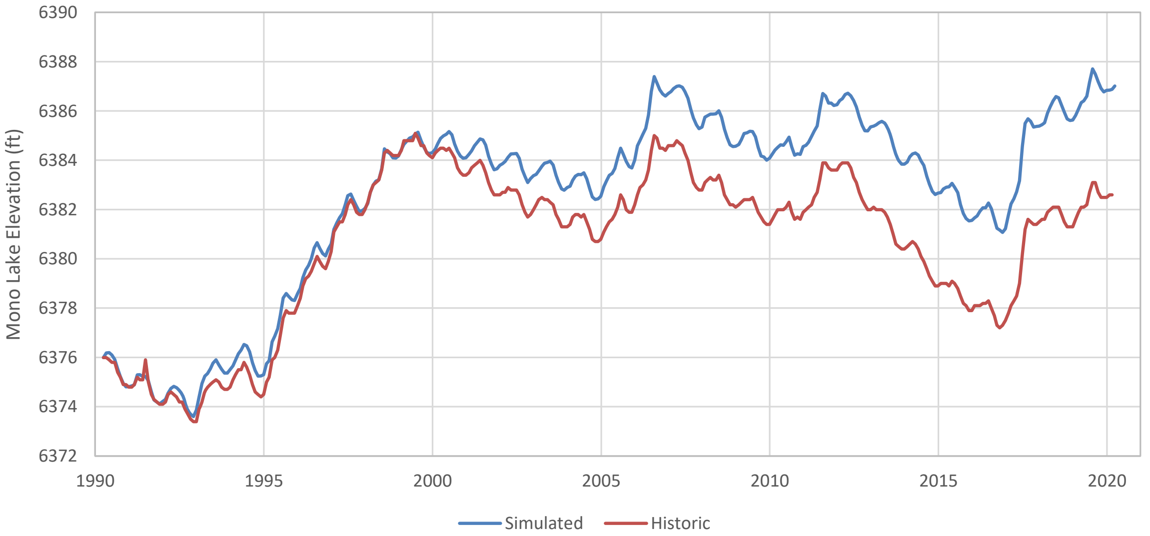

Figure 3. Simulated (blue) and historic (red) Mono Lake WSE (RY1990 to RY2019).

In response to the lake elevation declines during the RY1941 to RY1989 period, groundwater from the surrounding basin would likely drain into Mono Lake. A conceptual diagram illustrating the implications of a declining lake elevation on local groundwater storage conditions is shown in Figure 4. The LAAMP water balance equation uses a regression relationship to estimate ungaged inflow for RY1941 to RY1989. This regression relationship would include groundwater storage change as a positive inflow to Mono Lake, on average, over the 50-year period. When the same equation is used to assess proposed changes in operation that would lead to a rise in lake elevations, the result is an overestimate of inflow and simulated lake elevations that are too high (i.e., Figure 3). This result occurs, in part, because groundwater storage changes are not contributing in the same manner or magnitude to the lake during a period of rising elevations. On the contrary, as the lake rises there would be a recharge component (i.e., outflow) from the lake to refill depleted groundwater aquifer storage associated with the original lake elevation decline. DWR (1960) estimated that the total groundwater storage capacity in the Mono Valley basin was on the order of 3,400,000 acre-feet. While not all of this volume would interact over the range of lake elevations identified herein, the volume identified by DWR indicates the potential of groundwater to play an important role in transition time of the lake from lower to higher elevations. Further, this assessment did not examine potential uncertainty in precipitation assumptions (e.g., that Cain Ranch precipitation rates are representative of precipitation onto the Mono Lake surface), evaporation assumptions (e.g., that the 48-inch per year average rate of evaporation from Mono Lake is representative of evaporation from the surface of Mono Lake), or other assumptions associated with hydrology information used in the LAAMP water balance equations.

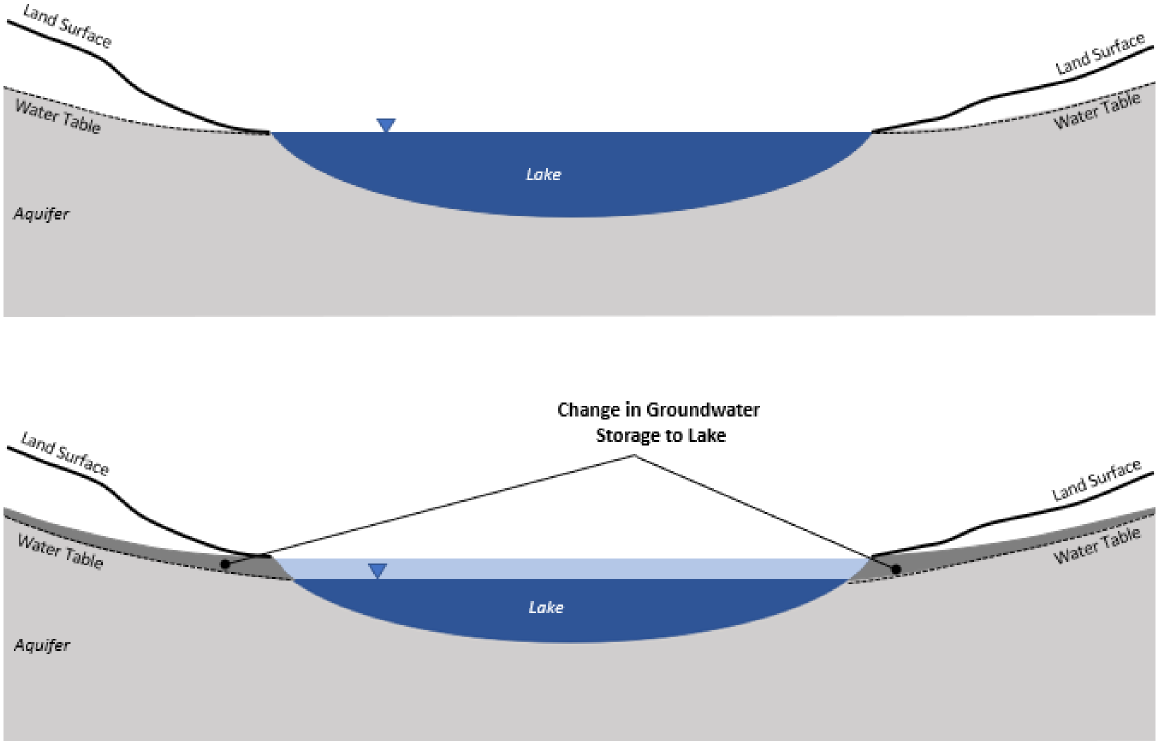

Figure 4. Conceptual model of groundwater changes associated with a declining lake elevation: (top) original conditions, (bottom) groundwater storage change (dark grey) associated with a lake elevation decline.

3. Mono Lake Storage Regression Equations

The original Mono Lake storage change regression equations, developed in the 1990s for the Los Angeles Aqueduct Simulation Model (LAASM), were based on monthly Cain Ranch precipitation ($CAINPR_m$), total monthly conveyance release to Mono Lake ($MBTTR_m$), Mono Basin runoff ($MBRUN_m$) and Mono Lake adjusted surface area ($ADJSA_m$). The monthly regression equation can be shown as:

$$MLSTC_m = \alpha_m CAINPR_m + \beta_m MBTTR_m + \gamma_m MBRUN_m + \delta_m ADJSA_m + \varepsilon_m$$

Where $MLSTC_m$ is the Mono Lake storage change for month m. α_m, β_m, γ_m, δ_m, and ε_m are the regression equation coefficients that can vary by month. The estimated change in storage is then added to the known storage at the start of the month to estimate the storage at the end of the month (which is equal to the next first of month storage).

$$MLStor_{m+1} = MLStor_m + MLSTC_m$$

The storage-surface area-elevation relationships are used to determine the Mono Lake elevation and surface area associated with the storage. The elevation is used for reporting results, while the surface area is used to determine the updated adjusted surface area.

The original regression equations were developed using a hydrologic data set from 1940 to 1990. However, this period was shortened to 1970 to 1990. This latter period was used in the development of the LAASM by LADWP. These equations were the subject of a peer review (Draper et al. 1993). In response to this peer review, the form of the equations identified above was identified and applied.

As part of the Mono Basin Facilitated Process (FP), the coefficients were re-calculated using data from runoff year 1980 through 2010 (inclusive). The purpose of this work was to (a) move the starting date to 1980 – to minimize the period when lake elevation decline was a dominant condition in the basin, and (b) extend the data set (an additional nine (9) years of data are available; runoff years 2011 through 2019, inclusive) while maintaining the same general regression equation format. The results are presented herein.

3.1. Data Development

The existing regression equations use four monthly data sets: Cain Ranch precipitation, conveyance releases to Mono Lake, Mono Basin runoff, and Mono Lake adjusted surface area. All of the data sets use a monthly time step and storage change is calculated at the end of each month.

Cain Ranch precipitation ($CAINPR_m$), measured in inches per month, is reported directly by LADWP (station [*5116*]).

Conveyance releases to Mono Lake ($MBTTR_m$), measured in acre-ft per month, are the sum of the release from Lee Vining, Walker, and Parker Creeks and Grant Lake Reservoir to Mono Lake. This value is calculated by LADWP (station [*MBRML*]).

Mono Basin Runoff ($MBRUN_m$) is the runoff into the Mono Basin from the Lee Vining ($LEVRUN_m$), Walker ($WALRUN_m$), Parker ($PARRUN_m$), and Rush ($RUSRUN^m$) Creeks system.

$$MBRUN_m = LEVRUN_m + WALRUN_m + PARRUN_m + RUSRUN_m$$

$$LEVRUN_m = [5008_m] + [GCDAS_m] + [5048_m] + [5173_m]$$

$$WALRUN_m = [5016_m]$$

$$PARRUN_m = [5017_m] + [PCDAS_m]$$

$$RUSRUN_m = [5013_m] + [5172_m]$$

Where station [5008_m] is the Lee Vining Creek above the LVC, $GCDAS_m$ is the Gibbs Diversion, station [5048_m] is the flow in O Ditch, and station [5173_m] is the Lee Vining Creek Southern California Edison storage change. Station [5016_m] is Walker Creek above the LVC. Station [5017_m] is Parker Creek above the LVC and $PCDAS_m$ is the Parker Creek diversion. Finally, station [5013_m] is Rush Creek at Damsite and station [5172_m] is Rush Creek Southern California Edison storage change.

The last parameter, Mono Lake adjusted surface area ($ADJSURF_m$) has to be calculated based on Mono Lake elevation and bathymetry. The Mono Lake elevations are reported by LADWP and then adjusted to the USGS datum by adding 0.37 ft. The first of month storage ($Stor_{ML,m}$) is used along with the bathymetry to determine the first of month surface area ($SA_{ML,m}$). The specific gravity of water ($SG_{ML,m}$) is determined based on the first of month storage in Mono Lake. The specific gravity must be adjusted to account for the salinity effects of a highly saline lake ($AdjSG_{ML,m}$). Finally, this adjusted specific gravity is applied to the surface area of the lake to determine an adjusted surface area.

$$SG_{ML,m} = \frac{(Stor_{ML,m} * 1359) + 230000000}{(Stor_{ML,m} * 1359)}$$

$$AdjSG_{ML,m} = \begin{cases} -0.744SG_{ML,m} + 1.744 & SG_{ML,m} < 1.121 \\ -0.968SG_{ML,m} + 1.995 & SG_{ML,m} \geq 1.121 \end{cases}$$

$$AdjSA_{ML,m} = SA_{ML,m} * AdjSG_{ML,m}$$

3.2. Regression Analysis

Three different sets of regression equation coefficients were developed using the extended hydrologic data set (spanning runoff years 1980 to 2019). The analyses were performed using a statistical analysis software package, Systat V11. A multiple least-squared linear regression analysis method was used to estimate the annual and monthly-varying regression equation coefficients. The regression analyses were “forced” to use the same parameters to be consistent with the FP formulation (based on the original LAASM equations).

The regression equations, including the ones previously developed for the FP, were then assessed using the 1980 to 2019 data. The method used the April 1, 1980 starting Mono Lake storage as the starting point and then used the calculated end of year/month storage as the next start of year/month storage. The method identifies how the equations would perform over time.

The FP data set was extended to include runoff years 2011 through 2019 (nine additional years) and then re-assessed. The coefficients and adjusted R-squared value are presented in Table 5.

Table 3. Regression equation coefficients and adjusted multiple R-squared for the 1980 to 2019 data analysis.

Month *m*	**Coefficient***					**Adjusted R^2**
	α_m	**β_m**	**γ_m**	**δ_m**	**ε_m**	
Jan	1869.043	1.02100	0.66900	0.06300	-4033.136	0.818
Feb	2427.516	1.38000	1.18300	-0.56700	19730.831	0.719
Mar	2982.740	0.63000	0.80400	0.04900	-5790.034	0.674
Apr	2406.051	1.09500	-0.02800	-0.40600	10183.388	0.671
May	3747.121	1.07900	-0.00500	-0.35600	3303.589	0.871
Jun	3725.968	0.90500	0.12500	-0.80700	16943.951	0.842
Jul	5393.076	1.00700	0.08300	-0.93900	18810.394	0.852
Aug	2691.978	0.93800	0.35200	0.03600	-24132.350	0.913
Sep	1834.983	0.78800	0.37100	-0.84400	17072.671	0.574
Oct	955.144	0.86200	0.97000	-0.46500	5419.289	0.742
Nov	1659.268	0.97000	1.20400	-0.07700	-7496.882	0.662
Dec	1677.487	1.05200	2.40100	-0.00800	-9143.327	0.729

*$MLSTC_m = \alpha_m{*}CAINPR_m + \beta_m{*}MBTTR_m + \gamma_m{*}MBRUN_m + \delta_m{*}ADJSURF_m + \varepsilon_m$

Over the course of the 40 years, the average difference between the calculated elevation and the historic elevation was 0.37 ft (individual monthly differences ranged from 1.63 ft to -1.22 ft) (Figure 1 and Figure 2). At the end of the 40-year simulation period, the calculated elevation was approximately 1.0 ft higher than the historic.

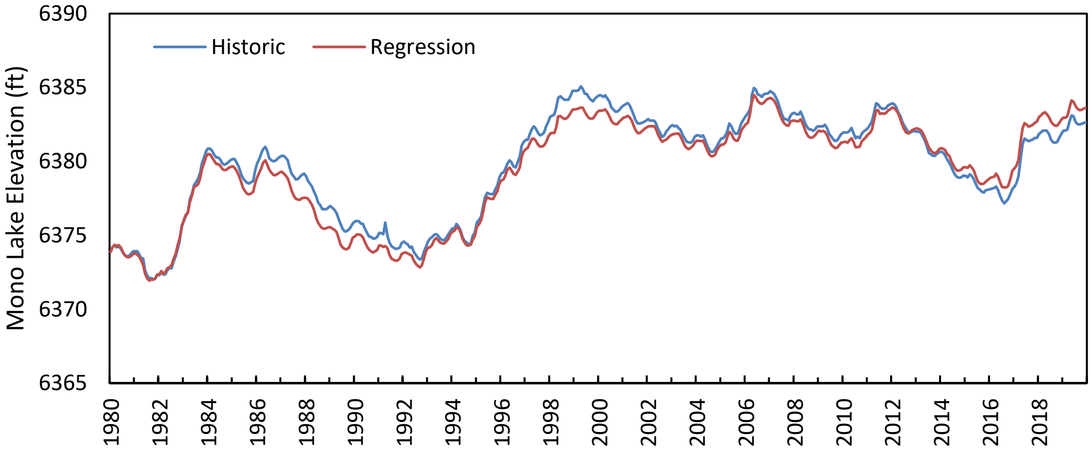

Figure 5. Comparison of predicted (monthly regression equation, 1980 to 2019 data set) versus historic Mono Lake elevations.

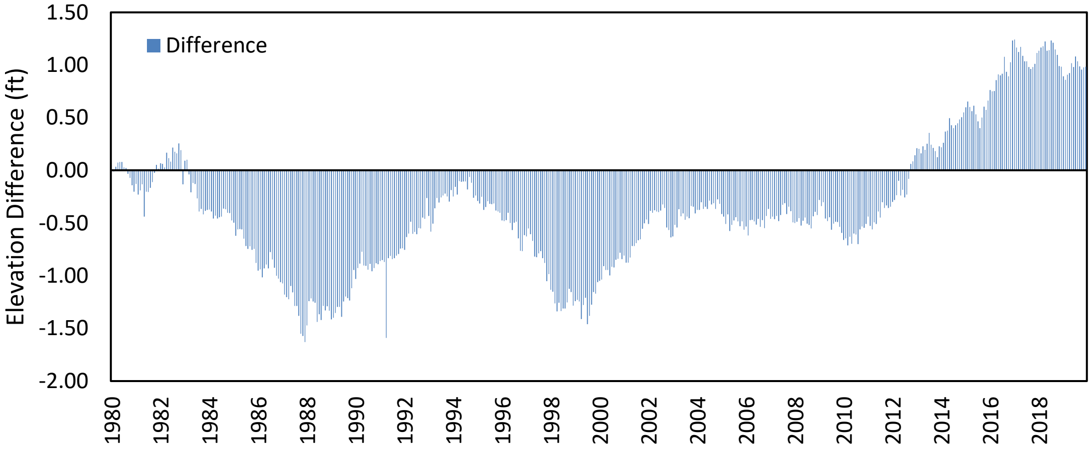

Figure 6. Difference between the regression equation calculated Mono Lake elevation and the historic Mono Lake elevations for 1980 through 2019. A positive value indicates that the regression equation elevation is higher than the historic.

These updated regression relationships were subsequently used in the *e*STREAM model to conduct analysis of Mono Lake elevation impacts associated with additional exports that are part of the Settlement Agreement.

4. Analysis of Mono Lake Elevation Effects with Additional Export of 12,000 acre-feet

The purpose of this analysis was to assess the effects that the proposed additional exports identified in the Settlement Agreement on the number of years it would take Mono Lake elevation to reach 6,391.0 ft.

4.1. eSTREAM Introduction

*e*STREAM represents LADWP's Lee Vining Conduit (LVC) system within the Mono Basin, including Lee Vining, Walker, Parker, and Rush Creeks, Grant Lake Reservoir

(Grant Lake), LVC, including the 5 Siphon Drain, the Mono Gate One Return Ditch, and the Mono Craters Tunnel (Figure 7).

*e*STREAM uses the historic 1980 to 2019 runoff year hydrology (April 1st to March 31st) to estimate system responses to changes in operating conditions. Developed as part of the FP, the model is capable of assessing the stream ecosystem flow (SEF) requirements for the four creeks downstream of the diversion points, as well as the response of Grant Lake to changes in operations and requirements.

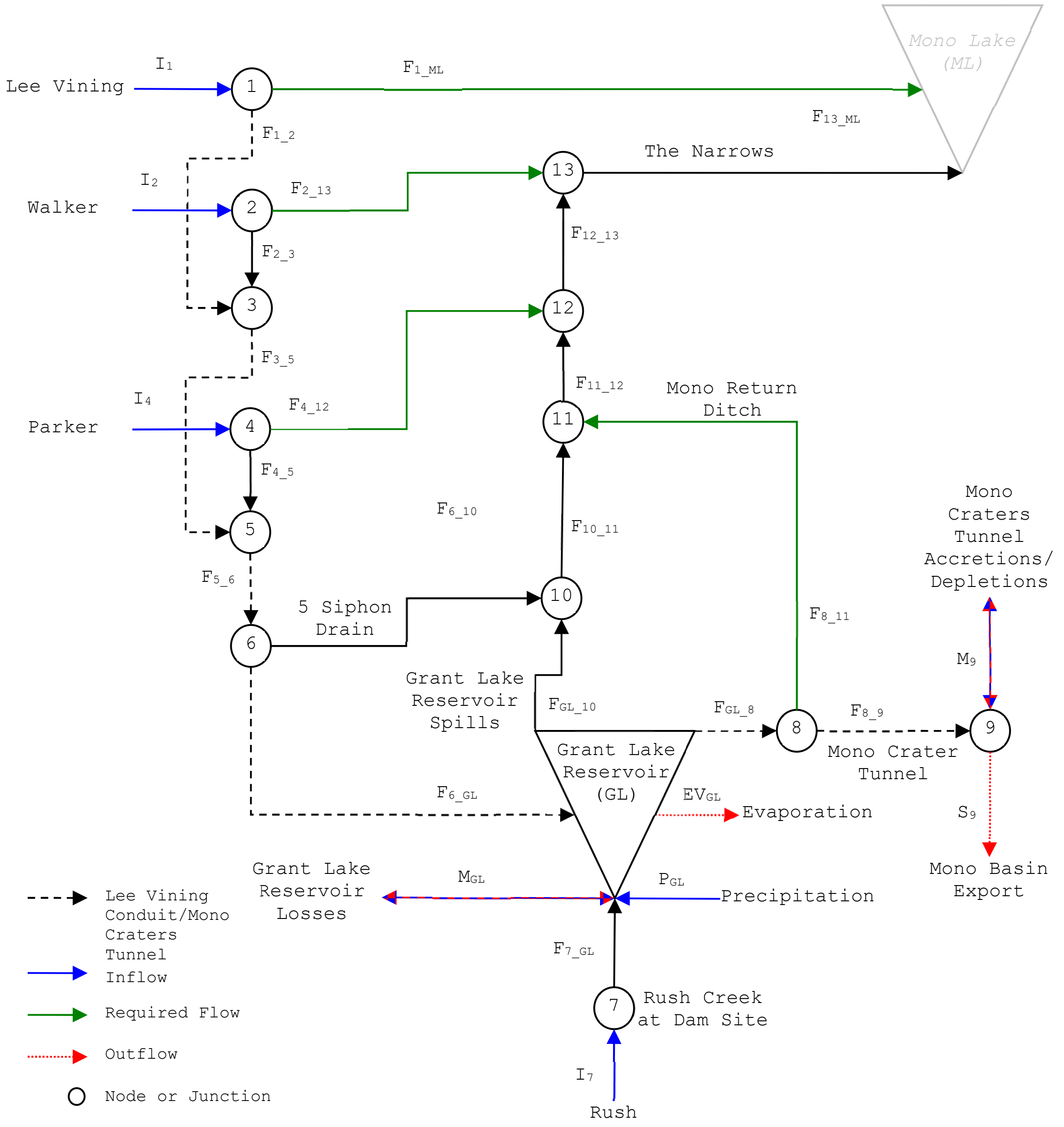

Figure 7. Schematic Representation of the Mono Basin as represented in eSTREAM.

4.1.1. Flows

There are three sources of inflow to Grant Lake and five sources of outflows (Table 4). The major inflow sources are the LVC and Rush Creek. Flows from these sources vary from year-to-year, but are largely assumed to be independent of operations in Grant Lake. Precipitation is the other inflow source and it varies by year and depends on the exposed water surface area (larger surface area leads to higher precipitation flows because precipitation is measured as the precipitation rate (i.e., inches per day) times the surface area of the lake).

There are five outflow sources, four of which depend on conditions within Grant Lake. Evaporation, like precipitation, depends on the exposed water surface area. SEFs and exports depend on available water and operational limits and requirements. Spill only occurs when stored water volumes exceed the capacity of the reservoir. Miscellaneous losses are assumed to be constant by season (i.e., April to September and October to March).

Table 4. Inflow and outflow sources for eSTREAM.

Name	Type	Grant Lake Storage Dependent
Lee Vining Conduit	Inflow	No
Rush Creek at Damsite	Inflow	No
Precipitation	Inflow	Yes
Evaporation	Outflow	Yes
Export	Outflow	Yes
Spill	Outflow	Yes
Stream Ecosystem Flow	Outflow	Yes
Miscellaneous Loss	Outflow*	No

*Miscellaneous loss can be an outflow or an inflow. It is assumed to be an outflow. If the calculated value is positive, then it is an outflow. If the calculated value is negative, then it is an inflow.

4.1.2. Grant Lake Operations

As part of developing a model run, the user must specify the outflow requirements, operational limits, and other capacity constraints for the system. The requirements and constraints (physical and operational) provide the framework from which the model allocates flows.

4.1.2.1. Stream Ecosystem Flow Requirements

The primary outflow requirements are the SEFs for the four creeks downstream of the diversion locations or Grant Lake. The operations on the three LVC creeks (e.g., Lee Vining, Walker, and Parker) are constrained by the flows upstream of the LVC diversion point. *e*STREAM does not have the ability to modify upstream operations (e.g., *e*STREAM does not model operations at Ellery Lake). As a result, the flow downstream of the conduit and within the LVC is insensitive to Grant Lake operations in most cases[1].

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[1] The Settlement Agreement included the recommendation that flows in the Lee Vining Conduit be released via the 5 Siphon Drain under certain circumstances. When Grant Lake storage is at or below 25,000 af on

Rush Creek, downstream of the Return Ditch, depends on releases from the LVC via the 5 Siphon Drain, releases via the Return Ditch (Mono Gate #1), and spill from Grant Lake. All other sources of inflows and outflows to Rush Creek downstream of Grant Lake are omitted (e.g., toe drain flows and/or seepage from the Dam). Return Ditch capacity can be specified by the user and any SEF requirements that exceed the capacity of the Return Ditch (or Grant Lake withdrawal structure) must be meet through spill (either controlled or uncontrolled).

Below Grant Lake, the Rush Creek SEF requirements vary by year type. Peak flows range from 70 cfs in a Dry year to 380 cfs in a Normal year to 750 cfs in an Extreme Wet year (Table 5 and Figure 8). Volumetrically, Rush Creek SEF requirements range from 26,061 af/yr (Dry) to 61,210 af/yr (Extreme Wet) (Table 5). Peaking operations, where SEFs exceed the capacity of the Return Ditch, are limited to the wetter year types.

Table 5. Summary of SEF requirements.

Year Type	Total SEF Volume (af/yr)	Peak SEF Flowrate (cfs)
Dry	26,061	70
Dry-Normal I	27,737	80
Dry-Normal II	27,971	200
Normal	37,052	380
Wet-Normal	44,359	550
Wet	52,533	650
Extreme Wet	61,210	750

July 1st in a Dry or Dry-Normal I year, all flow in the LVC is released to Rush Creek via the 5 Siphon Drain. This was assumed to continue through September 30th (the end date was not specified in the Settlement Agreement).

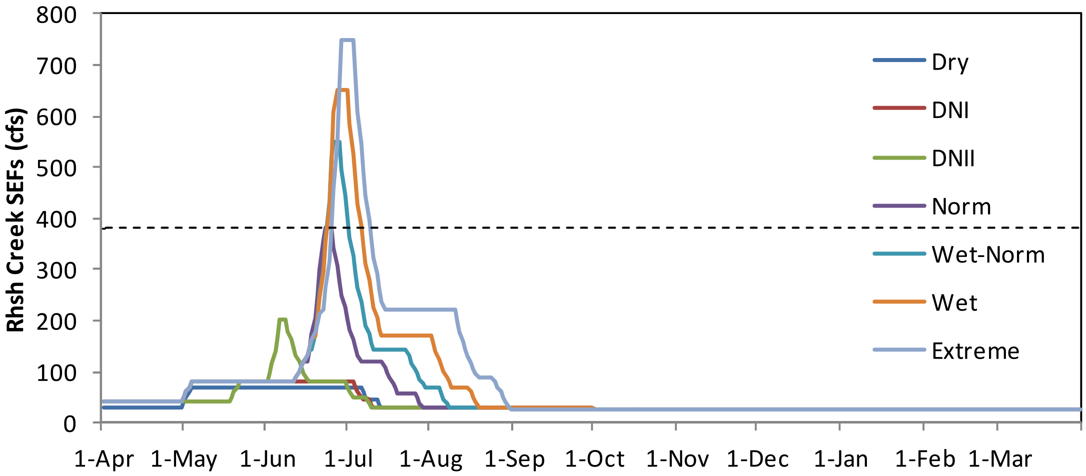

Figure 8. Rush Creek SEF targets (cfs). The dashed line represents the maximum capacity of the Return Ditch (380 cfs). Any required flow above the capacity of the Return Ditch can only be meet through spill from Grant Lake (either controlled or uncontrolled).

Grant Lake can spill in two ways: 1) uncontrolled and 2) controlled. An uncontrolled spill occurs if the volume of water in Grant Lake exceeds the maximum storage capacity (47,171 af or a water surface elevation of 7,130 ft) (Figure 3). When the water surface elevation in Grant Lake exceeds 7,130 ft, uncontrolled spill occurs based on the known weir equation ($Q=aH^b$, where Q is the flow, H is the elevation head, and a and b are coefficients) (see Section 2.1).

For the purposes of this model analysis, it is assumed that an automated Langemann weir gate has been built into the spillway. The weir is approximately 20 ft in width and is 10 ft deep (weir crest elevation is 7,120 ft). The flow through the weir is based on the water surface elevation above the weir (up to the maximum depth of the weir). The user must specify the head versus flow relationship for the weir (Figure 9).

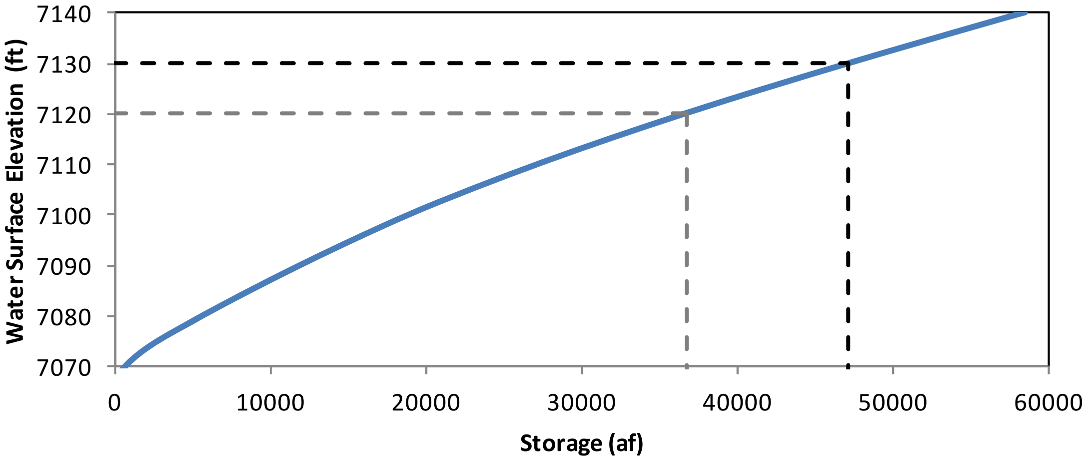

Figure 9. Relationship between storage (af) and water surface elevation (ft) for Grant Lake. The black dashed line represents the current spillway elevation (7,130 ft msl and 47,171 af). The grey line represents the water surface elevation for 10 ft below the current spillway (7,120 ft msl and 36,691 af).

4.1.2.2. Grant Lake Operating Rules

In addition to the capacities, the user must specify the operating rules for Grant Lake by year type. The operating rules are designed to manage Grant Lake to avoid SEF shortfalls and avoid falling below key storage volumes at certain times of the year. The operating rules developed for *e*STREAM have not been verified by operators and, as such, are only valid for modeling scenarios within *e*STREAM. Actual operating rules would need to be developed and refined by Grant Lake operators.

There are operating rules for all seven year types (Figure 10). The Wet-Normal, Wet, and Extreme Wet years have the same operating rules. All year types end with a target storage of 36,000 af on March 31st. The starting storage ranges from 25,000 af to 40,000 af. Storage targets remain high throughout the first part of the runoff year (April to July) in the wetter years to force the reservoir to fill so that it can spill to meet the SEF requirements.

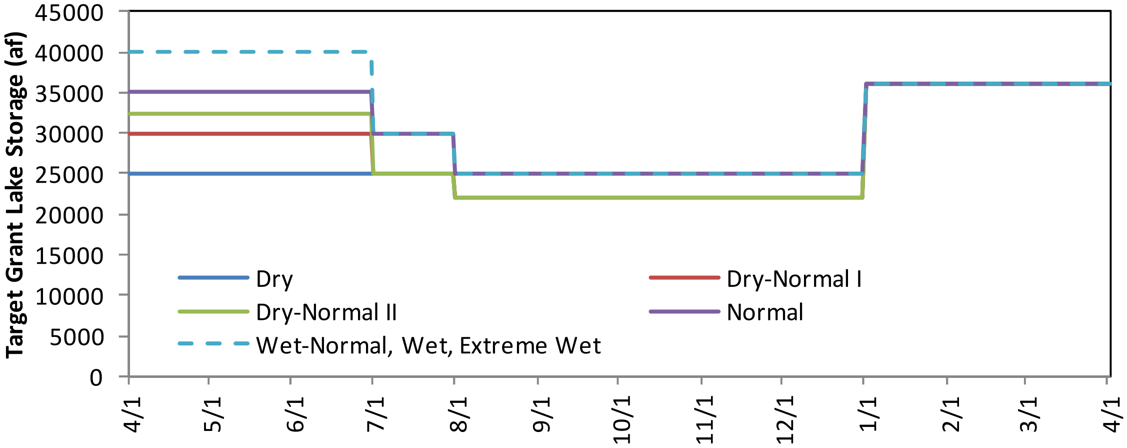

Figure 10. Grant Lake operating rules used by eSTREAM.

4.2. Modeling Scenarios

The primary purpose of this analysis was to assess the effects that an additional 12,000 acre-feet of export would have on the number of years it takes Mono Lake to achieve a water surface elevation of 6,391 ft. To facilitate this, *e*STREAM was run with and without additional exports.

Other modeling assumptions included:

- When additional export was allowed, the first two Normal or wetter years had an additional 4,000 af of export. Subsequently, the next two Wet-Normal or wetter years had an additional 2,000 af of export. Additional export was only allowed prior to transition being achieved (6,391 ft in Mono Lake).
- Grant Lake operating rules were the same for all model runs, regardless of additional export targets (Figure 4).

- Mono Basin exports did not begin until August 1. Prior to that (April 1 to July 31), there were no exports allowed from the Mono Basin to the Mono Craters Tunnel.
- The 5 Siphon Drain is only active in Dry and Dry-Normal I year types when the July 1 Grant Lake storage is at or below 25,000 af. Use of the 5 Siphon Drain ceases on September 30.
- The SEF requirements have been set to model the flows in the Settlement Agreement. This includes eliminating diversions from Walker and Parker Creeks.
- The maximum capacity of the Return Ditch was set to 380 cfs.
- The starting storage in Grant Lake Reservoir was set to 26,920 af, the observed storage on April 1, 2020.
- The starting elevation of Mono Lake was set to 6,382.6 ft, the observed elevation on April 1, 2020. This is below the transition elevation, so routine exports from the Mono Basin are limited to 16,000 acre-feet per year (af/yr) until Mono Lake elevation exceeds 6,391 ft.
- The Mono Lake storage change regression equations were developed using historic data from runoff year 1980 through 2019 (April 1, 1980 through March 31, 2020).
- A 20-foot-wide, 12-foot-deep Langemann Gate (weir) is assumed to have been added to the Grant Lake Reservoir spillway.

4.2.1. Wrapped Analysis

The model was run in “wrapped” mode to allow for assessment of how starting year conditions affected long-term operations. Each model run spanned 40-years, with the first starting year being 1980 and the last starting year being 2019. The hydrology was wrapped (meaning the historic hydrology was repeated for future years). The wrapped hydrology was developed using 1980 as a surrogate for 2020, 1981 as a surrogate for 2021, 1982 was a surrogate for 2022, etc. The hydrology was not modified when it was wrapped, except to account for leap days.

As a result of the wrapped analysis, each time *e*STREAM was run it produced forty sets of model results. The wrapped analysis allows the user to assess the impacts that the starting year(s) may have on the long-term results. For example, the results tend to differ if the model starts at the beginning of a dry period versus a wet period. On a year-to-year basis, the results may be similar, but the results can be markedly different in terms of when transition is achieved, Grant Lake Reservoir storage, and annual average exports. The wrapped analysis also allows the user to identify the sequence(s) and/or specific years that may be the most challenging in terms of achieving Rush Creek SEF requirements.

4.2.2. Model Runs

*e*STREAM was run for two model scenarios: without additional export and with additional export. For the model alternatives where additional export was allowed, the target volume (12,000 af) was divided into two periods. In the first two Normal or wetter years, up to 4,000 af/yr of additional exports were allowed. After that, in the next two Wet-Normal or wetter years, up to 2,000 af/yr of additional exports were allowed. If transition is achieved, no additional export is allowed. While this does not completely reflect the Settlement Agreement, it was the closest representation that was possible within the existing *e*STREAM framework.

4.3. Results

Two model scenarios were run in the wrapped mode (without and with additional export). Each wrapped run produced forty sequences spanning forty years. The results in terms of time to transition and Mono Lake elevations and exports are presented below.

4.3.1. Transition of Mono Lake Elevation

The number of years until when Mono Lake water surface elevation reaches 6,391 ft is relatively insensitive to the additional export.[2] The average number of years it took for transition to occur was 22 (this is the average of all 40 runs for each alternative) with and without additional export. The minimum number of years to achieve transition increased from 5 to 6 when additional export was allowed. The number of runs when transition was not achieved also increased from 3 to 4 (Table 6).

Table 6. Average and minimum number of years to achieve transition (6,391 ft) and number of sequences where transition did not occur for the without additional export and with additional export wrapped runs.

	Without Additional Export	With Additional Export
Average Number of Years:	22	22
Minimum Number of Years:	5	6
# of Runs When Transition Did Not Occur	3	4

An important consideration when interpreting these results is that the runs are sensitive to starting Mono Lake elevation. The average number of years to reach elevation 6,391.0 in Watercourse (2013) was 19 years – a shorter period than this analysis. This difference is due to several factors including different starting elevations and different (longer) hydrology time series. For example, Griffin and Anchukaitis (2014) identify that the 2012-2014 three-year dry period was the most severe drought in the last 1200 years, and the span from fall 2011 to fall 2015 was the driest since record keeping began in 1895 (Hanak et al. 2016). This remarkable dry period was not included in the Watercourse (2013) analysis.

When there no additional export is allowed, the sequence to achieve 6,391 ft in the least number of months began with 2019. When using the wrapped hydrology, this is the start of a generally wet period (Table 2). When additional export was allowed, the sequence that began in 1980 (although start years 2017 and 2018 were nearly the same) achieved transition in the least number of months. Both sequences began at the start of relatively

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[2] This eSTREAM analysis assumes that transition is completed when Mono Lake elevation exceeds 6,391 ft msl for the first time regardless of month.

wet periods (see Table 2). Conversely, when a wrapped simulation starts at the beginning of a dry period, Mono Lake can fall notably and lead to a simulation not achieving transition in the 40-year period. Thus, in addition to starting lake elevation and the length and type of events in the hydrologic time series (e.g., wetter, drier, or normal conditions), the order of a hydrologic sequence also directly impacts time to transition to 6,391 ft msl.

Finally, Mono Lake water surface elevations barely exceeded the transition target in some instances (e.g., the April 1 elevation was 6,391.1 ft); however, in the model logic, transition is achieved when the elevation is at or above 6,391 ft regardless of the amount in excess. Thus, small differences in estimated Mono Lake elevations can have significant impacts on the model results. Consider Figure 2, each model run began in 2016. When additional export was allowed, the water surface elevation on August 1, 2024 was 6,390.9 ft (one-tenth of a foot below the transition elevation). When no additional export was allowed, the elevation was 6,391.1 ft (one-tenth of a foot above the transition elevation). As a result, the no additional export model achieved transition on August 1, 2024, while the additional export sequence did not achieve transition until June 1, 2026. Overall, given the assumptions in the *e*STREAM model and the bathymetry data for Mono Lake, a difference of a few tenths of a foot are likely to be within the error margin of the model and results.

Table 7. Year types for 1980 to 1986 and 2017 to 2023.

Year (Starting Year 1980)	Year Type	Year (Starting Year 2017)	Year Type
1980	Wet	2017	Extreme Wet
1981	Dry-Normal II	2018	Wet
1982	Extreme Wet	2019	Normal
1983	Extreme Wet	2020 (1980)	Wet
1984	Wet-Normal	2021 (1981)	Dry-Normal II
1985	Normal	2022 (1982)	Extreme Wet
1986	Wet	2023 (1983)	Extreme Wet

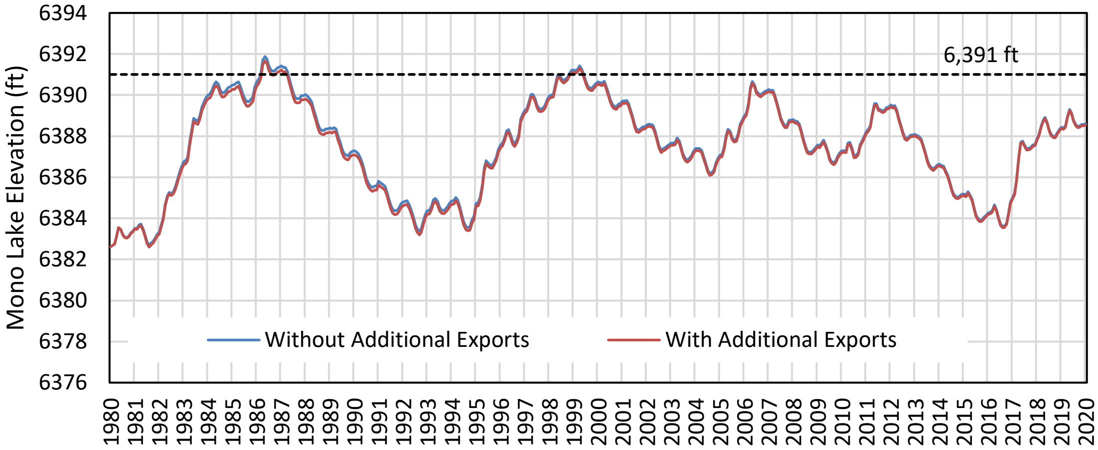

Figure 11. Mono Lake water surface elevation for the runs that started in 1980 without (blue line) and with (red line) additional export.

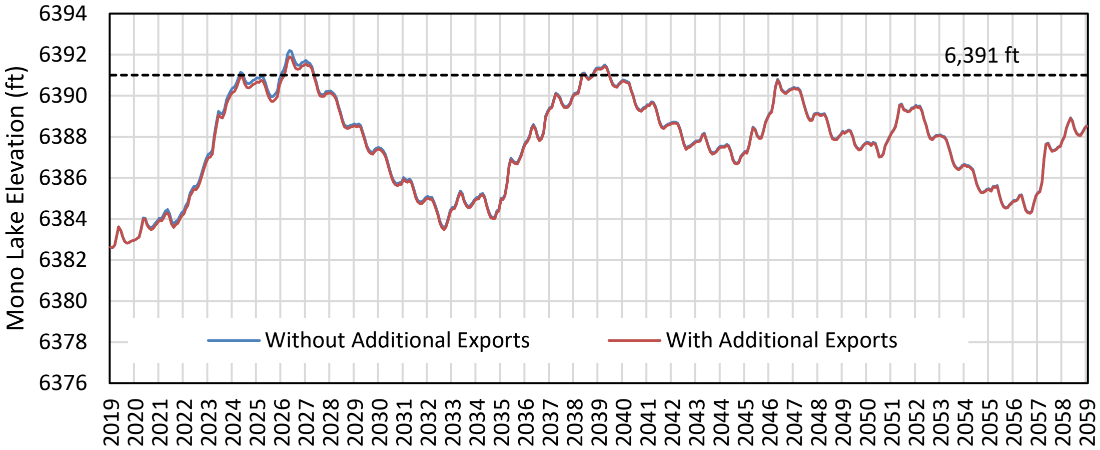

Figure 12. Mono Lake water surface elevation for the runs that started in 2016 without (blue line) and with (red line) additional export.

4.3.2. Annual and Additional Export Volumes

Without additional export, the average Mono Basin export prior to Mono Lake reaching 6,391 ft was 14,870 af/yr (Table 8). The maximum allowable annual export depends on April 1 Mono Lake elevation. If the elevation is below 6,377 ft, then no exports are allowed. If the elevation is between 6,377 ft and 6,380 ft, up to 4,500 af/yr of export is allowed. If the elevation is between 6,380 ft and 6,391 ft, then up to 16,000 af/yr of export is allowed.

*e*STREAM was configured so that the additional export target was added to the annual export target based on Mono Lake elevation. The additional 12,000 af of export target (specified as two years of 4,000 af/yr and two years of 2,000 af/yr), resulted in the average annual export increasing to 15,543 af/yr (Table 8). The average additional export was 11,379 af, approximately 620 af short of the 12,000 af target (Table 9). The full additional export volume was achieved in 28 out of the 40 sequences (approximately 70 percent). The lowest additional export volume was 8,297 af. The intention of the additional export is to offset a portion of the spillway construction cost. As such, a mechanism should be included in the project description to allow for banking of water for export in a future year or years if operational constraints limit total additional export to achieve the target of 12,000 af.

Table 8. Average Mono Basin export (including additional export) prior to Mono Lake reaching 6,391 ft (i.e., during transition).

	Without Additional Export	With Additional Export
Average Wrapped Average (af/yr)	14,870	15,543
Maximum Wrapped Average (af/yr)	16,000	18,732
Minimum Wrapped Average (af/yr)	12,413	13,523

Table 9. Average additional Mono Basin export prior to Mono Lake reaching 6,391 ft (i.e., during transition).

	Target	With Additional Export			
		Avg	Max	Min	Count
Additional Export Volumes (af)	12,000	11,379	12,000	8,297	28

4.4. Limitations

*e*STREAM has a number of assumptions built into it, foremost are limited foresight and idealized operations, along with using historic hydrology. Limited foresight means the model knows what is going to happen in the future in some cases. For *e*STREAM, it means that the model knows the year type of April 1, without any uncertainty. The year typing is used to determine outflow requirements and Grant Lake storage targets.

Idealized operations mean that the flow rates can be perfectly specified and met on a daily basis. *e*STREAM calculates the target flow for each day and then releases as close to that value as possible. However, in practice, it is unlikely that operations at Grant Lake Reservoir can be managed at that fine of a scale without additional automation being added to the system.

Finally, *e*STREAM uses the historic hydrology. Future hydrology is unlikely to be the same as the historic hydrology. Even with the same year type, the historic hydrology has a range for flows for any given day. In general, historic hydrology is useful to identify how the system could have been operated if different requirements or facilities had been in place, but it is not necessarily an indicator of how the system will respond to future conditions, especially if future hydrology is expected to be markedly different from the historic (e.g., climate change).

Overall, these assumptions tend to lead to idealized operations and an over-estimate of how precisely the system can be operated to meet stream flow requirements and export targets.

5. Assessing Long Term Export and Mono Lake Elevation – Post-transition

The updated *e*STREAM model (extended to hydrology through RY2019 and updated regressions) was used to simulate existing license conditions to assess the implications of export volumes and Mono Lake elevation in a post-transition environment. The export rules under license conditions include the export of excess available water[3] when Mono Lake is at or above 6,391.0 ft msl and 10,000 AF/yr maximum export for Mono Lake elevations at or above 6,388.0 ft msl and below 6,391.0 ft msl. When Mono Lake

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[3] Available water is defined as water in excess of required stream flow releases, Grant Lake storage requirements, and within conveyance system capacities when the first of month storage is above 6,391 ft msl.

elevation falls below 6,388.0 ft msl export is not allowed. A summary of the various export and lake level metrics from this analysis are presented in Table 10.

Table 10. Average export and Mono Lake elevation metrics for simulated License Conditions using *e*STREAM.

Metric	Value
Average Export[1] (TAF)	15.5
Avg # of Years with Export[2]	28.2
Average Median Export[3] (TAF)	10.0
Average Elevation[4] (ft msl)	6,389.4
Maximum Elevation[5] (ft msl)	6,396.3
Minimum Elevation[6] (ft msl)	6,383.1
Median Elevation[7] (ft msl)	6,389.1
Percent of Months ≥ 6,391 ft msl[8] (%)	25

[1] Average export is the average of the 40 years in the wrapped *e*STREAM simulation. For the License Conditions scenario, the maximum annual export in any one year was approximately 74.5 taf.
[2] Average number of years (out of 40) that total annual export is greater than zero.
[3] Average median export is the median values form the 40 years in the wrapped *e*STREAM simulation.
[4] Average of the wrapped run averages (i.e., average of the 40 average values)
[5] Maximum elevation across all 40-wrapped runs
[6] Minimum elevation across all 40-wrapped runs
[7] Average of the wrapped run medians (i.e., average of the 40 median values)
[8] Average percent of months above 6,391 ft msl (i.e., average of the 40 values for percent of months for each year)

These results reflect averages of 40-year simulations and indicate that the long-term export for the City is approximately 15.5 taf/yr for the license conditions. This value is approximately 50 percent of the long-term export identified in D1631. The notable reduction is due in part to operational constraints (e.g., Grant Lake storage target) and the stream release schedule prescribed in the Synthesis Report (MTA and RTA 2010), updated Mono Lake forecasting equations, and use of the latest hydrologic data (e.g., 1990-2020) in *e*STREAM.

Mono Lake surface elevation response under a post-transition analysis with license conditions applied suggests a potential lake elevation range from 6,383.1 ft msl to 6,396.3 ft msl with an average of 6,389.4 ft msl (median of 6,389.1 ft msl). An additional statistic included in Table 10 is percent of months at or above 6,391.0. Under the license conditions, Mono Lake surface elevation would be at or above 6,391.0 approximately one in four years (25 percent).

6. Citations

California Department of Water Resources (DWR). 1960. Reconnaissance investigation of water resources of Mono and Owens Basins, Mono and Inyo Counties: California Department.

Draper, D., and G. Michailidis, and A. Braverman. 1993. Evaluation of the Los Angeles Aqueduct Simulation Model and Runoff Forecast Model, Department of Water and Power, City of Los Angeles. September 20.

Hanak, E., J. Mount, C. Chappelle. 2016. “California’s latest Drought.” Just the Facts. Public Policy Institute of California, Water Policy Center. July.

Griffin, D., and K. J. Anchukaitis. 2014. How unusual is the 2012–2014 California drought? Geo-phys. Res. Lett., 41, 9017–9023, doi:10.1002/2014GL06243

Hutchison, William R., Russel T. Brown. and Paul Wisheropp. 1994. Program to simulate the operation of the Los Angeles Aqueduct; modified and enhanced from a LADWP simulation model. July 15, 1991. Last modified January 17, 1994.

Jones & Stokes Associates (J&S) 1993. Draft Environmental Impact Report for the Review of Mono Basin Water Rights of the City of Los Angeles. Prepared for the California State Water Resources Control Board, Division of Water Rights. May, 1993.

Jones & Stokes Associates (J&S) 1994. Final Environmental Impact Report for the Review of Mono Basin Water Rights of the City of Los Angeles. Prepared for the California State Water Resources Control Board, Division of Water Rights. September. 1994.

McBain & Trush, Inc. and Ross Taylor and Associates (MTI and RTA). 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. Final Report." A Report for State Water Resources Control Board and the Los Angeles Department of Water and Power. April.

Pelagos Corporation (Pelagos). 1987. A bathymetric and geologic survey of Mono Lake, California. San Diego, Calif.

Watercourse Engineering, Inc. (Watercourse). 2013. Analysis of Mono Lake Elevation Effects with Additional Exports. Technical Memorandum prepared by S. Tanaka, Watercourse Engineering, Inc. Submitted to P. Pau, B. Moges, and E. Tillemans, Los Angeles Department of Water and Power. December 18.