Appendix HYDRO-3

SSAM

Estimating Salton Sea Elevation and Salinity for Future Inflow Scenarios for the Imperial Irrigation District

Prepared by: Tetra Tech for the Salton Sea Management Program

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Introduction

The Salton Sea is a terminal lake in Riverside and Imperial Counties, California, receiving runoff from Imperial Valley and Coachella Valley watersheds, including runoff from exports originating in the Colorado River basin. Over the past decades, the Sea's water level has been declining, and it has been the subject of various modeling efforts to quantify the decline and assess the resulting environmental impacts. This memo summarizes a modeling methodology and analysis to evaluate the consequences of water conservation actions being proposed by the Imperial Irrigation District over three calendar years, from 2024 to 2026.

The US Bureau of Reclamation developed a spreadsheet model in the early 2000s called the Salton Sea Accounting Model (SSAM) [1]. SSAM balances the Sea's water and salt mass on an annual timestep, assuming the Sea is uniformly mixed. The primary SSAM inputs are 1) a projected hydrology for the major inflows to the Sea 2) salinity-dependent evaporation, and 3) direct precipitation terms. The mass balance equation calculates the change in volume at each timestep, and the Sea's total volume is simulated for the duration of the projected hydrology. An elevation-area-capacity (EAC) curve derived from Sea bathymetric survey data allows for a singular relationship between the Sea's volume, surface area, and surface elevation.

Starting in the mid-2010s, Tetra Tech began updating the SSAM model (SSAM 2.0) to incorporate the latest available hydrological data, bathymetry data [2], and add new features to simulate water needs for various habitat projects, such as concepts in the Salton Sea Long Range Plan (LRP) [3] or projects that are part of the Phase 1 Salton Sea Management Program. This document describes the model framework, inputs, and outputs.

In response to ongoing drought, SSAM 2.0 is currently being used to estimate water management scenarios on the Colorado River. SSAM 2.0 calculates changes in salinity and exposed playa at Salton Sea based on contemplated allocation reductions. As part of this effort, Tetra Tech evaluated a set of scenarios with different levels of reduction and incorporated multiple fallowing and water-use efficiency considerations. The model assumptions and outputs were reviewed by IID, CVWD, the Bureau of Reclamation and the California Natural Resources Agency in a series of meetings in mid- to late-2022. A final set of updates were made in 2023 and are presented in this document.

Model Hydrology used in SSAM 2.0

The Salton Basin is the northern arm of the former Colorado River delta system. Agricultural return flows and drainage from these valleys and parts of the Mexicali Valley, in addition to municipal and industrial discharges in the watershed, feed the major rivers flowing to the Salton Sea. The Salton Sea watershed encompasses an area of approximately 8,000 square miles from San Bernardino County in the north to the Mexicali Valley (Republic of Mexico) to the south.

The principal sources of inflow to the Salton Sea are the Whitewater River to the north (also known as the Coachella Valley Stormwater Channel [CVSC]), the Alamo and New Rivers to the south, and direct return flows from agricultural drains in the Imperial Valley and Coachella Valley. The riverine sources of inflow are recorded by United States Geological Survey (USGS) gage stations situated at the river mouths, with observations dating back to at least 1988.

The Whitewater River (CVSC) is the primary river drainage channel of CVWD. It brings stormwater runoff, agricultural return flows, and municipal and fish farm discharges from the Coachella Valley to the Salton Sea. In the last few years, flows recorded by the Whitewater River USGS gage (USGS Station ID: 10259540) have been less than 50,000 AF/year.

The Alamo River originates approximately two miles south of the International Border with Mexico and flows north and into the Salton Sea. The USGS station that records Alamo River inflows into the Salton Sea is located near this point of discharge into the Sea (USGS Station ID: 10254730). The Alamo River is dominated by agricultural return flows from IID. In recent years, this flow has averaged 560,000 AF/year.

The New River also originates in Mexico. It travels through the Mexicali Valley, crosses the International Border, and flows into the Salton Sea. The New River carries urban runoff, industrial and municipal flows, and agricultural runoff from the Mexicali Valley. There are two USGS gages along the New River. One is in the Imperial Valley, near the mouth of the river at the Salton Sea (USGS Station ID: 10255550). The other is at the International Border (USGS Station ID: 10254970). Since 2018, flows at the New River (Imperial Valley) station have been consistently less than 350,000 AF/year. Flows at the New River (International Border) station have remained stable between 60,000 AF/year and 64,000 AF/year in the same timeframe.

Other outflows to the Salton Sea include a system of agricultural drains in the Imperial Valley, which discharge surface runoff into the Alamo and New Rivers, and agricultural drains in the Coachella Valley.

The agricultural drains in the Imperial Valley introduce approximately 830,000 AF/year of surface runoff to the Alamo and New Rivers.

The relationship between these flows, the Salton Sea, and the IID and CVWD watersheds are illustrated in **Figure 1**. Other losses are from IID and CVWD watershed evapotranspiration (ET) and evaporation out of the Salton Sea. Other inflows include precipitation, local watershed, and groundwater inflows into the Sea. The ungaged flows (italicized in **Figure 1**) can be estimated by using the reported irrigated acreage and ET rates in the valleys and local weather data that are available for Imperial County, California.

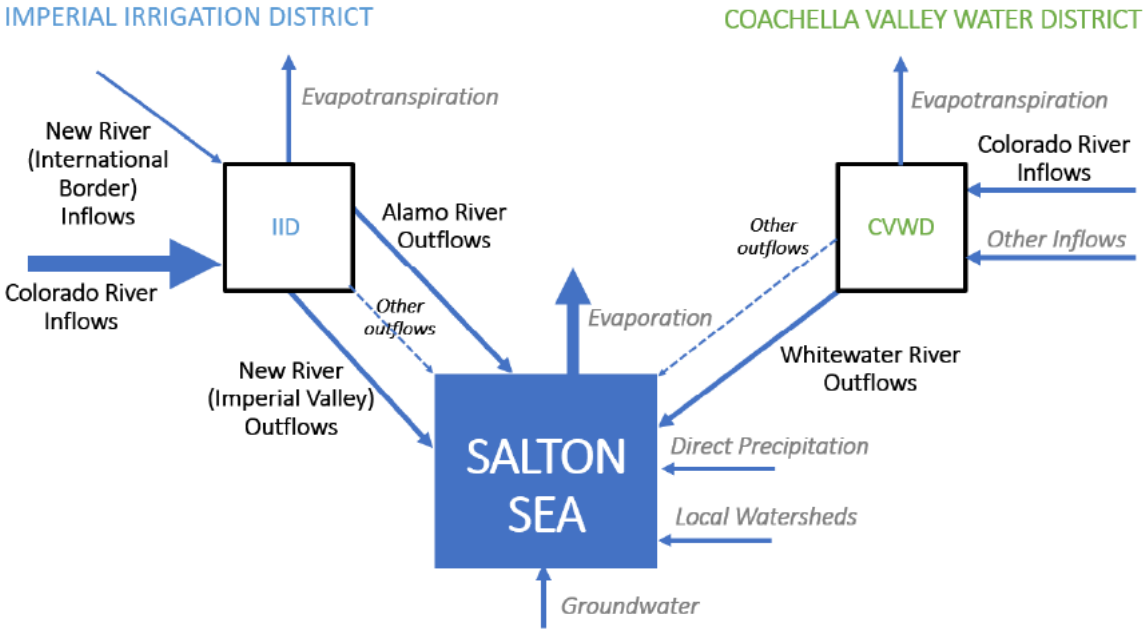

Figure 1. Flows into and out of the Imperial Irrigation District (IID), the Coachella Valley Water District (CVWD), and the Salton Sea. Flows that are italicized are ungaged but can be estimated.

Future Hydrology: Delivery allocations and climate change

The development of future inflow to the Sea is centered around determining how much the total freshwater inflow may change due to effects of climate change, including basin-wide ET changes for the areas producing the Sea's runoff, as well as any hypothetical changes to Colorado River water allocations, which make up the majority of Salton Sea inflows.

Long-term Colorado River allocations to Imperial Valley were made by considering the output of the Colorado River Simulation System (CRSS) model, which is used by USBR to provide long-term projections at the Colorado River basin.

On October 5, 2022, California users of Colorado River water released a statement proposing to conserve 400,000 AF of water each year from 2023 to 2026 to contribute towards stabilizing elevations in Lake Mead.[1] IID pledged to cut 250,000 AFY, an amount contingent on federal funding and voluntary participation of water users.[2] Other California users of Colorado River water that signed the statement were the Metropolitan Water District, CVWD, and the Palo Verde Irrigation District.

For the purpose of the EA for IID's Temporary Colorado River Conservation Project, developed in late 2023, the amount of targeted conservation examined for this memorandum is 300,000 AFY for the period 2024 to 2026, for a total of 900,000 AF of conservation. This amount forms the basis for the short-term (2024-2026) inflow reductions considered here, with two different total amounts based on the specific implementation of the reduction:

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[1] http://crb.ca.gov/2022/10/california-water-agencies-pledge-to-conserve-additional-water-to-stabilize-the-colorado-river-basin/

[2] https://calmatters.org/environment/2022/10/california-colorado-river-water/

- Fallowing conservation program (300 TAFY)
- Hybrid conservation program (50 TAFY efficiency and 250 TAFY fallowing)

Based on a review of records over the past 5 years, the fallowing effect represents a 35.7% loss to the Sea, derived from the fraction of Salton Sea inflow compared to Colorado River water supply to IID. The resulting inflow reductions for the conservation programs over the years 2024 – 2026 are shown in Table 1.

Table 1. Inflow reduction to the Salton Sea as a consequence of reduction in water supplies from the Colorado River to IID.

Assumption	**Inflow Reduction for 300,000 AFY Drought Reduction**	**Equation for Inflow Reduction**
Baseline - No drought reduction	0	-
Fallowing (35.7% Loss)	107,100	35.7% * 300,000
50 TAFY Efficiency & Fallowing (35.7% Loss)	139,250	50,000 + 35.7% * (300,000 - 50,000)

These reductions are expected to be met through a combination of an On-Farm Efficiency Conservation Program, an Alternative Crop Efficiency Program, a Deficit Irrigation Program, and a Farm Unit Fallowing Program. It is to be understood that many of these programs do not constitute conventional all-or-nothing fallowing; nevertheless a "fallowed acres equivalent" can be computed based on the net ET and the overall average ET rate. A schematic of the inflow reduction scenarios, their net IID inflows to the sea, and the fallowed equivalents is shown in Figure 2.

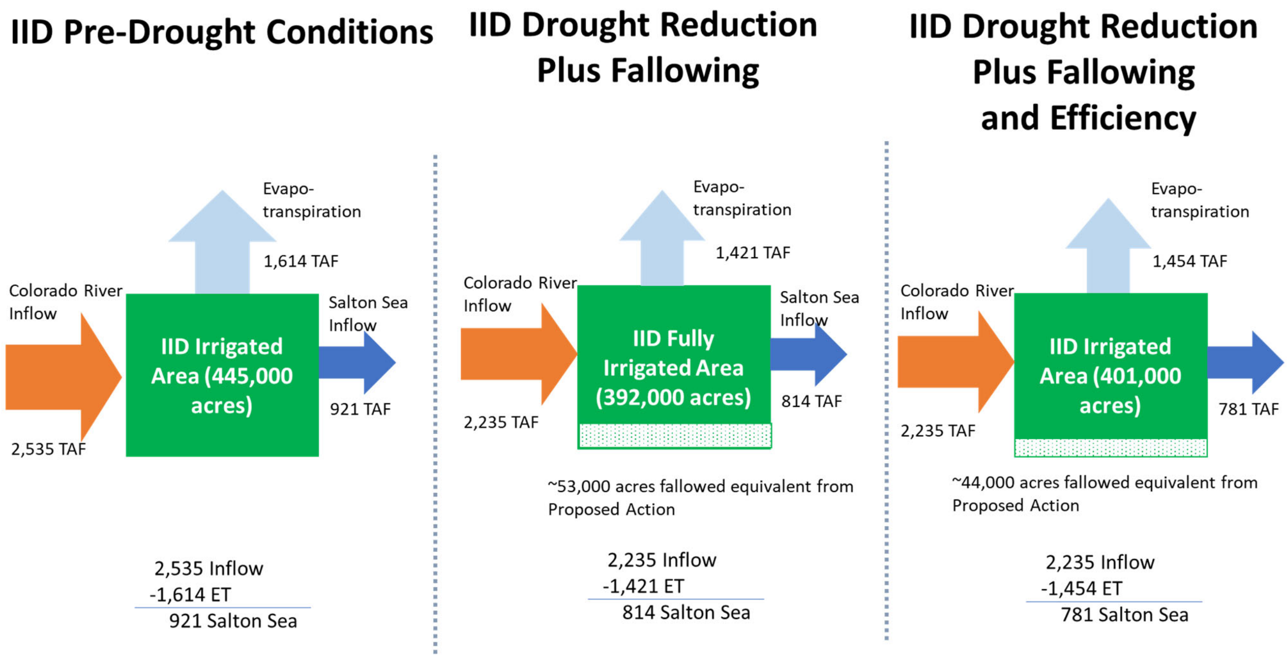

Figure 2. Schematic of the effects of Colorado River allocations on IID inflow to the Sea (modified from a previous version provided to Reclamation)

During earlier planning in 2022, CVWD suggested using delivery reductions of 25 TAFY (10% of inflow reduction to IID). The reduction would be achieved through voluntary Colorado River Water Conservation Program up to 10 TAFY. Average return flows to drains are 20%, so the maximum potential reduction in flows to Salton Sea over the four-year period would be approximately 2,000 AFY. The remainder and any amount that cannot be achieved by the Colorado River Water Conservation Program would be achieved by reducing recharge at CVWD groundwater recharge facilities, which would have no impact to flows to the Salton Sea for the four-year period. The impact on flows to the Salton Sea from Coachella Valley will be small, and therefore are not included in the modeling.

Projections of future IID water delivery were produced using the Colorado River Simulation System (CRSS) model developed by the US Bureau of Reclamation. The CRSS model was developed and is used by Reclamation to provide long-term projections at the Colorado River Basin (Reclamation, 2012 [4]). The June 2021 version of the CRSS model was obtained from Wheeler et al. (2022) [5] and was provided with the initial conditions in June 2021. Future water demands as the "2016 demands" (2016 Upper Colorado River Commission Schedule for the Upper Division States; and 2007 Final Environmental Impact Statement for the Colorado River Interim Guidelines with the update on Nevada demand in 2019 for the Lower Division States) provided in the CRSS June 2021 version (Wheeler et al. 2022 [5]) were used. The projections of water delivery and other conditions at the Colorado River Basin were obtained from the CRSS model during the period 2022–2060. For this work, a baseline water delivery of 2.535 MAF to IID was assumed, to which the drought reductions were applied.

The projected temperature and windspeed changes from California's Cal-Adapt RCP8.5 climate scenarios[3] were incorporated into estimates of ET using the Penman-Monteith equation. For both maximum/minimum temperature and windspeed, the projected change between 1991-2020 and 2035-2064 was added to a set of observed baseline numbers. For temperature, the baseline numbers were a seasonal pattern (monthly) of maximum/minimum temperature observations from 2004-2021. For wind speed, the baseline number was based on an average of four windspeed stations near the Salton Sea from 2015-2021. Based on these climate change effects, ET is expected to increase by 3.5 to 5.0% by 2035-2064 (see Table 2). As a conservative estimate for the future inflow scenarios, an increase of 5% is assumed. Therefore, the climate-adjusted ET rate is 3.78 AF/acre of irrigated land (or 5% increase from the current estimate of 3.60 AF/acre). The volume of water lost assumes an irrigated acreage value of 445,011 acres, which is the average over 2018 to 2021 for the Imperial Valley.

Table 2. Penman-Monteith estimates of ET.

Trace	**Annual average maximum temperature increase (°C)**	**Annual average minimum temperature increase (°C)**	**Average wind speed change (m/s)**	**Estimated % increase in ET (1971-2000 to 2035-2064) via Penman-Monteith Equations**
Low	1.69	1.66	0.987	3.56%
Average	2.01	1.96	0.988	4.46%
High	2.20	2.22	0.990	5.02%

In the Coachella Valley, the Indio Subbasin Water Management Plan Update (Indio Subbasin GSAs, 2021 [6]) was utilized as the source for future inflow to the Sea. The scenario representing future projects with climate change was selected as the most appropriate scenario with 70,000 AFY as the flow representing future conditions at the Sea. This represents the total inflow to the Sea from the Coachella Valley, including the gaged CVSC.

The model results shown here use a future hydrology that linearly decreases from current values to 889,448 (see Table 3) by 2040. Further details about the hydrology in the Salton Sea Long Range Plan modeling work can be found in Appendix B of [3].

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[3] https://cal-adapt.org/

Table 3. Future long-term hydrology based on LRP high probability inflow.

INFLOW TERM	**VALUE (AF/year)**	**JUSTIFICATION**
Imperial Valley	852,900	Inflow to Imperial Valley (2,535,000 AFY) minus ET at 3.78 AF/acre of irrigated land
Mexico	0	Mexico flows gradually decrease to zero from the Scenario #1 value of 66,100 AFY
Coachella Valley	70,000	Simulated drain flow for future projects with climate change scenario (Indio Subbasin GSAs, 2021)
Local watershed	4,680	See Section 5.3.4 of Appendix B in [6]
Groundwater	11,900	See Section 5.3.5 of Appendix B in [6]
Lithium Allocation	-50,000	Lithium is a new and growing water use in the basin.
TOTAL	**889,000 AF/year**	

Primary Model Calculations

The model operates by water and salt mass conservation of the Sea. At each annual timestep, the following quantities of water volume are added (+) or subtracted (-) from the volume that was present at the beginning of the year:

- (+) Freshwater Inflows, a time series input from the relevant estimated hydrology scenario, as discussed above.
- (-) Total Water Volume needed to satisfy evaporation demands of fixed-size conservation projects, when applicable.
- (-) Total Water Volume needed to meet dust suppression obligations, defined as 1 acre-ft of water annually per acre of area within the 2003 shoreline not covered by the remaining Sea or any planned conservation projects in a given year.
- (-) Direct evaporation volume from the dynamically sized Sea, dependent on the area and salinity of the Sea in a given year, using the same quadratic polynomial regression in USGS's original SSAM model (see below), which takes a baseline evaporation rate (calibrated to be 69.9 inches annual, see below) and returns a smaller evaporation rate with increasing salinity.
- (+) Direct precipitation volume on the Sea. Values from 2004-2012 are from PRISM. More recent years (2013-2022) are filled in from California Irrigation Management Information System (CIMIS) Imperial Valley data. The historical average of the updated dataset is approximately equal to 2.5 inches per year, and that is the value used for all future years.

Similarly, salt mass has the following additions (+) and subtractions (-) at each timestep, assuming direct evaporation and precipitation of water to have minimal effect on salt balance:

- (+) Salt coming in with freshwater inflows, using the inflow-dependent regression present in USGS's original SSAM model, which has higher salt concentrations with lower inflow volumes.
- (-) Annual salt precipitation of 0.15% of the current salt mass in the Sea.
- (-) Any salt above saturation salinity of 280 ppt.

Bathymetry data and EAC curve

For any state of the Sea, there is a 1-1-1 relationship between its elevation, area, and capacity (volume), also known as the EAC relationship or EAC curve (see Figure 3 and Figure 4). This relationship was estimated from the latest available bathymetry data (interpolated to the nearest 0.1 ft using the underlying raster dataset in [3]) and is available to view in the model spreadsheet EACInput. For each model run, this EAC curve is used to get the initial Sea volume (as the initial conditions are specified as an elevation) and to convert the Sea volume at each timestep to a Sea area and Sea elevation (interpolated to the nearest tenth of a foot, NAVD88).

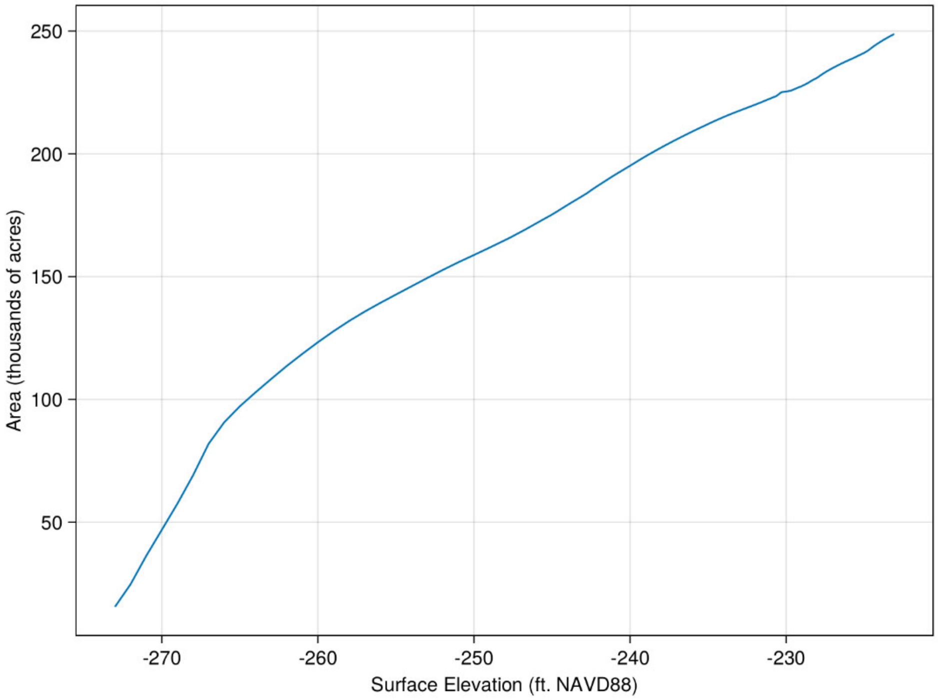

Figure 3. Relationship between elevation and area in the EAC curve used in these SSAM 2.0 modeling efforts.

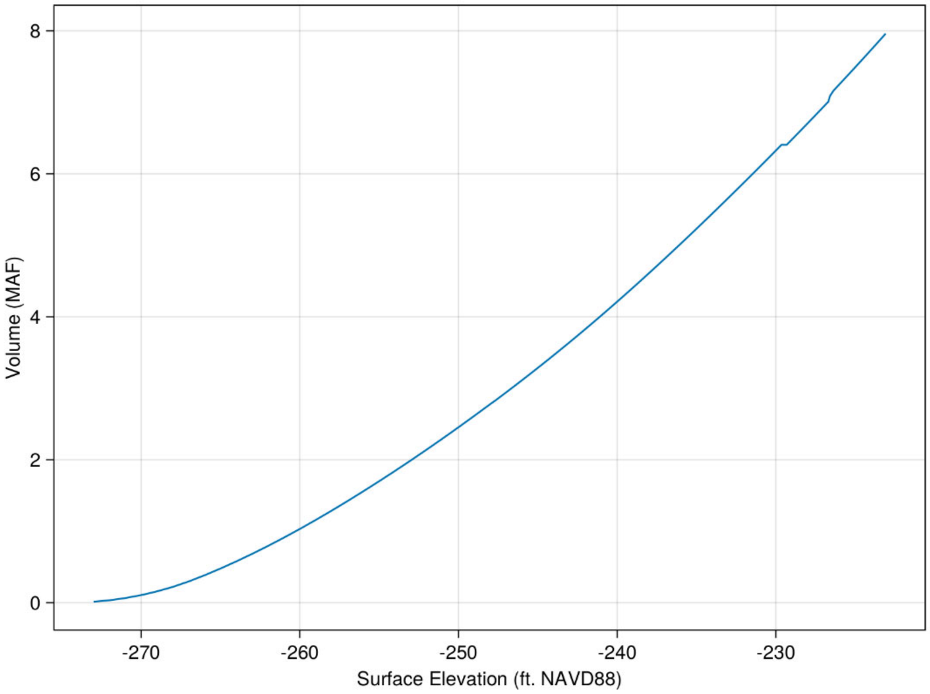

Figure 4. Relationship between elevation and volume in the EAC curve used in these SSAM 2.0 modeling efforts.

Salinity-Dependent Evaporation

The evaporation rate from the Sea's surface is reduced as salt concentration in the Sea increases. The original USBR SSAM modeled this effect using a regression of the form:

$$E_{net} = E_{base} \cdot \left(\frac{a + b \cdot (S/1000)^{2.5}}{a + b \cdot \left(S_{ref}/1000\right)^{2.5}} \right)^2 ,$$

where:

- E_{base} is the baseline evaporation amount for freshwater,
- S, is the Sea's salinity at the current timestep,
- S_{ref} is a reference salinity value (set to 45723.33 ppm),
- a and b are model constants with values 0.981902618 and -1.39819E-07, respectively.

The same equation was used in the SSAM 2.0 updated by Tetra Tech and is illustrated in Figure 5.

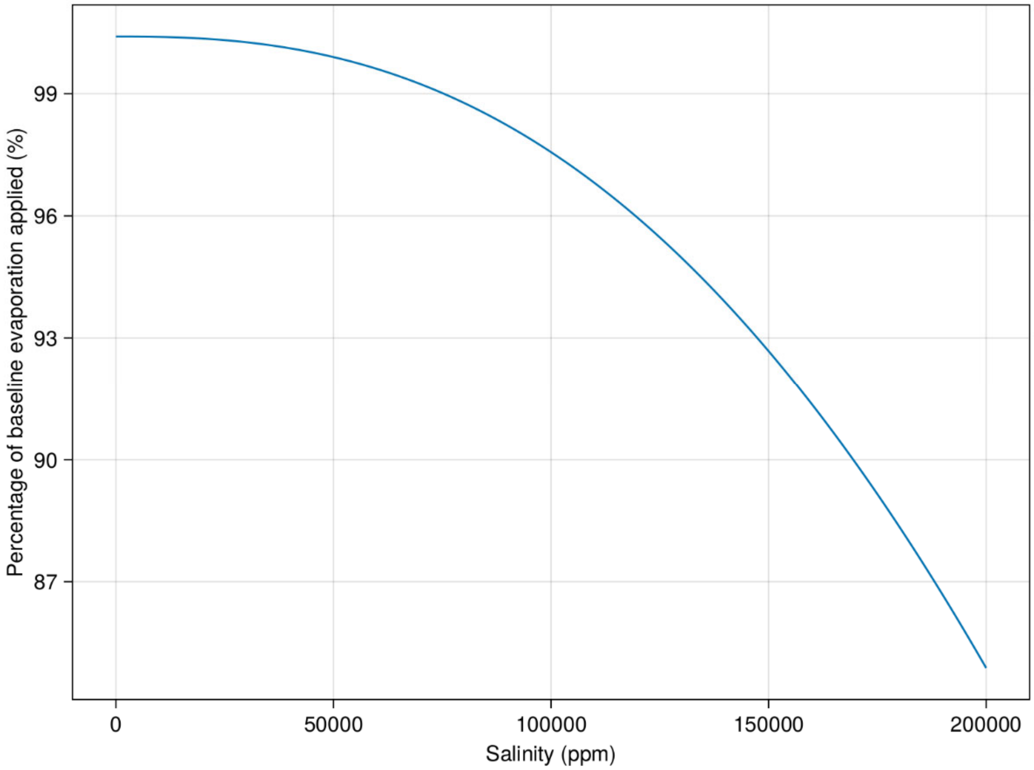

Figure 5. Illustration of decrease in net evaporation with salinity.

Salinity-Dependent Inflow Salinity

The salinity of the water specified as total inflow depends on the inflow volume in the form of a linear regression used in the original USBR model. $S_I = a + b \cdot V_I$, where $a = 5016.07448$ and $b = -0.00204508$, and this formulation has been retained in the Tetra Tech-updated version of SSAM.

Model Inputs

The main inputs the user is required to provide to the model are the following:

- The model begins in 2020 at an elevation of -235.5 ft NAVD88 with an initial salinity of 74,250 ppm.
- Total freshwater inflow each year, specified as a time series from the chosen starting year to 2100. This is the input that was modified to consider different drought mitigation scenarios.
- The baseline evaporation (i.e., evaporation before salinity-based modification) for each year. This was derived as a calibrated average value from historical data from 2004 to 2021. This average, i.e., a constant value of 69.9 inches per year, is used for all future years (2022 onwards).
- Although the model can simulate water use from conservation projects, the results shown in this memo do not include the effects of 10-Year plan projects, including SCH.

These input data are shown in **Table 4**.

Table 4. Primary SSAM 2.0 input data

Year	Inflow Baseline (af)	Inflow Fallowing (af)	Inflow Fallowing and Efficiency (af)	Base evaporation (in)	Precipitation (in)
2004	1,205,693	1,205,693	1,205,693	66.0	4.4
2005	1,252,187	1,252,187	1,252,187	66.0	4.4
2006	1,214,560	1,214,560	1,214,560	70.0	0.7
2007	1,206,227	1,206,227	1,206,227	66.0	1.9
2008	1,166,790	1,166,790	1,166,790	74.0	2.7
2009	1,058,828	1,058,828	1,058,828	66.0	1.0
2010	1,190,201	1,190,201	1,190,201	69.0	4.9
2011	1,172,468	1,172,468	1,172,468	66.0	1.9
2012	1,267,420	1,267,420	1,267,420	68.0	2.2
2013	1,143,849	1,143,849	1,143,849	74.0	1.8
2014	1,098,163	1,098,163	1,098,163	66.0	0.6
2015	1,126,640	1,126,640	1,126,640	73.0	1.5
2016	1,148,693	1,148,693	1,148,693	74.0	1.9
2017	1,104,305	1,104,305	1,104,305	74.0	4.0
2018	1,065,116	1,065,116	1,065,116	74.0	2.3
2019	1,044,076	1,044,076	1,044,076	68.0	3.4
2020	1,053,611	1,053,611	1,053,611	71.0	2.0
2021	1,093,575	1,093,575	1,093,575	74.0	2.0
2022	1,090,859	1,090,859	1,090,859	69.9	2.5
2023	1,080,139	1,080,139	1,080,139	69.9	2.5
2024	1,064,483	957,383	925,233	69.9	2.5
2025	1,048,826	941,726	909,576	69.9	2.5
2026	1,033,169	926,069	893,919	69.9	2.5
2027	1,017,513	1,017,513	1,017,513	69.9	2.5
2028	1,001,856	1,001,856	1,001,856	69.9	2.5
2029	986,199	986,199	986,199	69.9	2.5
2030	970,543	970,543	970,543	69.9	2.5
2031	954,886	954,886	954,886	69.9	2.5
2032	939,229	939,229	939,229	69.9	2.5
2033	923,573	923,573	923,573	69.9	2.5
2034	907,916	907,916	907,916	69.9	2.5
2035	892,259	892,259	892,259	69.9	2.5
2036	891,695	891,695	891,695	69.9	2.5
2037	891,131	891,131	891,131	69.9	2.5
2038	890,567	890,567	890,567	69.9	2.5
2039	890,003	890,003	890,003	69.9	2.5
2040	889,438	889,438	889,438	69.9	2.5

Model Outputs

The primary outputs of interest are Sea area, elevation, and salinity. These are all reported on an annual timestep in the ModelCalcs spreadsheet.

Model Calibration

No sufficiently robust sources of direct Salton Sea evaporation data exist, so the baseline evaporation rate was treated as a calibration parameter. Daily Sea elevation data from 2004-2021 and periodic salinity data (approximately every three months) from 2004-2020 were available for use in calibration.

The model was initialized to January 2004 based on the average data of the first month of each of the above series. Then, historical inflow from 2004-2020 was input into the model.

First, evaporation was initialized to 68 inches for all years. Then an iterative calibration process was then applied to each year from 2004 to 2020 to better match observed salinity and elevation data as follows:

- Evaluate the effect of setting the evaporation of the year in question to each value in the set of candidates: {66, 67, 68, …, 74}. This range was deemed to be consistent with previously used estimates of annual evaporation in other analyses.
- Linearly interpolate the model output within the calendar year since the observed data are daily while the model output is annual.
- Note the rank for each candidate according to best sum of squared error performance on each for salinity and elevation only within the year being evaluated.
- Choose the candidate salinity with the best performance according to the weighted average of three times the elevation rank and one times the salinity rank. The elevation data were given more weight because there is less noise in that dataset.
- Proceed to the next year and repeat the process.

The model was able to match the observed elevation and salinity data well after calibration (see Figure 6 and Figure 7). The resulting average annual evaporation used for all future years was 69.9 inches.

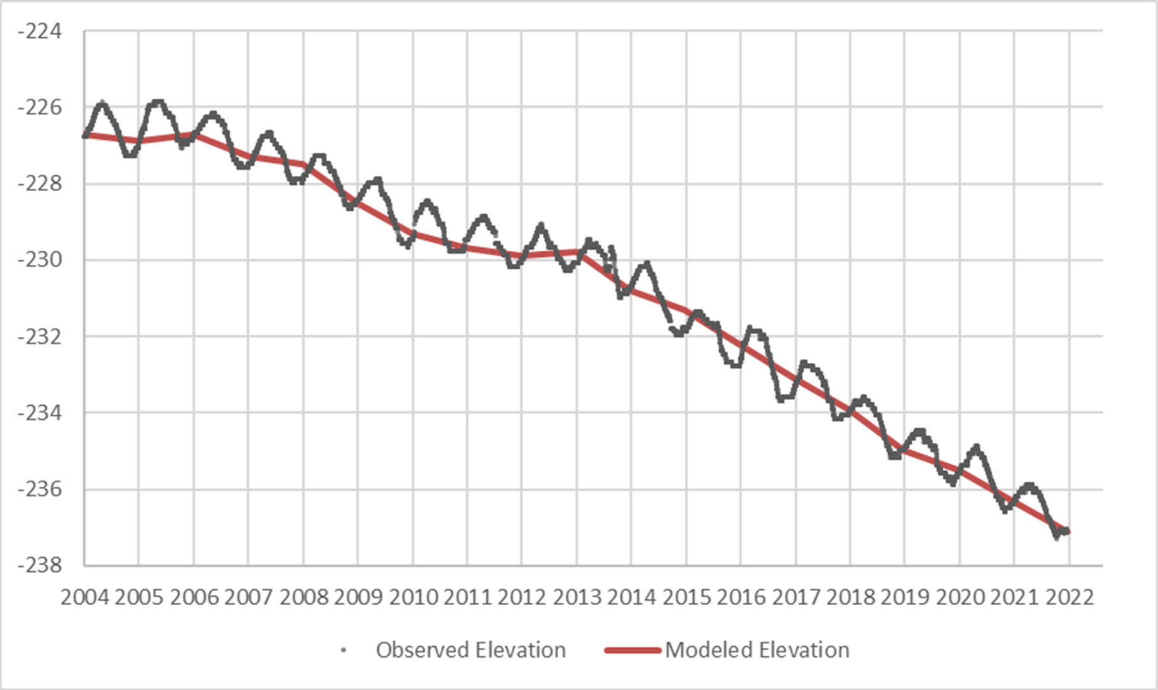

Figure 6. Observed and Calibrated Salton Sea Elevation (ft NAVD88)

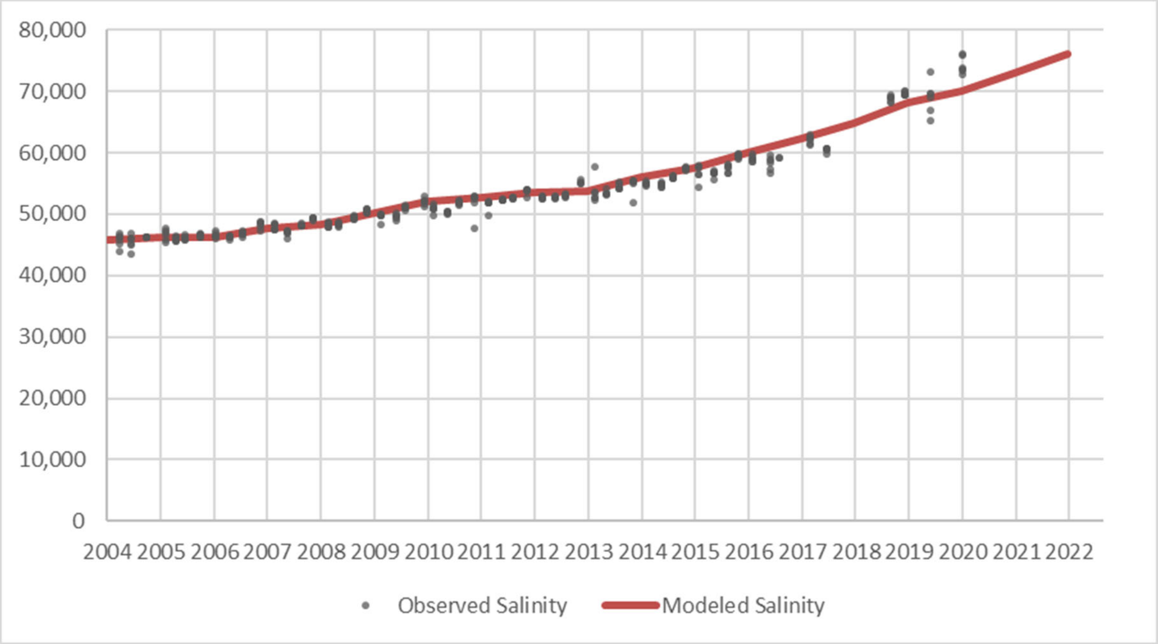

Figure 7. Observed and Calibrated Salton Sea Salinity (ppm)

As a sensitivity analysis, we also repeated the entire calibration with best-estimate historical inflows perturbed by +/- 5%. The case with 5% less inflow decreased the calibrated average evaporation to 68.0 inches, whereas the case with 5% more inflow increased it to 71.0 inches.

Modeled Inflow Scenarios

Figure 8 shows the three inflow scenarios used for the projections in this study, the baseline projected flow, and with drought conservation with fallowing on IID lands and with fallowing and efficiency on IID lands. Fallowing and efficiency results in lower inflows to the sea than fallowing alone. The drought conservation was applied for 3 calendar years (2024-2026). The results for other variables, including exposed lakebed and salinity, are shown in Figure 9 through Figure 12.

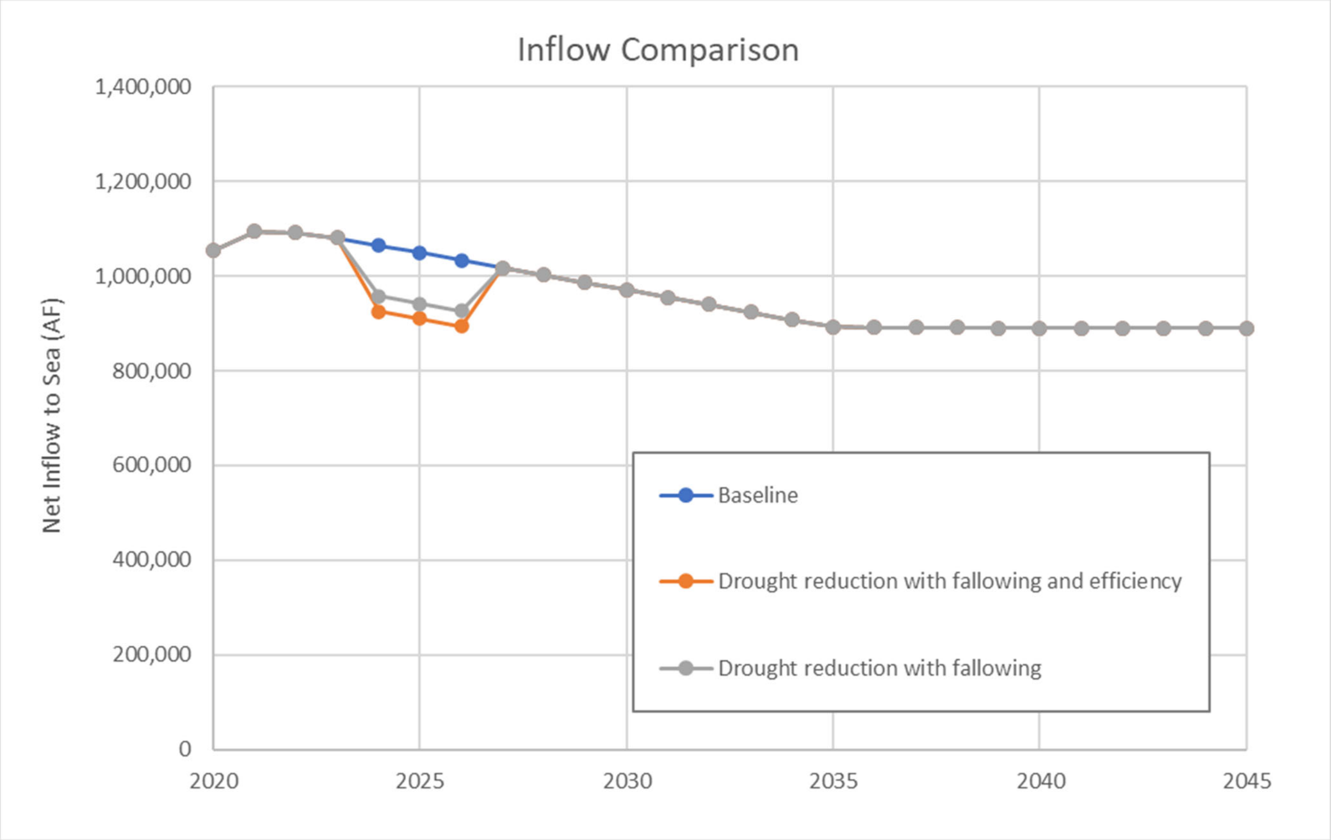

Figure 8. Effect of estimated drought reduction inflows on total inflow to Sea used by the model.

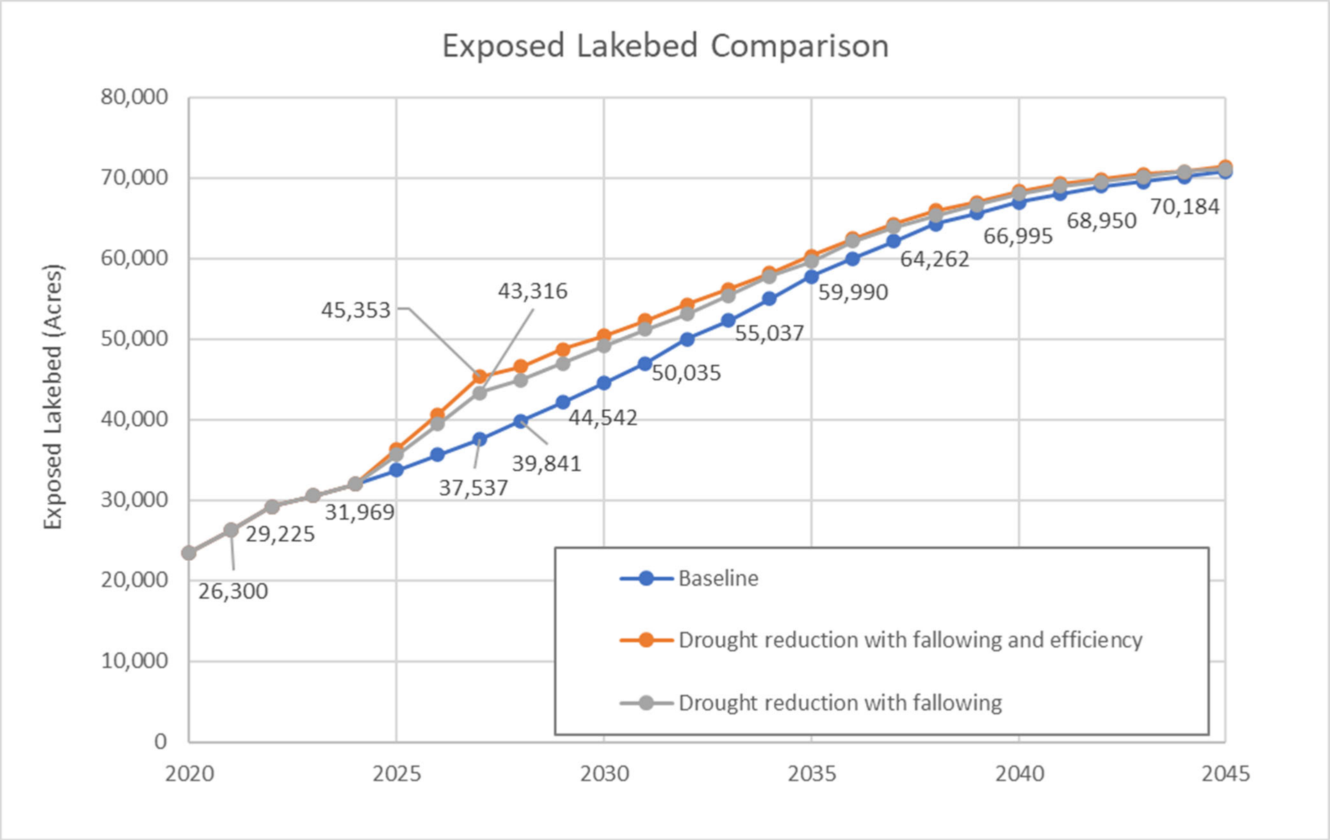

Figure 9. Impact to exposed lakebed from drought reduction scenarios (2020-2045)

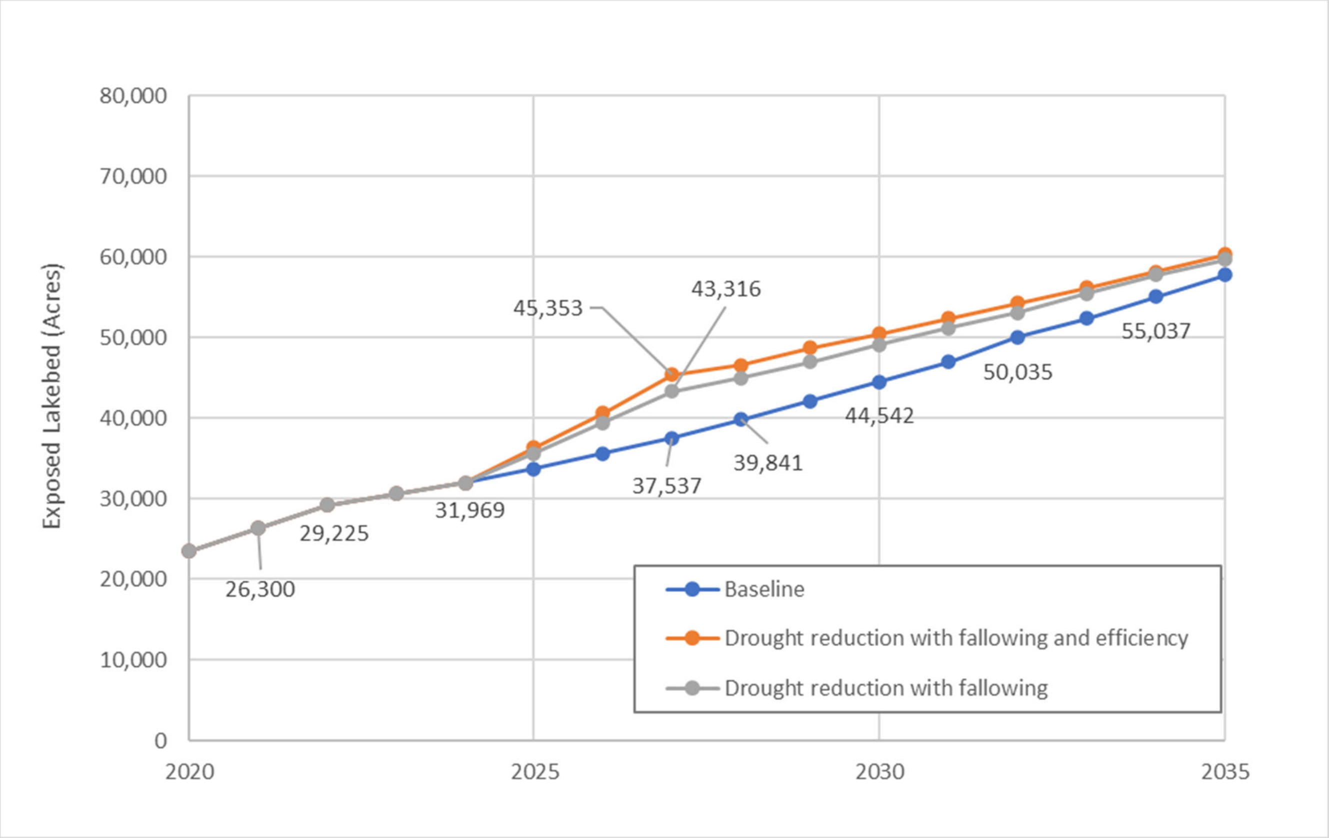

Figure 10. Impact to exposed lakebed from drought reduction scenarios (2020-2035)

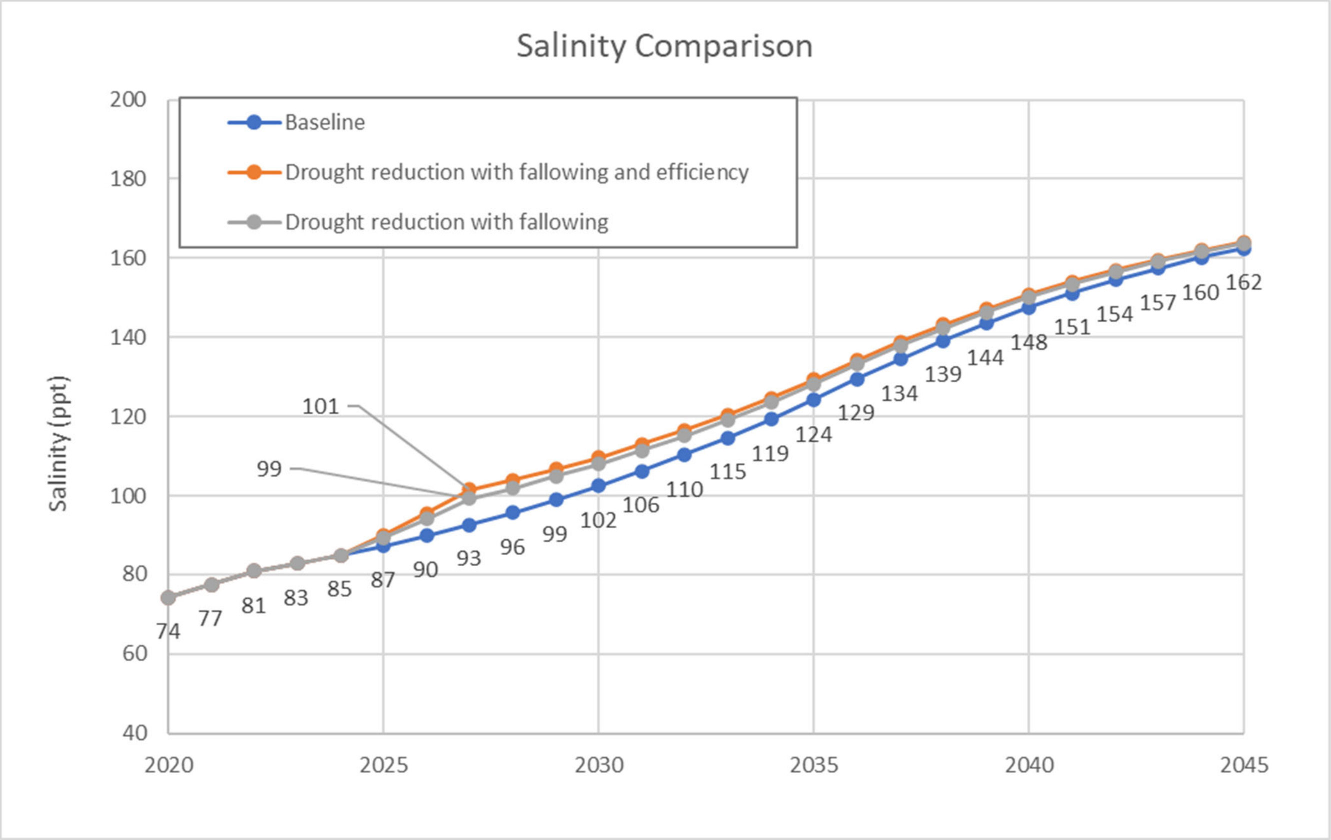

Figure 11. Impact to salinity from drought reduction scenarios (2020-2045)

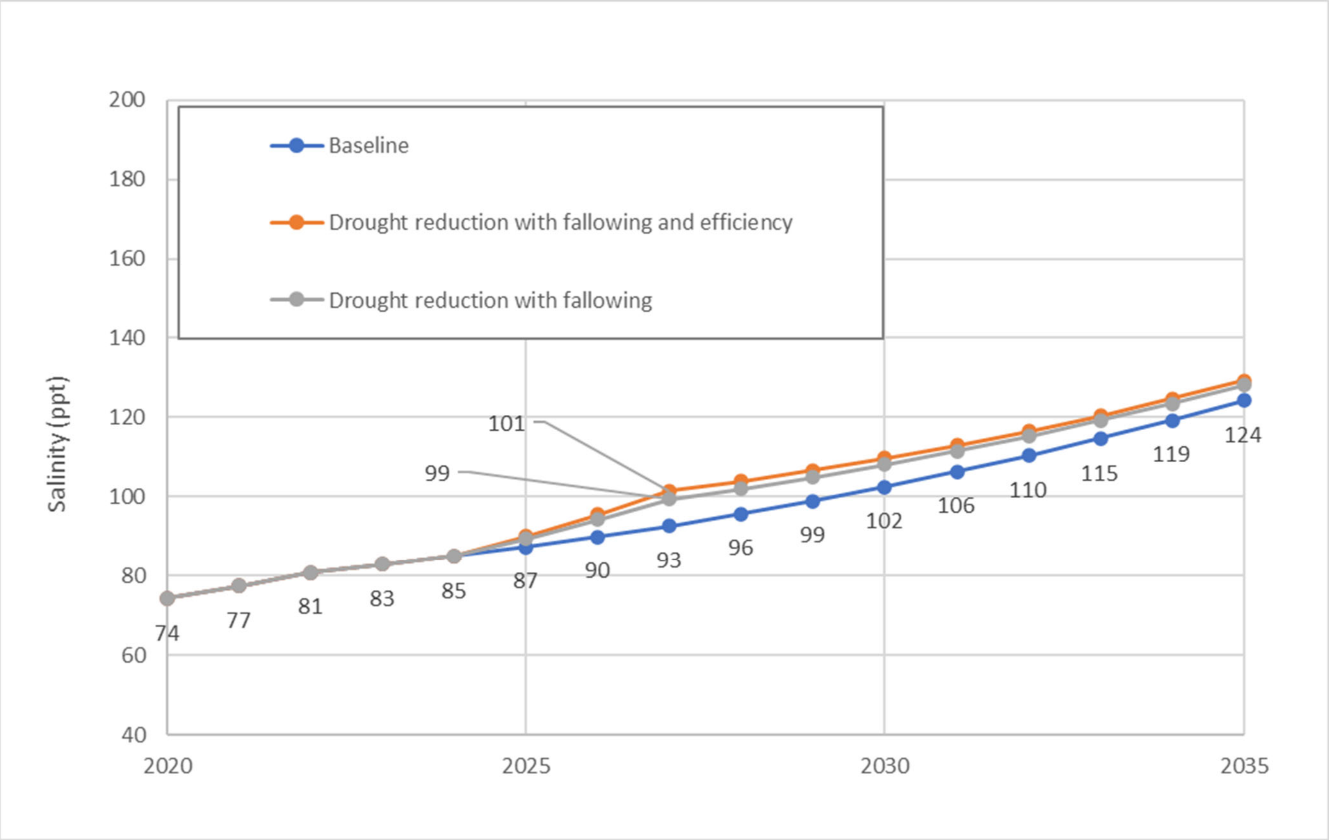

Figure 12. Impact to salinity from drought reduction scenarios (2020-2035)

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[1] US Bureau of Reclamation (USBR) 2000."Salton Sea Accounting Model," https://www.usbr.gov/lc/region/saltnsea/pdf_files/daar/daar_att-b.pdf

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