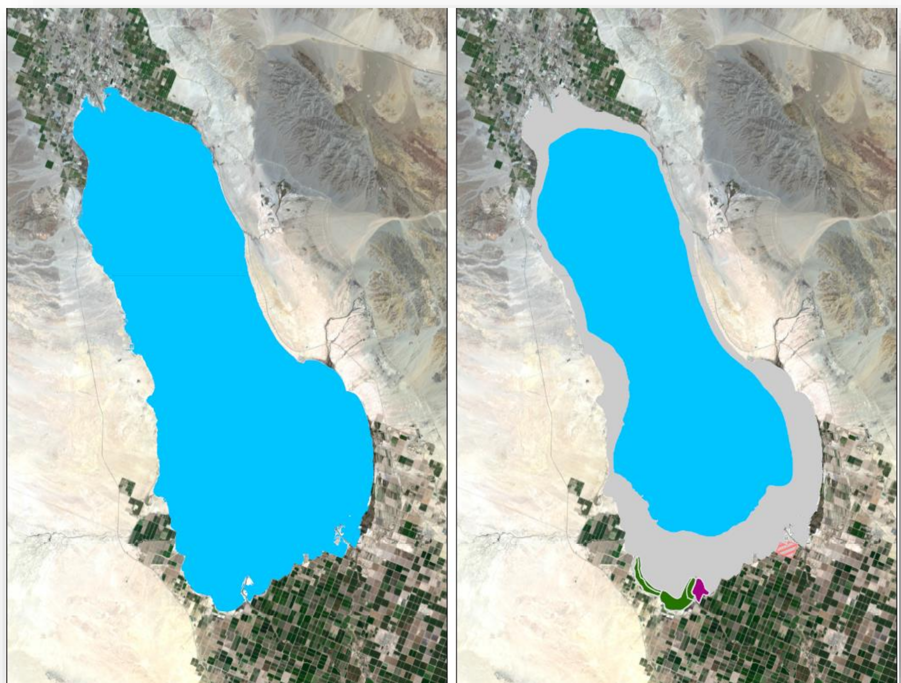
TECHNICAL REPORT

Salton Sea Hydrological Modeling and Results



Prepared for

Imperial Irrigation District

October 2018

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Introduction

As efforts continue to develop a range of long-term management options for the Salton Sea, the basis for planning requires and understanding of the historical and future hydrology at the Salton Sea. This technical report describes the hydrological model, SALSA2, which simulates the overall the water and salt balance for the Salton Sea for future conditions. This report is meant to serve as a technical reference for the methods, assumptions, and results for SALSA2 model and simulations under Future No Action hydrologic conditions. The development of Historical and Future No Action inflows and salt loads are described separately in the technical report Salton Sea Hydrology Development (CH2M 2018a).

This technical report and, therefore, the hydrological model, SALSA2, uses the estimates for inflows to the Salton Sea from the Coachella Valley provided to IID by Coachella Valley Water District. This data was not collected or validated by IID and use of such data in SALSA2 does not constitute IID's acceptance or agreement with such data. Further, IID reserves its rights to challenge this data, but, in the interest of time for providing hydrology modeling and analysis about the future of the Salton Sea to the public, IID is publishing this report using Coachella Valley Water District's data.

SECTION 2

Description of Study Area

The Salton Sea is a terminal, saline lake located in the southeastern corner of California, within one of the most arid regions in North America. The Salton Sea is the largest lake in California, measuring approximately 35 miles long and 9 to 15 miles wide with about 360 square miles of water surface area and 120 miles of shoreline. The Salton Sea lies in a geographic depression known as the Salton Basin located approximately 278 feet below mean sea level. The water surface elevation on December 31, 2015, was approximately 232.8 feet below mean sea level at the North American Vertical Datum of 1988 (NAVD88) (U.S. Geological Survey [USGS], 2016). At this elevation the Salton Sea has a water storage volume of approximately 5.7 million acre-feet (maf).

2.1 Background

The Salton Basin is the northern arm of the former Colorado River delta system. Throughout the millennia, the Colorado River has deposited water and sediments across its delta through many channels; sometimes discharging south to the Gulf of California and sometimes discharging floodwater north into the Salton Basin. The floodwaters in the Salton Basin formed a large, temporary lake known as Lake Cahuilla (Pomeroy and Cruse, 1965; Ogden, 1996). The Colorado River would eventually return to its southerly path and, without a water supply source, the lake waters would evaporate leaving behind millions (if not billions) of tons of salts. The last transient existence of Lake Cahuilla may have been as recent as 300 or 400 years ago and is described in Native American folklore and verified through carbon dating (Ogden, 1996). Eventually the floods of the Colorado River built a slight natural berm that topographically separated the Salton Basin from the Gulf of California.

During large floods of the Colorado River, however, flood flows are reported to have reached the Salton Basin in at least 8 years during the 19th century (Ogden, 1996). The current Salton Sea was formed from 1905 to 1907 as a result of a failure of a diversion structure during flood conditions on the Colorado River in which the Colorado River flowed uncontrolled into the Salton Basin (Ogden, 1996, Hely et al., 1966). The water surface elevation of the Salton Sea rose to a maximum of 195 feet below mean sea level by the time the diversion dike was repaired in 1907, but rapidly receded to approximately 250 feet below mean sea level in 1925 as evaporation exceeded the rate of agricultural return flows to the Salton Sea. In 1925, the elevation of the Salton Sea started to increase due to increased discharge of drainage from agricultural areas in Imperial, Coachella, and Mexicali valleys. Drainage flows from these areas have generally sustained higher water surface elevations since the 1980s.

Similar to other closed-basin lakes, the Salton Sea is saline due to the accumulation of salts left behind through evaporation. The Colorado River water which formed the Salton Sea during 1905 to 1907 is estimated to have had an average salinity of about 500 milligrams per liter (mg/L) (Hely et al., 1966). However, the large amount of salts that had accumulated during previous inundations in past centuries rapidly dissolved into the fresh water. This redissolution of salts, combined with high evaporation rates and minimal inflows, caused the salinity to rapidly rise to above 40,000 mg/L total dissolved solids (TDS) by 1925. The salinity decreased in the late 1920s as irrigated agriculture expanded and resulted in greater drainage flows to the Salton Sea. During the Great Depression, in response to a decrease in agricultural drainage flows, the salinity increased again and exceeded 43,000 mg/L. After decreasing during the 1940s and 1950s to near ocean salinity (35,000 mg/L), the Salton Sea salinity has slowly risen to exceed 60,000 mg/L in June 2017 (Hely et al., 1966; Tostrud, 1997; Reclamation, 2017).

2.2 Salton Sea Watershed

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 Salton Sea lies at the lowest point in the watershed and collects runoff and agricultural return flows from most of Imperial County, a portion of Riverside County, smaller portions of San Bernardino and San Diego Counties, as well as the northern portion of the Mexicali Valley (Figure 1). Mountains on the west and northeast rims of the basin reach elevations of 3,000 feet in the Coyote Mountains to over 11,000 feet in the San Jacinto and San Bernardino mountains. To the south, the basin extends to the crest of the Colorado River Delta. About one-fifth of the basin is below or only slightly above mean sea level (Hely et al., 1966). Annual precipitation within the watershed ranges from less than 3 inches near the Salton Sea to up to 40 inches in the upper San Jacinto and San Bernardino Mountains. The maximum temperature in the basin exceeds 100 degrees F on more than 110 days per year. The open water surface evaporation rate at the Salton Sea is estimated at approximately 69 inches per year and the average annual crop reference evapotranspiration rate at Brawley is reported to be approximately 71 inches per year (California Irrigation Management Information System [CIMIS] 2012).

Agriculture in the Imperial and Coachella valleys is sustained by Colorado River water diverted at Imperial Dam and delivered via the All-American and Coachella canals. In recent years, total diversions at the Imperial Dam have ranged from approximately 3.0 to 3.6 maf/yr to support over 500,000 acres of irrigated agriculture in the Imperial and Coachella valleys (Reclamation 1999-2003). Agricultural return flows from these areas and parts of the Mexicali Valley, as well as municipal and industrial discharges in the watershed, feed the major rivers flowing to the Salton Sea. The principal sources of inflow to the Salton Sea are the Whitewater River to the north, the Alamo and New rivers to the south, and direct return flows from agricultural areas in both Imperial and Coachella valleys. Smaller contributions to inflow come from San Felipe Creek to the west, Salt Creek to the east, direct precipitation, and subsurface inflow. Total average annual inflow to the Salton Sea over the period from 1950 to 2015 is estimated to be approximately 1.3 maf, but have been as low as 1.0 maf in the recent decade.

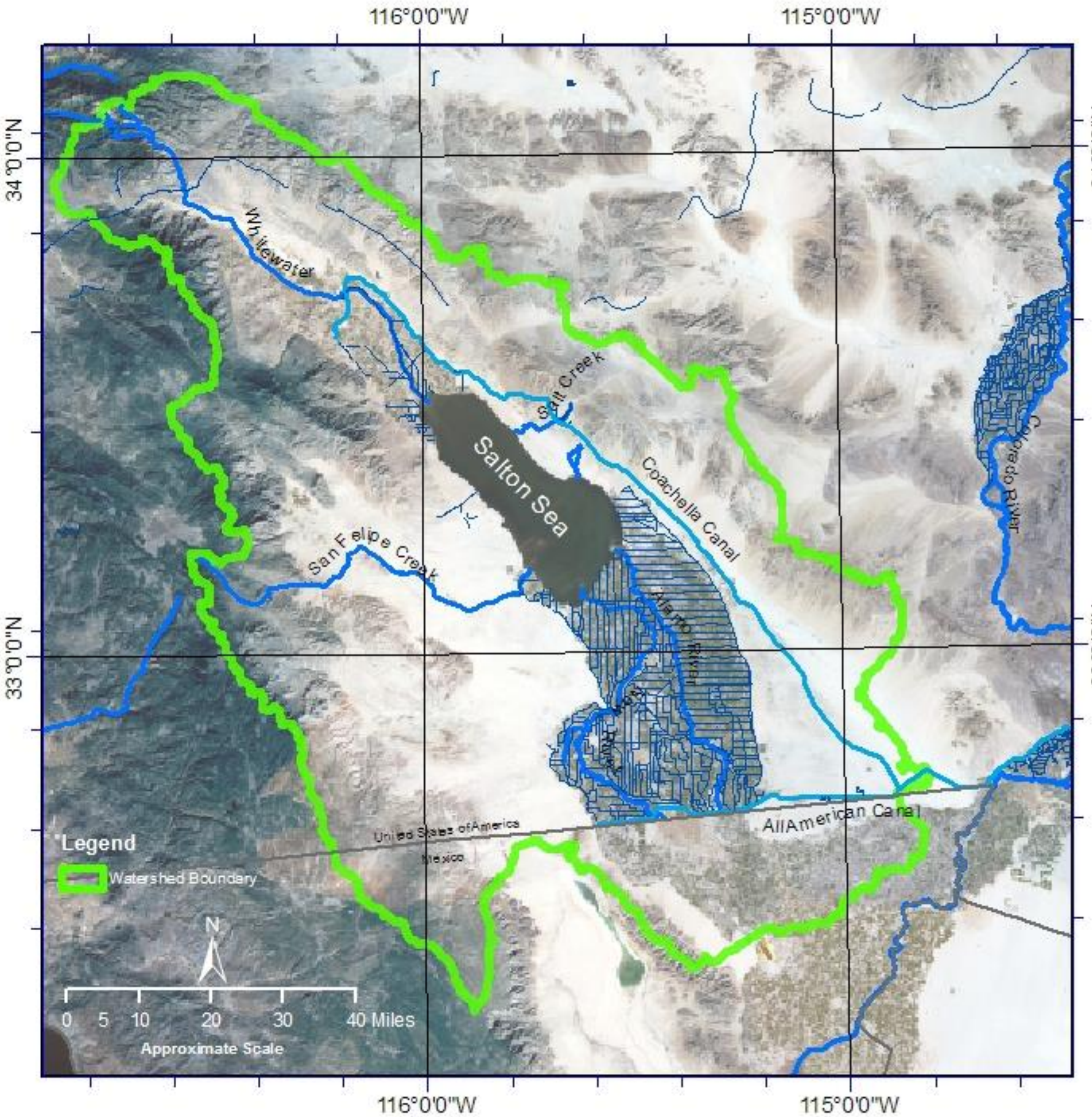


Figure 1. The Salton Sea Watershed and Major Contributing Streams

SECTION 3

SALSA2 Model Description

The SALSA2 model has been developed within a generalized system dynamics modeling platform named GoldSim, which greatly facilitates evaluation of alternatives in an uncertainty framework. The overall objective of model development and application was to provide tools for the analysis of hydrologic and salinity conditions at the Salton Sea. The following requirements were established for the model during development: (1) simulate future Salton Sea elevation and salinity under varying inflow assumptions; (2) account for full water and salt balances; (3) allow simulation of daily time steps to capture seasonal variation; (4) incorporate water demands from air quality and habitat mitigation measures as part of likely alternatives; (5) incorporate functional relationships of evaporation suppression with increasing salinity, salt precipitation, and salt re-dissolution; and (6) incorporate a stochastic simulation mode to analyze uncertainty.

GoldSim is a general simulation software solution for dynamically modeling complex systems in business, engineering, and science. GoldSim supports decision and risk analysis by simulating future performance while quantitatively representing the uncertainty and risks inherent in all complex systems (http://www.goldsim.com). Organizations worldwide use GoldSim simulation software to evaluate and compare alternative designs, plans, and policies to minimize risks and make better decisions under uncertainty. GoldSim can handle all the complexities of the system, provide for ease of use and alternative analysis, provide a state-of-the-art modeling platform that will not become outdated in a short time, allow for ease of linkage to other analysis tools used by the IID and, is relatively economical.

The GoldSim modeling platform has the ability to achieve the following objectives:

1. Customize simulation procedures
2. Transfer information with existing external dynamic link libraries (DLLs)
3. Create submodels for subsystem partitioning
4. Perform probabilistic simulation for use in alternative proposed project analyses, climate change studies, or stochastic simulations.

Other factors that were considered important are the ability of the platform to exchange data between other programs or spreadsheets and the handling of array constructs.

The model files include GoldSim files, MSExcel input and output spreadsheets, and a range of post processing files. The post processing tools were developed to facilitate the interpretation of the model results.

The first model task was to define how the physical Salton Sea system would be represented in the GoldSim model. This representation of the system in GoldSim was achieved in two steps. For the first step, the previous SALSA model developed as part of the *Draft Programmatic Environmental Impact Report for the Salton Sea Ecosystem Restoration Program*, schematic networks were used as a starting point to represent the system and major components. For the second step, a system connectivity schematic was developed by incorporating the key components and connections that would be modeled in GoldSim. The SALSA2 model represents the water resources system, consisting of reservoirs, channels (natural and artificial), and demand locations, as a network of elements and links. Elements in the network may represent reservoirs, junction points of two or more flows, or simply a point of interest on a channel. Links represent water flows between elements or out of the system; there may be inflows, channel flows, return flows, or diversions to consumptive uses. Figure 2 shows the main dashboard in the SALSA2 model for the Salton Sea.

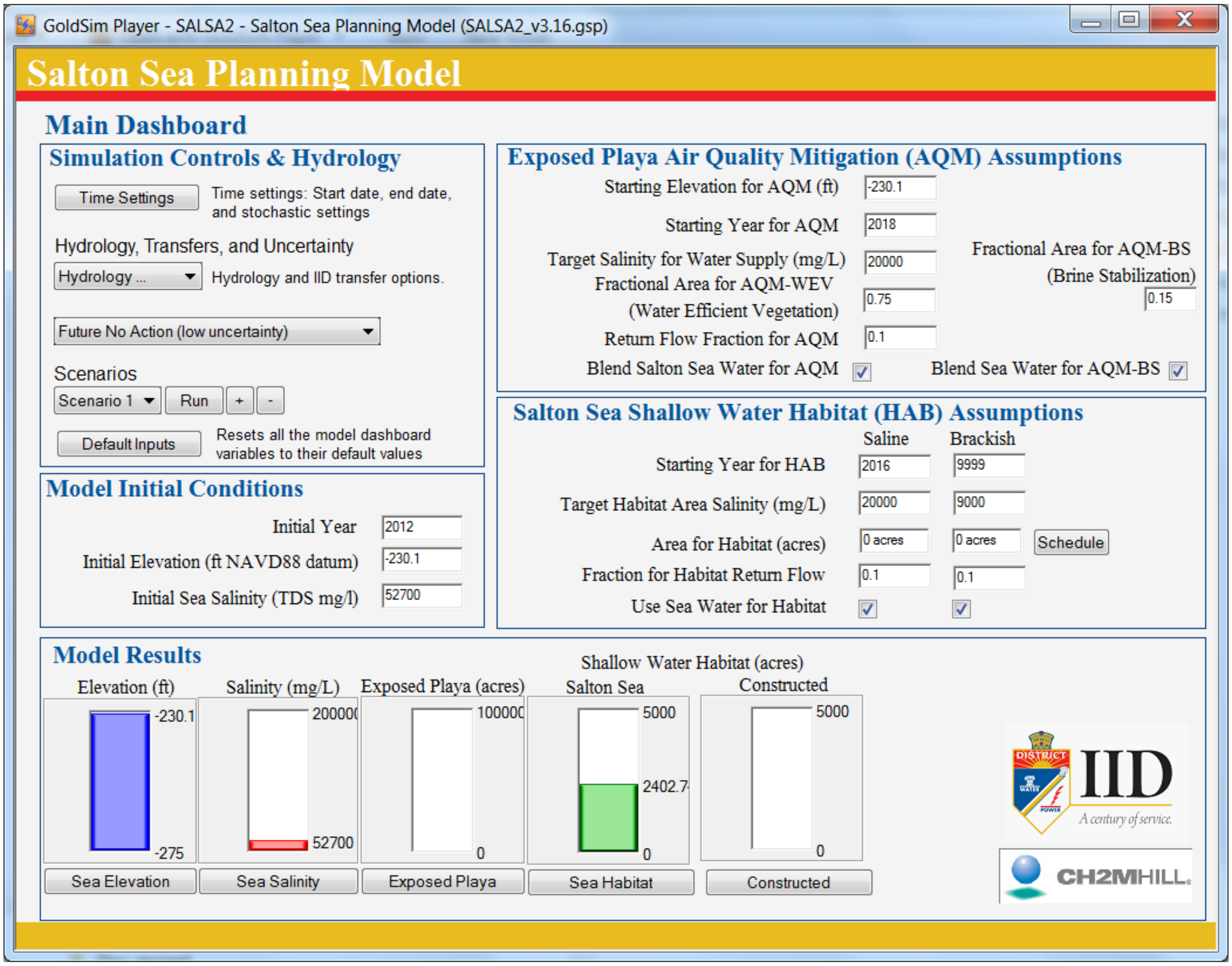


Figure 2. Main Dashboard of SALSA2 Model for the Salton Sea

3.1 Time Step

A daily simulation time step is used in the SALSA2 model. Annual input data are internally disaggregated into monthly data based on a review of historical monthly flow patterns. Monthly values are used as constant daily values for the model simulations.

3.2 Air Quality Mitigation and Habitat Components Incorporated into SALSA2

The SALSA2 model incorporates approximations of the key components of the Salton Sea environment including open water storage elements (SEA), habitat wetlands (HAB) and air quality management (AQM) areas (see Figure 3). The AQM and HAB components are included that could be used for air quality and Species Conservation Habitat (SCH) managements as part of any likely alternatives. These components require drain or saline water demands that would affect inflows to the Salton Sea.

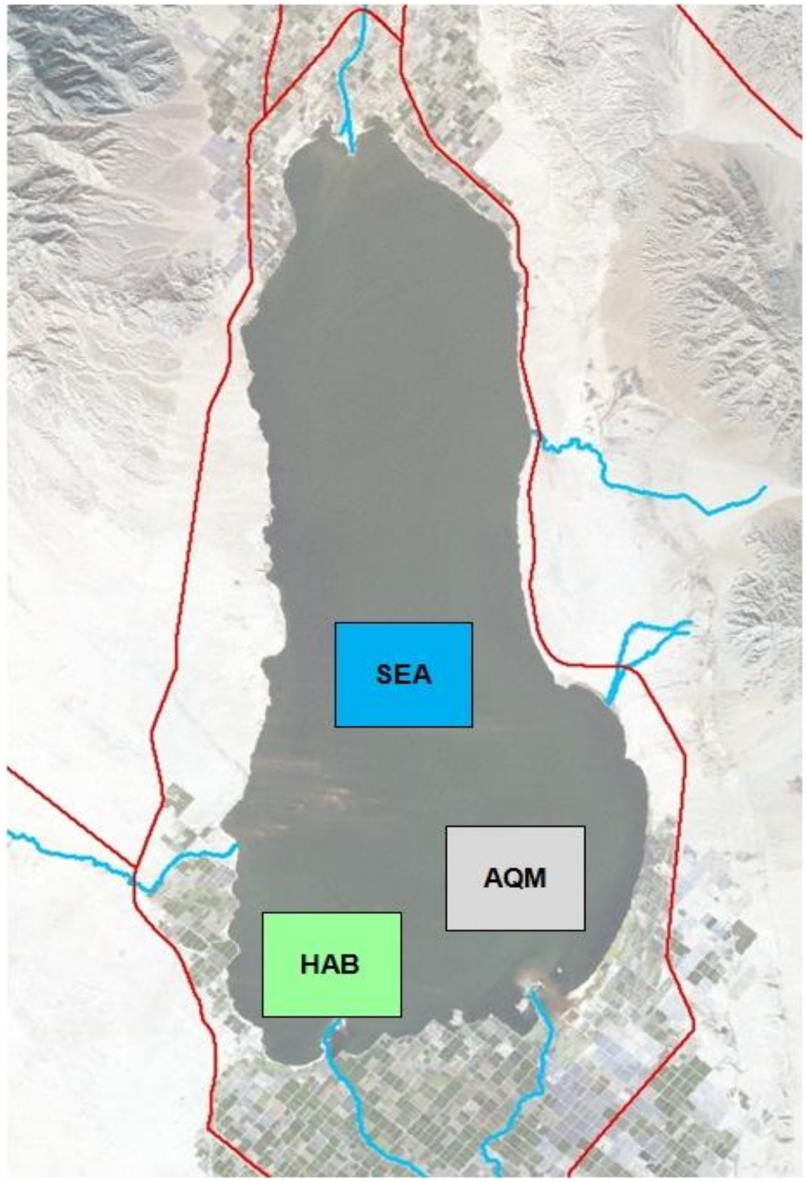


Figure 3. Main Model Demand Components in the SALSA2 Model for the Salton Sea

The SEA component was simulated as storage reservoir in the SALSA2 model. Water volume, surface area, elevation, and salinity are specifically calculated for this component. The SEA component requires bathymetric data to describe the elevation-area-capacity (EAC) relationship and evaporation rates.

The shallow cells associated with the Species Conservation Habitat (SCH) were simulated as the HAB component. Water volume, elevation, and salinity are not explicitly tracked for this component. The water surface area, land area, time-varying reference evapotranspiration rates (ETo) or evaporation rates, time-varying crop coefficients (Kc), and return flow fractions may be specified for this component. Depending on the vegetation coverage, if any, of these shallow water bodies, evaporation rates may be directly specified or computed based on reference ETo and Kc. User has an ability to change the habitat area and implement a schedule of SCH.

The air quality management areas are considered as the AQM component. Similar to the HAB component, the water demand of the type of AQM control (vegetation) is computed from time-varying ETo, Kc, and return flow fractions. The user specifies what fraction of the exposed playa would require a water demand and from which elevation to begin delivery of water to this component. The SALSA2 model dynamically tracks the area of the exposed playa, considering water surface area of the SEA and HAB components and the land area of the HAB component.

3.3 Simulations of Water and Salt Balance

3.3.1 Inflows

Inflows into the SALSA2 model are required as input data. The SALSA2 model does not incorporate a watershed runoff model. Typical inflows to the model are supplied from analysis of historical data or from the results of other models of data used as input to the SALSA2 model include U.S. Geological Survey (USGS) and IID flow records; results from the IIDSS, Colorado River Simulation System data, CVWD groundwater models used in the original SSAM analysis for the Transfer Project; and updated rainfall-runoff and regression models.

3.3.2 Consumptive Use Demands and Deliveries

The HAB and AQM components each represent a consumptive use and associated water requirement. The water requirement can be specified directly by the user, computed based on an evaporative demand, or computed based on vegetation water use characteristics. The water delivery requirement is increased from the consumptive demand to account for a user-specified return flow fraction. The area for the HAB component is specified by the user. The AQM component dynamically computes the area of the exposed playa. The water requirement is implemented as shown in Equation 1:

$$demand = \frac{ETo * Kc * A}{(1 - rfactor)} \tag{1}$$

Where:

ETo = reference evapotranspiration rate
Kc = crop coefficient
A = irrigated area
rfactor = return flow fraction

3.3.3 Salton Sea Evaporation

Salton Sea surface water evaporation is computed as the period unit evaporation rate multiplied by the period average surface water area. This implies that the beginning and end of period surface water area, a function of reservoir storage, must be known before evaporation can be computed. Although the beginning of period surface water area can be computed from the reservoir storage at the beginning, the end of period storage is unknown.

The rate of evaporation decreases as the salinity of the water increases. Although this increase is insignificant for many water resources problems, it has a pronounced effect on the rate at which a hyper-saline terminal lake would decrease in size. For the application to the Salton Sea, an evaporation-salinity relationship was developed to better simulate this process. Using the results from Reclamation's Salton Sea Salinity Control Research Project (Reclamation 2004), the Salton Sea Solar Ponds Pilot Project at Bombay Beach (Agrarian Research and Management 2009), and comparing to previous work on Bonneville Salt Flats (Turk 1970) and Owens Lake brines, a revised evaporation-salinity relationship was developed for the Salton Sea.

Evaporation suppression is governed by several factors including the molecular activity of the water, the size and number of salt molecules, and the water temperature. The evaporation-to-specific gravity (SG) relationship developed by Reclamation during the Salton Sea Salinity Control Research Project (Reclamation 2004) was used directly. However, because the SALSA2 model only tracks salinity (not SG), an approximate relationship between SG and total dissolved solids (TDS) of Salton Sea brines was developed (see Figure 4). Despite differences in the chemical composition of the Owens Lake brines and those at the Salton Sea, the SG-TDS relationship is similar (see Figure 5). The final evaporation-TDS relationship used in the SALSA2 model is derived from regressions on Figures 4 and 5 and is shown on Figure 6 (Eq 7). This figure indicates considerable reductions in evaporation rates as the salinity increases (up to 30 percent at 350,000 milligrams per liter [mg/L]) and reflects a greater reduction than that used in previous model applications.

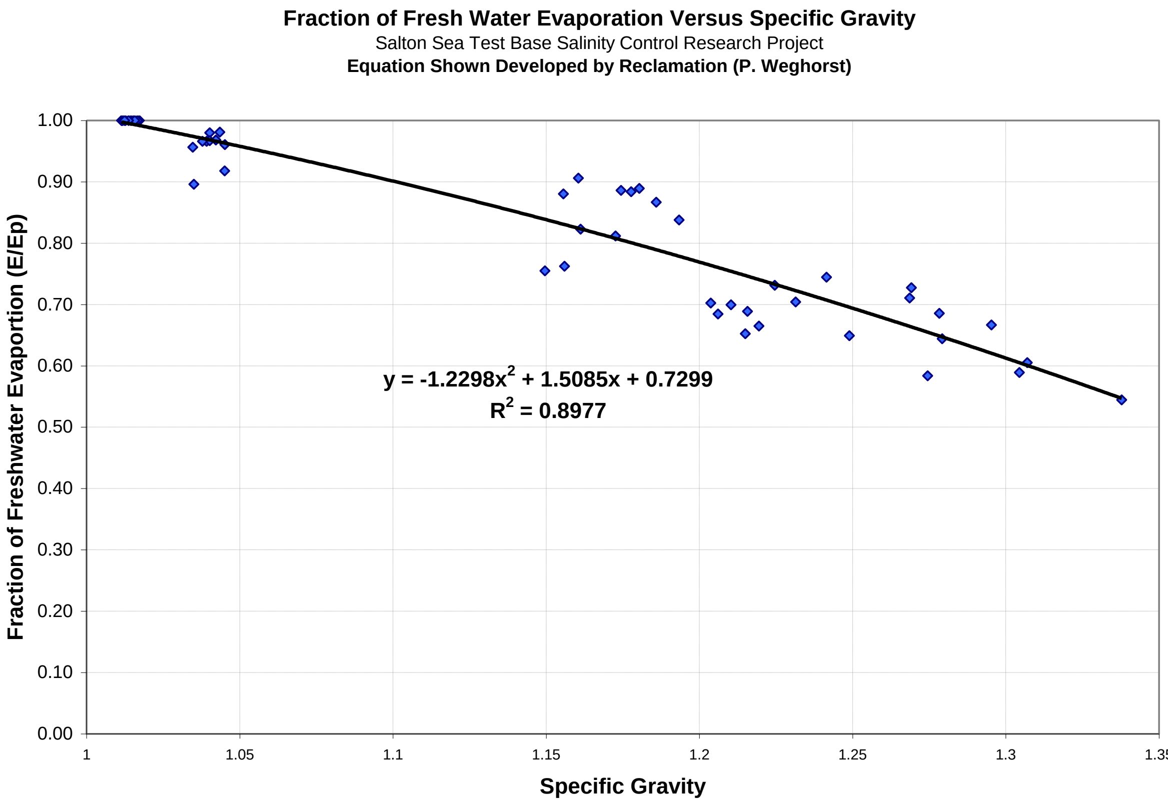


Figure 4. Fraction of Freshwater Evaporation to Specific Gravity Relationship from Salinity Control Research Project. Adapted from the Draft Programmatic Environmental Impact Report for the Salton Sea Ecosystem Restoration Program

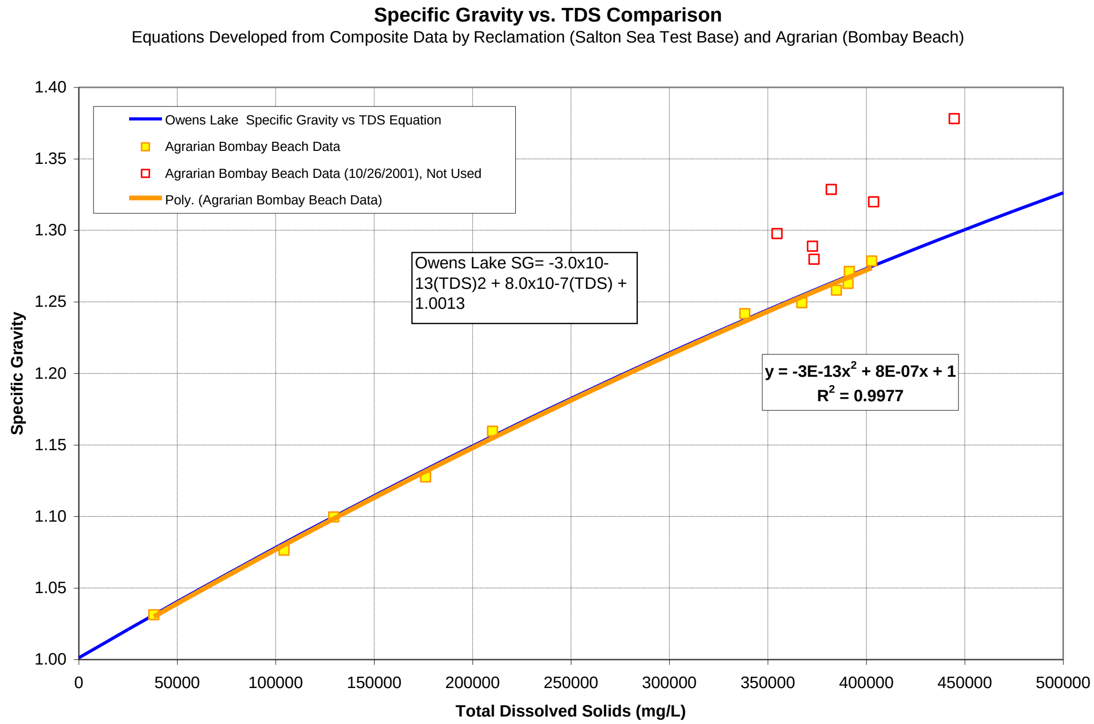


Figure 5. Salton Sea Brine Specific Gravity to Total Dissolved Solids Relationship. Adapted from the Draft Programmatic Environmental Impact Report for the Salton Sea Ecosystem Restoration Program

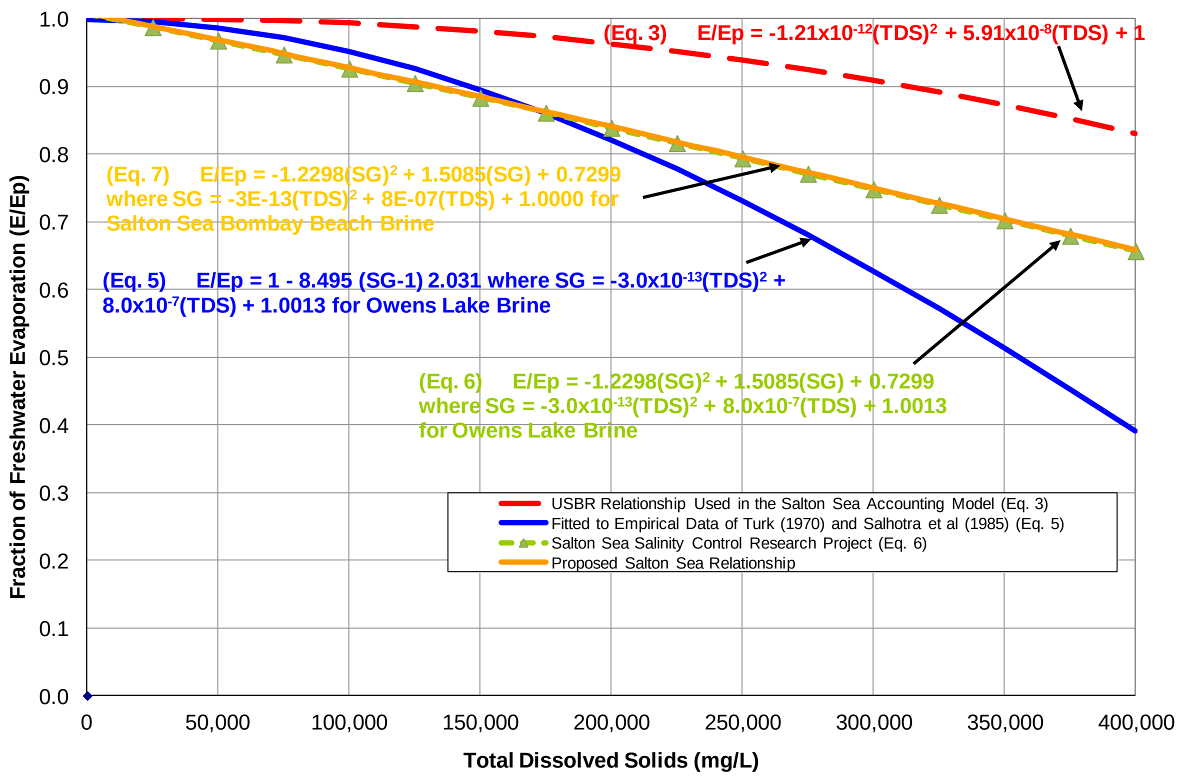


Figure 6. Salton Sea Relative Evaporation to Total Dissolved Solids Relationships. Adapted from the Draft Programmatic Environmental Impact Report for the Salton Sea Ecosystem Restoration Program

3.3.4 Salton Sea Salinity Simulation

As part of this analysis, a conservative constituent water quality algorithm was developed and incorporated into the SALSA2 model. The algorithm developed is based on a simple mass balance concept and assumes constituents are completely mixed at elements during each time step.

$$C_o^t = \frac{\sum Q_i^t C_i^t}{\sum Q_i^t} \tag{2}$$

Where:

C_o = constituent concentration in the flow links leaving an element

C_s = concentration in a storage element

S = storage in the storage element

Q_i = flow into the element

Q_o = flow out of the element

t = time step

$$C_s^t = \frac{\sum Q_i^t C_i^t + S^{t-1} C_s^{t-1}}{\sum Q_o^t + S^t} \tag{3}$$

Where:

C_s = concentration in a storage element

S = storage in the storage element

Q_i = flow into the element

Q_o = flow out of the element

t = time step

The SALSA2 model also includes the ability to specify a constituent removal term to approximate the precipitation of the constituent out of the water column. However, no geochemical processes are included in the model and the removal value is specified by the user. The model application is currently only configured using salt (salinity) as a constituent for simulation. At this point in the model development, the re-dissolution of salt from the inundation of previously dry shoreline areas is not included. Although this was an important process during the initial flooding of the Salton Sea in 1904–1907, it is likely to be less important in the future as the Salton Sea drops in elevation. There is a high degree of uncertainty in both the precipitation and re-dissolution of salts in the Salton Sea.

3.4 Data Requirements

Data requirements for the SALSA2 model include initial conditions, time-varying boundary conditions, and bathymetric data. Initial conditions consist of beginning storage and constituent concentration in all storage elements. Time-varying boundary conditions are primarily in the form of inflows and constituent loads. The bathymetry of the Salton Sea is input as tables relating elevation, area, and capacity.

3.5 Modes of Operation

The SALSA2 model can be operated under two different modes, deterministic and stochastic modes, as described below.

3.5.1 Deterministic

The deterministic mode of operation simulates the system performance by using a single trace (or sequence) of inflow or other boundary condition data. Although this is a common form of model simulation in various fields, it assumes that the future climate or hydrologic conditions can be represented by a single sequence.

3.5.2 Stochastic

The stochastic mode of operation allows consideration of multiple future traces or sequences. In this mode, the SALSA2 model generates multiple traces of input data, sampled from probability distributions or historical traces, and performs simulations of future Salton Sea conditions for each individual trace. This process may be repeated for hundreds or thousands of possible traces, and statistics related to the model results are compiled. Statistics generated for the Salton Sea included the mean, median (50th percentile), standard deviation, inter-quartile (25th and 75th percentiles), and the 5th and 95th percentile values.

SALSA2 Model Calibration and Validation

4.1 Model Calibration

The SALSA2 model uses evaporation rate and salt precipitation terms that were calibrated for the period of 1950 through 2015 because this period contained the most complete flow and salinity data for the Salton Sea. The evaporation rate and salt precipitation terms were calibrated using an external spreadsheet model. The spreadsheet model was calibrated to measured water surface elevation and average Salton Sea TDS. The calibration was first performed for water surface elevation through a Salton Sea water budget calculation for the unknown evaporation term. Once the historical water budget was estimated, a similar approach was taken to determine the historical salt budget. It was necessary to include a salt precipitation term beginning around 1990 to balance the historical salt budget. The observed water surface elevation was obtained from the USGS (2012), and measured salinity was averaged from four near-shore measurements reported by IID over the period 1950–2004. The salinity for the period 2005–2015 was obtained from Reclamation (Holdren 2012 and Passameneck 2016).

Figures 7 and 8 show the spreadsheet model performance for the calibration period that was applied to estimate the evaporation rate and salt precipitation terms used in the SALSA2 model simulations. The simulated water surface elevation is nearly identical to the measured values as the evaporation rate was computed external to the model as a water budget closure term. The simulated Salton Sea salinity is a direct result of the external salt loading from 1950 through 1989. However, from 1990 through 2015 it was necessary to remove salt in order to achieve a reasonable match with measured data. The onset of significant salt precipitation is believed to have started in the late 1980s or early 1990s and approximately 2,000,000 tons of salt precipitation (sink) was included in the SALSA2 model beyond this point in time.

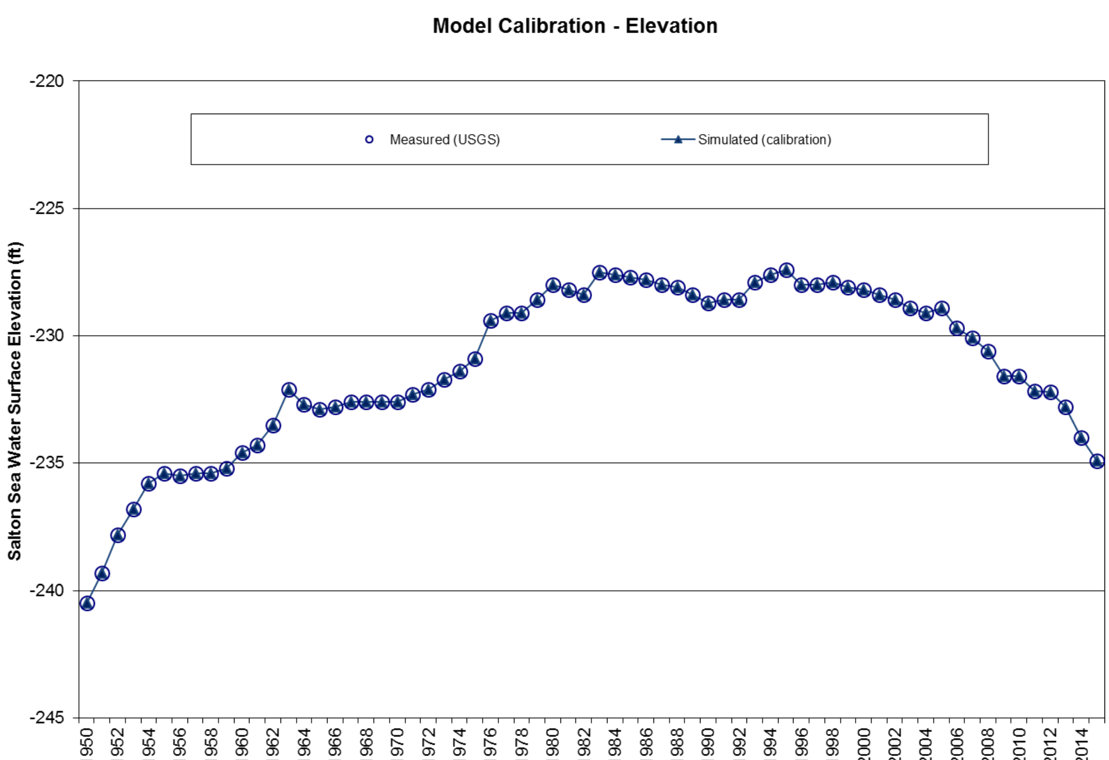


Figure 7. Simulated and Measured Salton Sea Water Surface Elevation, 1950–2015

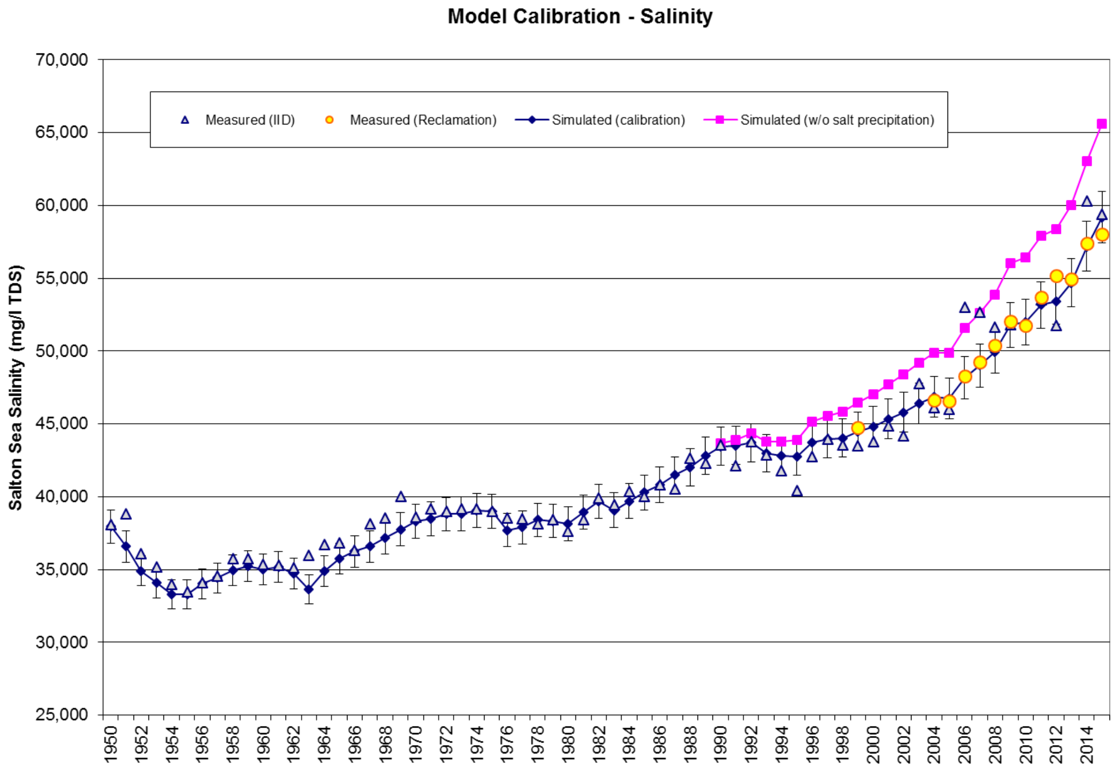


Figure 8. Simulated and Measured Salton Sea Salinity, 1950–2015

4.2 Model Validation

The SALSA2 model performance over the period from 2003 to 2047 is shown on Figures 9, 10, and 11. This period includes an historical observed period of 2003-2017 and a future period of 2018-2047. The SALSA2 model was simulated using actual measured elevation and salinity at the end of 2002, the *projected* inflows and salt loads from the Future No Action for 2003 to 2077, evaporation rates, and salt precipitation rates determined from the budget closure terms. The purpose of this model simulation is to evaluate the hydrological projections and SALSA2 computations against actual observed conditions. Since historical hydrology is not used, results are not expected to exactly match observations. However, since the SALSA2 model simulations use a stochastic approach, the observations would be expected to fall within the range of simulated conditions.

The SALSA2 model uses a daily time step and the Salton Sea water surface elevation and salinity are reported for the last day of the month and year. Figures 9, 10, and 11 compare observed Salton Sea water surface elevation, measured salinity, and estimated exposed playa over the period from 2003 to 2017 with simulated values. As shown in these figures, results from the SALSA2 model compare well to the observed elevation and salinity for 2003 through 2017. The median simulated water surface elevation is within 0.1 feet of observed elevation by 2017. The inner quartile of simulated results generally captures the observed values throughout the simulated period.

The simulated Salton Sea salinities also show very good correlation with the observed values. The differences between simulated and observed Salton Sea salinity are generally within 500 mg/L. The SALSA2 model performance for the amount of exposed playa, as for elevation, shows very good correlation. Differences by 2017 are within 300 acres, and the inner quartile of simulated results generally captures the observed values throughout the simulated period.

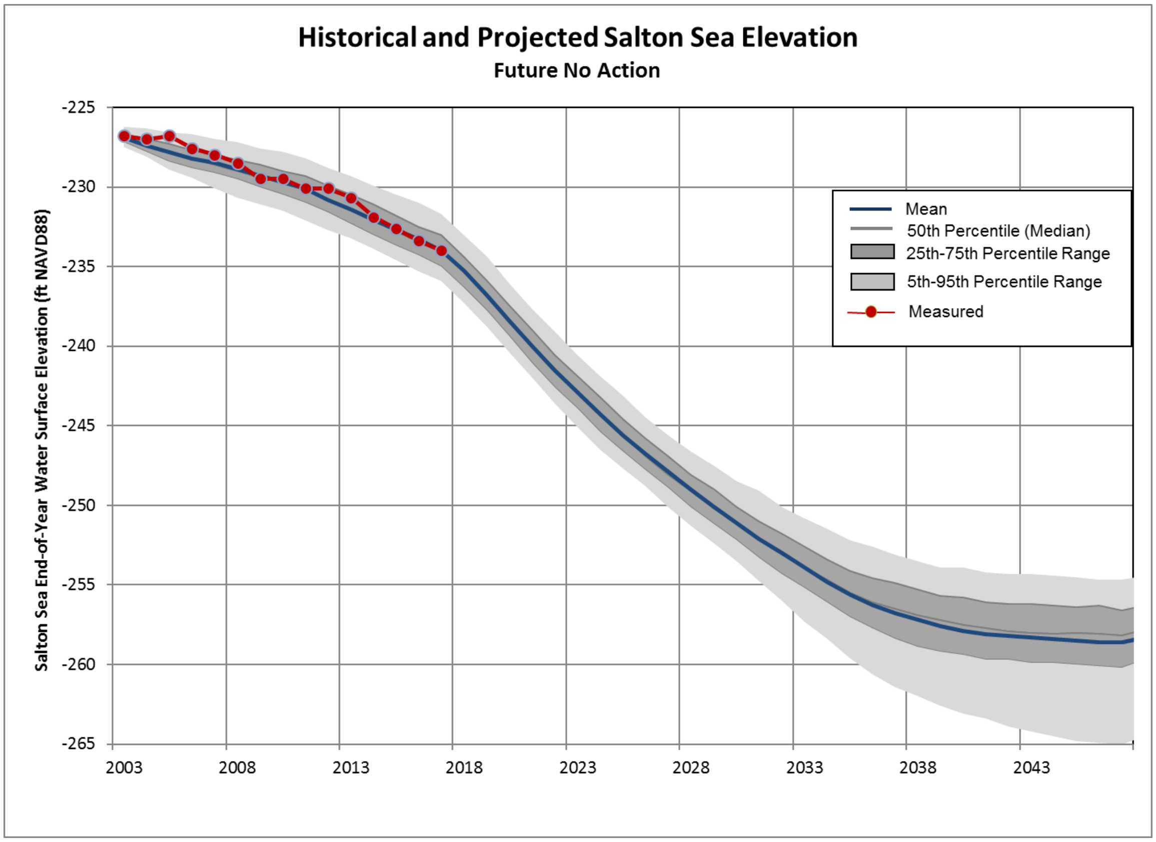


Figure 9. Simulated and Measured Salton Sea Water Surface Elevation, 2003–2047 (Validation)

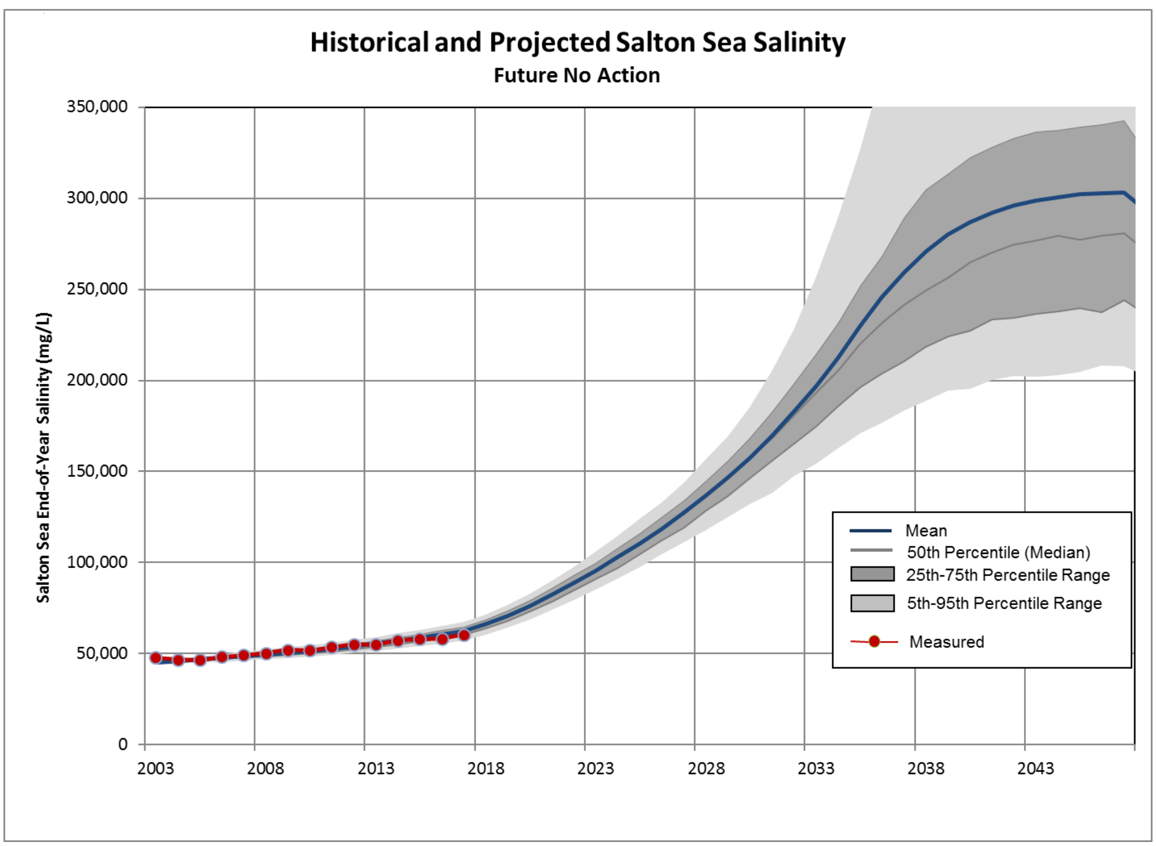


Figure 10. Simulated and Measured Salton Sea Salinity, 2003–2047 (Validation)

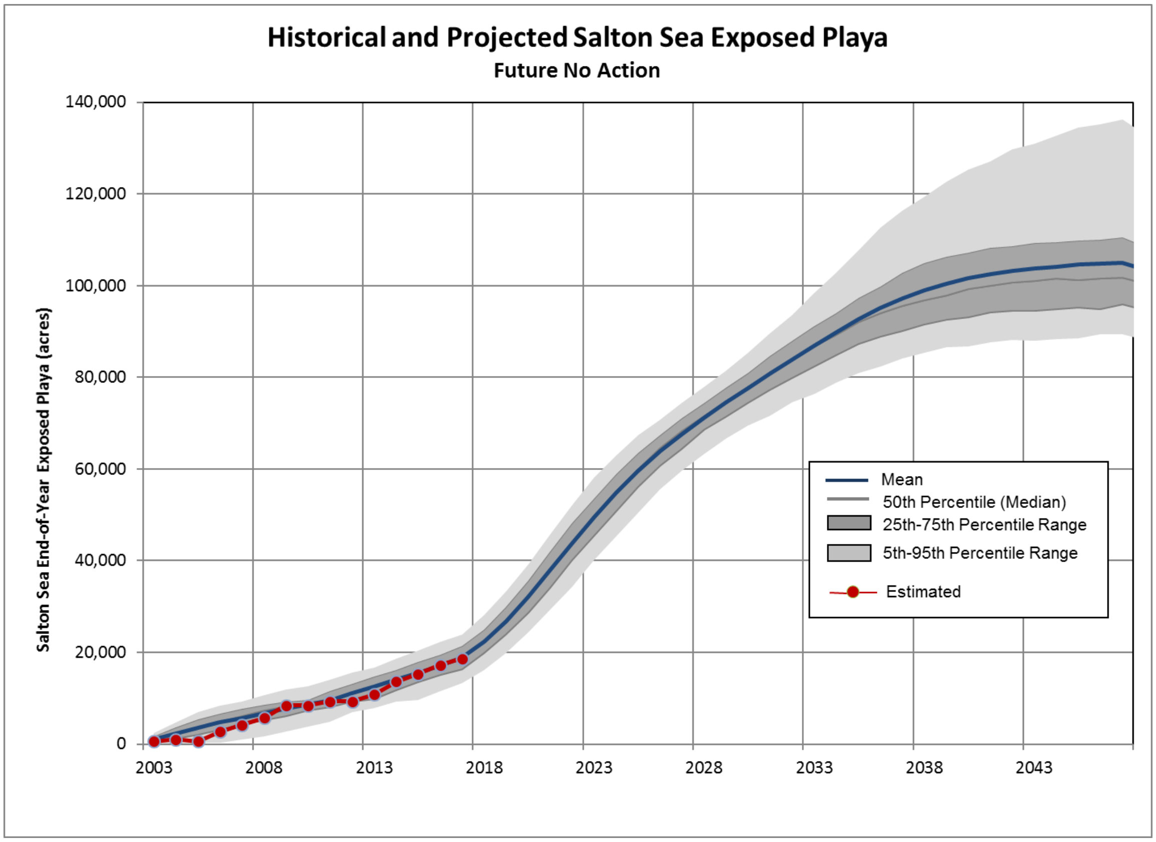


Figure 11. Simulated and Measured (Estimated) Salton Sea Exposed Playa, 2003–2047 (Validation)

SALSA2 Model Application for Future Alternatives

5.1 Modeling Approach and General Assumptions

The SALSA2 model application for the Salton Sea uses the well-known Monte Carlo technique for quantitatively characterizing the response of a system to uncertainty and variability. Monte Carlo analysis involves the identification of significant variability and uncertainty in the system, characterization of the uncertainty and variability through input probability distributions, random sampling of the input distributions, and multiple simulations with a computer model. The result of a Monte Carlo, or stochastic, analysis is a distribution of the possible values of a particular simulated response. Descriptive statistics can be generated from the multiple simulation results and the effects of input uncertainty on system response can be analyzed. A summary of the Monte Carlo analysis technique is provided by the U.S. Environmental Protection Agency (1997).

The modeling analysis utilized 500 random samplings of the input distributions to generate 500 different traces of possible future inflows, salt loads, and evaporation rates. Correlations in input data, such as rainfall and evaporation were retained in the future projections. The SALSA2 model was operated in the stochastic mode to simulate conditions in the Salton Sea for each of the possible input traces. Selected results such as water surface elevation and salinity are retained from each simulation and descriptive statistics are generated for end-of-year values based on the results of all simulations. The result is a timeline of the system response to a range of future conditions. No specific trace should be considered a prediction of future conditions, but the suite of model results and associated range of future outcomes is valuable for long-range planning at the Salton Sea.

The time period of analysis can vary depending on the study focus. However, the modeling data was projected for January 2018 through December 2077.

5.2 Initial Conditions

Initial conditions for the SALSA2 model are the Salton Sea elevation and salinity for December 31, 2017. The elevation data was obtained from USGS for December 31, 2017, and was recorded at -234.0 feet North American Vertical Datum of 1988 (NAVD88) (USGS 2016). The salinity of the Salton Sea was computed from the average of surface and bottom total dissolved solids measurements made by Reclamation (Reclamation 2017) at three locations in the Sea on June 28, 2017 (most recent available information). The average salinity from these measurements was approximately 60,500 mg/L.

5.3 Bathymetry Methods

Bathymetric data were provided by NewFields Agricultural & Environmental Resources, LLC (NewFields) based on a light detection and ranging (LiDAR) 200-kilohertz (kHz) survey of the Salton Sea. The projections of exposed playa and shallow water habitat for all simulations were derived from these data. The bathymetry provided by NewFields was in a raster grid format generated by fusing the boat-based acoustic survey data with data from the aerial LiDAR survey. These data are considered appropriate for planning level analysis of restoration alternatives but limit the precision of elevation, area, and capacity relationships, particularly at low elevation conditions. The collected data were converted to a 5- by 5-meter (m) (16.4- by 16.4-foot [ft]) horizontal resolution raster file projected to UTM Zone 11N NAD 1983 coordinates with elevation referenced to the NAVD88 datum. Vertical and

Horizontal units of the raster file were set in meters. The resulting raster file represented the Sea bathymetry and elevation on the proximities of the shore (see Figure 12). The EAC relationships necessary for model development were derived from the 5- by 5-m raster file provided by NewFields. The method used to develop the EAC tables included the conversion of the 5- by 5-m bathymetry raster into a Triangulated Irregular Network surface and the use of a ArcGIS script developed to get Sea area and volume at 0.1-ft elevation increments from the Sea bottom at -83.8 m (-274.934 ft NAVD88) to elevation -68 m (-223.097 ft NAVD88). Figure 13 shows EAC curves for the Salton Sea.

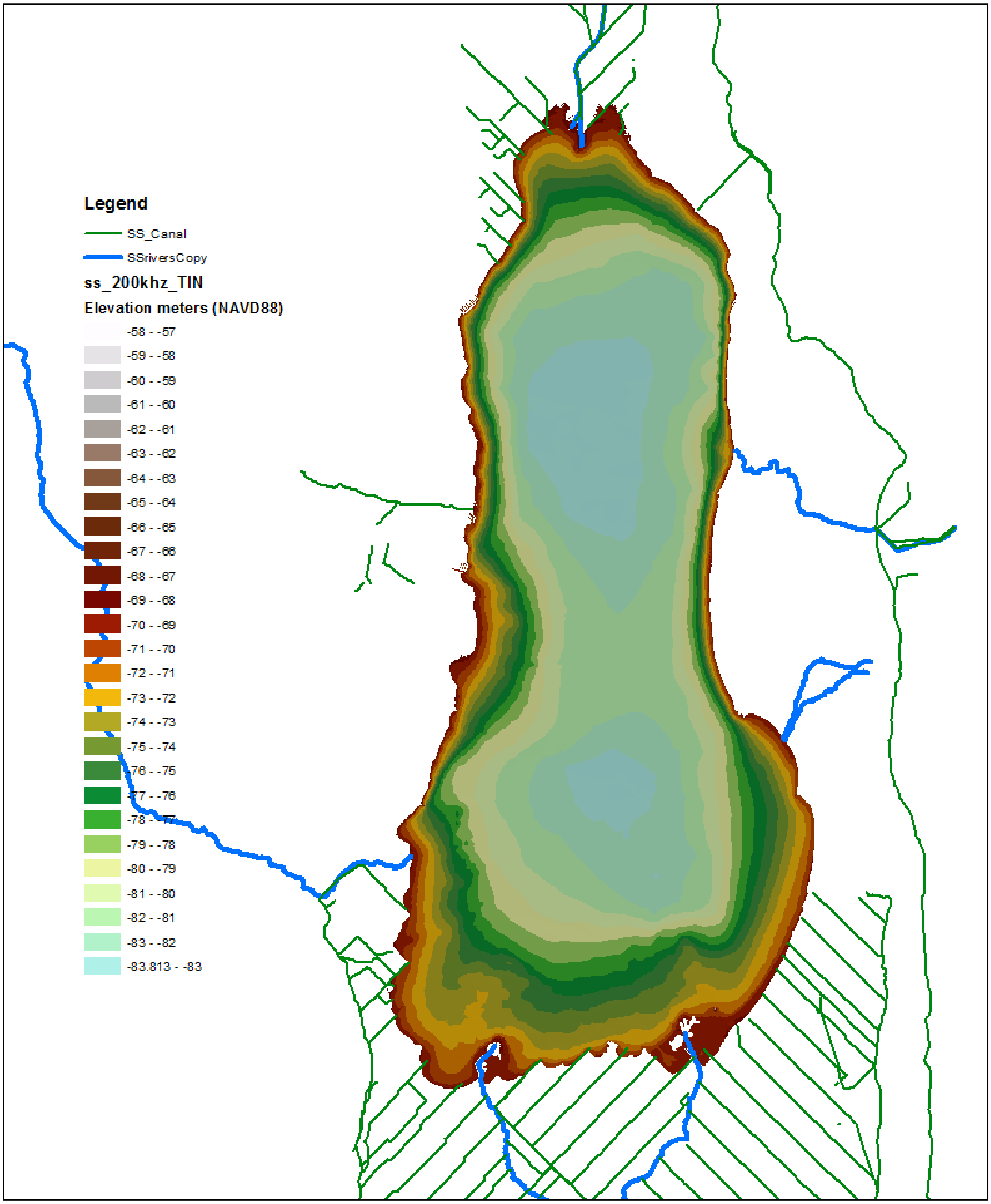


Figure 12. Elevation Data Points Collected from NewFields (200-kHz-Based Survey)

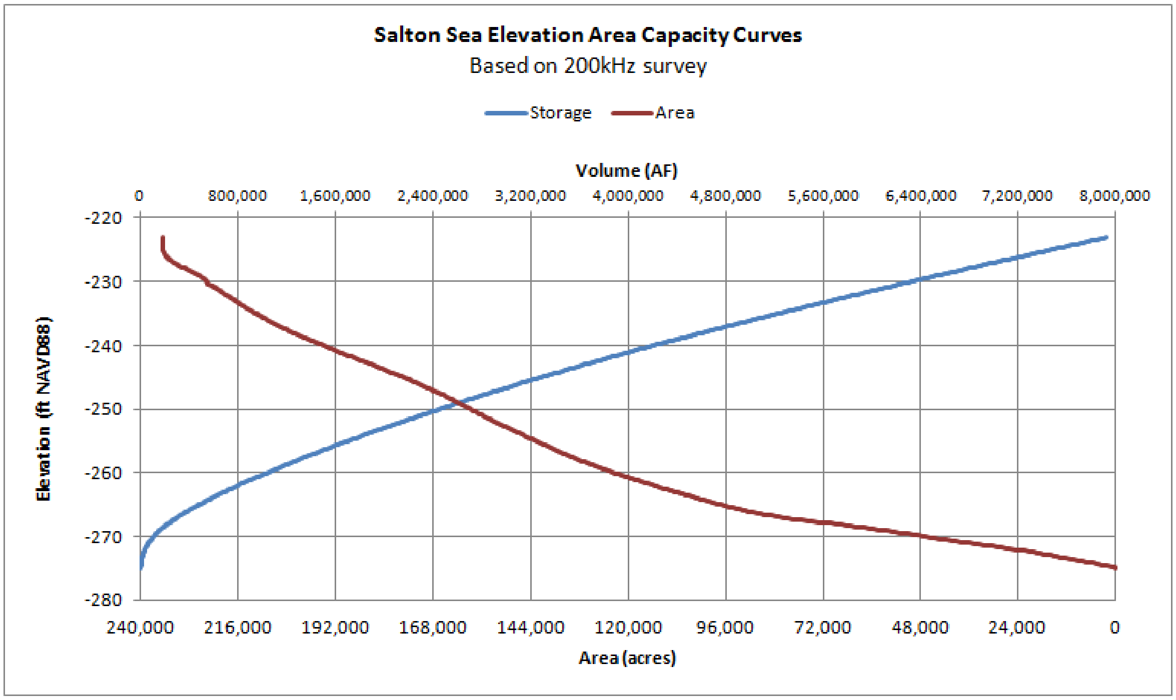


Figure 13. Salton Sea Water Surface Elevation-Area-Capacity Curves (Based on NewFields 200-kHz Survey)

5.4 Inflow and Salt Load Assumptions

The projected inflows and salt load assumptions were taken from the hydrology developed for the Future No Action as described in the technical report Salton Sea Hydrology Development (CH2M 2018a). The projected total annual average inflow to the Salton Sea for the 2016 to 2077 time period is estimated at approximately 732,000 acre-feet per year. Future No Action conditions are significantly lower than historical conditions due to both QSA and non-QSA conditions. The reduction in inflows from the Imperial Valley is primarily due to the QSA-related transfers from IID to SDCWA and CVWD and non-QSA related reductions in inflows from Mexico due to reduced surplus Colorado River flows, power plant use of New River flows, and treatment and conveyance of wastewater flows out of the Salton Sea watershed. A projected increase in Coachella Valley drain flows to the Salton Sea partially offsets reductions from the Imperial Valley and Mexico. The projected average salt load to the Salton Sea for 2016 to 2077 is estimated to be approximately 3,970,000 tons annually.

Table 1 presents the key assumptions affecting the water or salt balance with the Future No Action and Historical conditions.

Table 1. Assumptions for Hydrology, Air Quality Mitigation, and Habitat Components

Hydrologic Component	Historical Conditions	Future No Action
Climate	Historical climate using the following stations: • Brawley (1950-2013) • Imperial (1950-2015) • Mecca (1950-2015) Climate normal calculated in accordance with NOAA as 1981–2010.	Projected temperature and precipitation changes using median computed from 112 future climate projections (from 16 different climate models under 3 emission scenarios).
Salton Sea Evaporation	Estimated from average of IID sunken pan measurements (Sandy Beach, Imperial Salt Farm, and Devil's Hole) and adjusted based on historical Salton Sea water balance.	Net evaporation rate adjusted for increasing temperature (approximately 2 degrees Celsius by 2050) and change in precipitation (negligible).
Mexico	Updated historical measured inflows from Mexico in New and Alamo rivers (1950–2015) adjusted for Colorado River deliveries to Mexico variability.	Initial model conditions plus reduced New River flows for: • Mexicali Wastewater Improvements • Mexicali Power Plants • Further reductions based on recent water management trends
Imperial Valley	Estimated flows for 1980–1999 cropping patterns under 1925–1999 climate conditions; IIDSS simulations provided by IID. Changes for projects in-place since 2002: • Quantification Settlement Agreement IID Water Conservation and Transfer Project Inadvertent Overrun and Payback Policy • All American Canal Lining Project	Initial model conditions plus changes for: • Quantification Settlement Agreement • IID Water Conservation and Transfer Project • Entitlement Enforcement • Inadvertent Overrun and Payback Policy • All-American Canal Lining Project • Further reductions based on water management trends, urban growth, and Colorado River drought
Coachella Valley	Updated historical inflows from Coachella Valley from Whitewater River (Coachella Valley Storm Channel), direct drains, and groundwater. Coachella Canal Lining Project.	Initial model conditions plus changes for: • IID-CVWD Transfer • Coachella Valley Water Management Plan Update (2015) (uncertainty added to reflect current conditions and CVWD projected conditions)
Local Watershed	Derived surface water and flow estimates from rainfall-runoff regressions and previous studies.	Initial model conditions plus reduced flows from Salt Creek due Coachella Canal Lining Project.
Air Quality Mitigation		Dust control assumed for 75% of the exposed playa. Dust control measures (DCMs) assumed as follows: • Surface Roughening (40%) • Vegetation Enhancement (35%); annual ET estimated at 0.66 ft • Water Efficient Vegetation (20%); annual ET estimated at 1.01 ft • Brine stabilization (5%); annual application of 0.8 ft Source water salinity for air quality management of up to 20,000 mg/L TDS is assumed.
Species Conservation Habitat	None.	SCH Phase I and II and Red Hill Bay (total of 4390 acres by 2021).

5.5 Spatial and Temporal Disaggregation of Flows

The projected inflows for the Salton Sea were estimated for Mexico, Imperial Valley, Coachella Valley, and the local watershed on an annual basis. In order to facilitate more detailed hydrologic modeling of Salton Sea it was necessary to disaggregate the total flows from a grouped inflow projection to that in individual streams or drains. For example, flows from Imperial Valley had to be disaggregated into quantities for the Alamo River, New River, direct drains, and groundwater. After the disaggregation was achieved, the annual flows for individual streams were downscaled to monthly values. These processes are described below.

5.5.1 Spatial Disaggregation of Flows

As discussed above, the future Salton Sea inflows were developed for four major source areas on an annual time step. However, spatial disaggregation was carried to characterize in greater detail the spatial distribution of flows. Spatial disaggregation was performed based on historical percentages of individual flow component contribution to the total flow for each major source area. For example, the Imperial Valley total inflow to the Sea was disaggregated in to Alamo River, New River, direct drains-east, direct drains-west, direct drains-between rivers, and groundwater. Figure 14 shows a graphical representation of the process performed for all major source areas. In this figure, the boxes represent the level of aggregate information and the arrows indicate the spatial disaggregation. Table 2 outlines the general method that was applied for the development of each disaggregated flow point.

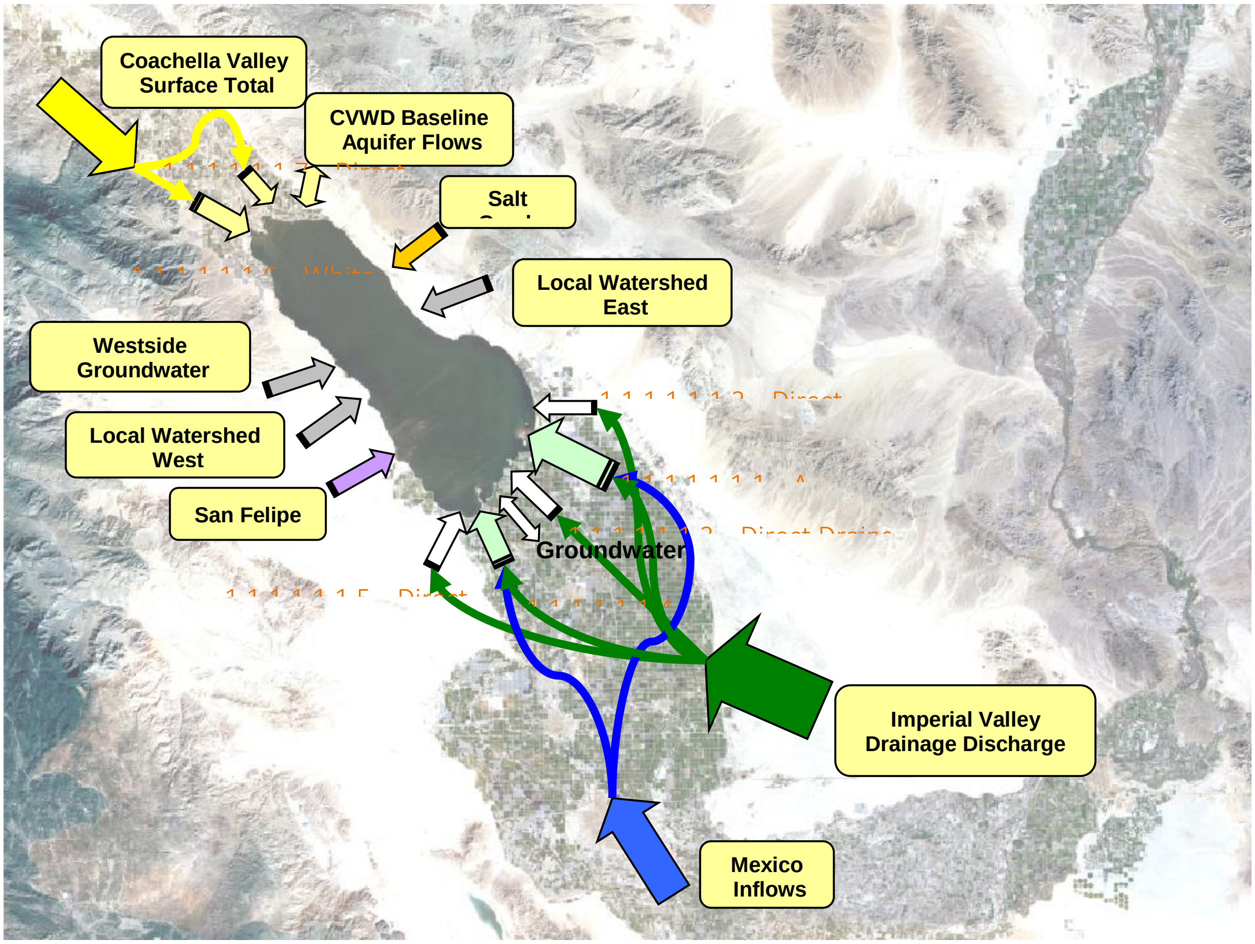


Figure 14. Schematic Diagram Used for Disaggregation of Flows into Salton Sea from Major Sources

Table 2. Spatial and Temporal Disaggregation Methods for Various Data Sources

Disaggregated Source	Aggregated Source	Method of Spatial Transformation	Monthly Downscaling Method
Imperial Valley Groundwater	N/A	Assumed 1 kaf/yr	Constant pattern.
Alamo River (Imperial Valley)	Imperial Valley Total *minus* groundwater	0.607 * (Imperial Valley + IOPP Adjustments - Imperial Valley Groundwater)	Pattern based on historical distributions.
New River (Imperial Valley)	Imperial Valley Total *minus* groundwater	0.29 * (Imperial Valley + IOPP Adjustments - Imperial Valley Groundwater)	Pattern based on historical distributions.
Imperial Valley Direct Drains-East	Imperial Valley Total *minus* groundwater	0.0242 * (Imperial Valley + IOPP Adjustments - Imperial Valley Groundwater)	Pattern based on historical distributions of Alamo River.
Imperial Valley Direct Drains-West	Imperial Valley Total *minus* groundwater	0.0285 * (Imperial Valley + IOPP Adjustments - Imperial Valley Groundwater)	Pattern based on historical distributions of Alamo River.
Imperial Valley Direct Drains-Between Rivers	Imperial Valley Total *minus* groundwater	0.0503 * (Imperial Valley + IOPP Adjustments - Imperial Valley Groundwater)	Pattern based on historical distributions of Alamo River.
Alamo River (Mexico)	N/A	Assumed at recent historical 2 kaf/yr	Pattern based on historical distributions.
New River (Mexico)	Mexico Total *minus* Alamo	Mexico total minus 2 kaf/yr	Pattern based on historical distributions.
Coachella Valley Groundwater	N/A	As per CVWD	Constant pattern.
Whitewater River	Coachella Valley Total *minus* groundwater	0.5946*(Coachella Valley Total – Coachella Valley Groundwater)	Pattern based on historical distributions.
Coachella Valley Direct Drains	Coachella Valley Total *minus* groundwater	0.4054*(Coachella Valley Total – Coachella Valley Groundwater)	Pattern based on historical distributions.
San Felipe Creek	San Felipe Creek	N/A	Pattern based on historical distributions.
Salt Creek	Salt Creek	N/A	Pattern based on historical distributions.
Ungaged Watershed West	Ungaged Watershed West	N/A	Pattern based on historical distributions.
Ungaged Watershed East	Ungaged Watershed East	N/A	Pattern based on historical distributions.
Local Groundwater	N/A	Assumed 10 kaf/yr	Constant pattern.

5.5.2 Monthly Downscaling

The annual inflow data, now spatially-disaggregated by individual source, was downscaled into a monthly time series based on a review of historical monthly flow patterns. These monthly flow patterns were based on the work as a part of the Draft Programmatic Environmental Impact Report for the Salton Sea Ecosystem Restoration Program. For all rivers or creeks for which historical flow data could be obtained, the following process was performed:

1. Historical annual flow was computed from daily records for each source
2. Annual flows were sorted and divided into bins representing 0-20 percentile (bin 1), 20-40 percentile (bin 2), 40-60 percentile (bin 3), 60-80 percentile (bin 4), and 80-100 percentile (bin 5)
3. For each bin, and for an average of all years, determine the monthly percentage contribution to annual flow to determine if significant changes in patterns occur depending on hydrologic conditions

The monthly patterns developed from this approach are shown in Figures 15 through 21. The New River contribution from the Imperial Valley was computed as the difference between the gaged flow near the Salton Sea and the New River near Calexico. In the model average curves are used for the monthly downscaling as there were small differences among different bins except few exceptional years.

Some general conclusions were drawn from this analysis. First, only San Felipe Creek and, to a lesser extent, Salt Creek display widely-varying monthly patterns. These are the only two drainages that respond largely unimpeded by agricultural or urban development and reflect a stronger rainfall-runoff influence. Second, the Alamo, New, and Whitewater rivers display a very constant pattern governed by upstream agricultural and drainage practices. Monthly patterns do not show a significant variation from year to year. Finally, the New River at Calexico exhibits a strong agricultural return flow pattern, but shows a higher percentage of flows in wet years during the January through May period.

Based on this assessment of monthly pattern variations, it was determined that the application of an average pattern would provide a suitable representation of conditions for all drainages except Salt Creek. For Salt Creek, the average of the last five years of available data was used to define future patterns for this creek since this period better reflects the flows to be provided under the Coachella Canal Lining Project mitigation measures. Multiple patterns could have been applied for San Felipe Creek, but it was felt that the level of effort was not justified for this relatively small source. In addition, while the patterns do vary for this creek, the use of an average pattern would provide a representative seasonal variation. The average patterns used to downscale the annual flows are shown in Figure 20. The annual flows were multiplied by the appropriate percentage for each month to develop a monthly time series for use in hydrologic modeling.

The evapotranspiration pattern developed from measured ETo at Brawley is shown in Figure 22. The pattern reflects the long period of summer heating that is present in the watershed. This pattern was used for both evaporation and evapotranspiration in the hydrologic modeling analyses and contributes to a sharp increase in the water need for habitat areas and elevation control in the summer.

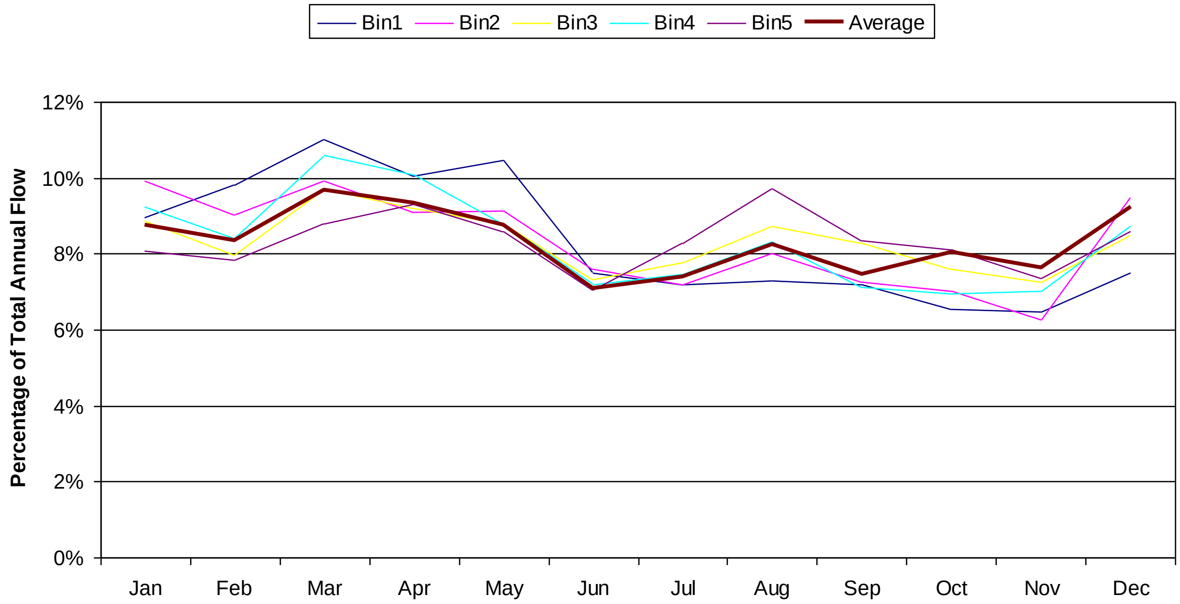


Figure 15. Monthly Flow Pattern for New River Near Calexico

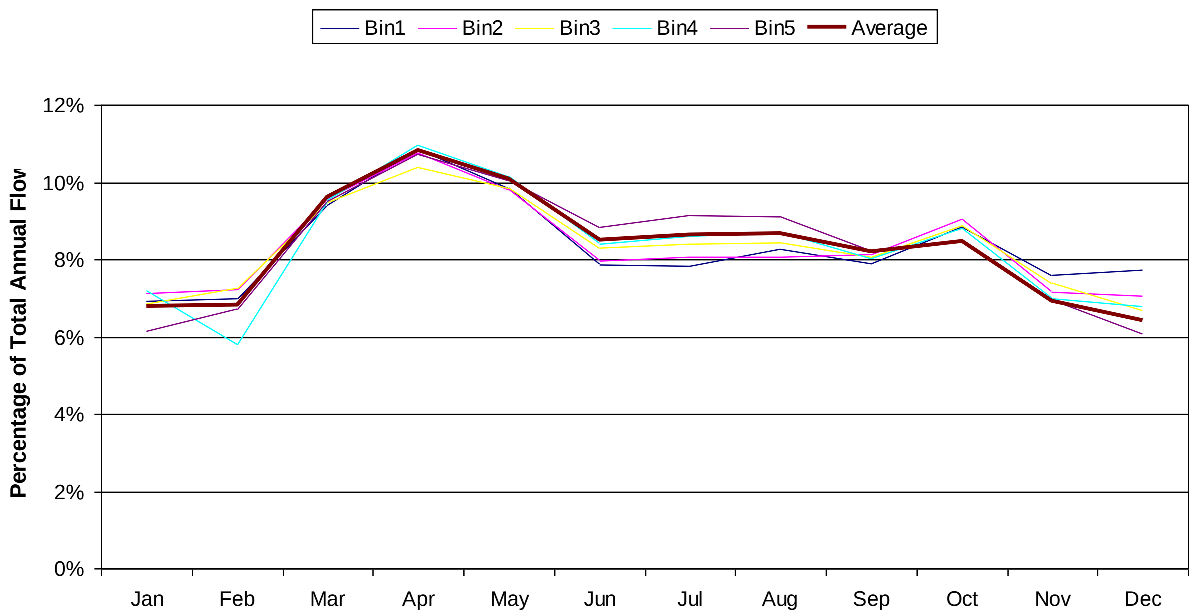


Figure 16. Monthly Flow Pattern for New River Contribution from the Imperial Valley

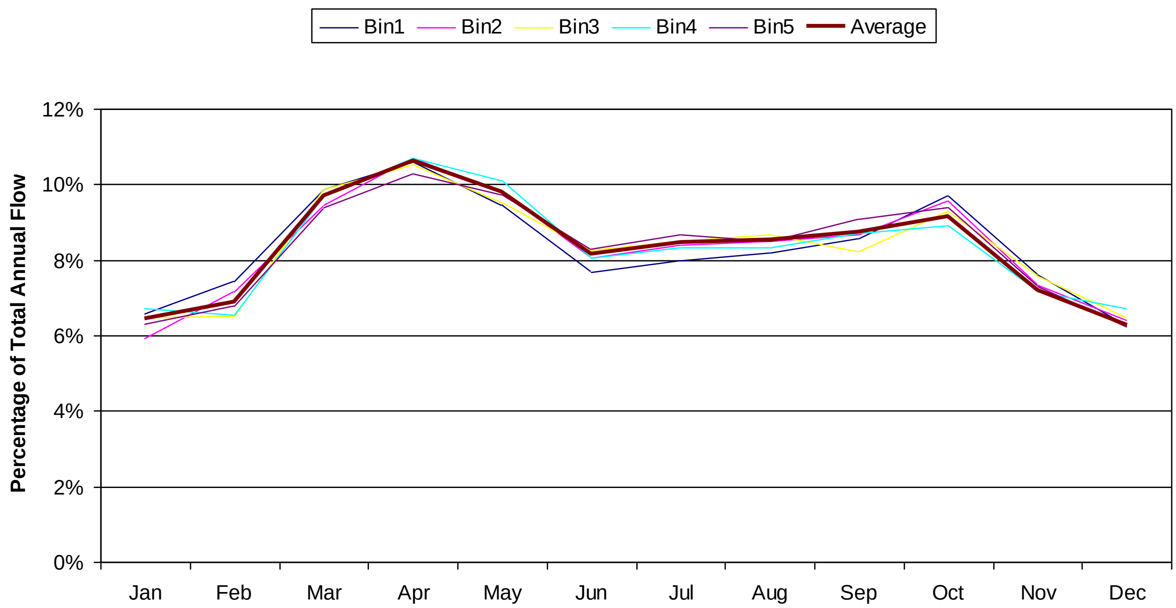


Figure 17. Monthly Flow Pattern for Alamo River Near Niland

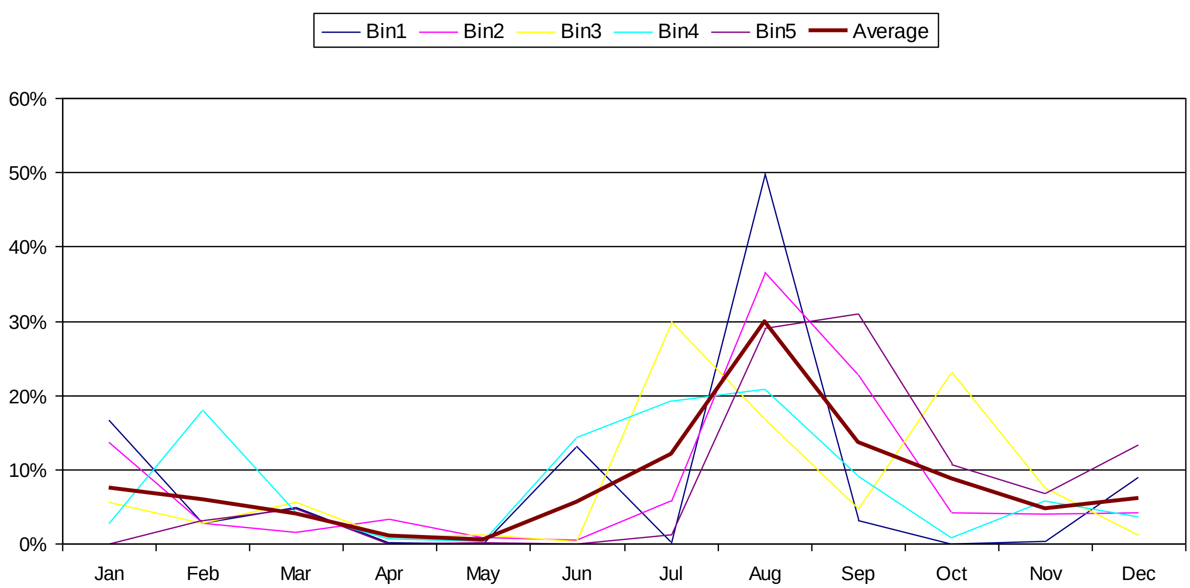


Figure 18. Monthly Flow Pattern for San Felipe Creek Near Westmoreland

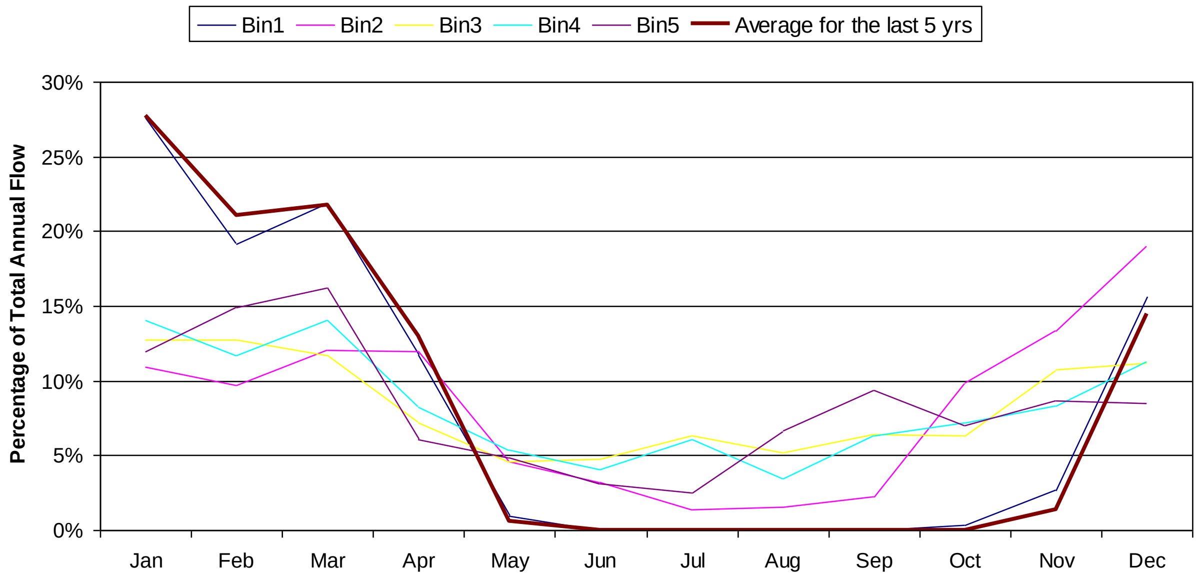


Figure 19. Monthly Flow Pattern for Salt Creek Near Mecca

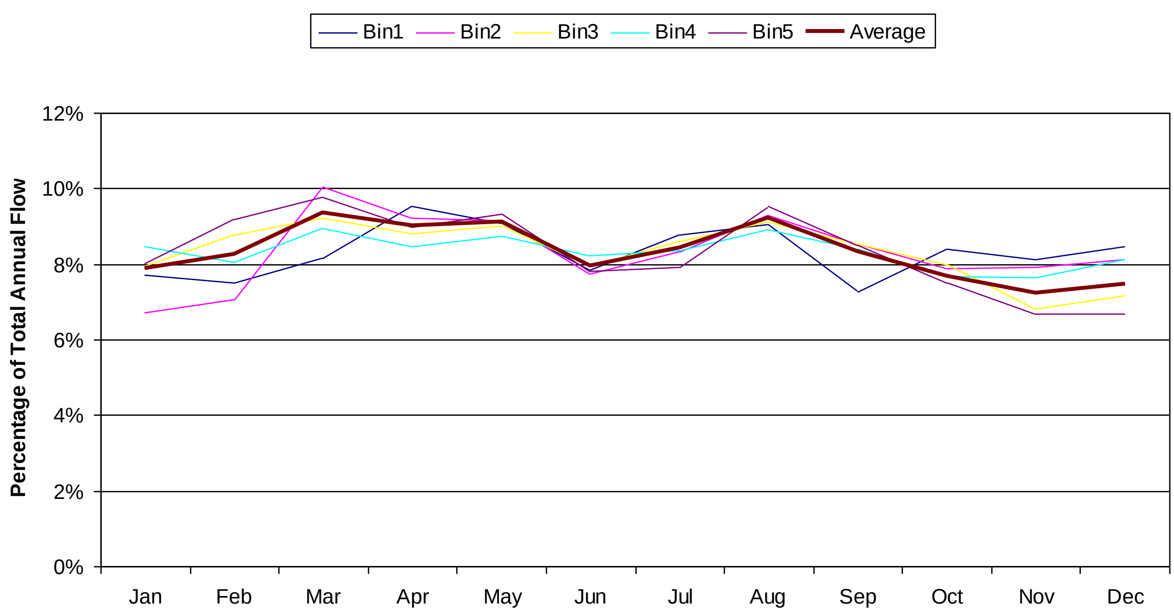


Figure 20. Monthly Flow Pattern for Whitewater River Near Mecca

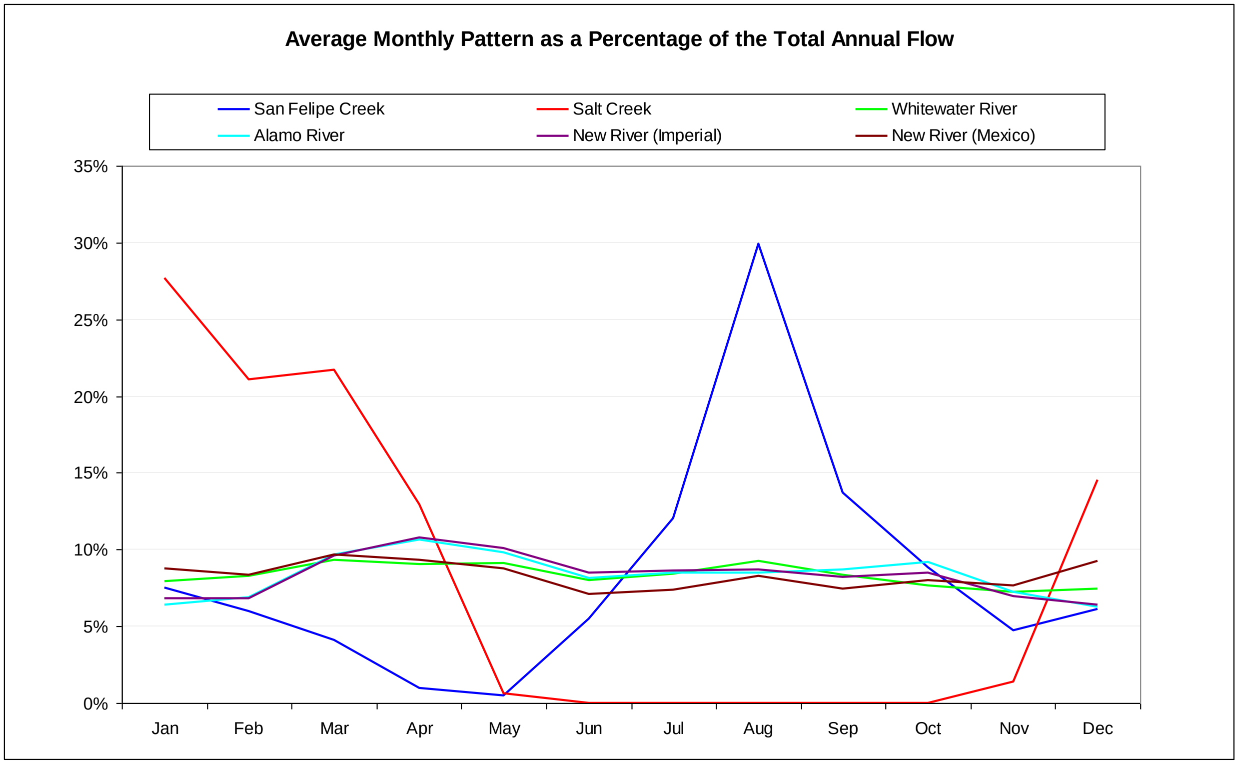


Figure 21. Average Monthly Flow Pattern for Gaged Streams Draining into the Salton Sea

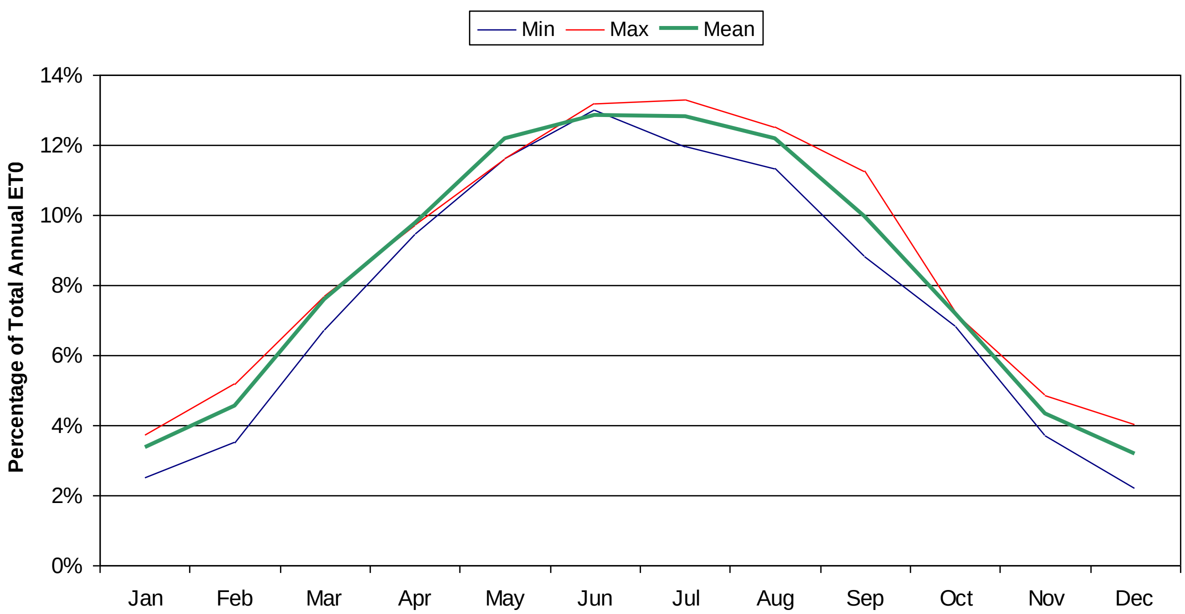


Figure 22. Monthly Pattern of Reference Evapotranspiration Near Brawley

5.6 Climate Change for Salton Sea

Figure 23 shows the range of simulated annual average temperature (top panel) and precipitation (bottom panel) derived from the 112 climate projections over the Salton Sea obtained from an existing publicly available database (http://gdo-dcp.ucllnl.org/downscaled_cmip3_projections/dcpInterface.html; Maurer et al. 2007). This archive contains climate projections, used in the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4), generated from 16 different General Circulation Models (GCMs) developed by national climate centers and for SRES emission scenarios A2, A1B, and B1. The results represent a range of potential future climate conditions resulting from climate change. Multiple downscaled climate data at 12-km gridcells centered on the Salton Sea are evaluated for the climate change assessment, however, no significant differences in the annual projected changes are found among the different 12-km gridcells. In this report, results are shown from a 12-km grid cell that is identified closest to the Salton Sea. As shown in the figure, annual temperatures are projected to continue an accelerated increase throughout the century. Annual temperatures are projected to increase by over 2.7 ºC by the end of century relative to the reference climate period (1985). The relatively narrow range in the projections indicates that general consensus exists amongst the projections. Projections of annual precipitation, however, do not exhibit strong consensus with some projections showing future decreases and some showing future increases.

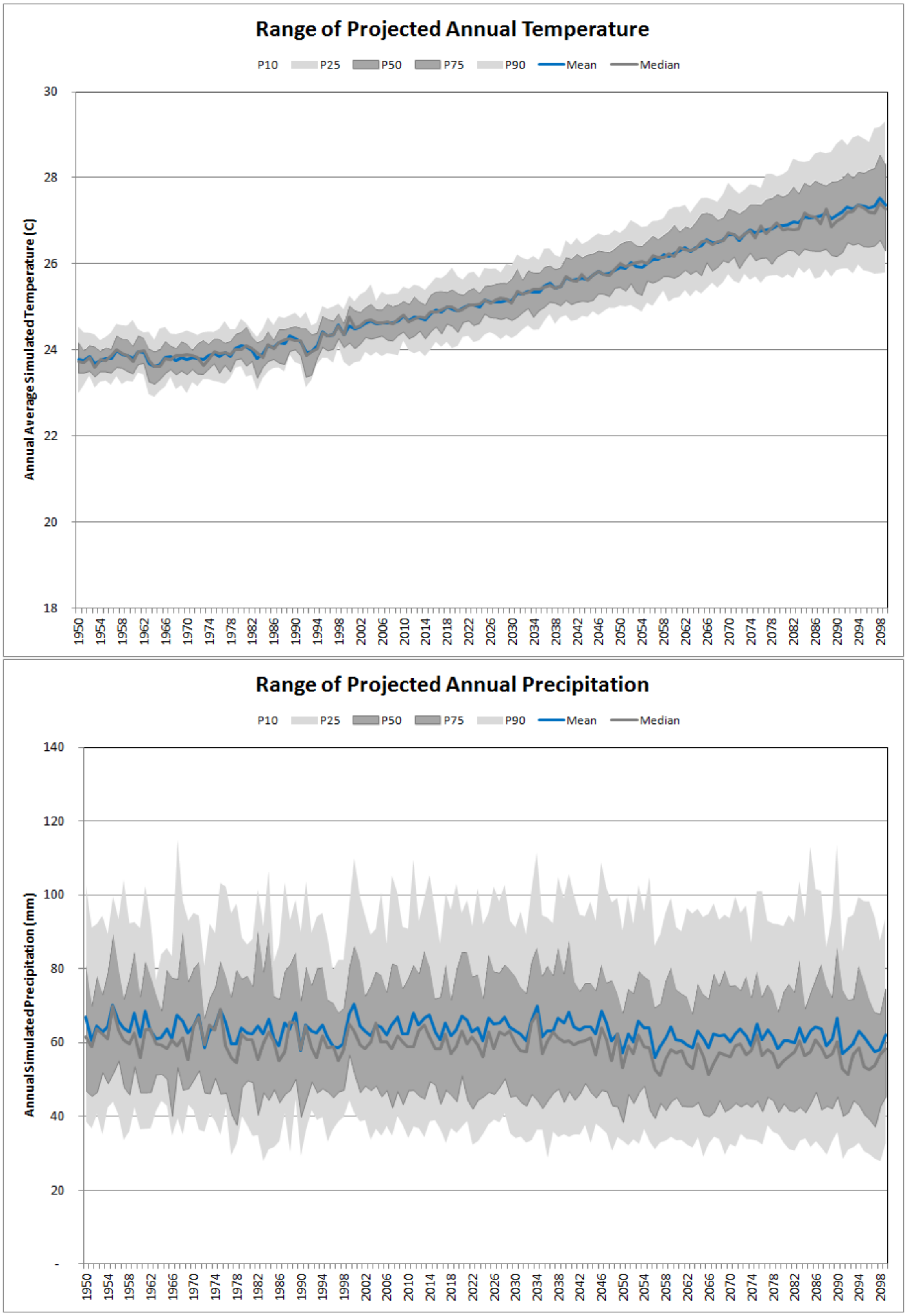


Figure 23. Simulated Historical and Future Average Annual Temperature (top) and Future Annual Precipitation (bottom).

Dark shading represents range between 25th and 75th percentile of results, light shading represents range between 10th and 90th percentile of results, blue line is mean, and gray line is median (50th percentile).

Table 3 summarizes the climate change results computed using the projections derived from 112 simulations. For each simulation, the annual and monthly temperature and precipitation were computed for three future periods centered at 2025 (2011 to 2040), 2050 (2036 to 2065) and 2075 (2061 to 2090). The changes were computed with respect to model simulated historical period 1985 (1971 to 2000). This approach was taken since climate is commonly defined as the average weather over a 30-year period (WMO, 2012). Historical simulation from GCM is used from period 1971-2000, because GCM in the CMIP3 database includes historical simulation up to 2000. Annual average temperatures are projected to increase by 1ºC by 2025, by about 2ºC by 2050, and up to 3º C by 2075, respectively, with less warming in winter and higher warming in summer. The projected changes vary considerably across the range of model simulations. The mean projected change in annual precipitation, when considering all simulations, is relatively small; increases of about 2 percent by 2025, and decreases by about 0.9 percent by 2050, and about 2.6 percent by 2075, respectively, with drying is projected in winter months and, with wetter conditions in the summer months.

Table 3. Projected Changes in Average Annual Temperature and Precipitation Relative to 1985

Statistic	Temperature Change (ºC)			Precipitation Change (%)		
	2025	2050	2075	2025	2050	2075
Mean	1.0	1.8	2.7	2.3	-0.9	-2.6
10th Percentile	0.8	1.5	2.1	-2.3	-7.8	-9.8
25th percentile	1.0	1.7	2.4	-2.0	-5.0	-8.5
50th percentile (median)	1.0	1.8	2.6	0.3	-3.6	-5.7
75th percentile	1.1	2.0	3.0	2.7	-1.8	-2.9
90th percentile	1.2	2.1	3.3	5.2	3.9	3.5

The uncertainty in projected changes can be assessed by the range between the 10th and 90th percentile results. The range of results for annual temperature changes is very small, especially through mid-century, indicating a strong concurrence of the GCMs toward future warming. These results for annual precipitation suggest that the future changes could range from almost 10 percent reduction to more than a 5 percent increase. The wider range, and particularly the difference in the sign of change, indicates that future precipitation projections for the study area are more uncertain (Table 3).

5.6.1 Evaporation

Temperature has been shown to increase in all future climate projections and is likely to have a considerable impact on evaporation and evapotranspiration. Evaporation is the single largest component in the water budget equation for the Salton Sea. Regarding the evaporation rate, it is also one of the few components over which future management decisions have no control. Under the future baseline, the historical climate conditions and variability are assumed to be a reasonable estimate of future conditions and the evaporation rate is assumed to be represented by the historical estimated rates. The evaporation rates determined from the annual water budget analysis were found to average 69 inches/yr as total evaporation or 66.4 inches/yr as net evaporation.

The rate of evaporation, however, is sensitive to small changes in meteorological conditions which are influenced by long-term climate trends. In order to address the potential effects of climate change on the future Salton Sea evaporation an uncertainty analysis similar to that for inflows from Coachella Valley was applied. Uncertainty was evaluated by relating changes in evaporation to changes in predicted temperature. The effect of the increased temperature on future evaporation was evaluated through an analysis of CIMIS reference evapotranspiration (ETo) rates, temperature, wind, net radiation, and other meteorological data. Sensitivity analysis on the parameters influencing ETo at the Salton Sea indicated that temperature and net radiation are the dominant controls. The historical evapotranspiration of CIMIS station #41 (Calipatria/Mulberry) was adjusted by modifying the mean temperature input to the modified Penman-Monteith equation as part of the Salton Sea Ecosystem Restoration Draft PEIR, while holding other meteorological data to historic values. Annual ETo was found to increase between 3 and 4% for each degree Celsius of temperature change. The effect of the future uncertainty is dependent on the water surface area of a particular alternative; the evaporation rate (as opposed to volumetric evaporation) is the appropriate parameter to be addressed in the model. The changes due to climate warming as suggested by the Parallel Climate Model (PCM) from the National Center for Atmospheric Research (NCAR) and the U.S. Department of Energy (DOE), and the Geophysical Fluids Dynamics Laboratory (GFDL) CM2.1 model from the National Oceanographic and Atmospheric Administration (NOAA) under two future emission scenarios are translated to increase evaporation by about 0.03 inch/per year to 0.11 inch/per year, as estimated for the Salton Sea Ecosystem Restoration Draft PEIR using projected temperatures from two GCM. For the current model the values determined part of the Salton Sea Ecosystem Restoration Draft PEIR is used to express future uncertainty to the evaporation. However, to investigate the uncertainty due to future climate warming, changes in evaporation are computed using 32 future climate projections obtained from sixteen GCMs downscaled to 1/8 degree resolution using the BCSD technique. Two greenhouse gas emissions scenarios were included from each GCM, the lower B1 and the higher A2 pathway. The large ensemble of GCMs and the two pathways provides some ability to capture two dominant types of uncertainty: that due to unknown future atmospheric greenhouse gas concentrations and that due to imperfect understanding modeling of how climate will respond. The model projections considered all the climate projections included in the recent State of California's Climate Action Team Report (Cayan et al., 2009). The changes computed using the expanded climate model projections suggested a quite similar increase of evaporation by about 0.03 inch/per year to 0.12 inch/per year. A sensitivity of the model results were performed using the both change parameters. The sensitivity to the final impact results to Sea Salinity and exposed playa was less than 0.2% by the end of the simulation using the uncertainties of these two data sets.

5.7 Use and Interpretation of Model Results

The SALSA2 model generates daily results of Salton Sea water surface elevation and salinity. Furthermore, when operated in stochastic mode, the model generates 500 possible outcomes on a daily time step over the 65-year simulation period. Selected output results are retained from each simulation and descriptive statistics are generated from the entire suite of model results. Although daily model results are available, and statistics can be generated, the results of model simulations are presented as end-of-year values to facilitate understanding of the long-term trends as opposed to short-term fluctuations.

Graphs presented in this report show the mean, median (50th percentile), inter-quartile range (25th to 75th percentile range), and the 5th and 95th percentile range of outcomes from 2012 through 2047 for the Future Baseline (an example for elevation is shown on Figure 24). The water surface elevation and salinity of the Salton Sea for the Future Baseline are represented by separate graphs. In addition, separate graphs show the exposed playa area and area of shallow water habitat (less than 1-foot depth). It should be noted that a time series based on a statistic such as the 75th percentile is not the result of any one hydrologic trace. Rather the 75th percentile water surface elevation (or other output parameter) for a specific year is the elevation for which 75 percent of the outcomes yielded an elevation that was less.

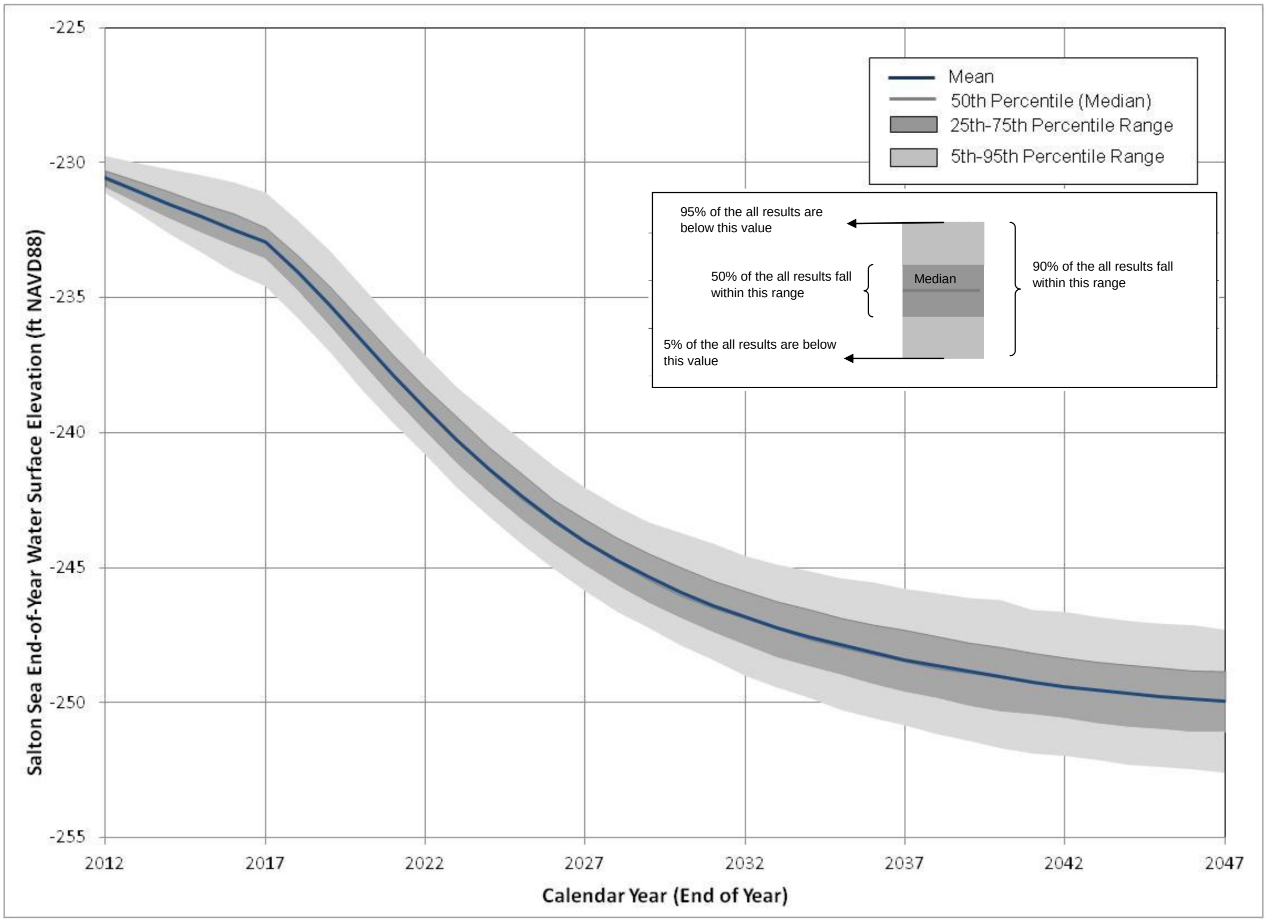


Figure 24. Example of Stochastic Results Presentation

5.8 Model and Data Limitations

Although the SALSA2 model is a significant improvement over previous modeling tools for the Salton Sea, there are several limitations associated with either the model or associated data. The SALSA2 model is a daily time step hydrologic, or water allocation model, but it uses annual input data. As such, it does not incorporate hydraulic calculations for features such as pumps, spillways, or control structures. The model is primarily concerned with the water and salt balance of the Sea. The SALSA2 model assumes complete mixing of water at confluences of channels and within storage elements over the model time step. However, salinity gradients in the Salton Sea do not suggest that this is a significant limitation. Another limitation regards the availability of data and scientific information related to salt precipitation and re-dissolution. A constant value of 1.5 million tons of salt per year was assumed to continue to precipitate out of the water column of the brine sink. In addition, the ratio of saline water evaporation to drain water evaporation was computed for salinities up to 350,000 mg/L. The evaporation-salinity relationships are not likely to be valid for salinities beyond this value. The geochemical processes at the Salton Sea are complex and are beyond the scope of this modeling effort.

SECTION 6

SALSA2 Application for Future No Action

Results for SALSA2 modeling using the hydrology and assumptions as described in the Future No Action are presented in this section. Model results are presented for simulated Salton Sea water surface elevation, salinity, and exposed playa. Since 500 individual realizations are simulated within the stochastic model of operations, summary statistics are presented for each year of the simulation period. The results of model simulations are presented as end-of-year values to facilitate understanding of the long-term trends as opposed to short-term fluctuations.

Projected Salton Sea water surface elevation is shown in Figure 25. As shown in the figure Salton Sea water surface elevation will continue to decline rapidly until a new quasi-equilibrium is reached where evaporation balances with inflows. Substantial declines are expected through 2047.

Projected salinity of the Salton Sea is shown in Figure 26. As shown in the figure, the Salton Sea salinity is projected to continue to rise rapidly over the next two decades or more. Salinity already exceeds 60,000 mg/L, and is likely to exceed 90,000 mg/L by 2023. There is considerable uncertainty regarding the extent of precipitation of salts at higher salinities (greater than 200,000 mg/L) as the sea approaches saturation for various salts.

Projected exposed playa at the Salton Sea is shown in Figure 27. As shown in the figure, an estimated 18,600 acres have already been exposed in the 14 years between 2003 and 2017. Continued, and accelerated, increases in exposed playa are projected. Total exposed playa, without restoration beyond SCH and Red Hill Bay, is projected to exceed 100,000 acres by around 2038 and stabilize consistent with the elevation results.

Spatial maps of the initial (2003) and projected (2047) conditions at the Salton Sea from the SALSA2 Future No Action simulation are shown in Figure 28. Tables 4, 5, and 6 presents the numeric results as described in the figures for Salton Sea water surface elevation, salinity, and exposed playa, respectively.

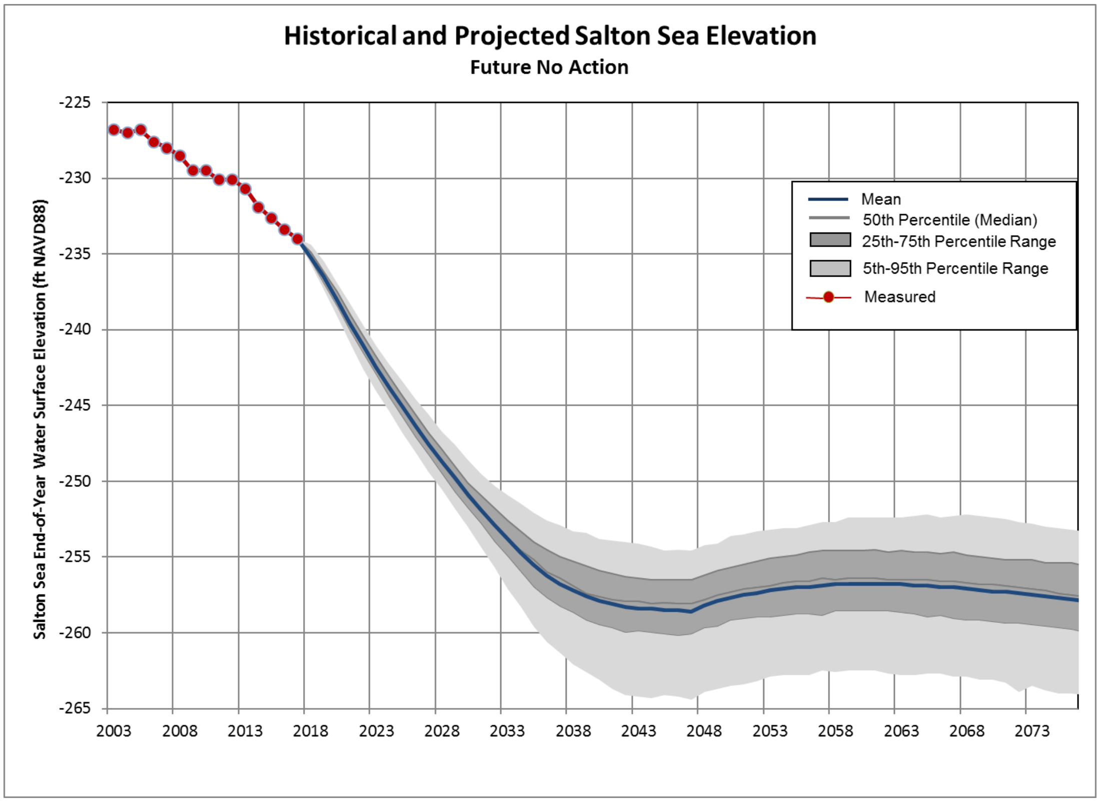


Figure 25. Historical and Projected Salton Sea Elevation

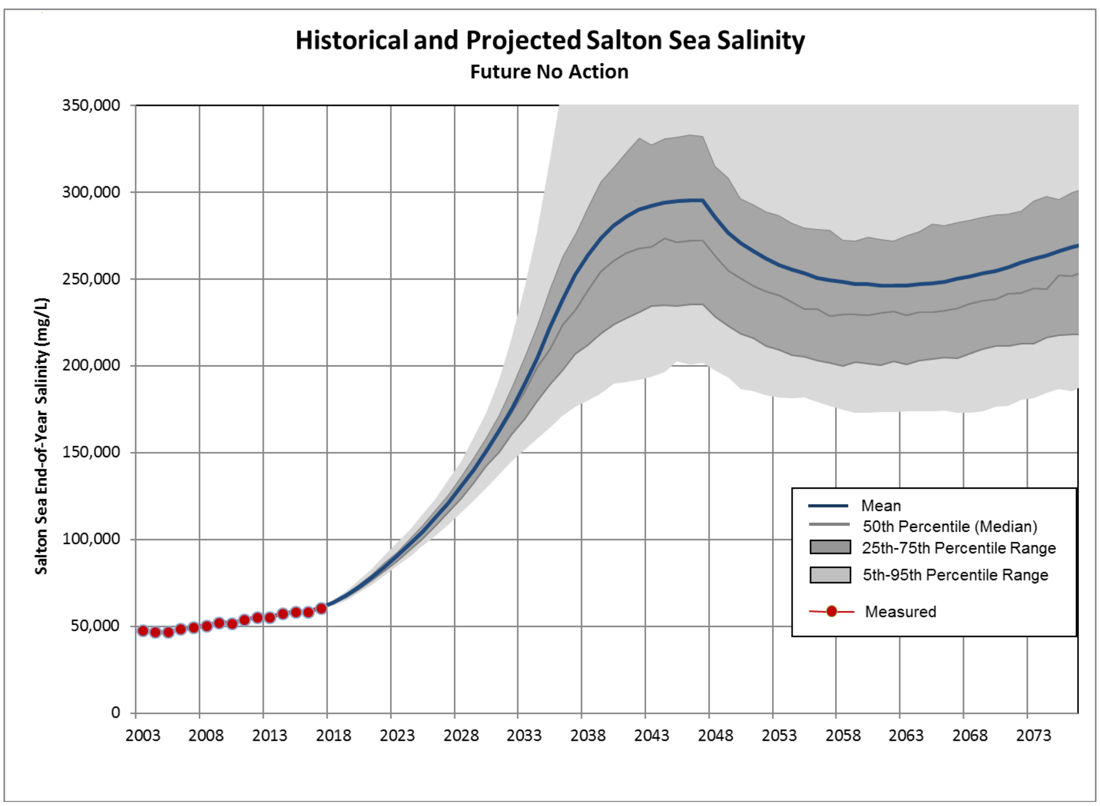


Figure 26. Historical and Projected Salton Sea Salinity

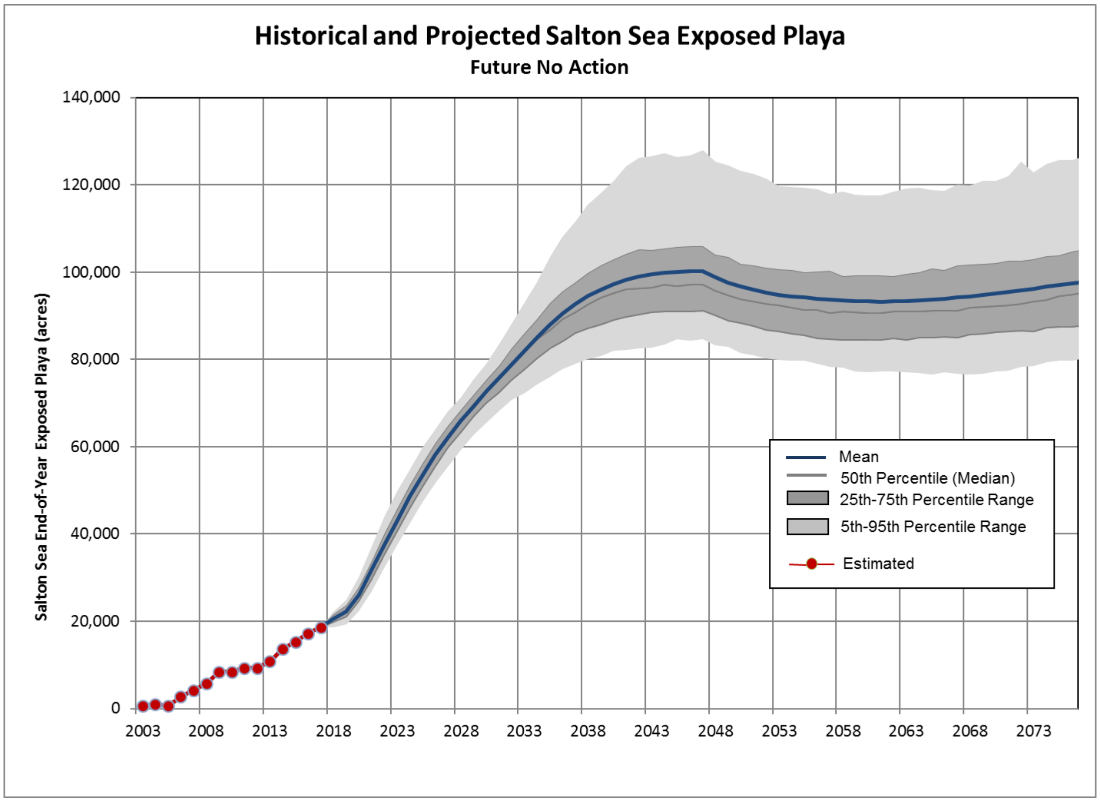


Figure 27. Historical and Projected Salton Sea Exposed Playa

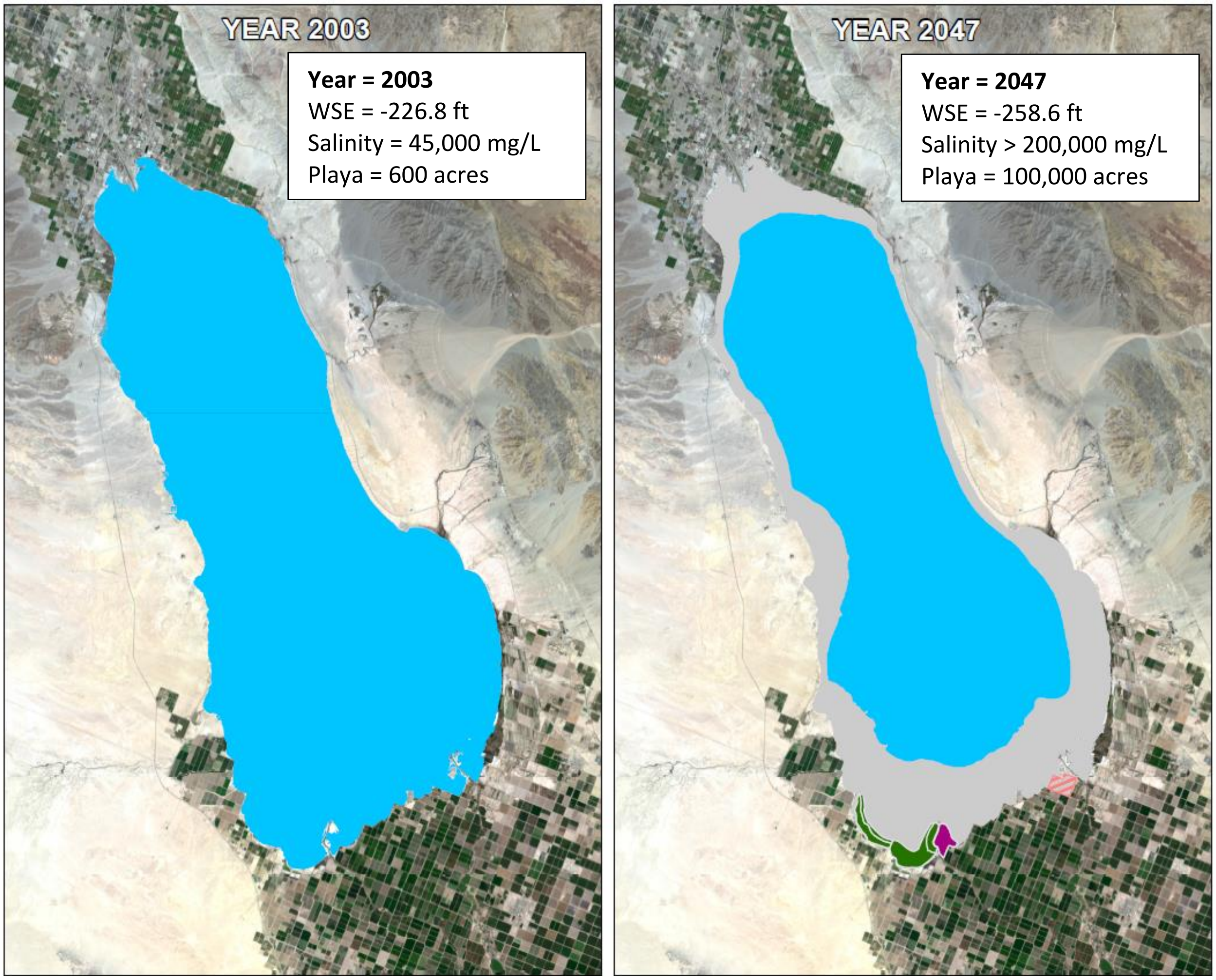


Figure 28. Initial (2003) and Projected (2047) Salton Sea Conditions under the Future No Action Simulation

Table 4. Projected Salton Sea Water Surface Elevation

Year	Elevation (ft NAVD88)					
	Mean	5%	25%	Median	75%	95%
2018	-235.2	-235.7	-235.5	-235.2	-234.9	-234.4
2019	-236.5	-237.4	-237.0	-236.5	-236.2	-235.5
2020	-238.0	-239.1	-238.5	-237.9	-237.5	-236.9
2021	-239.6	-240.9	-240.1	-239.5	-239.0	-238.3
2022	-241.0	-242.6	-241.6	-241.0	-240.4	-239.7
2023	-242.5	-244.1	-243.0	-242.4	-241.8	-241.1
2024	-243.8	-245.4	-244.5	-243.7	-243.1	-242.3
2025	-245.1	-246.8	-245.8	-245.1	-244.4	-243.4
2026	-246.4	-248.1	-247.1	-246.4	-245.6	-244.6
2027	-247.6	-249.4	-248.3	-247.6	-246.8	-245.6
2028	-248.7	-250.5	-249.5	-248.8	-247.9	-246.7
2029	-249.8	-251.8	-250.7	-249.9	-249.0	-247.6
2030	-250.9	-253.0	-251.8	-251.0	-250.1	-248.6
2031	-251.9	-254.3	-252.8	-252.0	-250.9	-249.5
2032	-252.9	-255.7	-254.0	-252.9	-251.8	-250.3
2033	-253.8	-257.1	-255.0	-253.8	-252.6	-250.9
2034	-254.7	-258.3	-256.0	-254.6	-253.3	-251.5
2035	-255.5	-259.6	-257.0	-255.2	-254.0	-252.1
2036	-256.2	-260.6	-257.7	-256.0	-254.5	-252.6
2037	-256.8	-261.3	-258.3	-256.4	-255.0	-252.9
2038	-257.2	-262.1	-258.7	-256.9	-255.3	-253.3
2039	-257.6	-262.6	-259.2	-257.4	-255.6	-253.4
2040	-257.9	-263.1	-259.5	-257.6	-255.9	-253.8
2041	-258.1	-263.7	-259.7	-257.8	-256.1	-253.9
2042	-258.3	-264.1	-260.0	-257.9	-256.3	-254.0
2043	-258.4	-264.2	-259.9	-257.9	-256.4	-254.1
2044	-258.4	-264.3	-260.0	-258.1	-256.5	-254.3
2045	-258.5	-264.1	-260.1	-258.0	-256.5	-254.6
2046	-258.5	-264.2	-260.2	-258.1	-256.5	-254.5
2047	-258.6	-264.4	-260.1	-258.1	-256.5	-254.6
2048	-258.2	-263.9	-259.7	-257.8	-256.2	-254.2
2049	-257.9	-263.7	-259.6	-257.5	-255.9	-254.1
2050	-257.7	-263.5	-259.2	-257.3	-255.7	-253.6
2051	-257.5	-263.4	-259.1	-257.1	-255.5	-253.5
2052	-257.4	-263.2	-259.0	-257.0	-255.3	-253.3
2053	-257.2	-262.9	-259.0	-256.9	-255.1	-253.2
2054	-257.1	-262.8	-258.9	-256.7	-255.0	-253.1
2055	-257.0	-262.8	-258.8	-256.6	-254.9	-253.1
2056	-257.0	-262.8	-258.8	-256.6	-254.7	-252.9
2057	-256.9	-262.5	-258.9	-256.4	-254.6	-252.7
2058	-256.8	-262.6	-258.6	-256.5	-254.6	-252.7
2059	-256.8	-262.5	-258.6	-256.4	-254.6	-252.4
2060	-256.8	-262.5	-258.6	-256.4	-254.6	-252.4

Table 4. Projected Salton Sea Water Surface Elevation

Year	Elevation (ft NAVD88)					
	Mean	5%	25%	Median	75%	95%
2061	-256.8	-262.5	-258.6	-256.4	-254.5	-252.4
2062	-256.8	-262.7	-258.6	-256.5	-254.7	-252.4
2063	-256.8	-262.8	-258.7	-256.5	-254.6	-252.4
2064	-256.9	-262.8	-258.8	-256.5	-254.7	-252.3
2065	-256.9	-262.7	-259.0	-256.5	-254.7	-252.2
2066	-257.0	-262.7	-258.9	-256.6	-254.8	-252.4
2067	-257.0	-262.9	-259.1	-256.6	-254.7	-252.3
2068	-257.1	-262.9	-259.2	-256.7	-254.9	-252.2
2069	-257.2	-263.1	-259.2	-256.8	-255.0	-252.3
2070	-257.3	-263.1	-259.3	-256.8	-255.1	-252.4
2071	-257.3	-263.3	-259.4	-256.9	-255.2	-252.5
2072	-257.4	-263.9	-259.4	-257.0	-255.2	-252.7
2073	-257.5	-263.5	-259.5	-257.1	-255.2	-252.8
2074	-257.6	-263.8	-259.6	-257.2	-255.4	-253.0
2075	-257.7	-264.0	-259.7	-257.4	-255.4	-253.1
2076	-257.8	-264.0	-259.8	-257.5	-255.4	-253.2
2077	-257.9	-264.1	-260.0	-257.6	-255.6	-253.3

Table 5. Projected Salton Sea Salinity

Year	Salinity (mg/L)					
	Mean	5%	25%	Median	75%	95%
2018	63,735	61,876	63,047	63,836	64,608	65,127
2019	67,693	64,924	66,625	67,538	68,981	70,146
2020	72,536	69,132	71,029	72,288	74,058	76,218
2021	78,115	73,685	76,251	77,831	79,981	83,123
2022	84,138	78,967	81,655	83,642	86,414	90,434
2023	90,526	84,595	87,587	90,130	92,930	97,923
2024	97,315	90,008	93,854	96,736	100,615	105,501
2025	104,572	96,088	100,375	104,247	108,242	114,504
2026	112,394	102,058	107,654	112,192	117,006	123,493
2027	120,788	108,188	115,531	120,713	125,694	133,925
2028	129,940	115,164	123,282	129,978	135,948	144,623
2029	139,891	122,056	132,168	139,965	146,669	158,431
2030	150,556	129,683	142,147	150,628	158,885	172,874
2031	162,259	137,544	150,412	161,676	171,792	192,451
2032	175,161	145,143	160,386	172,744	187,532	215,700
2033	189,092	151,445	169,352	185,458	205,077	245,063
2034	204,695	157,705	179,469	198,913	222,812	276,688
2035	221,672	164,445	189,067	209,757	244,657	319,096
2036	238,143	170,916	197,262	223,206	262,711	361,311
2037	252,233	176,399	206,821	232,380	276,198	393,307
2038	263,877	179,741	211,711	243,137	291,074	434,329
2039	273,487	183,942	218,374	254,419	305,902	463,658
2040	280,727	189,501	223,722	260,481	314,574	498,142
2041	285,839	190,495	227,446	264,853	323,092	500,000
2042	289,921	191,961	230,815	267,443	331,209	500,000
2043	292,285	193,714	234,298	268,295	327,285	500,000
2044	293,793	196,222	234,647	273,320	331,063	500,000
2045	294,902	202,499	234,502	271,076	331,714	500,000
2046	295,076	200,550	235,051	271,888	333,275	500,000
2047	295,130	201,815	235,389	271,885	332,112	500,000
2048	284,970	197,405	228,238	262,996	315,038	500,000
2049	276,758	193,326	222,880	254,635	308,464	500,000
2050	270,562	186,474	218,625	250,403	296,467	474,317
2051	265,995	185,440	215,752	245,802	292,663	460,633
2052	261,593	182,921	211,435	242,926	288,781	444,692
2053	257,904	181,868	209,207	240,473	286,501	412,823
2054	255,573	181,206	205,924	236,404	281,972	408,931
2055	253,079	181,663	205,340	232,755	279,339	407,762
2056	250,608	179,097	202,815	232,464	278,728	400,317
2057	249,258	176,916	201,691	228,693	278,007	377,870
2058	248,144	174,499	200,022	229,719	272,382	384,720
2059	246,879	173,020	201,877	229,572	271,964	381,374
2060	246,838	173,058	201,177	229,257	274,346	375,375

Table 5. Projected Salton Sea Salinity

Year	Salinity (mg/L)					
	Mean	**5%**	**25%**	**Median**	**75%**	**95%**
2061	246,037	173,250	200,515	230,439	272,755	368,728
2062	246,022	173,494	202,552	231,300	272,108	369,342
2063	246,228	173,874	200,899	229,152	274,978	369,853
2064	246,785	173,668	202,820	230,642	277,515	370,450
2065	247,537	173,618	203,812	231,014	281,551	376,446
2066	248,328	174,206	204,624	231,759	281,044	365,340
2067	250,069	173,072	204,357	232,843	282,715	378,780
2068	251,387	172,950	207,071	235,824	283,962	382,461
2069	253,013	173,549	209,473	237,409	285,564	386,556
2070	254,551	176,517	211,203	238,184	286,949	383,613
2071	256,796	176,977	211,251	241,467	287,318	396,802
2072	259,495	180,284	212,750	242,056	289,196	413,836
2073	261,509	181,158	212,575	244,514	295,138	409,913
2074	263,560	184,199	216,128	244,205	297,867	400,458
2075	265,930	186,488	217,533	251,892	295,986	408,018
2076	268,183	185,299	218,032	251,777	299,983	410,506
2077	269,882	188,999	218,189	254,509	302,254	420,888

Table 6. Projected Salton Sea Exposed Playa

Year	Exposed Playa (acres)					
	Mean	**5%**	**25%**	**Median**	**75%**	**95%**
2018	20,549	18,520	19,810	20,662	21,494	22,022
2019	22,271	19,262	21,126	22,120	23,676	24,925
2020	26,124	22,367	24,527	25,860	27,732	30,113
2021	31,713	26,901	29,656	31,427	33,747	36,995
2022	37,507	32,178	35,059	37,052	39,879	43,835
2023	43,229	37,482	40,527	42,950	45,721	49,711
2024	48,638	42,458	46,008	48,292	51,370	54,801
2025	53,559	47,272	50,809	53,643	56,132	59,823
2026	58,059	51,740	55,487	58,158	60,836	63,992
2027	62,130	55,434	59,758	62,422	64,664	67,996
2028	65,840	59,245	63,395	66,190	68,445	71,295
2029	69,274	62,553	66,777	69,635	71,698	75,320
2030	72,536	65,429	70,057	72,792	75,235	79,080
2031	75,753	68,247	72,555	75,875	78,658	83,651
2032	78,923	70,660	75,345	78,781	82,437	88,173
2033	81,977	72,333	77,796	81,823	86,055	93,076
2034	85,008	74,308	80,215	84,632	89,268	97,744
2035	87,947	76,060	82,505	86,712	92,846	103,428
2036	90,545	77,828	84,071	89,269	95,572	108,132
2037	92,714	79,001	86,034	90,768	97,744	111,500
2038	94,521	80,034	87,026	92,528	99,727	115,506
2039	96,071	80,713	88,017	94,186	101,623	118,107
2040	97,303	81,960	89,031	95,152	102,890	120,922
2041	98,289	82,253	89,758	96,014	104,178	124,186
2042	99,017	82,548	90,293	96,324	105,305	126,287
2043	99,551	82,765	90,723	96,380	105,015	126,527
2044	99,828	83,421	90,918	97,165	105,420	127,330
2045	100,001	84,591	90,895	96,787	105,697	126,381
2046	100,167	84,300	91,054	97,171	105,993	126,745
2047	100,303	84,578	91,176	97,127	105,921	127,899
2048	98,800	83,284	90,063	95,813	103,967	125,369
2049	97,556	82,907	88,915	94,617	103,440	124,371
2050	96,689	81,393	88,313	93,843	101,911	123,152
2051	95,989	80,987	87,670	93,233	101,458	122,417
2052	95,344	80,300	86,826	92,753	100,974	121,444
2053	94,818	79,807	86,403	92,404	100,659	119,717
2054	94,451	79,650	85,928	91,863	100,561	119,476
2055	94,144	79,666	85,575	91,334	99,987	119,399
2056	93,829	78,999	84,878	91,283	100,089	119,034
2057	93,621	78,251	84,653	90,554	100,264	117,870
2058	93,450	78,033	84,412	90,919	99,044	118,366
2059	93,289	77,232	84,497	90,774	99,177	117,780
2060	93,311	77,035	84,473	90,693	99,312	117,509

Table 6. Projected Salton Sea Exposed Playa

Year	Exposed Playa (acres)					
	Mean	**5%**	**25%**	**Median**	**75%**	**95%**
2061	93,257	77,148	84,369	90,575	99,327	117,646
2062	93,312	77,259	84,879	90,938	99,121	118,530
2063	93,406	77,078	84,436	91,043	99,518	119,097
2064	93,547	76,886	84,910	91,004	99,966	119,333
2065	93,718	76,547	84,931	91,190	100,859	118,816
2066	93,919	77,076	85,093	91,216	100,551	118,650
2067	94,185	76,700	85,042	91,219	101,461	119,958
2068	94,467	76,591	85,622	91,842	101,764	119,788
2069	94,769	76,734	85,925	92,009	101,877	120,880
2070	95,073	77,312	86,292	92,122	102,034	120,972
2071	95,442	77,418	86,423	92,445	102,641	121,901
2072	95,887	78,217	86,500	92,791	102,562	125,233
2073	96,248	78,473	86,481	93,243	103,037	122,887
2074	96,625	79,351	87,273	93,636	103,724	124,751
2075	97,068	79,688	87,424	94,484	103,872	125,670
2076	97,474	79,770	87,404	94,765	104,656	125,673
2077	97,836	80,155	87,864	95,292	105,314	126,485

SALSA2 Model Application for SSRREI and Perimeter Lake Alternatives

In addition to the Future No Action simulation, two Salton Sea future restoration alternatives were simulated with the SALSA2 model. These alternatives are the Salton Sea Restoration and Renewable Energy Initiative (SSRREI) alternative and the Perimeter Lake alternative. Each of these alternatives is briefly described in the following sections, followed by summary results for water surface elevation, salinity, and exposed playa.

7.1 Salton Sea Restoration and Renewable Energy Initiative (SSRREI) Alternative

The SSRREI includes a phased build-out of shallow, saline water habitat areas as the Salton Sea progressively recedes and exposes more playa in the future. The SSRREI alternative, as simulated, includes up to 23,000 acres of saline water habitat that would restore some of the past and current Salton Sea shallow water habitat, would provide air quality mitigation by covering portions of the emissive playa, and would also include renewable energy access to some of the exposed playa areas for both geothermal development and solar generation. The saline habitat areas would be constructed on the southern portion of the Sea with access to the New River, Alamo River, and IID direct drains; and in the northern portion of the Sea with access to the Whitewater River. Conceptual designs have been prepared to develop the backbone infrastructure to manage the diversion and conveyance of Imperial Valley flows to supply the proposed habitat areas.

The shallow water habitat would be managed for salinity around 15,000 to 20,000 mg/L (TDS) by blending lower TDS drainwater with higher Salton Sea water. Habitat area construction would be phased to allow for the playa to be exposed and sufficiently stable for berms to be developed. For modeling purposes, it is assumed that the habitat would be constructed in approximately 2,000 acre increments as water surface elevation permits. Full build-out of the habitat, based on elevation sufficiency, was assumed to be complete by 2029.

A summary of the main modeling assumptions associated with the SSRREI alternative are provided in Table 7.

7.2 Perimeter Lake Alternative

The Perimeter Lake alternative has been proposed by the Salton Sea Authority (Tetra Tech 2016) and consists of over 61 miles of levees to develop a 23,000-acre perimeter lake along the shoreline of the existing Sea. Water from the New River, Whitewater River, and San Felipe Creek would supply inflow to the perimeter lake. Water surface elevation of the perimeter lake would be managed at -235’ NGVD29 and salinity would be targeted for 15,000 to 20,000 mg/L. In order to maintain these elevation and salinity levels, the perimeter lake will need to discharge water to the downstream brine pool. Seepage through the extensive levee system has been estimated between 80 and 120 gallons per day per foot of levee length. These estimates suggest discharge from the perimeter lake, through both seepage and managed spills, may be between 20 percent and 40 percent of lake inflow. Water quality concerns in the long, narrow water body may require higher levels of flow-through to improve circulation.

A summary of the main modeling assumptions associated with the Perimeter Lake alternative are provided in Table 7.

Modeling assumptions for the Perimeter Lake were derived from the available information in the TetraTech status report (2016). No additional analyses were performed as part of this modeling effort to validate or modify assumptions associated with this alternative.

Table 7. Comparison of Key SALSA2 Modeling Assumptions for Future No Action, SSRREI, and Perimeter Lake Alternatives

Parameter	No Action	SSRREI	Perimeter Lake
Initial Conditions	December 31, 2017: WSE = -233.99 ft NAVD88; Salinity = 60,451 mg/L	Same as No Action	Same as No Action
Inflows Available for Restoration Elements	All	New River, Alamo River, Direct Drains, and Whitewater River	New River, San Felipe Creek, Salt Creek, and Whitewater River
Species Conservation Habitat (SCH)	Phases 1 and 2: 640 acres by 2019; 3770 acres by 2021	Same as No Action	Same as No Action
Red Hill Bay	620 acres by 2019	Same as No Action	Same as No Action
Saline Habitat Wetlands	No Additional	23,000 acres	No Additional
Wetland Salinity Range	N/A	approx. 20,000 mg/L	N/A
Wetland Release Rates	20% of wetland inflows	20% of wetland inflows	20% of wetland inflows
Perimeter Lake	No	No	23,000 acres
Perimeter Lake Salinity Range	N/A	N/A	approx. 20,000 mg/L
Perimeter Lake Release Rate	N/A	N/A	20-40% of lake inflow (80-120 gpd/ft seepage)
Air Quality Mitigation on Exposed Playa	Yes	Yes	Yes

7.3 Results

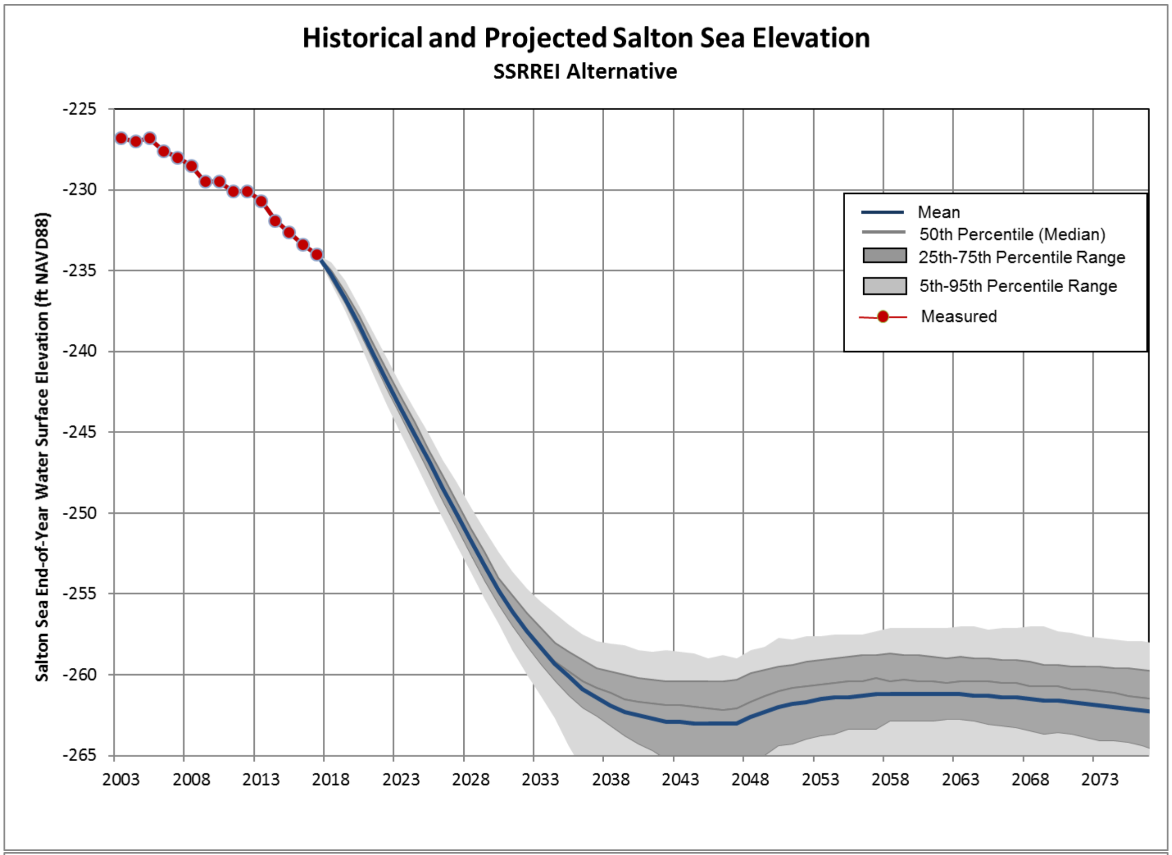
Results for SALSA2 modeling using the hydrology and assumptions as described above for the SSRREI and Perimeter Lake alternatives are presented in this section.

Projected Salton Sea water surface elevation for both SSRREI and Perimeter Lake alternatives is shown in Figure 29. As shown in the figure Salton Sea water surface elevation will decline more rapidly than the No Action due to additional consumptive uses on the playa (either shallow water habitat or perimeter lake). While the water surface elevation of the habitat and perimeter lake are stabilized under these alternatives, the Salton Sea water surface elevation is projected to decline by about 4 feet as compared to the No Action by 2047.

Projected salinity of the Salton Sea for both SSRREI and Perimeter Lake alternatives is shown in Figure 30. As shown in the figure, the Salton Sea salinity under these alternatives is projected to rise more rapidly than for the No Action. However, simulations suggest that the No Action, SSRREI, and Perimeter Lake will all have salinity exceeding 90,000 mg/L by 2023. There is considerable uncertainty regarding the extent of precipitation of salts at higher salinities (greater than 200,000 mg/L) as the sea approaches saturation for various salts.

Projected exposed playa at the Salton Sea for both SSRREI and Perimeter Lake alternatives is shown in Figure 31. As shown in the figure, exposed playa will continue to increase as elevation decreases through 2047 and then stabilize. The SSRREI alternative gradually converts some newly exposed playa into wetland habitat. The Perimeter Lake alternative covers some of the exposed playa when the lake levees are completed. Both alternatives have similar final exposed playa areas at build-out, and are similar to the No Action in terms of total playa area that may need to be managed for air quality impacts. Total exposed playa in all alternatives is projected to approach 100,000 acres by around 2047 and stabilize consistent with the elevation results.

Spatial maps of the projected (2047) conditions at the Salton Sea for the SSRREI and Perimeter Lake alternatives are shown in Figure 32.



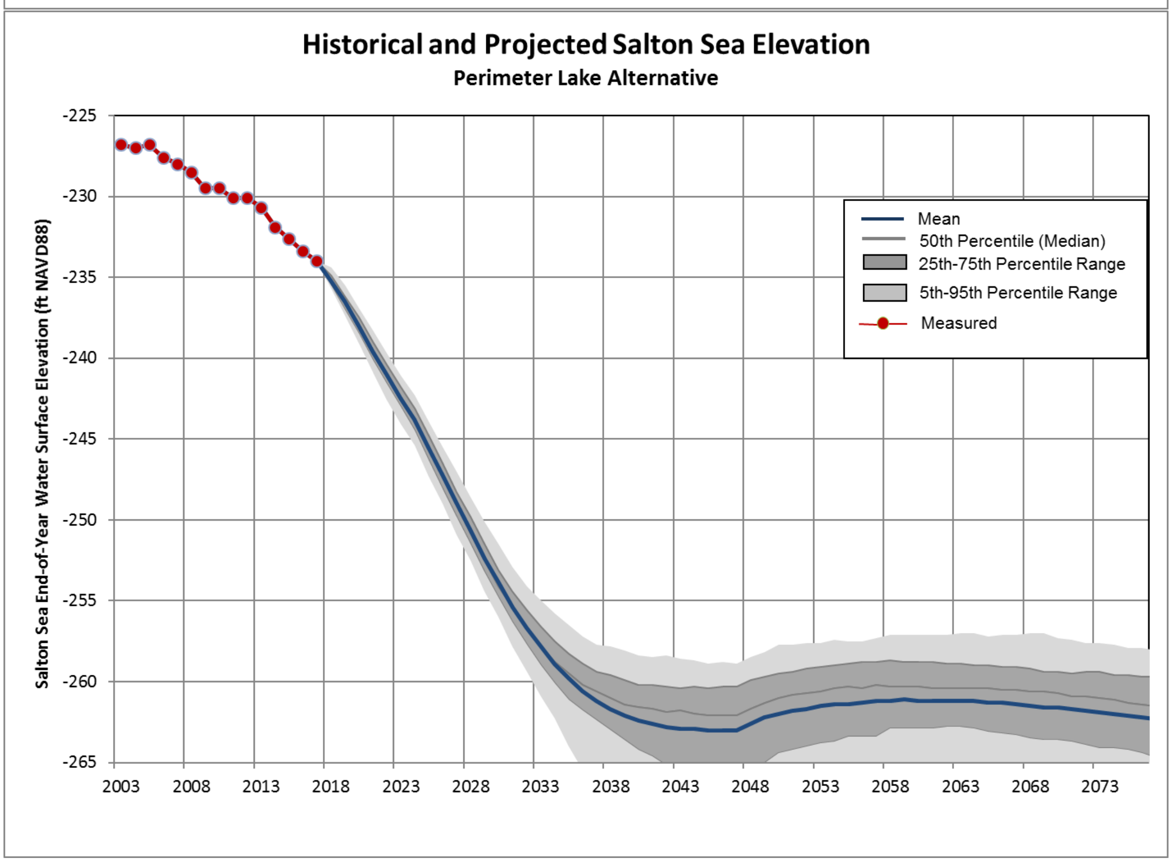
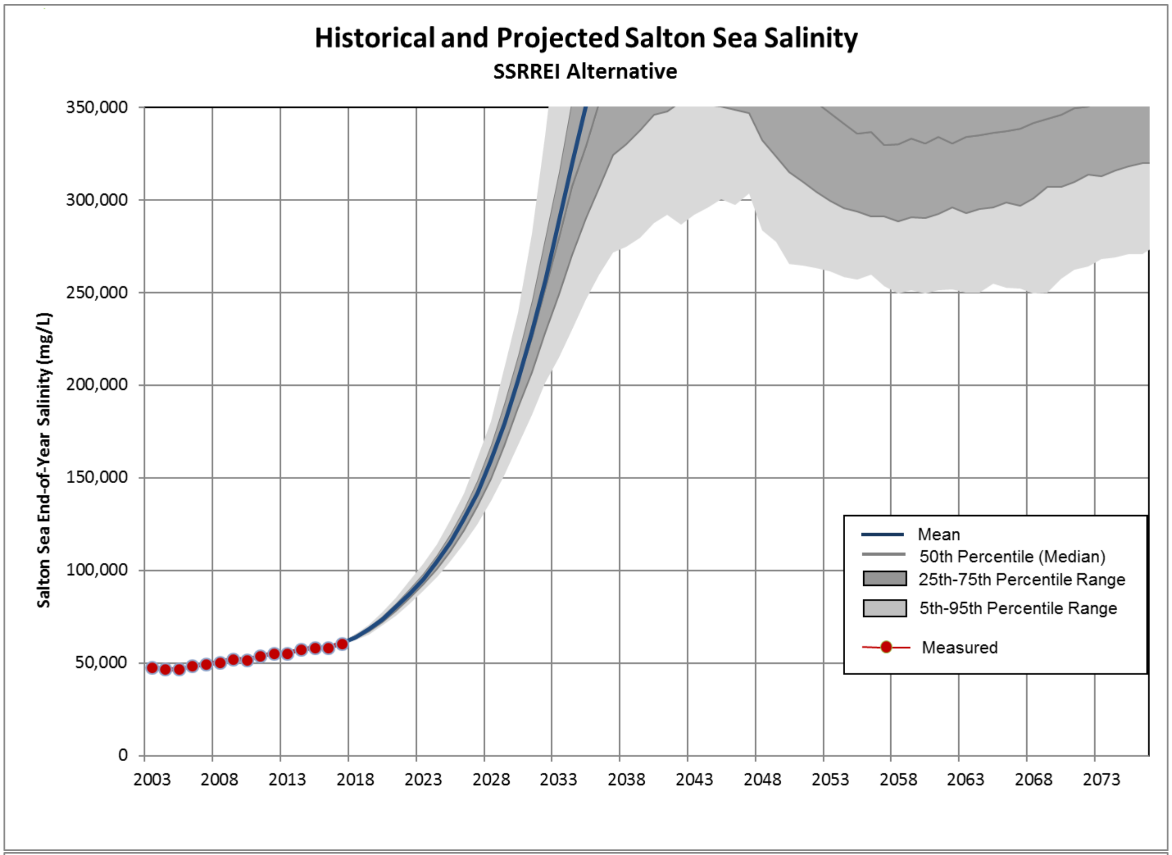


Figure 29. Historical and Projected Salton Sea Elevation



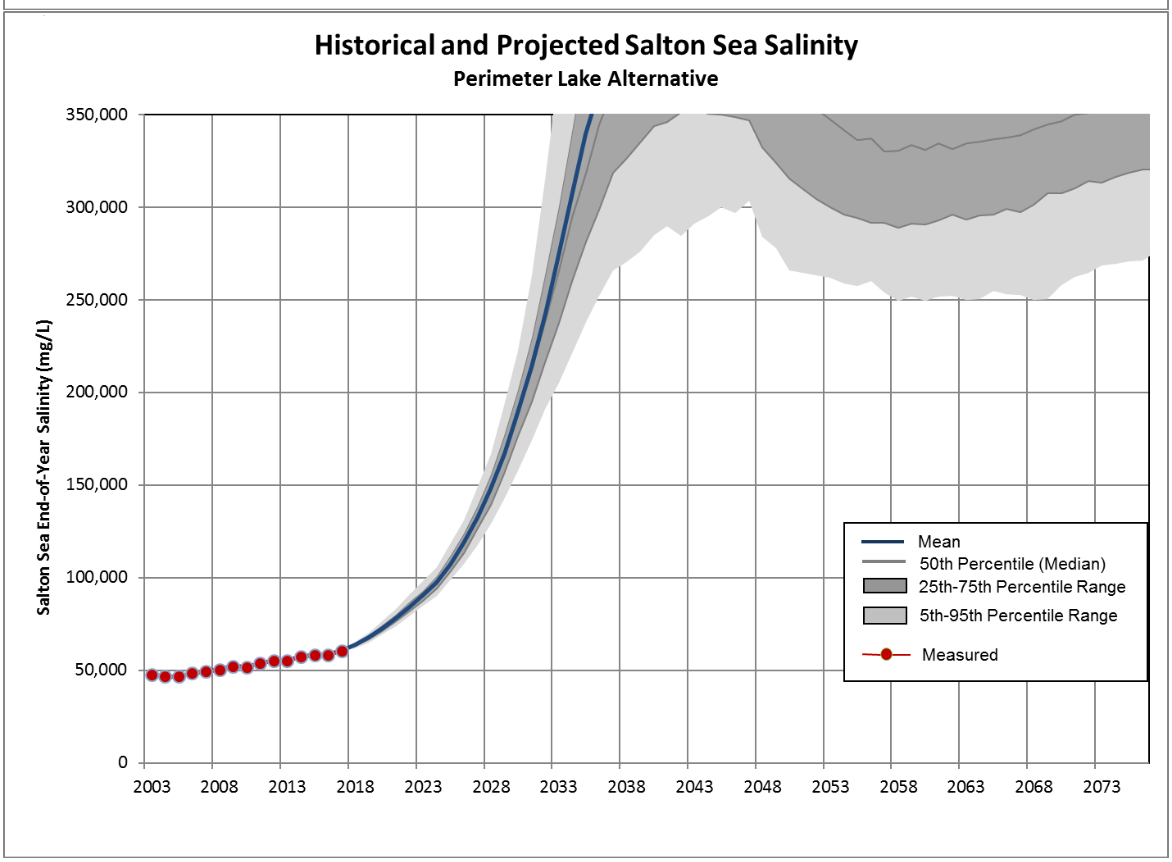
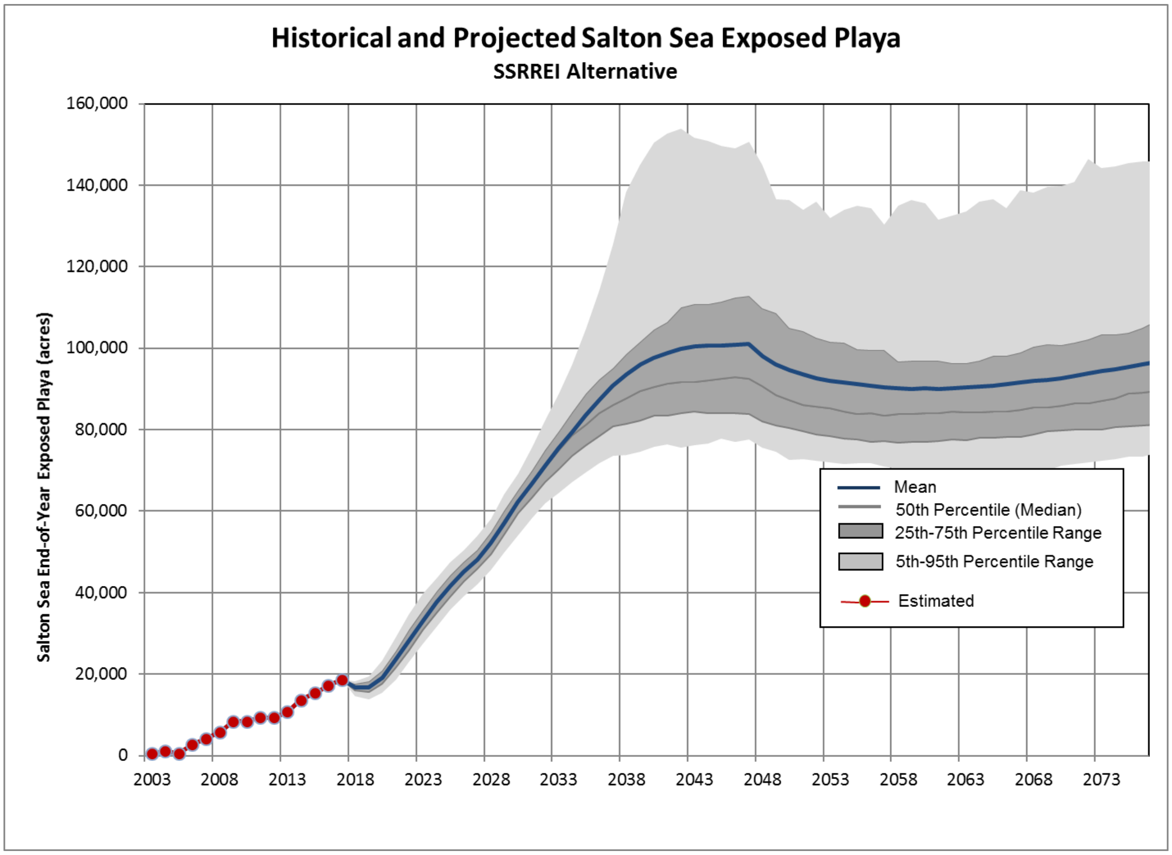


Figure 30. Historical and Projected Salton Sea Salinity



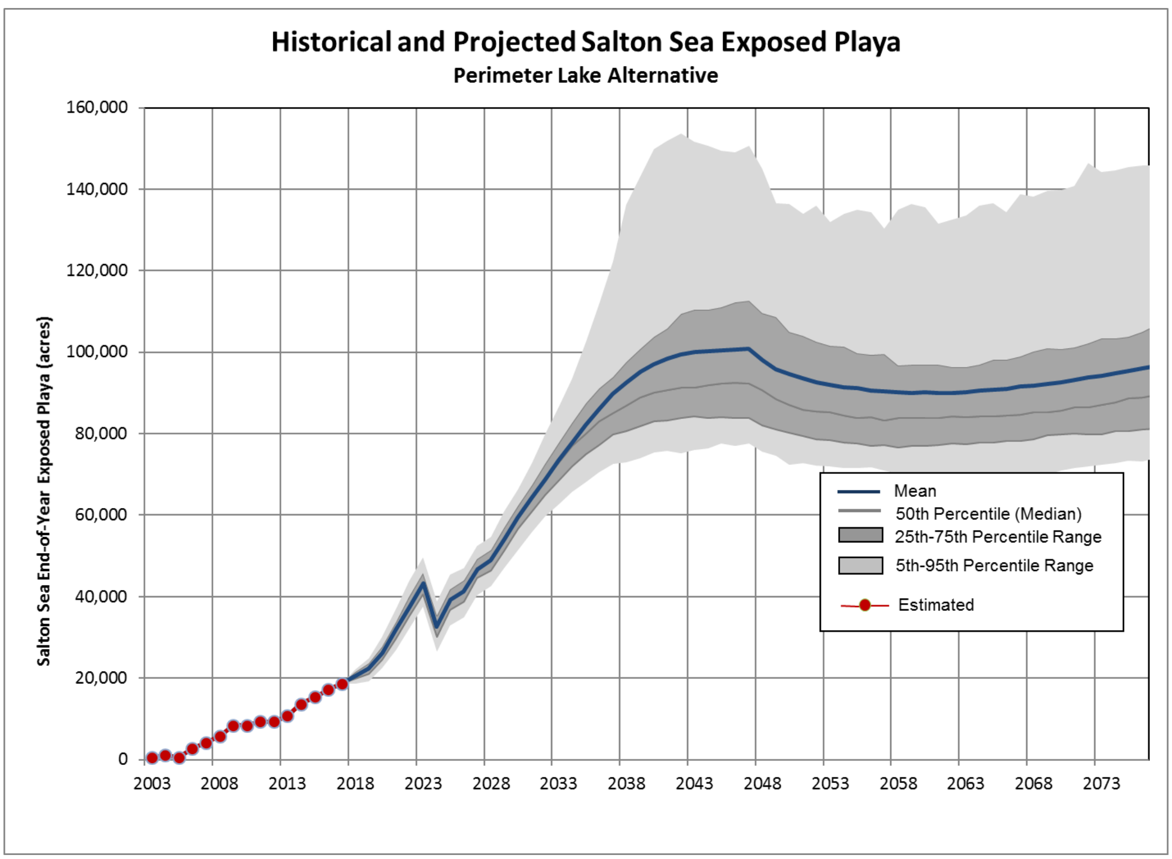


Figure 31. Historical and Projected Salton Sea Exposed Playa

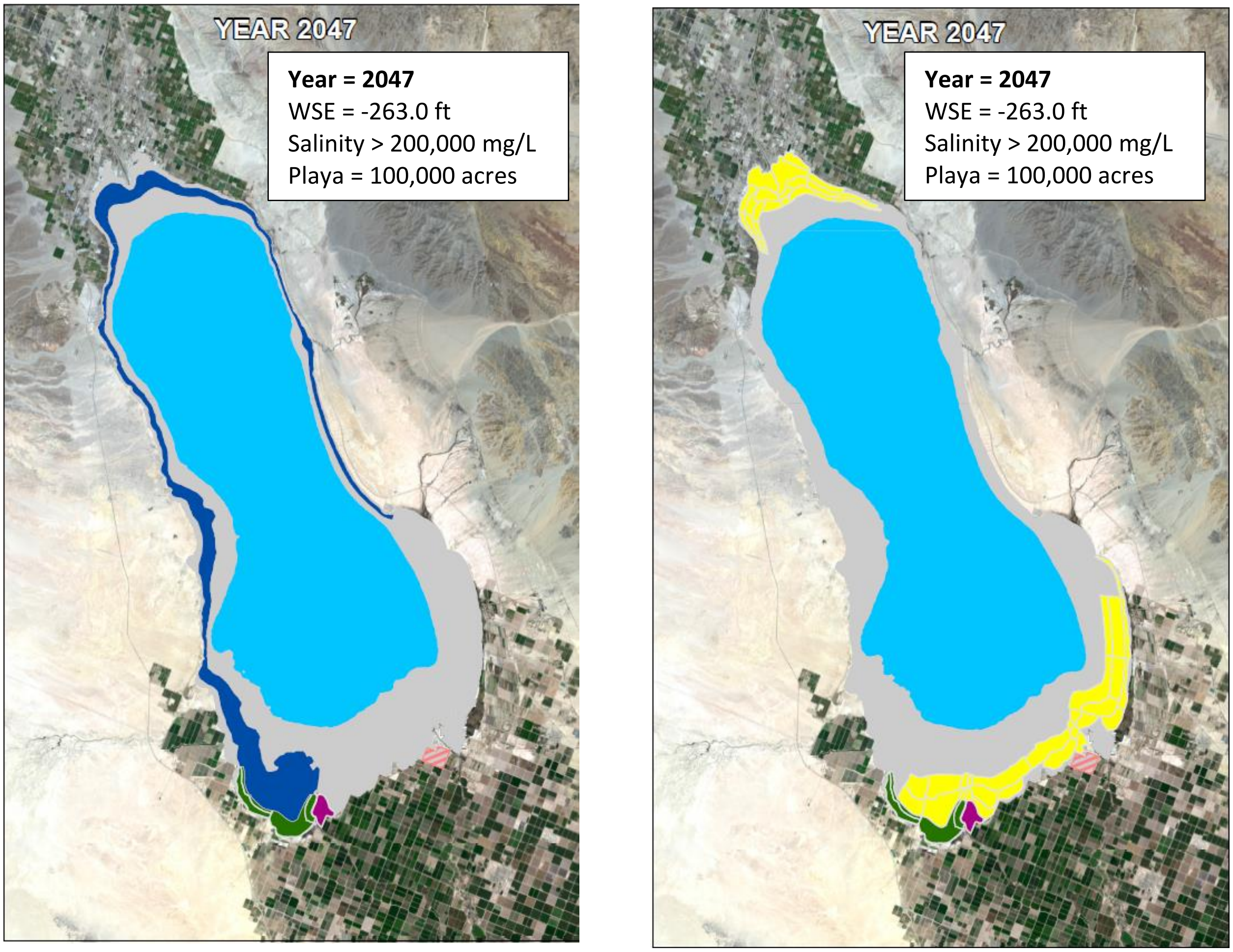


Figure 32. Historical and Projected Salton Sea Exposed Playa for SSRREI (right) and Perimeter Lake (left) Alternatives.

SECTION 8

Summary

This technical report describes the development and application of the SALSA2 model of the Salton Sea. The SALSA2 model is a comprehensive water and salt balance model for the Salton Sea, and is capable of simulating a wide range of configurations and water management actions at the Sea. The SALSA2 model has been updated in conjunction with the most recent updates to the hydrology and salt loads at the Salton Sea. The historical validation simulations using SALSA2 suggest very good correlation between observed and simulated water surface elevation, salinity, and exposed playa. The validation results, particularly considering that the SALSA2 model was simulated with projected rather than observed flows over the historical period, provide a high degree of confidence in the use of the model to simulate future conditions. The SALSA2 model was applied to simulated three future alternatives: a No Action, SSRREI alternative, and the Perimeter Lake alternative. These three alternatives suggest different management pathways to restore and manage the Salton Sea under the rapidly declining inflows. While the No Action has the slowest decline in water surface elevation, it does not provide replacement habitat for that being lost at the Salton Sea. The SSRREI alternative includes a flexible approach toward habitat restoration while supporting air quality mitigation on the playa. The Perimeter Lake alternative provides somewhat deeper, but narrower habitat in the form of the lake which also covers a substantial portion of the playa. All three options result in similar acreage of exposed playa at the end of the modeling period, but differ considerably on the location and timing of exposure and habitat development.

The modeling included in this report is intended to support a common base of understanding of the water and salt balances at the Salton Sea, and the interrelated components of hydrology, restoration, salinity, and playa management. The SALSA2 model can be further applied to test more complex or hybrid alternatives for restoration at the Salton Sea.

References

Agrarian Research and Management. 2009. *Salton Sea Solar Ponds Pilot Project*. Project results presentation. Available at: http://www.agrarian.org/documents/saltonsea_ponds_results.pdf.

Bureau of Reclamation (Reclamation). 2004. *Salinity Control Research Project*. Joint research project of the U.S. Department of the Interior Bureau of Reclamation Lower Colorado Region Boulder City, Nevada, and Salton Sea Authority, La Quinta, California. August.

Cayan, D., Tyree, M., Dettinger, M., Hidalgo, H., Das, T., Maurer, E., Bromirski, P., Graham, N., and Flick, R. 2009. Climate Change Scenarios and Sea Level Rise Estimates for the California 2008 Climate Change Scenarios Assessment.

Coachella Valley Water District (CVWD). 2010. *Coachella Valley Water Management Plan Update*. Draft.

Holdren C. 2012. Unpublished data. Various water quality data for the Salton Sea. Prepared for Bureau of Reclamation.

Imperial Irrigation District and Bureau of Reclamation (IID and Reclamation). 2002. *Final Environmental Impact Report/Environmental Impact Statement for the IID Water Conservation and Transfer Project*. June.

Intergovernmental Panel on Climate Change. 2007. Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the

Maurer, E. P., L. Brekke, T. Pruitt, and P. B. Duffy. 2007. Fine-resolution climate projections enhance regional climate change impact studies, Eos Trans. AGU, 88(47), 504.

NewFields Agricultural & Environmental Resources, LLC (NewFields). 2012. Bathymetric data for the Salton Sea (various geographic information system files).

Resources Agency. 2006. *Draft Programmatic Environmental Impact Report for the Salton Sea Ecosystem Restoration Program.*

TetraTech. 2016. Salton Sea Perimeter Lake Design Concept. Status Report. January 20.

Turk, L.J. 1970. Evaporation of Brine: A Field Study on the Bonneville Salt Flats, Utah. *Water Resources Research*. August.

U.S. Geological Survey (USGS). 2012. Provisional Salton Sea elevation data, compiled from various USGS and California Department of Water Resources sources.

U.S. Environmental Protection Agency. 1997. *Guiding Principles for Monte Carlo Analysis*. EPA/630/R-97/001. March.

World Meteorological Organization (WMO). 2012. WMO Climatological Normals. Available at: https://www.wmo.int/pages/prog/wcp/wcdmp/GCDS_1.php