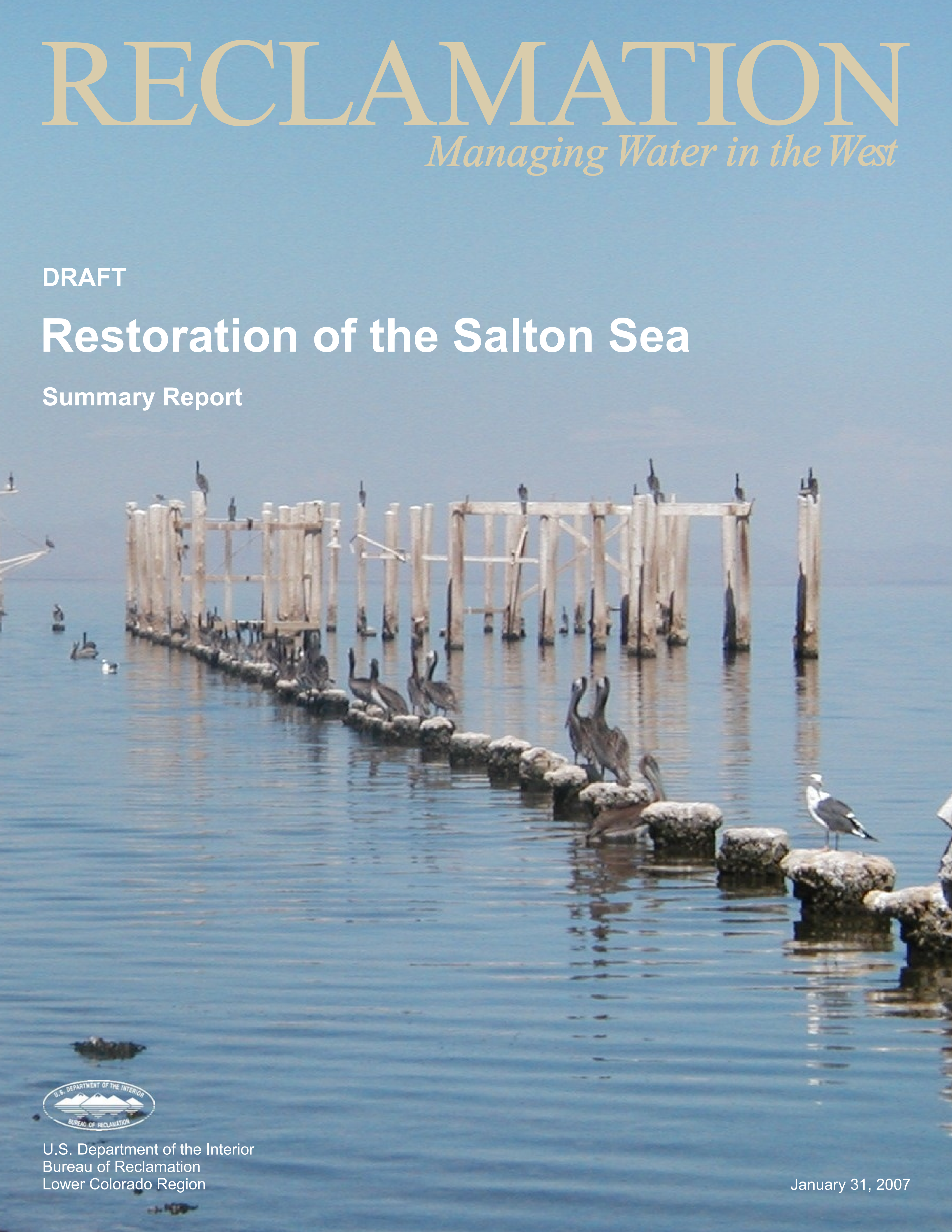

RECLAMATION
Managing Water in the West

DRAFT

Restoration of the Salton Sea

Summary Report

U.S. Department of the Interior
Bureau of Reclamation
Lower Colorado Region

January 31, 2007

Mission Statements

The mission of the Department of the Interior is to protect and provide access to our Nation's natural and cultural heritage and honor our trust responsibilities to Indian Tribes and our commitments to island communities.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

DRAFT

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Boulder City, Nevada

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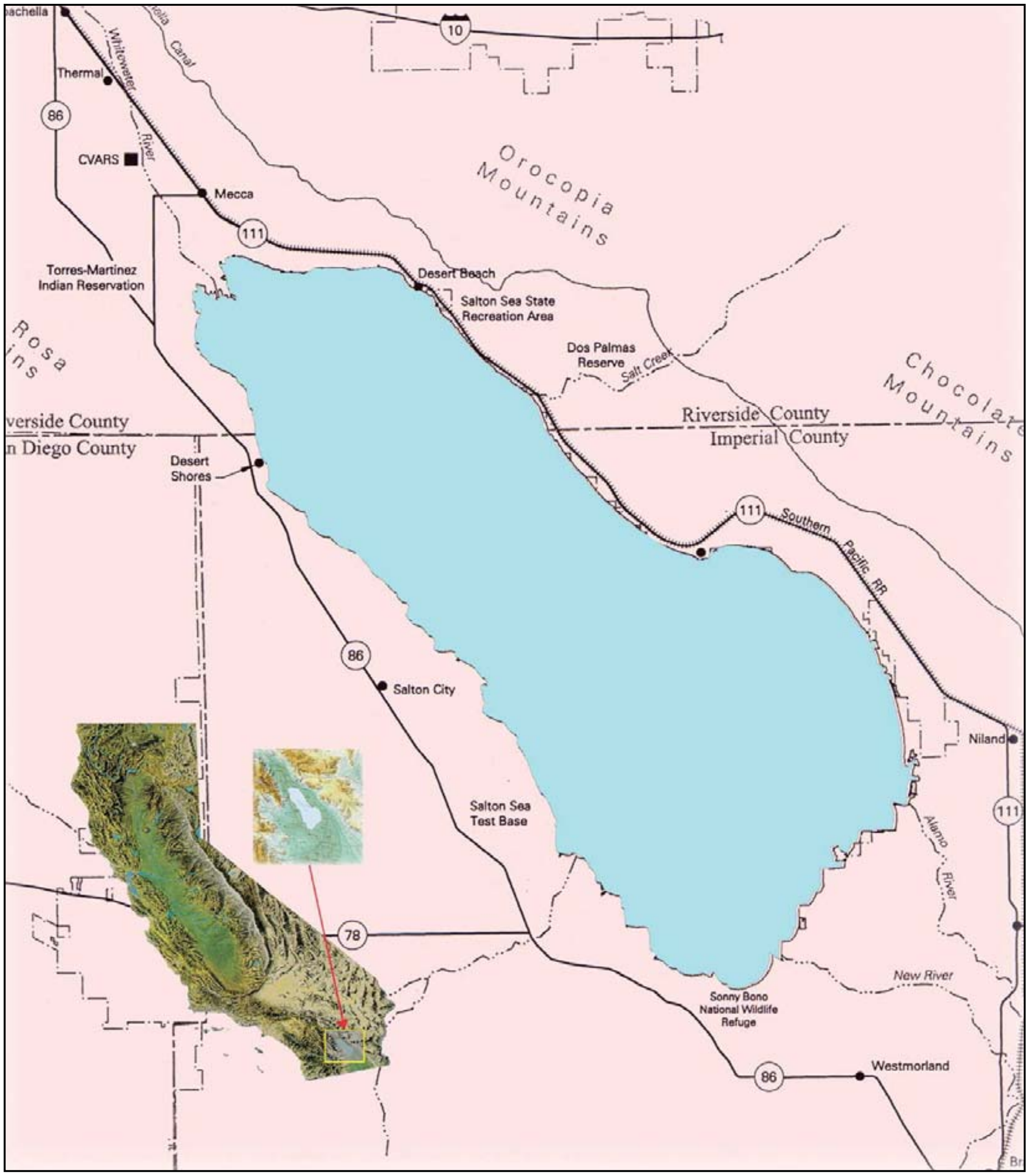

Salton Sea location map.

Abbreviations and Acronyms List

ALL	Annualized Loss of Life
APF	Annualized Probability of Failure
AQM	air quality mitigation
BMPs	best management practices
CEQA	California Environmental Quality Act
CVWD	Coachella Valley Water District
DEIS	Draft Environmental Impact Statement
DO	dissolved oxygen
DWR	California Department of Water Resources
EIR	Environmental Impact Report
ERS	Ecosystem Restoration Studies
H_2S	hydrogen sulfide
IID	Imperial Irrigation District
IMPLAN	IMpact Analysis for PLANning
IPCC	Intergovernmental Panel on Climate Change
LOL	loss of life
m	meters
µg/L	micrograms per liter
maf/yr	million acre-feet per year
mg/L	milligrams per liter
msl	mean sea level
NaCl	halite
NED	national economic development
NEPA	National Environmental Policy Act
NH_3	ammonia
NWR	National Wildlife Refuge
OMER&R	operation, maintenance, energy, replacement, and risk
P	Phosphorus

P.L.	Public Law
PEIR	Programmatic Environmental Impact Report
P&Gs	Principles and Guidelines
PHDA	Progressive Habitat Development Alternative
PPG	Reclamation's Dam Safety Guidelines for Achieving Public Protection
QSA	Quantification Settlement Agreement
Reclamation	Bureau of Reclamation
RED	regional economic development
Se	selenium
Sea	Salton Sea
SHC	saline habitat complex
SSA	Salton Sea Authority
SSAM	Salton Sea Accounting Model
TMDL	total maximum daily load
TSI	trophic state index

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Chapter 1. Introduction

Purpose

This report is intended to provide a summary of the Bureau of Reclamation's (Reclamation) recent study effort to determine a preferred alternative action for restoring the Salton Sea (Sea). This effort is being performed in fulfillment of the requirements of Public Law (P.L.) 108-361, the Water Supply Reliability and Environmental Improvement Act, November 2004.

Authority

This study is being conducted under the authority of P.L. 108-361, titled the Water Supply Reliability and Environmental Improvement Act. Specifically, the act requires that:

> "Not later than December 31, 2006, the Secretary of the Interior, in coordination with the State of California and the Salton Sea Authority, shall complete a feasibility study on a preferred alternative for Salton Sea restoration."

Study Location

The Sea, a terminal hypersaline lake, is the largest inland body of water in California. It is located in the southeastern corner of the State and spans Riverside and Imperial Counties (location map). The closest cities include Palm Springs, Indio, Brawley, and El Centro.

The northern portion of the study area is drained by the Whitewater River and its tributaries, reaching the northern end of the Salton Sea within the Coachella Valley not far from the town of Mecca. Salt Creek drains the southern slope of the Orocopia Mountains and the northern end of the Chocolate Mountains, entering the northeast portion of the Sea within the Salton Sea State Park boundaries. The most important western drainage is San Felipe Creek, with headwaters near Julian, about 50 miles west of the Salton Sea. The New and Alamo Rivers drain the Imperial Valley and, to a lesser extent, the Mexicali Valley to the south.

Study Objectives

The primary focus of this study is to identify and evaluate a preferred action that ensures the restoration of the Salton Sea ecosystem and permanent protection of wildlife dependent on that ecosystem. The degree of restoration desired is based on historic habitat capabilities for providing an abundant and diverse assemblage of fish and wildlife at a level sustainable within the constraints of future water availability. Although wildlife and wildlife habitat objectives were considered primary for this study, all objectives listed in the Salton Sea Reclamation Act (P.L. 105-372) were given significant consideration and adopted to the greatest extent possible. P.L. 105-372 identified the following objectives:

- Permit the continued use of the Salton Sea as a reservoir for irrigation drainage
- Reduce and stabilize the overall salinity of the Salton Sea
- Stabilize the surface elevation of the Salton Sea
- Reclaim, in the long term, healthy fish and wildlife resources and their habitats
- Enhance the potential for recreational uses and economic development of the Salton Sea

Emphasis was given to permitting the continued use of the Salton Sea for irrigation drainage and for reclaiming fish and wildlife resources and their habitats. An additional objective was considered relative to minimizing exposed areas subject to potential air quality problems. This additional objective was not included in the Salton Sea Reclamation Act. It was added for this study because of its importance to restoration feasibility and for consistency with the State of California's Salton Sea Ecosystem Restoration Study (ERS).

Project features are designed in this study to function at current and reduced inflows, as directed by P.L. 105-372.

History and Physical Setting of the Sea

The Salton Sea lies at the northern reach of the former delta of the Colorado River (Sykes, 1937) in a large, seismically-active rift valley that was once the northernmost extent of the Gulf of California. Before 1900, the river periodically emptied northwest into the Salton Basin, forming the ancient Lake Cahuilla, which was several times the size of the current Sea. The present-day Sea formed in 1905, when Colorado River flood flows breached an irrigation control structure in Mexico and were diverted into the Salton Basin for about 18 months. Since then, agricultural drainage flows from nearby Imperial, Coachella, and Mexicali

Valleys and smaller contributions from municipal effluent and storm water runoff have sustained the Sea.

The present-day Salton Sea occupies a below-sea-level desert basin known as the Salton Basin (or Salton Sink or Salton Trough). The Salton Basin is located in a highly active tectonic region with frequent earthquakes. Tectonically, the vicinity is dominated by the San Andreas, Imperial, San Jacinto, and Elsinore fault systems. Many moderate-to-large earthquakes have occurred on faults in the Salton Basin. **Figure 1.1** displays historic earthquakes in the Salton Basin from the 1860s through the year 2005.[1]

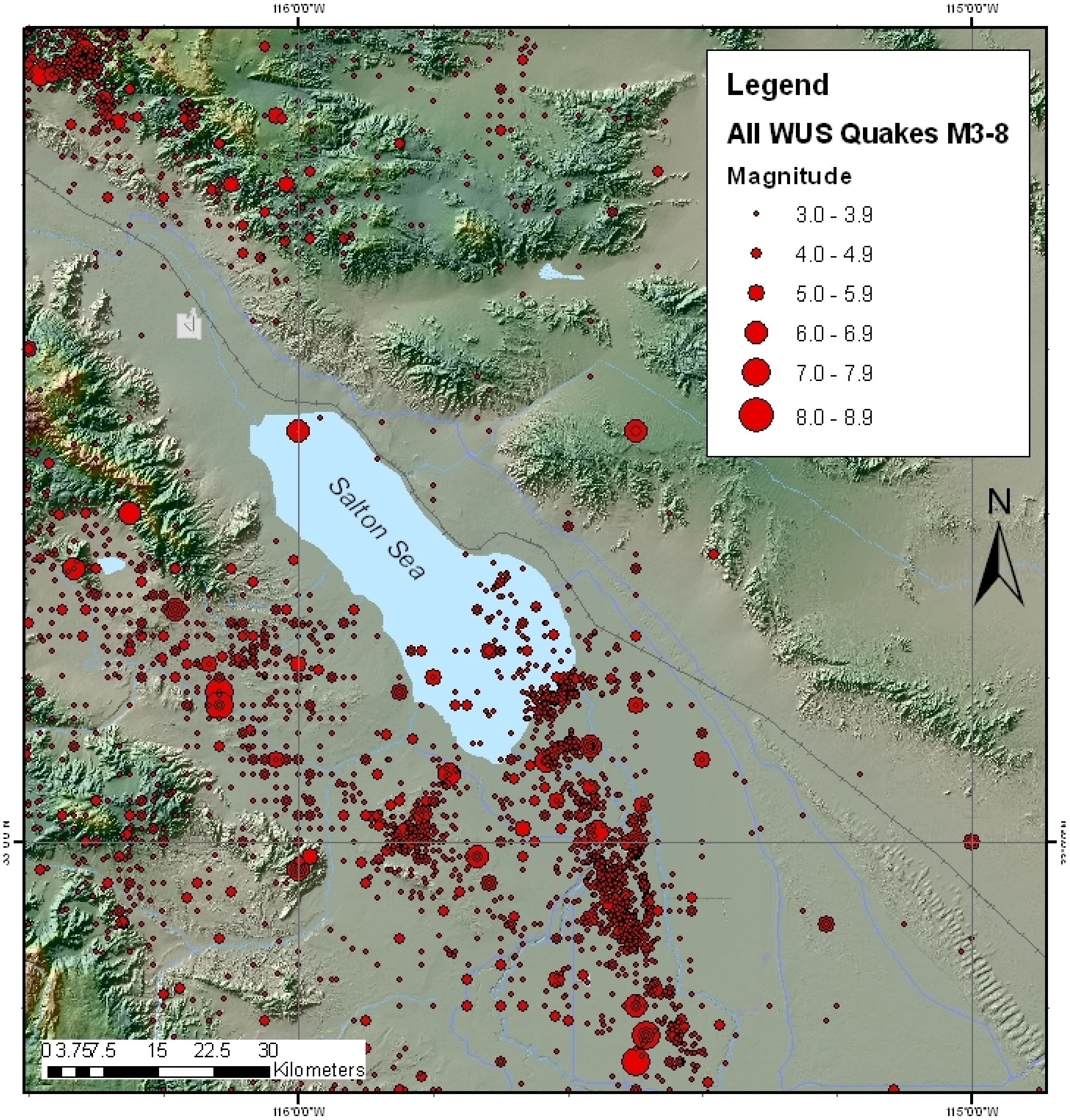

Figure 1.1 Historic Earthquakes Magnitude 3 to 8.

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[1] This map was obtained from Reclamation's Western United States Earthquake Database.

The Salton Basin extends from Banning, California, on the north to near the international border of Mexico on the south. The Sea itself is about 35 miles long and 15 miles wide. Recently, the elevation of the Sea has been about -228 feet mean sea level (msl) (228 feet below sea level), with annual fluctuations of about 1 foot. At this elevation, the Sea has a maximum depth of about 50 feet, with an estimated surface area of 232,000 acres (362 square miles). The lowest Seafloor elevation is about -278 feet msl. The current Sea has a storage volume of approximately 7.2 million acre-feet.

The Sea's recent salinity concentration (48,000 milligrams per liter [mg/L]) is about 37 percent saltier than ocean water. In the recent past, annual inflows to the Sea have been in balance with its annual evaporation. Inflows add about 4 million tons of salt each year. Because the Sea has no natural outlet, the salinity in the Sea continues to rise each year as salts (or total dissolved solids) are left behind when water evaporates from the Sea surface. Salton Sea salinity will increase dramatically in the near future as inflows to the Sea are reduced due to implementation of existing water transfer agreements. This accelerated increase will occur because of an imbalance between inflow and evaporation. Rising salinities have affected, and are expected to continue to affect, the once highly productive fishery of the Sea.

Important Resources

Fishery

The fishery of the Salton Sea is an important (but declining) resource for both fish-eating birds and the local economy through recreational sport fishing. Beginning in 1929, the California Department of Fish and Game introduced more than 30 marine fish species to the Salton Sea. Only three of those species, sargo (*Anisotremus davidsoni*), Gulf croaker (*Bairdiella icistia*), and orangemouth corvina (*Cynoscion xanthulus*), adapted and became established. A fourth species, tilapia (*Oreochromis mossambicus* x *O. urolepis hornurum*), was unintentionally introduced to the Sea from agricultural drains in 1964-65. By the early 1970s, tilapia dominated the fish community in the Sea. Extensive surveys in 1999–2000 (Reidel et al., 2002) indicated that growth rates of tilapia in the Salton Sea were among the highest reported anywhere in the world as a result of the high nutrient concentrations and warm temperatures. In addition to the game fish, the endangered desert pupfish (*Cyrinodon macularius*) inhabits the Sea and adjoining drains and creeks and is of concern with respect to restoration alternatives.

Increasing salinity and dissolved oxygen (DO) levels currently pose the greatest threat to the Salton Sea fishery, although temperature fluctuations may become of concern as water levels drop. Reidel et al. (2002) reported that the optimum salinity range for food consumption and conversion, growth, and respiration for sargo, croaker, and orangemouth corvina was 33-37 grams per liter. Furthermore, current salinities in the Sea appear to be nearing the upper tolerance limits for all four of major species. In fact, recent increases in salinity may have already impaired the Salton Sea fishery. Crayon et al. (2005) recently reported that populations of sargo, Gulf croaker, and orangemouth corvina have been below detectable levels since May 2003. Tilapia populations have also been drastically reduced. Although tilapia numbers appear to be increasing, current populations are still more than 90 percent lower than the levels reported in 1999–2000.

Migratory Birds

The seasonal movements of migratory species of birds follow general, but complex, pathways that take birds from their breeding grounds to wintering areas and, subsequently, back to these breeding grounds. That journey must be supported by the availability of appropriate habitat and an adequate food base. Those essential factors must be satisfied within the limits of flight and bioenergetic considerations to provide for the return of sufficient numbers of birds in a physical condition that facilitates long-term population maintenance. The Pacific Flyway is an important migratory pathway for birds traveling between the breeding grounds in Canada, Alaska, the Pacific Northwest, and the Northern Great Plains and wintering grounds along the Gulf of California, extending into Central and South America (**Figure 1.2**).

The Salton Sea is an important link in the habitat and food chain that sustains the perpetual migratory cycles for many species of birds within Western North America. This linkage is that of a habitat for all seasons by providing an important crossroad and way station for seasonal resting and feeding needs, wintering, spring conditioning, and breeding habitat. Records of the U.S. Geological Survey's Bird Banding Laboratory disclose that birds banded at the Salton Sea have been reported from Russia and the North American Arctic to Latin America and from Hawaii to the Maritime Provinces of Eastern Canada (**Figure 1.3**). The considerable interchange evident with birds of the Pacific and Central Flyways indicates that the importance of the Sea is far greater than transient local and regional bird use.

The Salton Sea ecosystem supports some of the highest avian biological diversity in North America as well as the world. The more than 400 bird species that have been reported within the Salton Sea ecosystem comprise approximately 70 percent of all the bird species recorded in California. In addition, approximately 100 species, or one-third of all species that are known to breed in California, are breeders

Wood Storks

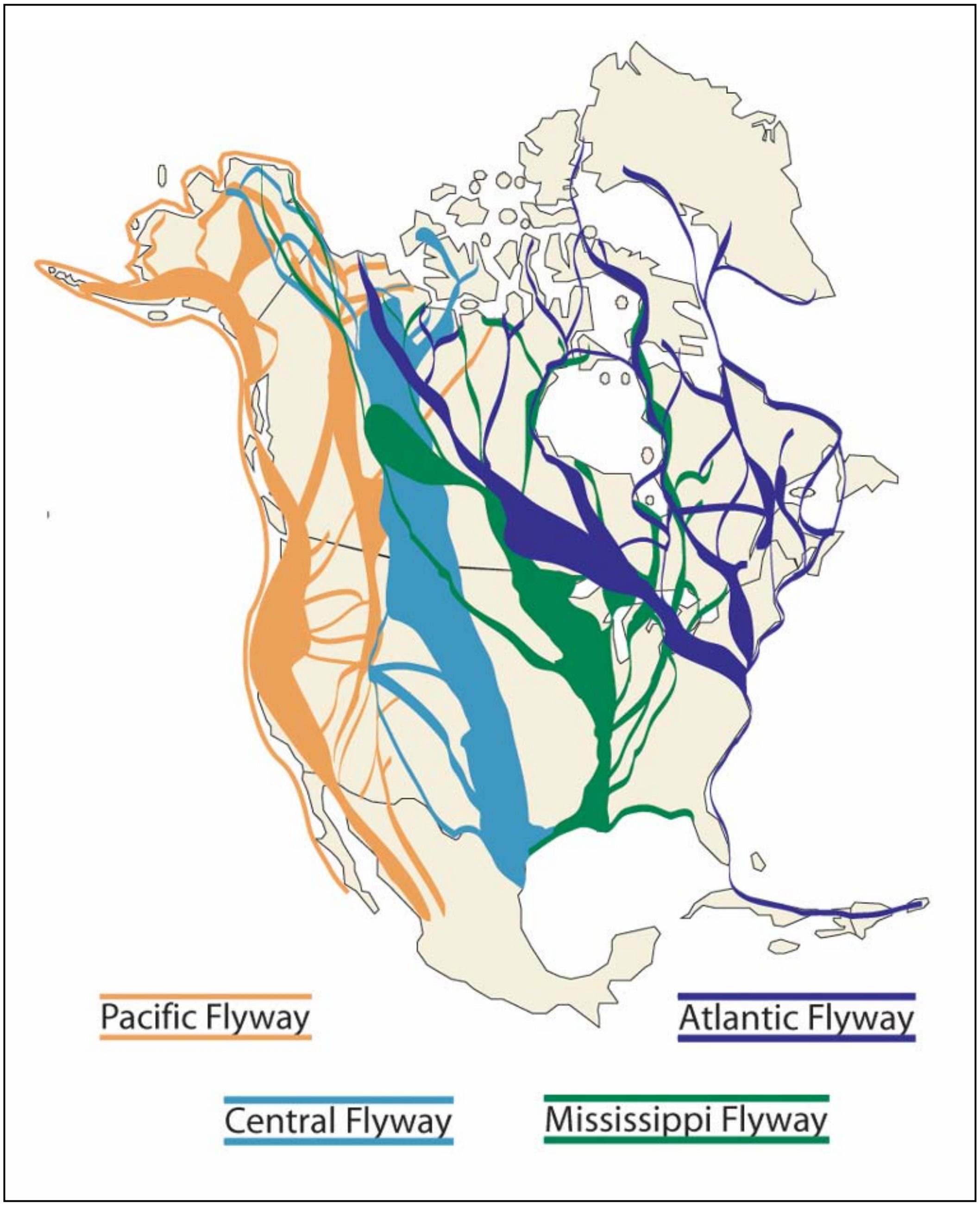


Figure 1.2 Flyways for migratory birds.

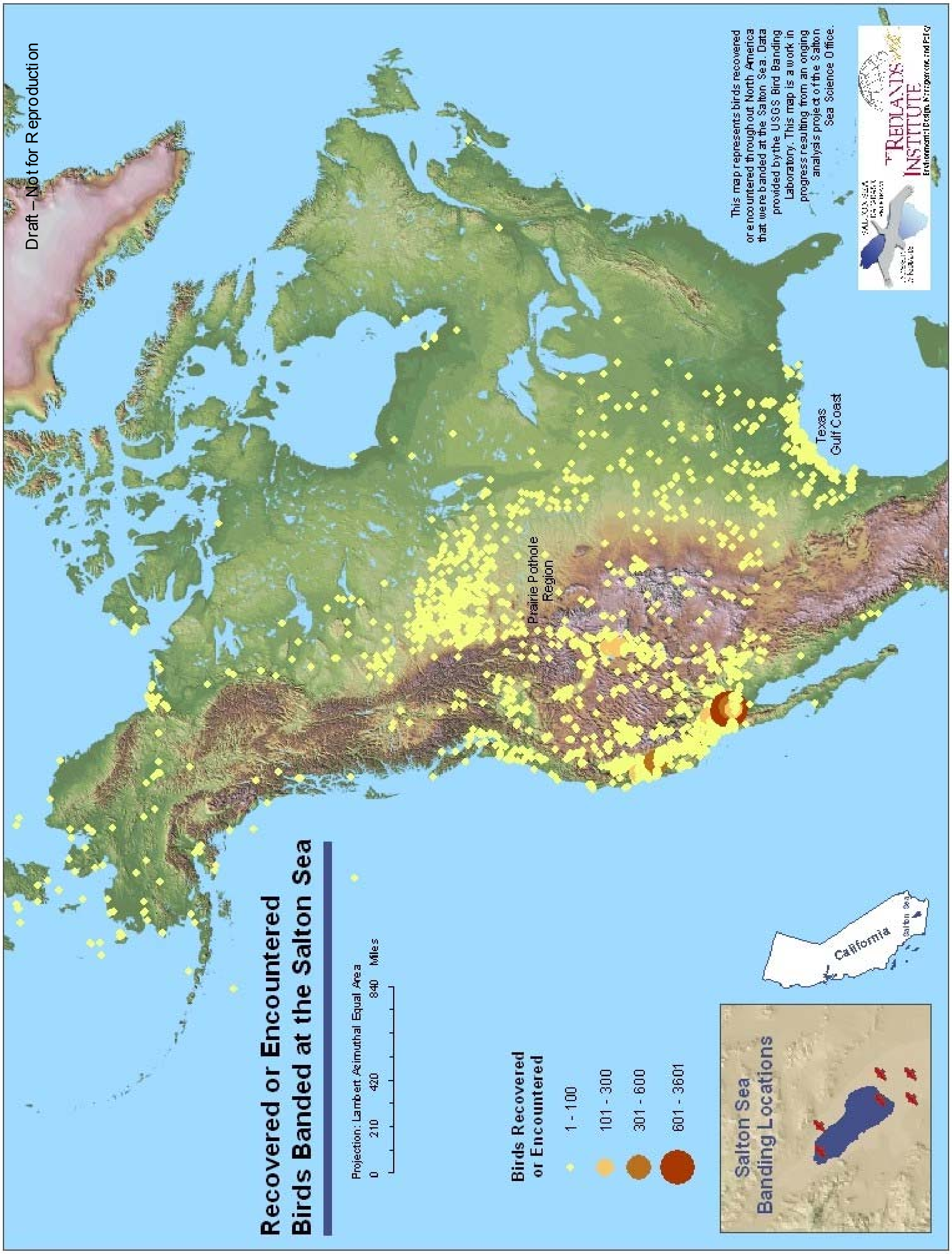


Figure 1.3 Recovered and encountered birds banded at the Salton Sea.

within the Salton Sea ecosystem. This combination of avian biodiversity and importance as breeding habitat is unsurpassed by any limited geographic area within the contiguous 48 states and Latin America.

Among the birds using the Salton Sea are 19 species of waterbirds classified by the Federal government, California, or both, as species of high conservation concern because of their population status. More than 14,000 pairs of colonial breeders, comprised of 11 species representing three families of birds, were tallied during a 1999 survey (Shuford et al., 2000).

The Salton Sea ecosystem is also an important area for landbirds. Investigators from the Point Reyes Bird Observatory during surveys in 1999 in areas adjacent to the Salton Sea tallied numerous neotropical migrants. More Wilson's warblers (*Wilsonia pusilla*) were caught at the Salton Sea during spring migration than at any other mist-netting site in California. The abundance of neotropical migrants recorded during spring and fall included 11 species of statewide concern in riparian habitats and is evidence that the area is used extensively by migrating passerines (Shuford et al., 2000).

In general, the Salton Sea is of regional or national importance to various groups of birds such as pelicans and cormorants, wading birds, waterfowl, shorebirds, gulls and terns, and some passerines. The Salton Sea ecosystem is a migratory bird habitat for all seasons that serves waterbirds and landbirds alike.

Recreation

Soon after its creation, the Salton Sea became a mecca for outdoor recreation. By 1958, the North Shore Beach area had been developed with an airfield and a yacht club. The North Shore Yacht Club was touted as a $2 million marine paradise, with one of the largest marinas in Southern California. The development of Salton City also began in earnest during the 1950s on the west side of the Salton Sea.

The development included a championship golf course and the Salton Bay Yacht Club, both of which were frequented by Southern California sportsmen and Hollywood celebrities. Developers claimed that Salton City would become the most popular marine resort in all of Southern California. The Salton Sea State Park (later the Salton Sea State Recreation Area) was dedicated on February 12, 1955. It served as an important inland recreation area until the late 1970s when visitation declined markedly because of the deteriorating environmental quality of the Sea. This facility has 1,400 campsites, hundreds of day use sites, and other amenities. Current annual visitor use at the park is about 250,000 people.

Waterfowl hunting has been a popular activity at the Salton Sea since at least the 1920s. There are numerous private duck clubs along the Sea and on adjacent areas. Hunters are also provided waterfowl opportunities on portions of the

Sonny Bono Salton Sea National Wildlife Refuge (NWR) and on the State's Imperial Wildlife Area Wister Unit.

The annual Salton Sea International Bird Festival attests to the popularity of the Salton Sea ecosystem as a haven for bird watching. An earlier economic analysis of bird watching at the Salton Sea reported substantial contributions to the economy of the small local communities around the Salton Sea.

A variety of other recreational activities also take place at the Salton Sea, including photography, camping, and kayaking. Because of its relative proximity to the large metropolitan areas of San Diego and Los Angeles, the Salton Sea is a valuable recreation resource.

Endangered Species

Several species listed under the Federal Endangered Species Act use habitat resources associated with the Salton Sea; however, four species are directly linked to future changes in Salton Sea water quantity and quality. For example, the desert pupfish is the only native fish inhabiting the Salton Sea. Designated critical habitat includes San Felipe Creek, Carrizo Wash, and Fish Creek Wash; however, pupfish also occur in wastewater drains discharging into the Sea, in shoreline pools of the Sea, artificial refugia, and in washes at San Felipe and Salt Creeks (Sutton, 2000). There is some indication that pupfish may use the Sea to move between sites providing habitat resources. As the Sea becomes more saline and the shoreline recedes in the future, there is concern that local pupfish populations may become isolated as they loose habitat connectivity with adjacent populations. All alternatives contain some provisions to maintain connectivity among local pupfish populations.

Three listed bird species may also be affected by future changes in the Sea. Brown pelicans use the Sea for feeding, nesting, and roosting. As the Sea becomes more saline and the shoreline recedes in the future, fish will disappear and the small islands used by pelicans will become connected to shore—thus loosing their security value. There are also concerns of selenium (Se) bioaccumulation in food chains used by fish-eating birds such as pelicans. The western snowy plover winters and breeds at shoreline sites with sand and barnacle beaches. As the Sea becomes more saline and the shoreline recedes in the future, the invertebrate food chains used by snowy plovers will change and eventually disappear, and historic nesting sites will become isolated from shorelines. Dust mitigation activities may discourage plovers from relocating nest sites close to receding shorelines. There is also concern of Se bioaccumulation in food chains used by invertebrate-eating birds such as snowy plovers. Finally, Yuma clapper rails use freshwater marshes managed as wildlife habitat at the south end of the Sea, and some brackish sites associated with wastewater drains and river deltas. These brackish areas will likely disappear as the Sea becomes more saline and the shoreline recedes. There is also concern of Se bioaccumulation in food chains used by invertebrate-eating birds such as rails as Se concentrations in wastewater increase.

Significant Problems and Challenges

Among the problems and challenges facing the Salton Sea are increasing salinity, air quality concerns, Se, and eutrophication, as discussed in this section.

Salinity

Salinity is the more time-sensitive problem and must be dealt with so that the Sea survives long enough for the other, more complex problems to be addressed. This is not an either/or situation, as the investment in controlling salinity will be lost if the other problems are not also addressed.

As noted previously, the Sea has salinity measured recently at about 48,000 mg/L. In the absence of more definitive current information, at a salinity of 60,000 mg/L, the majority of the fishery is projected to be lost. Historically, the fishery supported species with differing levels of tolerance to salinity. In recent years, the sport fishery has declined dramatically. Sargo, croaker, and orangemouth corvina currently are not being detected in gill net samplings. Tilapia currently are rebounding from dramatic reductions that occurred over the last few years. It has been predicted that some age classes and species would likely to be lost at lower levels of salinity, thereby initiating a general decline in the fishery several years before a salinity of 60,000 mg/L is reached. This could be what has been occurring over the last few years.

The impacts of salinity on invertebrate populations also have significant biological ramifications. The pileworm (*Neanthes succinea*) is a major food source for some species of fish and birds. As salinity increases, a time will occur in the near future when pileworms will no longer be present in this ecosystem. Other invertebrates, such as brine flies (*Ephybra spp.*), will be favored by increased salinity. The shift in invertebrate populations will be beneficial for a few species of birds, but not for many others.

Air Quality Concerns

Winds in the Salton Sea basin generate large dust storms. As the Sea recedes in the future, there could be as much as 140 square miles of lake bed ("playa") exposed that could significantly increase fugitive dust in the basin. Human health is a concern related to these potential increases. Particles with a diameter of less than 10 microns (PM10) are of primary concern. The Imperial Valley already suffers from the highest childhood asthma rate in the State. Furthermore, elderly people are especially susceptible to poor air quality (Cohen, 2006).

Sediment moisture, salt and sediment composition, and the extent of vegetation establishment all have major influences on the susceptibility of exposed sediments to wind erosion. Active disturbance of any exposed sediments can significantly increase the potential for wind erosion. Many major reservoirs experience significant seasonal changes in water elevation without generating serious fugitive dust problems during periods of low water levels. But serious fugitive dust problems have developed at two alkaline lakes in California—Owens Lake and Mono Lake. It is not known to what extent the Salton Sea will contribute to dust emissions.

Selenium

Se is a naturally occurring semi-metallic trace element with biochemical properties similar to sulfur, and it is an essential trace nutrient necessary for normal metabolic functions. However, there is a narrow margin between nutritionally optimal and potentially toxic dietary exposure concentrations of Se for vertebrates. Effects of Se toxicity can range from hair/feather loss to death. Reproductive impairment—a common concern in Se studies—is exposure responsive, meaning the higher the concentration, the greater the effect. Se is a consideration in Salton Sea studies because of the potential for bioaccumulation in aquatic food chains supporting abundant and diverse bird use of the area. Bioaccumulation can occur when Se is acquired from one level of a food chain and passed on to the next higher level. For example, Se can be accumulated from water and/or sediments by bacteria and algae and passed on to macro-invertebrates that feed on them. Birds that feed on the macro-invertebrates would then accumulate larger amounts of Se. Under certain conditions, Se can accumulate to toxic levels in food chains (e.g., in birds).

Se cycling involves the interaction of physical, chemical, and biological components of aquatic systems. The processes and interactions are complex and can possess system unique characteristics. For example, Se concentrations in drainage water entering the Salton Sea are at levels that would normally cause concern for bioaccumulation within the Sea's food chains. However, the interaction of system components currently characterizing the Sea results in a sequestering of Se in bottom sediments. Se levels available for accumulation in food-chains originating in the Sea are, therefore, lower than would be expected from a different blend of system components. Se concerns for the Salton Sea focus on the uncertainties associated with the interactions of the physical, chemical, and biological components that would characterize the future under the No-Project Alternative and/or the future under the restoration alternatives. The future Salton Sea system may support Se cycling similar to the current situation, or a different system—with different Se risk to local food chains—may be supported.

Eutrophication

Eutrophication is the enrichment of lakes by nutrients, typically nitrogen and phosphorus (P). High concentrations of nutrients can lead to increased growth of algae and aquatic plants and decreased species diversity. Eutrophication is a natural aging process in some lakes, but it is frequently accelerated by nutrient loadings arising from human activity.

Nutrient loadings to the Salton Sea are very high because of the variety of both nonpoint sources (primarily agricultural runoff) and point sources (wastewater treatment plant effluent) of nutrients in the watershed. As a result, the Sea is classified as hypereutrophic, a term used for lakes with the highest nutrient and chlorophyll *a* concentrations and the lowest transparency. In hypereutrophic lakes, algae and other organic matter decompose, creating severe oxygen depletion. Oxygen depletion at the Salton Sea has caused fish kills and has contributed to other chemical changes that create odors and other nuisance conditions.

The size of the Sea would be reduced under the various alternatives, which could result in intense and persistent thermal stratification at depths greater than 10 meters (m) (33 feet). (Thermal stratification refers to the layering that occurs, particularly in the warmer months, when a warmer, less dense layer of water [the epilimnion] overlies a colder, denser layer [the hypolimnion]). As a result, the Sea would switch from a system with several mixing events per year, to a system that is mixed for a relatively brief period in the winter. This stability and the expected continuing eutrophication would make the hypolimnium of the Sea anoxic (i.e., contain no DO) for most of the year.

With this extensive anoxia, hydrogen sulfide (H_2S) and ammonia (NH_3) could build up to unprecedented levels because of the lack of mixing. When the Sea does mix, the rapid breakdown of the stratification could potentially lead to a sudden redistribution of anoxia, H_2S, and NH_3 throughout the water column and the release of gaseous NH_3 and H_2S to the air. The effect of this could be an annual die off of most fish in the Sea and serious odor problems. There are also potential human health impacts, including headache and nausea, as well as more serious problems for sensitive individuals.

Chapter 2. History of Plan Formulation

This present study effort to determine a preferred alternative concept for restoring the Salton Sea uses information from both recent (1998–2005) and past (1960s to 2003) study efforts. The specific concepts evaluated in this present study were screened and selected from hundreds of ideas and concepts that ranged from circulating ocean water from the Gulf of California or the Pacific Ocean to removing salts at the Sea through the use of enormous desalination plants, solar pond systems and/or enhanced evaporation systems.

Rising salinity concentrations and the realization in the 1960s that increased salinity levels would eventually affect uses at the Sea led to various study efforts to determine methods to manage salinity. Early efforts and investigations to determine methods to reduce salinity in the Sea began in 1965 and resulted in the preparation of a 1969 Federal/State Reconnaissance Investigation Report and the 1974 Salton Sea Project Feasibility Report (Reclamation and State of California, 1974). Although numerous concepts for reducing salinity were studied and reported, rising water surface elevations at the Sea, due to increased agricultural development and subsequent drainage inflows into the Sea, muted the need for project implementation at that time.

In the mid-1980s, Federal and State agencies again began looking into ways of controlling salinity. P.L. 102-575, passed in 1992, gave Reclamation the authority to conduct salinity control studies. In response to that law, Reclamation and the Salton Sea Authority (SSA), which was established in 1993, published and provided a report to Congress in 1997 that contained an evaluation of a wide suite of proposed alternatives intended to address the salinity and elevation problems of the Sea.

In 1996, an initial screening study was conducted through an agreement with the SSA, the California Department of Water Resources (DWR), and Reclamation. In an effort to include a wide variety of potential solutions to the problems of the Sea, media announcements and public meetings were used to invite submittals of restoration alternatives. Through these efforts, 54 alternatives were identified and evaluated through a preliminary technical screening process. This preliminary screening effort provided the framework for developing alternatives in 1998 that would be analyzed and documented by various efforts, including a cooperative federal and state National Environmental Policy Act and California Environmental Quality Act (NEPA/CEQA) initiative.

Subsequent to the passage of the Salton Sea Reclamation Act of 1998, Reclamation and the SSA began the process of developing a Draft Environmental Impact Statement/Environmental Impact Report (DEIS/EIR). As part of this

NEPA/CEQA process, required public scoping meetings resulted in further alternative suggestions, as well as comments concerning the 54 alternatives that were derived from the previously mentioned screening process.

All 54 original alternatives were re-assessed, and new alternatives were considered, including those suggested by the public in 1998. The reassessment yielded 39 alternatives that were carried forward for additional screening analysis. A description of these alternatives is provided in the Salton Sea Alternatives Final Pre-Appraisal Report (November, 1998).

Subsequently, a January 2000 DEIS/EIR considered five project alternatives and compared each against three No Action/No-Project scenarios. Analysis of alternatives continued following publication of the DEIS/EIR and the receipt of public and agency comments. In addition, more information became available about the range of possible inflows to the Sea that could occur in the future. Restoration alternatives studies also continued following publication of the DEIS/EIR. In these studies, the strategy for salinity control presented in the DEIS/EIR was replaced by a strategy involving two basic types of modules for salinity control: salt removal modules and salt disposal modules. Using the modular strategy, eight salinity control alternatives, three salinity and elevation control alternatives, an alternative that would have involved construction on an impervious barrier across the middle of the Sea, and two specialized diking proposals were considered in a January 2003 status report (Reclamation, 2003).

After publication of the 2003 status report, the Quantification Settlement Agreement (QSA) was reached, and the associated Imperial Irrigation District (IID) -San Diego Transfer Agreement was approved. As a result, alternatives involving salt removal and disposal were abandoned in favor of equal head barriers and impervious dam alternatives as well as habitat-pond-based alternative concepts. Reclamation's current alternatives include only these types of alternatives. The current alternatives presented in this summary report are as follows:

- Mid-Sea Dam with North Marine Lake
- Mid-Sea Barrier with South Marine Lake
- Concentric Lakes
- North-Sea Dam with Marine Lake
- Habitat Enhancement without Marine Lake
- No-Project

Chapter 3. Restoration Alternatives

This chapter describes the primary structural and physical features of each alternative, including the No Project Alternative. Included are descriptions of alternative-specific features, such as water quality treatment systems and innovative construction methods. This chapter also describes common features associated with alternatives, e.g., saline habitat complexes (SHC), associated early start projects, and air quality mitigation (AQM) projects. Lastly, this chapter describes embankment designs, design criteria, design considerations, and comparisons to Reclamation's design criteria and guidelines for each of the action alternatives.

This report evaluates the following alternatives:

1. Mid-Sea Dam with North Marine Lake (proposed by the SSA)
2. Mid-Sea Barrier with South Marine Lake
3. Concentric Lakes (proposed by the Imperial Group)
4. North-Sea Dam with Marine Lake
5. Habitat Enhancement without Marine Lake
6. No-Project

Reclamation coordinated closely with the State of California DWR and the Salton Sea Authority in developing the alternatives presented in this report. Consequently, both the State and Reclamation have analyzed alternatives that are conceptually similar, yet have some differences. Variation between agencies in approaches to risk, uncertainty, complexity, and other factors contribute to differences in designs and costs. While Reclamation's design and cost estimating criteria and guidelines may be different than those used by other agencies and this may lead to different design conclusions and project costs, Reclamation makes no judgment relative to methods, assumptions, and criteria used by others.

It was Reclamation's intention to provide the highest quality design and cost estimates within the constraints of funding, schedule, and available information. Available knowledge of geologic conditions, in particular, was limited.

These factors should be taken into consideration when comparing costs of alternatives presented in this summary report to those presented in DWR's draft PEIR and to reports prepared by other organizations.

Common Features

Alternative Nos. 1, 2, 4, and 5 include SHCs formed by earthen embankments. All alternatives include an early start for development of SHCs or habitat areas. All alternatives also include facilities for performing AQM. A discussion of these common features follows.

Saline Habitat Complexes

Saline habitat complex.

About 20 percent of the total SHC would be deep open water (up to 10 feet) for fisheries. These deep-water pond areas would be constructed through excavation; the excavated material would be used to create islands behind cell embankments. The remaining portion of the SHC would be divided into areas suitable for different species and their use. The majority of these shallow-water pond habitats would be less than 3 feet deep; up to a quarter of these areas would be land. **Figure 3.1** depicts a cell in a typical SHC.

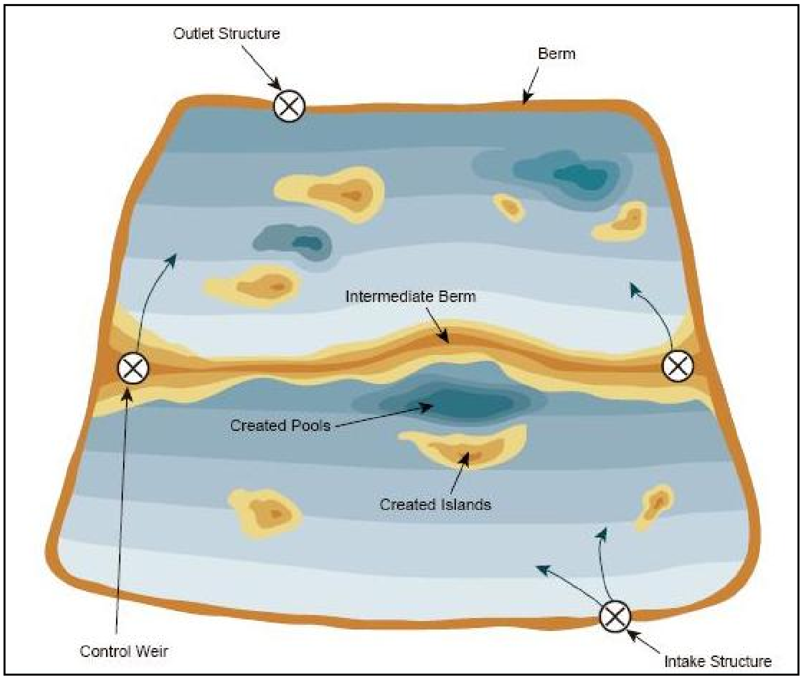


Figure 3.1 Cell in a typical SHC.

Inflows to the SHCs would be managed to achieve an average salinity of more than 20,000 mg/L and less than 35,000 mg/L through the mixing of waters from the rivers and alternative-specific marine lakes or brine pools. Water would flow by gravity through each of the habitat complex cells. The salinity would increase in each cell until it reaches about 150,000 mg/L, whereby discharges from the last cell would be made to the brine pool specific to each alternative. The water is expected to have habitat value up to a salinity of about 150,000 mg/L.

The SSA has recently proposed a different set of assumptions for the SHC design in its alternative. The SSA has proposed *not* to include deep-water pond areas in its SHC design. The SSA is also assuming that the SHC would be 50 percent water and 50 percent land. To ensure that all alternatives were evaluated and compared on an equal basis, Reclamation assumed the SSA alternative had the same type of SHC as the other alternatives, which includes deep water pond areas. Without deep holes for a fishery in the SHC, there would be no opportunity for an early start fishery under this alternative.

Early Start Projects

For all alternatives, it was assumed that construction would be completed in the year 2024. Assumptions for project completion are discussed in Chapter 4. Prior to termination of the IID-San Diego Transfer Agreement mitigation water and the end of alternative construction, the Sea is expected to experience environmental degradation involving the complete loss of the fishery and the collapse of the invertebrate food base by 2019. All alternatives were assumed to include early start SHC development features. These early start features would be designed to offset negative habitat impacts during the construction period and could be implemented in phases in 200 to 500-acre units. These units would be located in areas compatible with the SHC complex build out for each alternative and would likely be constructed in the south end of the Sea that would be exposed in the near future. Each phase would be constructed every 3 to 5 years.

The Concentric Lakes Alternative would also have an early start project and could involve the construction of small ring dike impounded areas that could be operated consistent with concentric lakes operation concepts as well as SHC operation concepts.

Early start areas would need to be monitored and adaptively managed over time to develop procedures to mitigate Se, eutrophication, and fishery sustainability problems. These areas would also be studied for habitat values and uses by functional bird groups, such as fish-eating birds, divers, shorebirds, long-legged waders, etc.

Air Quality Mitigation

Each alternative (including No-Project) includes an AQM component for control of emissions from exposed playa areas. The AQM component for all of the alternatives adheres to the methods described in DWR's Salton Sea Ecosystem Restoration Program Draft PEIR, Appendix H-3: "Identify and Outline Measures to Control Playa Emissions." The California legislature enacted certain laws in 2003 providing for preparation of the Salton Sea ERS and PEIR that include specific air quality monitoring and mitigation steps to be taken. Under the California State Water Resources Control Board Order (SWRCB, 2002) and the IID Water Conservation and Transfer Project Mitigation, Monitoring, and Reporting Program (IID, 2003) potential air quality impacts from exposed Salton Sea playa must be monitored and mitigated. It is assumed the State of California will manage AQM in coordination with landowners and other stakeholders.

The SSA has proposed use of salt crusting to eliminate most AQM requirements. SSA made this proposal under the premise that relatively pure halite (NaCL) crusts can be formed to eliminate the opportunity for playa emissions. The potential effectiveness of this approach has a high level of uncertainty. Research at the Salton Sea (Reclamation, 2004) indicates that the crusts that will be formed will predominantly be mixed-salts with continuous formation of a mixture of NaCL and bloedite ($Na_2Mg(SO_4)_24H_2O$). Based on these research observations, it is possible that sulfate salt transformations and associated crust friability could all lead to airborne particulate emissions from the salt crust areas. As a result, the SSA proposal to use salt crusting as a means of AQM was not used in the evaluation of the SSA alternative. A cost estimate that assumed use of salt crusting for AQM was made of the SSA's original alternative. These costs are presented in **Attachment A** of this report.

The approach used by DWR in the PEIR (for most alternatives) assumes that 30 percent of the exposed area would not require active AQM. This approach also assumes that 50 percent of the exposed area would require AQM using water-efficient vegetation, and 20 percent of the exposed area would require AQM using other methods. This approach to AQM was applied to all alternatives studied by Reclamation.

Table 4.1 in Chapter 4 lists exposed playa surface areas for each alternative and the acreages of each to be mitigated with water-efficient vegetation and non-water based control measures. These acreages were predicted using computer modeling, as described in Chapter 4.

Alternative No. 1: Mid-Sea Dam with North Marine Lake (SSA Alternative)

Alternative No. 1 was proposed by the SSA. It would provide both salinity and elevation control and up to 16,000 acres of SHC. **Figure 3.2** presents the alternative under mean possible future inflow conditions (727,000 acre-feet per year) as described in Chapter 4. The mid-Sea embankment location of

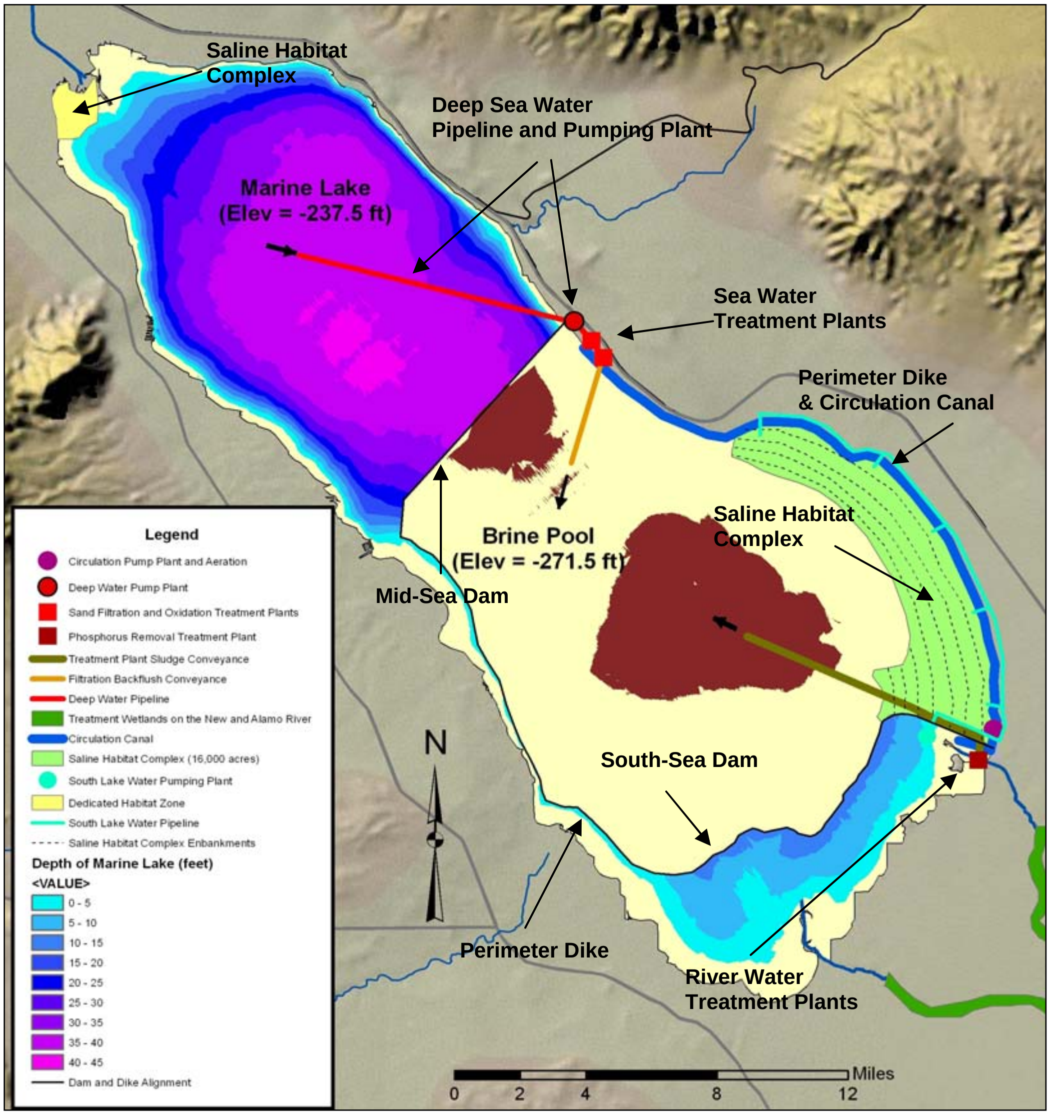


Figure 3.2 Alternative No. 1: Mid-Sea Dam with North Marine Lake (SSA Alternative).

this alternative was originally proposed by the SSA to be located approximately 1.5 miles south of the position shown in **Figure 3.2**. The SSA proposed the new location to allow for enhanced capabilities to manage for future salinity concentrations in the north marine lake. **Figure 3.2** and all analyses presented in the main body of this report are based on this new dam alignment. **Table 3.1** lists physical features associated with Alternative No. 1 under mean future inflow conditions in the year 2040. All depictions of alternatives in this chapter are associated with year 2040. In this year, all alternatives are expected to reach (or nearly reach) equilibrium with respect to environmental conditions.

Table 3.1 Physical features of Alternative No. 1: Mid-Sea Dam with North Marine Lake

Physical Feature	Value
Marine lake surface area	**98,900 acres**
Marine lake maximum depth	**43.5 feet**
SHC surface area	**16,000 acres**
Total open water habitat surface area	**106,900 acres**
Total shoreline habitat surface area	**26,600 acres**
Brine pool surface area	**17,600 acres**
Exposed playa surface area	**103,800 acres**

Alternative No. 1 (**Figure 3.2**) includes a total of four embankments: (1) an impervious mid-Sea dam, (2) an east-side perimeter dike, (3) a west-side perimeter dike, and (4) a south-Sea dam. These structures would be built using the sand dam with stone columns concept described later in this chapter. The embankments would provide for both static and seismic risk reduction. Reclamation evaluated the rockfill embankment concept proposed by the SSA and determined that it would not meet Reclamation's general design criteria. The embankments would be constructed so the water north of the mid-Sea dam would be maintained at a higher elevation than the brine pool on the south side. The area south of the mid-Sea dam would serve as an outlet for water and salt from the north and would rapidly shrink in size and increase in salinity to form a brine pool. In addition to the north marine lake, a smaller south marine lake would be created by the south-Sea dam. These two bodies of water would be connected along the western edge of the Sea by the west-side perimeter dike and along the eastern edge by the east-side perimeter dike and canal. The north marine lake would have a mean future water surface elevation of about -238 feet msl under mean possible future inflows as described in Chapter 4. The estimated long-term elevation of the brine pool is about -272 feet msl. The alternative includes 16,000 acres of SHC and a dedicated habitat area on the north end of the Sea. It also includes a deep water pipeline, an ozonation treatment plant, a water circulation system, and a phosphorous removal treatment plant.

Mean Possible Future Inflows: Without future assurances of inflows to the Salton Sea, there will be some degree of performance uncertainty (risk) for any Salton Sea restoration alternative. Under some scenarios, inflows to the Sea might be reduced to a level that puts the success of restoration in jeopardy. The impacts of the risks and uncertainties of inflows on each restoration alternative were assessed in this study. These assessments were made using advanced computer modeling techniques. Each alternative was modeled using a risk-based approach to inflows in which 10,000 different possible future Salton Sea inflows scenarios were simulated. The mean (or average) inflow computed from of all these possible futures is described as the "Mean Possible Future Inflow Condition" and would have a value of 727,000 acre-feet per year. The risk-based approach to inflows is described further in Chapter 4.

The conveyance features included in this alternative consist of a circulation canal, sludge conveyance pipeline, back-flush waste pipeline, three pumping plants, and two associated pipelines. These conveyance features would be used to provide water to AQM projects, to handle discharge to and from treatment plants, and to circulate water. These features also would provide marine lake water to be mixed with river water delivered to the SHCs.

This alternative was not studied under the assumption of a guaranteed minimum water supply. The Salton Sea has no assured water supply in the future. Therefore, the alternative was studied using the risk-based approach to inflow described in Chapter 4. On the basis of this risk-based approach to inflows, it was necessary to adjust the operating elevation of the marine lake to -238 feet. Without this flexibility in the operating elevation of the lake, the salinity levels cannot be reduced sufficiently (by the year 2040) to maintain a fishery under mean possible future inflow conditions. The SSA has proposed an operating elevation in the marine lake of -230 feet. On the basis of the risk-based approach to future inflows, this may not be possible until after the year 2055 when the salinity in the marine lake is reduced to 45,000 mg/L, under control, and then only under certain higher possible inflow conditions. If future inflow conditions are above mean possible estimates, then the operating elevation of the marine lake could be higher and potentially at a level consistent with the SSA's target if -230 feet. If future inflows are below mean possible future conditions, then the lake would have to be operated at elevations of less than -238 feet to maintain salinities at fishery-compatible levels.

Original SSA Alternative: The SSA's original alternative incorporated a mid-Sea dam about 1.5 miles farther south than what is presented in **Figure 3.2**. This alternative also included a smaller SHC of 12,000 acres. Cost estimates were prepared for the SSA's original alternative. These estimates provide a basis for making comparisons to cost estimates prepared by DWR and the SSA for this same original alternative. **Attachment A** of this summary report contains these cost estimates assuming that embankments would be built using rockfill embankments similar to those being proposed by the SSA (Alternative 1B). The estimate presented in Attachment A assumes the use of salt crusting (as originally proposed by the SSA) via construction of small earth embankments (2.5 feet tall) to impound brine released from the SHC. Reclamation evaluated the rockfill embankment concept and determined it would not meet Reclamation's general design criteria.

Alternative No. 2: Mid-Sea Barrier with South Marine Lake

Alternative No. 2 would provide salinity control but no elevation control and up to 21,700 acres of SHC. **Figure 3.3** presents the alternative under mean possible future inflow conditions (727,000 acre-feet per year). **Table 3.2** lists physical features associated with Alternative No. 2 under mean future conditions in the year 2040.

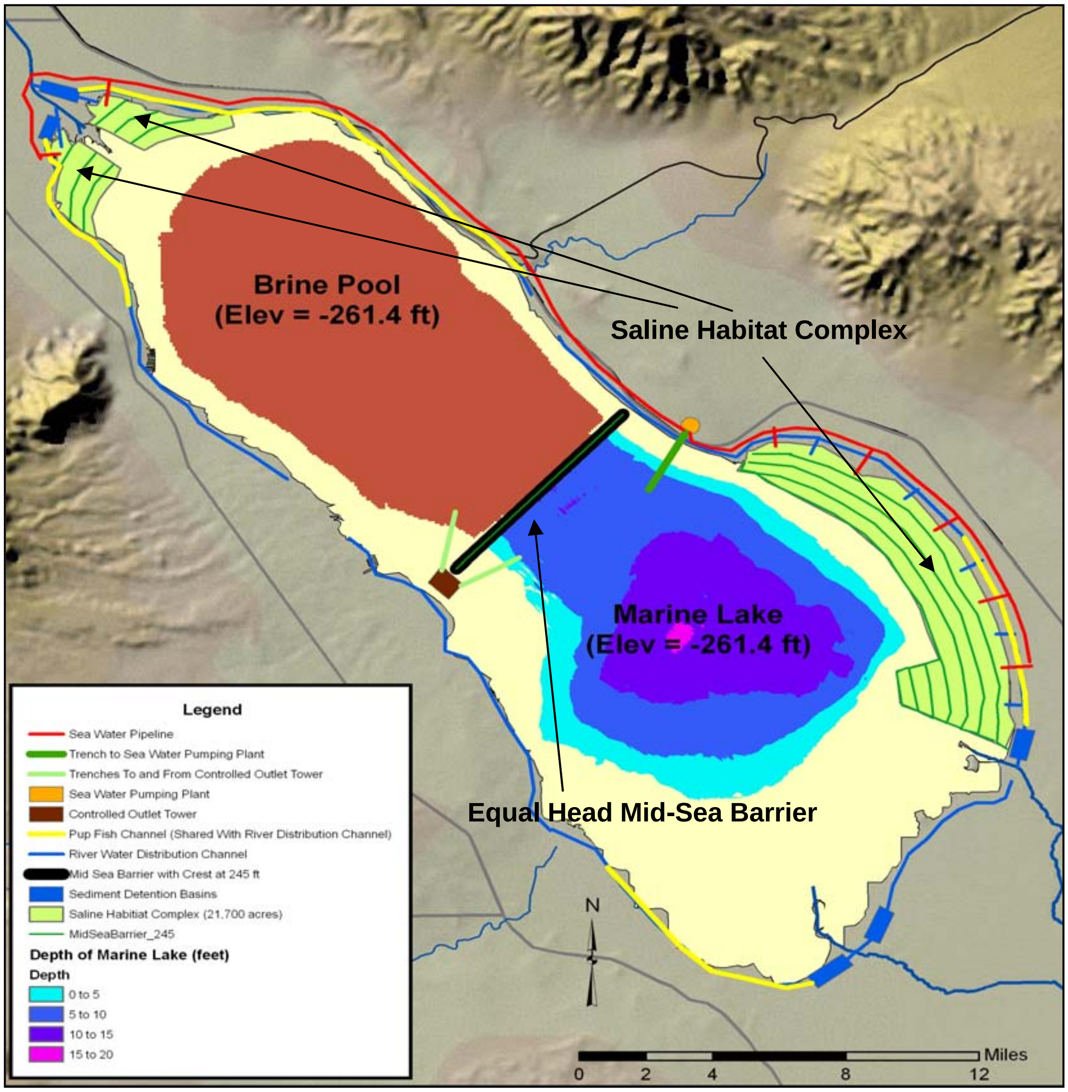


Figure 3.3 Alternative No. 2: Mid-Sea Barrier with South Marine Lake.

Table 3.2 Physical features of Alternative No. 2:
Mid-Sea Barrier with South Marine Lake

Physical Feature	Value
Marine lake surface area	59,700 acres
Marine lake maximum depth	15.5 feet
SHC surface area	21,700 acres
Total open water habitat surface area	49,000 acres
Total shoreline habitat surface area	34,700 acres
Brine pool surface area	66,000 acres
Exposed playa surface area	73,600 acres

The alternative includes a mid-Sea barrier designed to generally be operated with equal heads on both sides and to accommodate a differential head of up to 5 feet. The water entering the Sea from the south into the south marine lake would support a large marine habitat. The estimated long-term elevation of the marine lake and brine pool under mean future conditions is -261 feet msl. The majority of inflows are expected to occur from the south end; therefore, the area north of the barrier embankment is expected to serve as an outlet for water and salt from the south side. The north side would quickly form a brine pool. As the main body of the Sea shrinks, embankments would be constructed to create SHC. The mid-Sea barrier would be constructed with a crest elevation of -245 feet and would accommodate the forecasted reductions in inflows when mitigation water is terminated under the IID-San Diego Transfer Agreement.

The 21,700 acres of SHC would be constructed on the southeast and north ends of the Salton Sea.

The conveyance features included in this alternative consist of five diversion crests and sediment detention basins, four pupfish/river water channels, five river water channels, and a pumping plant and two associated pipelines. These conveyance features would be used to provide water to AQM projects as well as to provide marine lake water to be mixed with river water delivered to the SHCs. A controlled outlet tower on the west end of the barrier would provide the ability to maintain up to a 5-foot head differential between the marine lake and brine pool.

The mid-Sea barrier embankment would be built using the fundamental concepts of the sand dam with stone columns described later in this chapter. It would provide for both static and seismic risk reduction. Two designs were developed for the mid-Sea barrier to compare the annual risk costs of a structure that reduces both seismic and static risks (i.e., with stone columns) with the annual risk costs of a structure that reduces only static risks (i.e., without stone columns). Risk costs are described in Chapter 7. Annual risk costs can be compared using information presented in **Table 7.2** and **Attachment Table A-2**.

Alternative No. 3: Concentric Lakes (Imperial Group Alternative)

Alternative No. 3 was proposed by the Imperial Group. It provides both elevation and salinity control. **Figure 3.4** presents the alternative under mean possible future inflow conditions (727,000 acre-feet per year). **Table 3.3** lists physical features associated with Alternative No. 3 under mean future conditions in the year 2040.

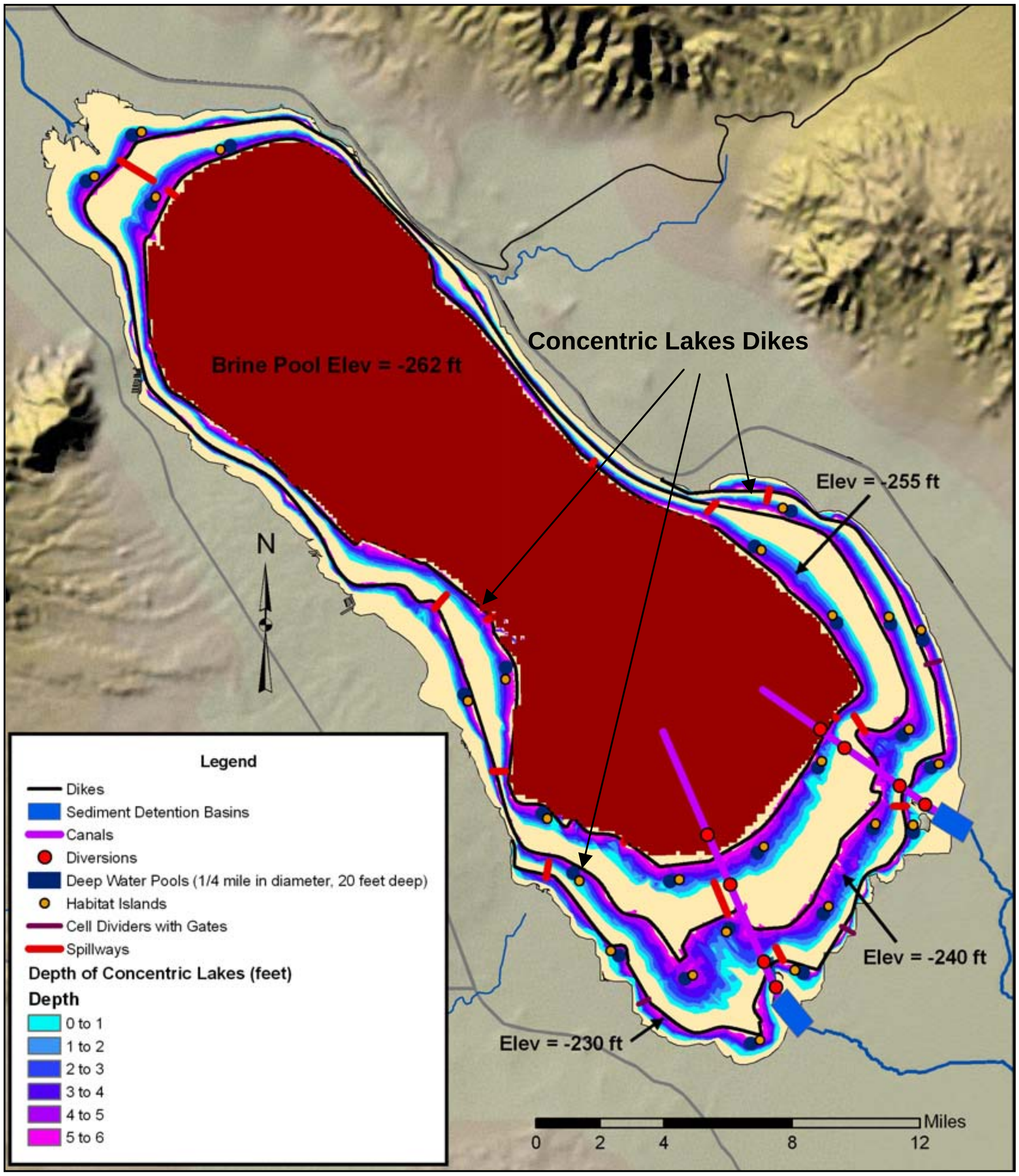


Figure 3.4 Alternative No. 3: Concentric Lakes.

Table 3.3 Physical features of Alternative No. 3: Concentric Lakes

Physical Feature	Value
Marine lakes surface area	**47,600 acres[1]**
Marine lakes maximum depth	**6 feet**
SHC surface area	**0 acres[2]**
Total open water habitat surface area	**817 acres**
Total shoreline habitat surface area	**46,800 acres**
Brine pool surface area	**127,800 acres**
Exposed playa surface area	**65,000 acres**

[1] The 47,600 acres shown are for three concentric lakes. The fourth lake proposed by the Imperial Group is not necessary under the risk-based approach to future inflows described in Chapter 4. Including the fourth lake proposed by the Imperial Group would result in a total marine lakes surface area of 88,000 acres.

[2] This alternative has habitat areas that are similar to SHC, which is reflected in the shoreline habitat surface area listed in this table.

The Imperial Group's proposal for this alternative included four lakes. Under the risk-based inflows discussed in Chapter 4, the alternative would require only three lakes. The alternative consists of a series of three (or four) independent lakes, with deep pools and habitat islands. Each lake would receive water directly from canals from the New and Alamo Rivers. Each lake would operate at increasingly higher salinities, with evaporation concentrating salinities from 20,000 to 60,000 mg/L. The lakes would be formed by constructing dikes in a concentric ring pattern. The outermost lake would be formed by a partial ring dike located at the south end of the project. A brine pool would exist within the area of the innermost dike. Deep pool areas would be formed within the lakes with adjacent habitat islands. The deep pools would support fisheries up to 20 feet deep. Outside of the deep areas, the maximum lake depth would be 6 feet.

The outer lake is shown with cell dividers that could allow different habitat types to be managed in a way similar to that under the SHC concept. The cell divider concept could be applied to any of the concentric lakes. However, costs presented in Chapter 7 of this report assume that the cell dividers are only incorporated into the outer partial concentric lake.

This alternative would be constructed in stages. The outermost lake features would be constructed first. The second, third, (and fourth) reservoir lakes would be constructed as the water surface of the residual Sea recedes to the target reservoir water surface elevation of the next lake to be constructed. The estimated time frame for completion of all construction stages is 40 years. The conveyance features included in this alternative consist of two river water channels to convey all flows from the Alamo and New Rivers into the concentric lakes and brine pools area. Diversion structures would provide for control of flows into each lake to manage salinity levels.

The Imperial Group has proposed using Geotube® technology to construct the concentric lakes dikes. Reclamation has studied three dike design options, one of which incorporates the Geotube® technology. The other two are sand dam with (and without) stone column embankment designs described later in this chapter. One sand embankment design includes features to reduce static loading risks (without stone columns). The other design includes features to reduce both static and seismic loading risks (with stone columns). The Geotube® design (Alternative No. 3C) would not reduce seismic or static loading risks.

The three designs were developed for the purpose of comparing the costs of constructing structures that reduce seismic and static risks with annual risk costs for structures that do not. Risk costs are described in Chapter 7. Annual risk costs can be compared using information presented in **Table 7.2** and **Attachment Table A-2**. Constructing concentric lakes dikes using Geotubes® would likely result in significant seismic, static, and constructability problems.

Alternative No. 4: North-Sea Dam with Marine Lake

Alternative No. 4 would provide both elevation and salinity control and up to 37,200 acres of SHC. **Figure 3.5** presents the alternative under mean future inflow conditions (727,000 acre-feet per year). **Table 3.4** lists physical features associated with Alternative No. 4 under mean future conditions in the year 2040.

Table 3.4 Physical features of Alternative No. 4: North-Sea Dam with Marine Lake

Physical Feature	Value
Marine lake surface area	**19,500 acres**
Marine lake maximum depth	**33 feet**
SHC surface area	**37,200 acres**
Total open water habitat surface area	**23,800 acres**
Total shoreline habitat surface area	**32,900 acres**
Brine pool surface area	**91,300 acres**
Exposed playa surface area	**91,800 acres**

Under Alternative No. 4, an impervious dam embankment would be constructed to impound Whitewater River inflows. The impervious dam would include an embankment built using the sand dam with stone columns concept as described later in this chapter. The embankment would provide both static and seismic risk reduction. Water north of the embankment would be maintained at a higher elevation than the brine pool on the south side. The area south of the embankment would serve as an outlet for water and salt from the north and would shrink in size to achieve equilibrium with inflows from the south and discharges from the north marine lake. The salinity of the brine pool would increase over time. The north marine lake would have a water surface area of up to 19,500 acres at elevation -229 msl and would be operated to maintain a salinity of 35,000 mg/L or less.

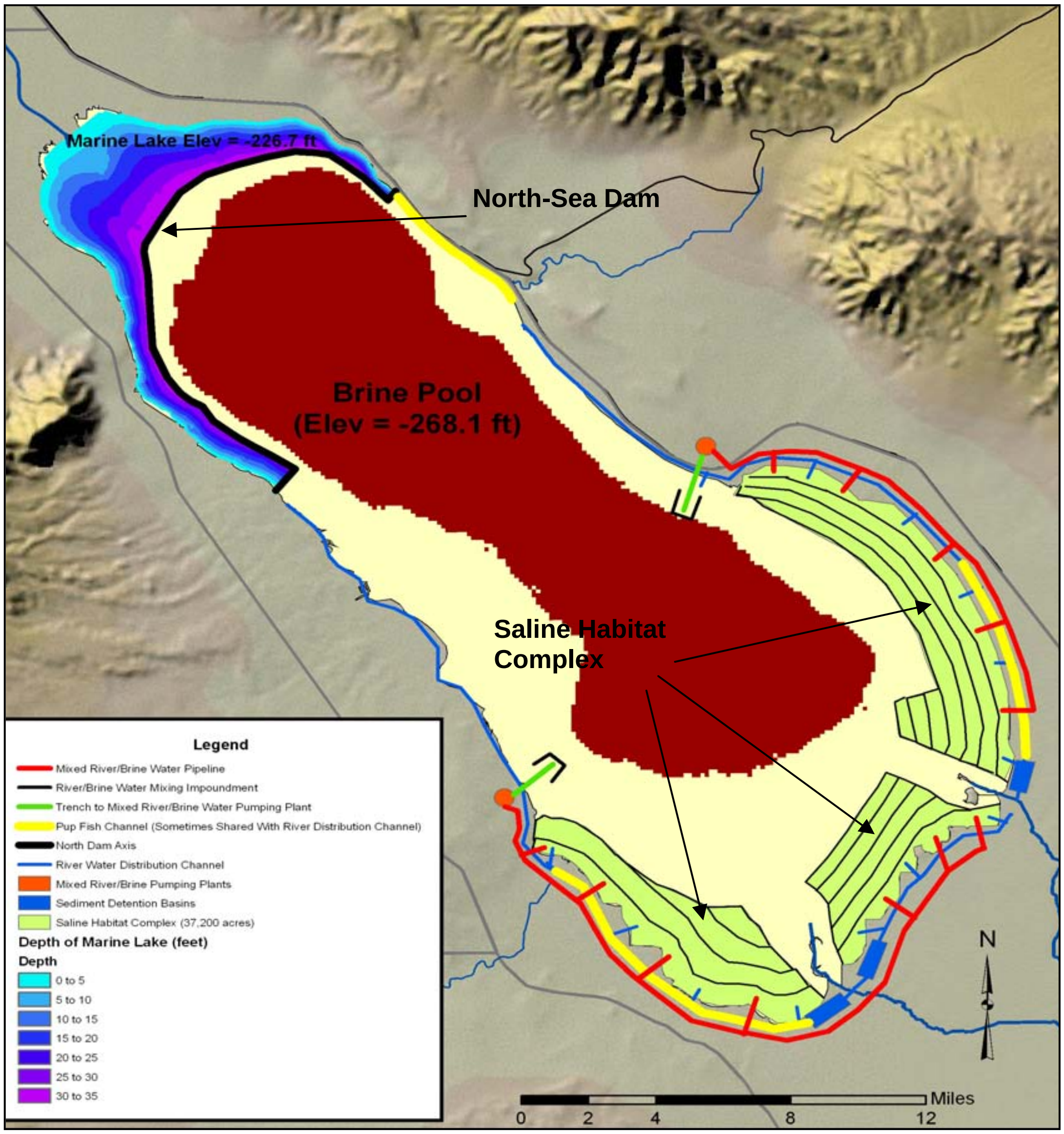


Figure 3.5 Alternative No. 4: North-Sea Dam with Marine Lake.

SHC (37,200 acres) would be constructed on the south end of the Salton Sea. As the main body of the Sea shrinks, these complexes would be constructed on the exposed Seabed to take advantage of the gently sloping Seafloor. The conveyance features included in this alternative consist of three diversion crests and sediment detention basins, three pupfish/river water channels, three river water channels, and two pumping plants and associated pipelines. These conveyance features would be used to provide water to AQM projects as well as to provide brine to be mixed with river water delivered to the SHCs. The brine and river water would be mixed in impoundments constructed in the Seabed. These mixing impoundments would need to be moved through time as the residual Sea recedes.

Alternative No. 5: Habitat Enhancement without Marine Lake

Alternative No. 5 provides no structural solution for a marine lake. The alternative would rely entirely upon SHC to provide open water and shoreline habitat. Under this alternative, SHCs would be constructed at the south and north ends of the Sea. Five separate complexes would be constructed, with a combined surface area of 42,200 acres as shown on **Figure 3.6**. **Table 3.5** lists physical features associated with Alternative No. 5 under mean future conditions in the year 2040.

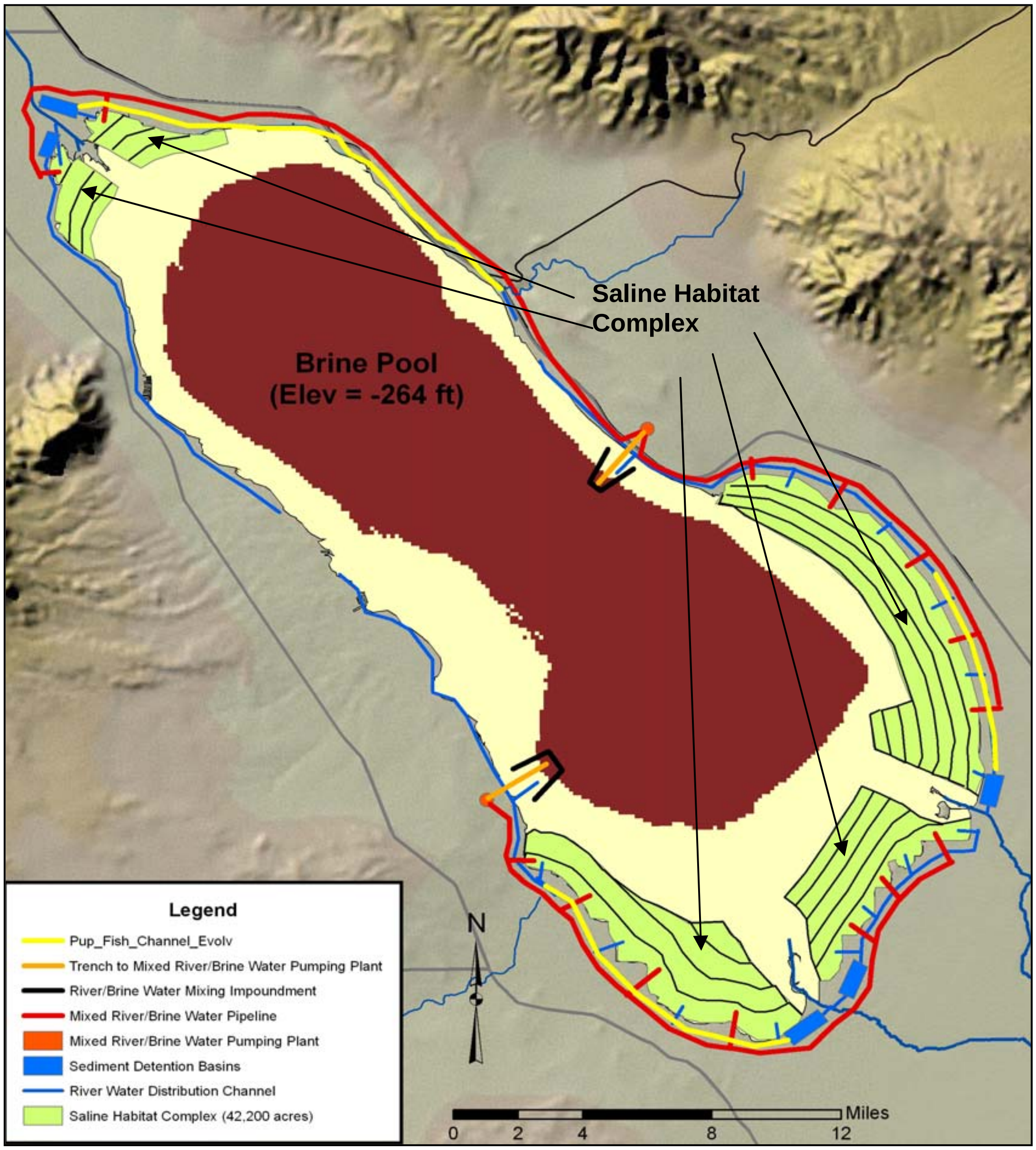


Figure 3.6 Alternative No. 5: Habitat Enhancement without Marine Lake.

Table 3.5 Physical features of Alternative No. 5: Habitat Enhancement without Marine Lake

Physical Feature	Value
Marine lake surface area	**0 acres**
Marine lake maximum depth	**---**
SHC surface area	**42,200 acres**
Total open water habitat surface area	**8,400 acres**
Total shoreline habitat surface area	**33,800 acres**
Brine pool surface area	**117,400 acres**
Exposed playa surface area	**81,200 acres**

Figure 3.6 presents the alternative under mean possible future inflow conditions (727,000 acre-feet per year). No in-Sea marine habitat would be provided. About 20 percent of the SHC would be deep open water (up to 10 feet) for fisheries. These deep-water pond areas would be constructed through excavation; the excavated material would be used to create islands behind cell embankments. The remaining portion of the SHC would be divided into areas suitable for different species and their use; up to a quarter of these areas would be land. The majority of these shallow water pond habitats would be less than 3 feet deep.

Inflows to the SHCs would be managed to achieve an average starting cell salinity of more than 20,000 mg/L through the mixing of waters from the rivers and residual Sea brine pool. The brine and river water would be mixed in impoundments constructed in the Seabed. These mixing impoundments would have to be moved through time as the residual Sea recedes. Water would flow by gravity through each of the SHC cells. The salinity of each cell would increase until it reaches about 150,000 mg/L, when discharges from the last cell would be made to the brine pool. The water is expected to have habitat value up to a salinity of about 150,000 mg/L.

The conveyance features included in this alternative consist of five diversion crests and sediment detention basins, three pupfish/river water channels, five river water channels, two mixing impoundments, three pipelines, and two pumping plants. These conveyance features would be used to provide water to AQM projects as well as to provide brine to be mixed with river water delivered to the SHCs.

Alternative No. 6: No-Project

Without a restoration project, the future Salton Sea would change dramatically. **Figure 3.7** presents the No-Project Alternative under mean possible future inflow conditions (727,000 acre-feet per year). **Table 3.6** lists the physical features associated with Alternative No. 6 under mean future conditions in the year 2040.

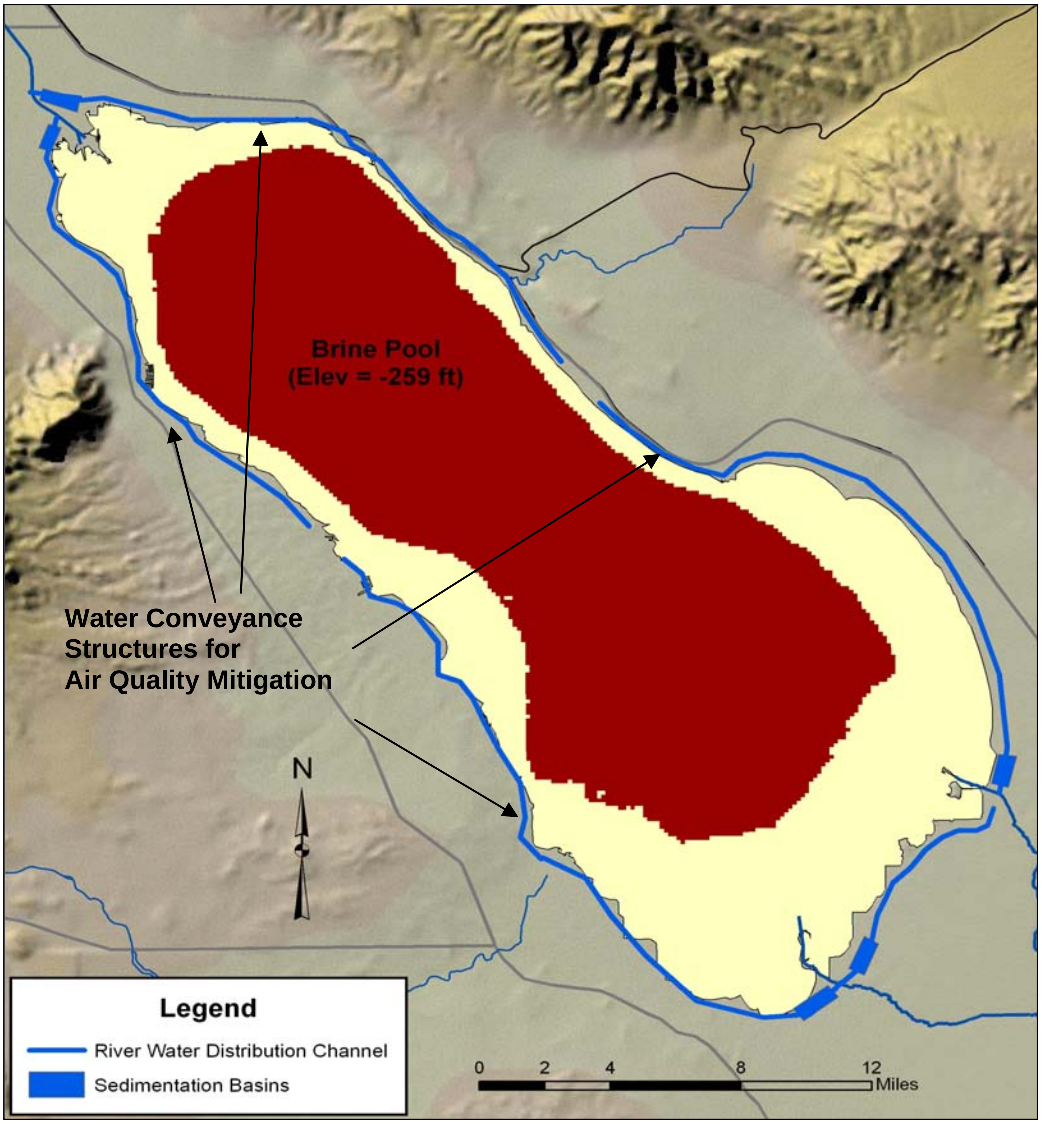


Figure 3.7 Alternative 6: No-Project.

Table 3.6 Physical features of Alternative No. 6: No-Project

Physical Feature	Value
Marine lake surface area	**0 acres**
Marine lake maximum depth	**---**
SHC surface area	**0 acres**
Total open water habitat surface area	**0 acres**
Total shoreline habitat surface area	**0 acres**
Brine pool surface area	**138,400 acres**
Exposed playa surface area	**92,200 acres**

Water would be required for AQM and the corresponding water distribution system is shown. The Salton Sea would suffer from "creeping environmental problems" similar to those at the Aral Sea (Glantz, 1999). The No-Project Alternative could carry significant costs in human health, ecological health, and economic development.

Water conveyance features included in this alternative consist of five diversion crests and sediment detention basins, and five river water channels. These conveyance features would be used to provide water to AQM projects.

By the year 2040, the Salton Sea would quickly shrink by 60 percent under mean possible future inflow conditions, and salinity levels would increase dramatically. During this time, the Sea would still receive additional loadings of salt, Se, nutrients, and other contaminants. Thus, the contaminant concentration could roughly triple in this period. Under the No-Project Alternative, the Salton Sea would experience degradation of environmental conditions, with the complete loss of the fishery and invertebrate food base, as discussed in more detail in Chapter 5.

Actions that would occur under the No-Project Alternative would also occur under each action alternative, including:

- Implementation of California's QSA of 2003, which would increase water moved from Imperial Valley to San Diego and decrease inflows to the Salton Sea, subsequent to the cessation of mitigation inflows.
- Implementation of Best Management Practices (BMPs) in Imperial Valley to meet the total maximum daily loads (TMDL) for nutrients and sediments, which would reduce standing water habitat for birds and reduce the annual input of biologically available P to the Sea by 13 to 20 percent.
- Implementation of water conservation measures from IID, which could increase Se concentrations in river inflows by as much as 46 percent.
- Construction of connections between individual drains in IID to facilitate pupfish movement between drains after salinity exceeds about 90,000 mg/L.
- Implementation of IID-San Diego Transfer Agreement, which would include a mitigation program to address potential dust emissions.
- Implementation of a four-step air quality monitoring and mitigating plan, as required by California's State Water Resources Control Board.
- Uncertainty in possible future inflows as described in the risk-based approach described in Chapter 4.

Embankment Design

Design Criteria and Considerations

The restoration alternatives include embankment structures at various locations around the Salton Sea. All embankment designs were developed to meet Reclamation's general design criteria and Public Protection Guidelines (Reclamation, 2003) where applicable.

The general design criteria determined for the mid-, south-, and north-Sea dams; the perimeter dikes; the concentric ring dikes; the mid-Sea barrier; and the habitat pond embankments would be as follows:

- Resist and control embankment seepage, foundation seepage, internal erosion, and static settlements
- Resist large offsets, slope instability, and deformations due to seismic loading, and flooding
- Provide for constructability using proven methods and safe construction

Evaluation of Embankment Designs

Detailed seepage, stability, deformation, risk, constructability, and cost evaluations were completed to support the evaluation of the various dam, dike, barrier, and habitat pond embankments that comprise the alternatives. The sequence of study tasks was as follows:

1. Existing information and construction material sources assessment
2. Seepage and stability evaluations
3. Seismic deformation evaluations
4. Formulation and initial screening of embankment cross-section options
5. Supplemental seepage and stability evaluations
6. FLAC (Fast Lagrangian Analysis of Continua) deformation evaluations
7. Finalize decision criteria and cross-section requirements
8. Final screening of embankment cross-section options
9. Selection of preferred cross-section option
10. Initial preferred cross-section optimization
11. Risk analysis
12. Final cross section optimization
13. Cost estimates for optimized embankments.

Following evaluation of the embankment design options, which included the SSA's rockfill design and DWR's rock dam design, Reclamation determined that an optimized "sand dam with stone columns" was the preferred basic configuration for all of the various embankments, except habitat pond embankments, which were optimized as earthfill embankments. Overviews of both configurations are provided in the following sections.

Embankment Risk Analysis

A risk analysis was conducted on the optimized embankment designs considered for the alternatives in this study. The purpose of the risk analysis was to provide decision inputs regarding conformance with Reclamation's Dam Safety Guidelines for Achieving Public Protection (PPG). On the basis of the PPG, the Salton Sea risk analysis provides estimates of life loss, expressed as the "Annualized Loss of Life" (ALL) and Probability of Failure, expressed as the "Annualized Probability of Failure" (APF) of the alternatives.

The sand dam with stone columns design was applied to each of the alternatives and the estimated APF and ALL values were compared with Reclamation's PPG and found to meet the guideline requirements.

Sand Dam with Stone Columns Embankment Design

Figure 3.8 provides the cross-section view of the basic sand dam with stone columns embankment design for a mid-Sea dam. Configurations for the shorter mid-Sea barrier, south and north-Sea dams, and concentric lakes dikes would be similar but with different heights. This design would meet Reclamation's general design criteria and PPG (Reclamation, 2003).

Existing very soft and weak foundation materials would be removed beneath the entire footprint of the embankment, and additional soft and weak materials would be removed beneath the central section. The sand dam with stone columns embankment would consist of sand/gravel materials forming the central section and the outer shells. To resist static loadings, the embankment cross-section would include filter and drainage zones to help control embankment and foundation seepage. To resist seismic loadings, the central section's sand/gravel material would be densified using stone columns. A soil-cement-bentonite wall would be constructed down through the middle of the central section and into the foundation. Riprap slope protection would be placed over the upstream and downstream embankment slopes. To resist seismic loadings, the embankment would be constructed using a combination of placement methods. Placement methods would include: (1) dumping/placing directly into the water from barges for the lower portion of the central section and for the outer portions of the embankment, including riprap slope protection and (2) end dumping or conveyor placement for the upper portions of the central and outer portions of the embankment. The size of this basic sand dam with stone columns design would be adjusted as required to meet the location and configuration requirements of the mid-Sea, south-Sea, and north-Sea dams; perimeter dikes; concentric ring dikes;

and mid-Sea barrier embankment designs. The basic embankment design also would be adjusted to address certain potential risks, such as the possibility of fault offsets of 2 to 5 m (6.6 feet to 16.4 feet) in the foundation beneath the south-Sea dam and the concentric ring dikes in the southern Sea.

Sand Dam without Stone Columns Embankment Design

The sand dam concept was considered with and without stone columns for the significant hazard structures in the following alternatives:

- Alternative No. 2: Mid-Sea Barrier with South Marine Lake
- Alternative No. 3: Concentric Lakes

The sand dam concept without stone columns was applied to these alternatives to allow comparison of the annual risk costs of structures that reduce both seismic and static risks (with stone columns) with the annual risk costs of structures that reduce only static risk (without stone columns). Costs are presented in Chapter 7 for the design that includes stone columns. The costs for Alternative Nos. 2 and 3 that do not include stone columns are presented in Attachment A. This sand dam without stone columns design would not meet Reclamation's general design criteria and PPG (Reclamation, 2003). Risk costs are described in Chapter 7. Annual risk costs can be compared using information presented in **Table 7.2** and **Attachment Table A-2**.

Habitat Pond Embankments Design

Figure 3.9 provides the cross-section view of the habitat pond embankment design. This design would be applied to habitat pond embankments associated with the SHC components in each of the alternatives. These low earthfill embankments would be very simple designs that would be constructed in the dry. The existing soft and weak foundation materials would be removed beneath the entire footprint of the embankment to achieve a competent foundation. The excavated material would be dried and reused as earthfill to construct the habitat pond embankments. The embankment cross-section would include a blanket layer of sand filter/drain material under the embankment's downstream shell. There would be no riprap slope protection. Because of its small size and shallow water depth, the habitat pond embankment design would likely not need to meet Reclamation's PPG.

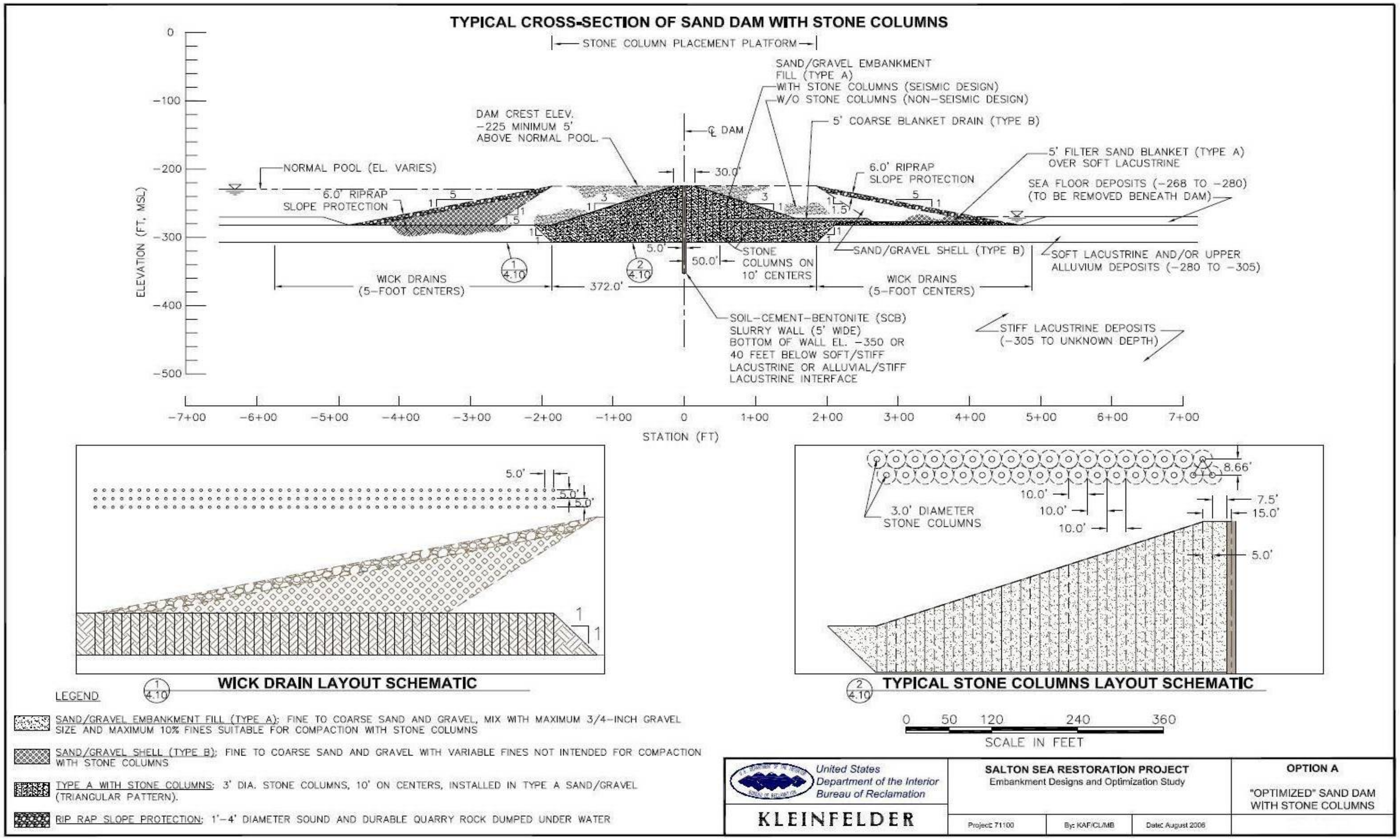


Figure 3.8 Typical cross-section of sand dam with stone columns.

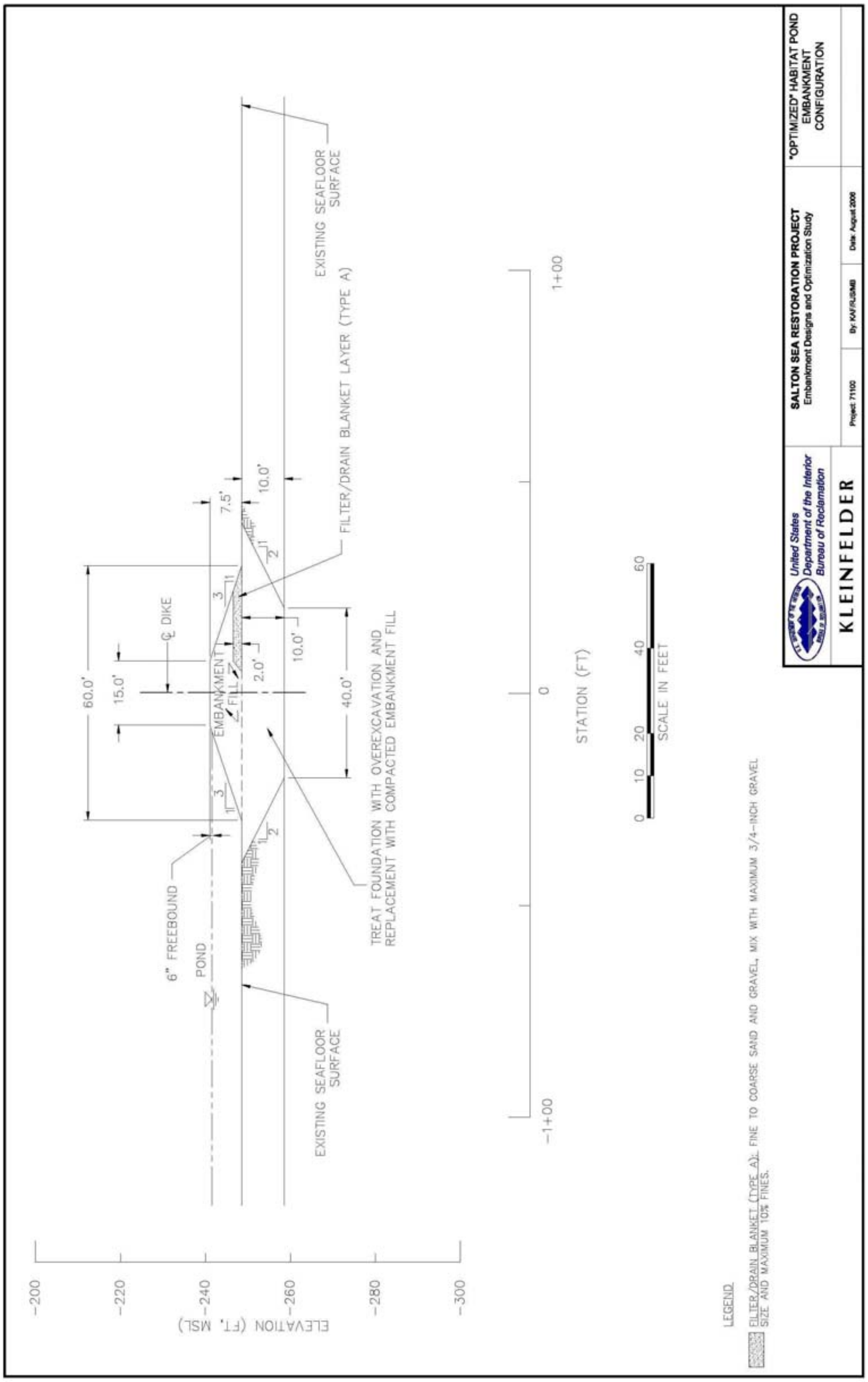


Figure 3.9 Typical cross-section of habitat embankment.

Geotube® Embankment Design

The Imperial Group has proposed using Geotube® technology to construct the concentric lakes dikes. Reclamation considered three concentric lake dike design options, and one incorporates the Geotube® technology (**Figure 3.10**). The other two options are zoned embankment designs based on the sand dam approach discussed above. One zoned embankment design includes features to reduce only static loading risks (without stone columns), and the other includes features to reduce both static and seismic loading risks (with stone columns). The Geotube® design would not reduce either seismic or static loading risks to a level that meets Reclamation's design criteria and guidelines.

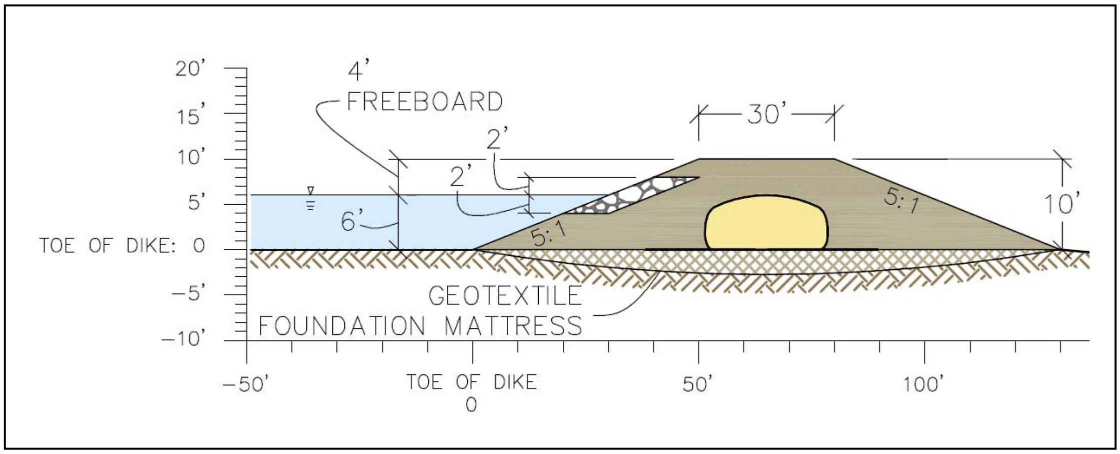


Figure 3.10 Typical Geotube® design.

The sand dam without stone columns and Geotube® designs would not meet Reclamation's general design criteria and PPG (Reclamation, 2003). Constructing concentric lakes dikes using Geotubes® would likely result in significant seismic, static, and constructability problems.

SSA Rockfill Embankment Design

The SSA has proposed using a rockfill embankment design for its proposed alternative as shown in **Figure 3.11.** Reclamation evaluated the rockfill embankment concept and determined it would not meet Reclamation's general design criteria. Use of traditional sand and gravel horizontal filters would not be possible without sacrificing stability under seismic loadings. Use of geocomposite filters would result in constructability problems and would result in unreliable filter performance. Cost estimates were prepared for the SSA's original alignment using the current rockfill concept. **Attachment A** of this summary report contains these estimates. The SSA's original alternative incorporated a mid-Sea dam about 1.5 miles farther south than what is presented in Figure 3.2. This alternative also included a smaller SHC of 12,000 acres.

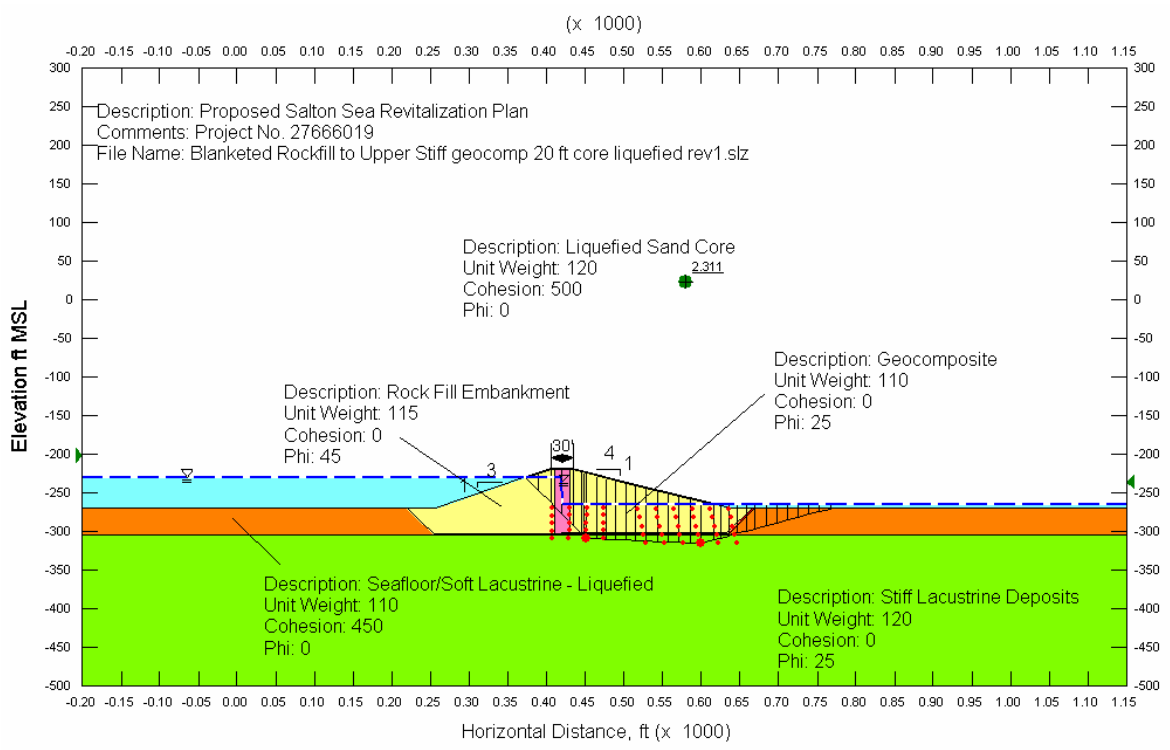


Figure 3.11 Typical cross-section of the SSA rockfill embankment.

Reclamation's cost estimates using the SSA rockfill design provide a basis for making comparisons to cost estimates prepared by DWR and the SSA for this same original alternative. The estimates presented in Attachment A assume the use of salt crusting (as originally proposed by the SSA) via construction of small earth embankments (2.5 feet tall) to impound brine released from the SHC

Comparisons to Design Criteria and Guidelines

Table 3.7 presents a comparison of embankment design concepts as applied to each restoration alternative and whether or not the designs meet Reclamation's general design criteria and PPG (Reclamation, 2003). On the basis of this comparison, the following alternatives have been identified as meeting Reclamation's requirements:

- Alternative No. 1A: Mid-Sea Dam with North Marine Lake – SSA Revised Alignment (sand dam design with stone columns)
- Alternative No. 2A: Mid-Sea Barrier with South Marine Lake (sand dam design with stone columns)
- Alternative No. 3A: Concentric Lakes (sand dam design with stone columns)

Table 3.7 Salton Sea Restoration Study: Embankment / Alternative Comparisons to Reclamation's Design Criteria and Guidelines

Alternative	Reclamation's general design criteria and guidelines	Notes
Alternative No. 1A: Mid-Sea Dam with North Marine Lake – Revised Alignment (sand dam design with stone columns)	Meets requirements	
Alternative No. 1B: Mid-Sea Dam with North Marine Lake –Original Alignment (SSA rockfill design)	Does not meet requirements	Use of traditional filters would not be possible without sacrificing stability under seismic loading. Use of geocomposite filters would result in constructability problems and would result in unreliable filter performance
Alternative No. 2A: Mid-Sea Barrier with South Marine Lake (sand dam design with stone columns)	Meets requirements	
Alternative No. 2B: Mid-Sea Barrier with South Marine Lake (sand dam design without stone columns)	Does not meet requirements	High probability of failure under seismic loading
Alternative No. 3A: Concentric Lakes (sand dam design with stone columns)	Meets requirements	
Alternative No. 3B: Concentric Lakes (sand dam design without stone columns)	Does not meet requirements	High probability of failure under seismic loading
Alternative No. 3C: Concentric Lakes (Geotubes® design)	Does not meet requirements	High probability of failure under seismic loading. High probability of static failure due to foundation seepage. Numerous constructability problems
Alternative No. 4: North-Sea Dam with Marine Lake (sand dam design with stone columns)	Meets requirements	
Alternative No. 5: Habitat Enhancement Without Marine Lake (habitat pond embankment design)	Meets requirements	

- Alternative No. 4: North-Sea Dam with Marine Lake (sand dam design with stone columns)
- Alternative No. 5: Habitat Enhancement Without Marine Lake (habitat pond embankment design)

Costs are presented in Chapter 7 for the alternatives that meet Reclamation's requirements. Attachment A provides cost estimates for the alternatives that do not meet Reclamation's requirements.

Chapter 4. Future Conditions

Water Supply Overview

The Salton Sea receives the majority of its water supply from agricultural runoff from the IID and the Coachella Valley Water District (CVWD). A very small percentage of inflows to the Salton Sea are derived from tributaries and direct precipitation. The closed basin lake has no guaranteed future water supply. The Salton Sea has historically received a total annual water supply of 1.34 million acre-feet per year (maf/yr). Under conditions identified as the baseline for the IID-San Diego Transfer Agreement and QSA, the Salton Sea would receive 1.23 maf/yr (IID, 2002). The projected future inflows to the Salton Sea, considering the effects of the IID-San Diego Transfer Agreement, would reach a low of 0.93 maf/yr (IID, 2002).

There are no guarantees that other actions that could occur in the future would not affect inflows. For example, the possibility exists that Mexico could significantly reduce deliveries across the border in both the New and Alamo Rivers. The possibility also exists that competing demands for water and/or water market conditions could result in additional reductions of tailwater discharges to the Salton Sea. In addition, uncertainty exists in future groundwater discharges from the Coachella aquifer as a result of the Coachella Valley Water Management Plan. With implementation of the Water Management Plan, CVWD expects (based on uncertain groundwater model predictions) future groundwater levels in the lower valley to increase, which would increase future discharges to surface drains and inflows to the Salton Sea by about 60,000 acre-feet per year. Currently, the Coachella Valley groundwater basin is in an overdraft condition and, as a result, discharges to the Salton Sea are being affected.

Without future assurances of inflows to the Salton Sea, there will be risk to any Salton Sea restoration project. Under such risk, inflows to the Sea might be reduced to a level that puts the success of restoration in jeopardy. The impacts of the risks and uncertainties of inflows on each restoration alternative were assessed. These assessments were made using stochastic computer modeling techniques. This chapter describes future risks and uncertainties relative to inflows and the results of computer model simulations of the future of each alternative.

Risk-Based Future Inflows

Each alternative was modeled using a risk-based approach to inflows. Under this approach, the full ranges of uncertainty in each of the major inflow sources were considered. The full ranges of uncertainty were considered without assigning specific probabilities of occurrence or specific actions that might contribute to the uncertainty. This method was developed and coordinated with modeling studies conducted within the DWR. The same type of approach to future inflows and alternative modeling is being used by DWR (DWR, 2006).

Under the risk-based approach, it is recognized that alternative concepts are subject to risk due to potential water conservation that could occur in response to non-specific reasons. For example, the Salton Sea could be subject to responses due to the following:

- Economic conditions
- Competing water demands
- Water market conditions

Uncertain responses could occur in Mexico, IID, or CVWD. When something is uncertain, it is possible to describe potential variability in the form of a distribution that describes the range in possible values that might be expected. The application of a risk-based method involved the development of distributions of the possibilities that depict full ranges in uncertainty of responses from Mexico, IID, or CVWD and resulting uncertainty of Coachella Valley surface-water and groundwater interactions. These distributions do not describe probability of occurrence but, instead, describe the full range of possibilities. The approach was applied within the Salton Sea Accounting Model (SSAM), starting with QSA level inflows and the implementation of the CVWD groundwater management program. Within SSAM, the uncertainty distributions were randomly sampled and applied to compute 75-year inflow traces. These traces were then used to perform the SSAM simulations.

Total Future Inflows

In the risk-based approach to future inflows to the Salton Sea, possibility distributions for Mexico, IID, and CVWD were sampled 1,500 times and combined with estimates of tributary and direct precipitation estimates for a 75-year future period. **Figure 4.1** shows the total inflow possibility distribution for average annual future inflow to the Salton Sea from all sources. Two lines are presented on **Figure 4.1**: the first (dashed line) represents average annual inflow conditions for the period 2003 to 2077, and the second (solid line) shows average annual inflow conditions for the period 2018 to 2077.

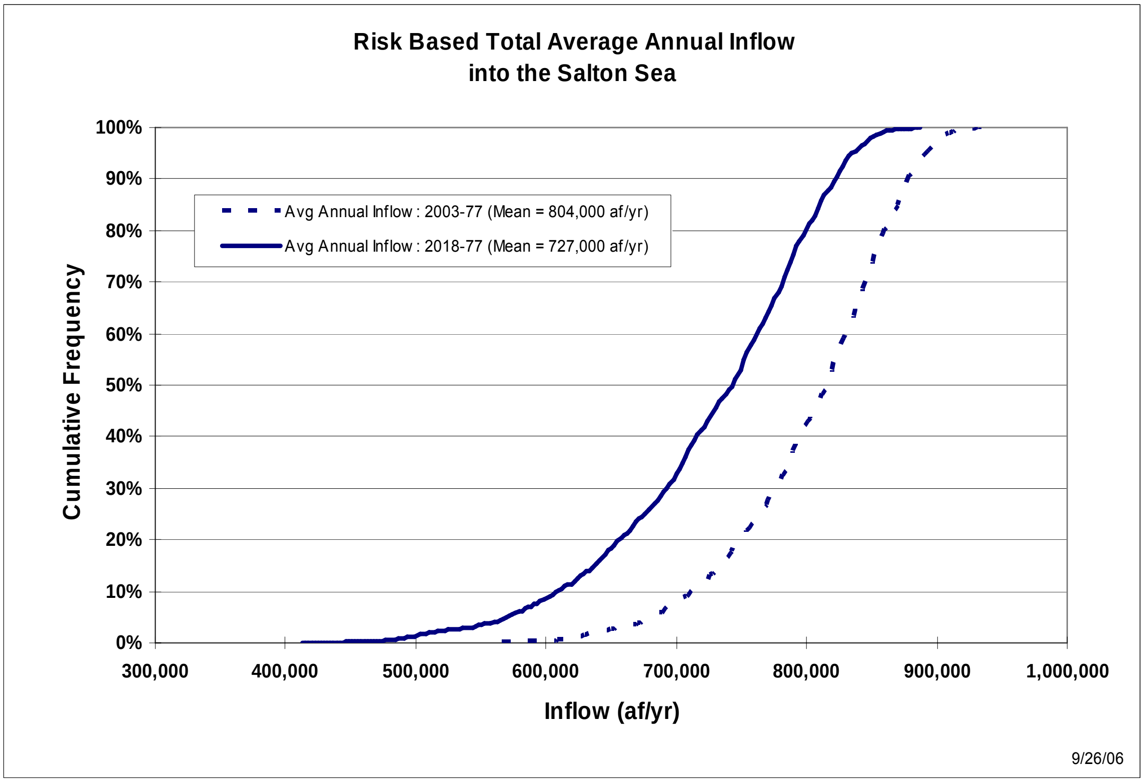


Figure 4.1 Risk-based possibility distribution of total inflows from all sources.

The curves presented in **Figure 4.1** represent the cumulative frequency of average annual inflows resulting from the random sampling of 10,000 different futures from each source possibility distribution. The range in average annual inflows from all sources for the period 2018 to 2077 can be described statistically as follows:

5 Percent of All Futures: Inflows will be less than or equal to 570,000 acre-feet per year

Mean of All Futures: Inflows will be 727,000 acre-feet per year

95 Percent of All Futures: Inflows will be less than or equal to 835,000 acre-feet per year

Climate Change Effects on Evaporation

Evaporation has a strong influence on the Salton Sea. In recent history, inflows to the Salton Sea have been in balance with evaporation–each equaling 1.34 maf/yr. Historic average annual net evaporation has averaged 66 inches at the Salton Sea. There is general scientific consensus that climate changes will occur in the future as a result of increasing concentrations of greenhouse gasses in the Earth's atmosphere (Intergovernmental Panel on Climate Change [IPCC], 2001). The highest and lowest IPCC emission scenarios and associated impacts to California were evaluated by Hayhoe et al. (2004). Information extracted from this study indicates that temperature increases by the end of century in the Salton Sea area will be between 2 and 4 degrees Celsius (3.6 and 7.2 degrees Fahrenheit). An analysis of historic California Irrigation Management Information System data from the Westmorland station (south of the Salton Sea) yields the conclusion that average annual evaporation will increase 5.4 percent per degree Celsius increase in temperature in the future, which translates to a 9-to-13-inches-per-year increase in evaporation by the end of the century.

The ranges in uncertainty of these increases in evaporation were incorporated into the SSAM. SSAM was used to predict future conditions relative to each restoration alternative. Within SSAM, increases in evaporation rates due to climate change were applied linearly from no change in the present to a full increase by the year 2074. The end-of-century impacts of climate change were represented in SSAM by increases in evaporation based on an uniform distribution from 9 to 13 inches.

Assumptions Modeled Related to Project Completion

In the SSAM simulations of restoration alternatives, the following assumptions were made about alternative project construction and completion. It was assumed that this schedule would begin in year 2008:

- Three years to complete environmental compliance work
- One year authorization to proceed
- Five years final design data acquisition and design
- One year to obtain construction funding
- Seven years of construction
- Project construction completed in 2024

Alternatives Modeling Results

Each alternative was simulated using the stochastic capabilities of SSAM. Each model was executed 1,500 times while sampling from the risk-based inflow distributions as described previously. SSAM model results include water surface elevation, water surface area, salinity, and exposed lake playa for all marine lakes and residual brine pools. A discussion of model results for these parameters follows.

Water Surface Elevations

Hydrographs of mean future water surface elevations (not including brine pools) for each restoration alternative are shown in **Figure 4.2,** which depicts elevations through time for years 2025 to 2074. These elevations are based on mean future risk-based inflows. Three elevation curves are shown for the Concentric Lakes Alternative; each curve represents one of three concentric lakes that would be constructed. The fourth and innermost concentric lake proposed by the Imperial Group would not be required under the risk-based inflows used in this study.

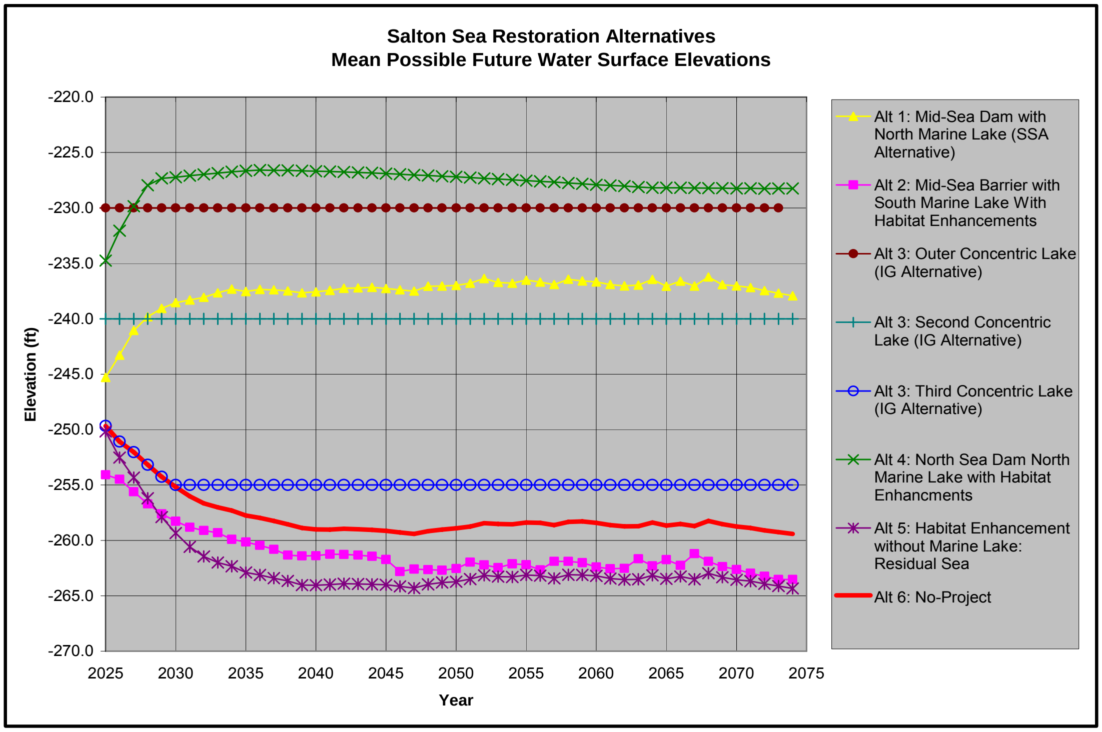


Figure 4.2 **Mean future water surface elevations for restoration alternatives.**

Water Surface Areas

Hydrographs of mean future water surface areas (not including brine pools) for each restoration alternative are shown in **Figure 4.3,** which depicts areas through time for years 2025 to 2074. These areas are based on mean future risk-based inflows. Three surface area curves are shown for the Concentric Lakes Alternative; each curve represents one of three concentric lakes that would be constructed.

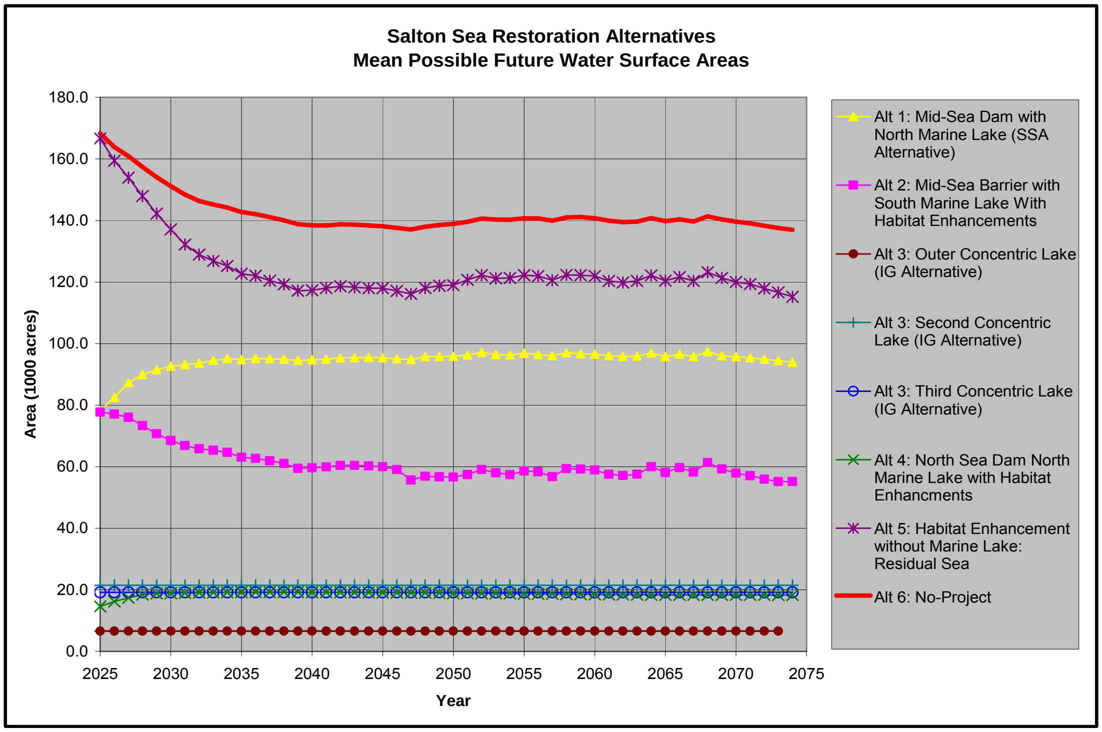


Figure 4.3 **Mean future water surface areas for restoration alternatives.**

Salinities

Hydrographs of mean future salinity in the marine lakes for each restoration alternative are shown in **Figure 4.4**, which depicts salinity through time for years 2025 to 2074. These salinity results are based on mean future risk-based inflows. Three curves are shown in **Figure 4.4** for the Concentric Lakes Alternative; each curve represents one of three concentric lakes that would be constructed.

Exposed Lake Playa and Air Quality Mitigation Water Requirements

SSAM also makes predictions of exposed lake playa surface areas in the future. For all alternatives, the exposed playa areas are determined from a baseline Sea elevation of -228 feet. Total exposed lake playa surface areas predicted by SSAM are presented in **Table 4.1**. The data presented are based on mean future stochastic model results for year 2040. On the basis of these predicted areas, SSAM estimates and takes into account AQM water and brine requirements. General AQM requirements are discussed in Chapter 3. The approach taken in this study adheres to the current DWR Salton Sea Ecosystem Restoration Program approach to AQM. DWR's approach identifies the need to make 1 acre-foot per acre of inflow water available for AQM purposes using water-efficient vegetation. In addition, DWR identifies the need to allocate 0.2 acre-feet per acre of brine water for AQM purposes. Exposed acres to be mitigated with water-efficient vegetation and other methods are also listed in **Table 4.1**.

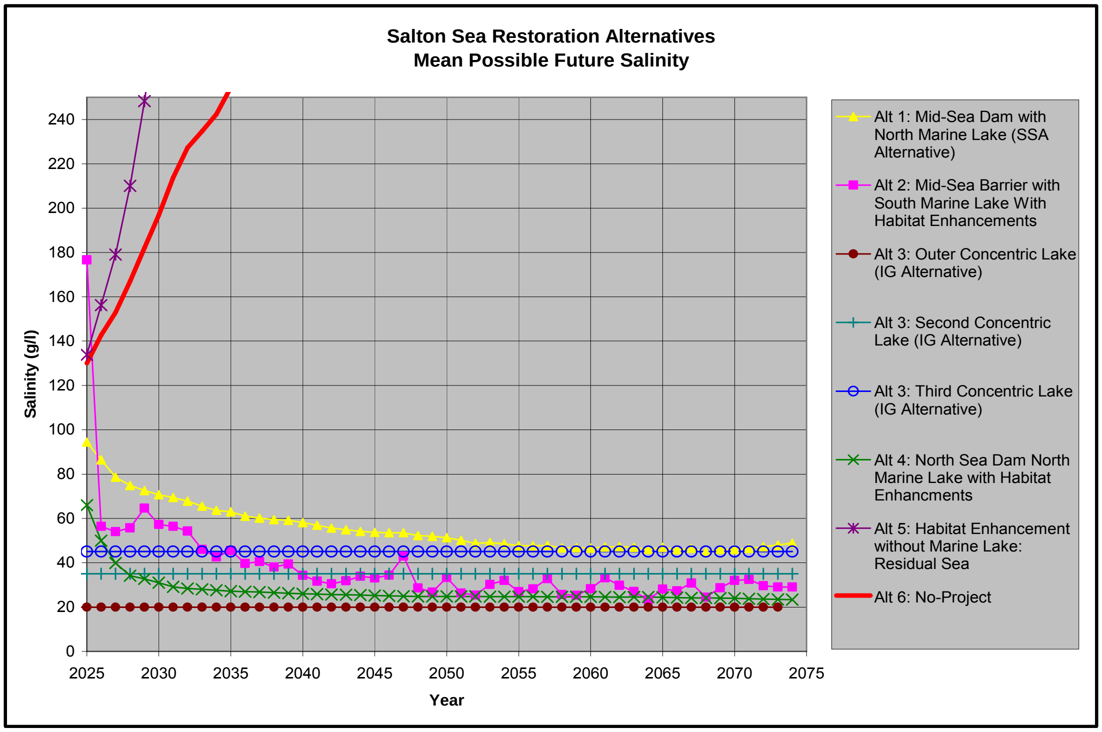


Figure 4.4 **Mean future salinity for restoration alternatives.**

Table 4.1 Exposed lake playa surface areas

Alternative	Exposed Lake playa surface areas (acres)	Exposed lake playa mitigated with water-efficient vegetation[1] (acres)	Exposed lake playa mitigated with other methods[2] (acres)
Alternative No. 1: Mid-Sea Dam with North Marine Lake	103,800	51,900	20,760
Alternative No. 2: Mid-Sea Barrier with South Marine Lake	73,600	36,800	14,720
Alternative No. 3: Concentric Lakes	65,000	32,500	13,000
Alternative No. 4: North-Sea Dam with Marine Lake	91,800	45,900	18,360
Alternative No. 5: Habitat Enhancement without Marine Lake	81,200	40,600	16,240
Alternative No. 6: No-Project	92,200	46,100	18,440

[1] 50 percent of exposed area is assumed to require mitigation using water-efficient vegetation.

[2] 20 percent of exposed area is assumed to require mitigation using other methods.

Viability of Alternatives Relative to Future Inflows

Without a guaranteed water supply, each of the alternatives would be subject to the risk-based inflows discussed above. The performance of each alternative under the range of future possible inflow helps to describe the viability of the alternatives. **Figure 4.4** presents future salinities of the marine lakes associated with each alternative under mean possible future inflows. A salinity of 60,000 mg/L has been identified as the threshold beyond which it will not be possible to maintain a fishery. This section includes a discussion of the viability of each alternative relative to future inflows. Viability is presented in terms of risk as defined by the following:

- ***Fatal*:** Nothing can be done to alleviate the problems and issues associated with variability in inflows.
- ***High Risk***: Problems are extreme and cannot be dealt with through changes in project feature operating criteria but instead would require relocating project structural elements.
- ***Serious Risk***: Problems threaten project performance but can be dealt with by making significant changes in project feature operating criteria.
- ***Moderate Risk***: Problems are evident that may require changes in project feature operating criteria.
- ***Low Risk***: Problems are not likely to occur.

Alternative No. 1: Mid-Sea Dam with North Marine Lake

The mean possible future inflow to the Salton Sea is expected to be 727,000 acre-feet per year. As shown in **Figure 4.4**, in year 2040, under Alternative No. 1 the mean future salinity would be 58,000 mg/L, which is very close to the 60,000 mg/L salinity threshold for a sustainable fishery. After construction is completed in 2024, salinity in the marine lake would not fall below 60,000 mg/L until year 2038. Not until after this time would a fishery be potentially viable. The early start features described in the discussion of SHC in Chapter 3 would be necessary to maintain a viable fishery prior to 2038.

Figure 4.4 depicts salinity conditions under mean possible inflow conditions. Alternative No. 1 was modeled assuming an operating water surface elevation of -238 feet so that salinity in the lake could be maintained below 60,000 mg/L in year 2040. The SSA desires to operate the lake at elevation -230 feet. From **Figure 4.4**, it can be seen that a salinity of 45,000 mg/L would not be reached until year 2055. Thus, if 45,000 mg/L were the target salinity, the SSA would not be able to slowly increase the operating elevation of the lake to -230 feet until after 2055. This salinity sensitivity to inflows and operating water surface elevation indicates that the viability of this alternative would be at **serious risk** relative to future inflows. This classification indicates that problems can be dealt with by making significant changes in project operating criteria which in this instance would be lake water surface elevation. If future inflow conditions are significantly above mean possible estimates then the operating elevation of the marine lake could be higher (and much sooner) and potentially at a level consistent with the SSA's target of -230 feet. Under lower-than-mean possible future inflow conditions, the operating surface elevation criteria for the marine lake would need to be reduced below the -238 feet simulated at mean possible future conditions.

If project construction were completed earlier than year 2024, it might be possible to raise the operating water surface elevation closer to the SSA's desired -230-foot elevation prior to year 2040. However, even if construction were completed earlier than year 2024 and lower-than-mean possible future inflow conditions prevail, the operating water surface elevation of the marine lake would have to be substantially lower than -230 feet.

Alternative No. 2: Mid-Sea Barrier with South Marine Lake

Under the risk-based inflow approach described above, it is expected that under Alternative No. 2, salinity would be 34,000 mg/L by the year 2040. Salinity in the marine lake would decrease only slightly beyond year 2040. By the year 2074, salinity would be 29,000 mg/L. Other stochastic model simulation results (not shown in **Figure 4.4**) for Alternative No. 2 indicate that salinities in the south marine lake would be highly variable, ranging from 5,000 to 52,000 mg/L. Thus, large variability would exist for inflows significantly below mean future levels. As a result of this potentially negative variability in salinity, the viability of this alternative would be at **serious risk** relative to future inflows. Problems could be dealt with by accepting a variable salinity operating criteria for lower inflow conditions.

Alternative No. 3: Concentric Lakes

Under the risk-based inflow approach described above, it is expected that under Alternative No. 3, target salinities and elevations would be achieved in each concentric lake. By year 2040, target salinities of 20,000, 35,000, and 45,000 mg/L would be achieved in the first (outer), second, and third concentric lakes, respectively. These salinities would be maintained under all possible futures through the year 2074. Because there would likely be no future problems associated with maintaining target salinities and elevations, the viability of this alternative would be at **low risk** relative to future inflows.

Alternative No. 4: North-Sea Dam with Marine Lake

Under the risk-based inflow approach described above, it is expected that adequate salinities and elevations in the north marine lake would be achieved under Alternative No. 4. Under mean possible future inflow conditions, future salinities would vary from 26,000 to 34,000 mg/L. Similar ranges in salinities would be maintained under all possible futures through the year 2074. Because there would likely be no future problems with maintaining salinities and elevations, the viability of this alternative would be at **low risk** relative to future inflows.

Alternative No. 5: Habitat Enhancement without Marine Lake

Under the risk-based inflow approach described above, it is expected that adequate water surface elevations and salinities in the SHC would be achieved under Alternative No. 5. Under mean possible future inflow conditions, future salinities in deep holes provided for fish refuge would vary from 20,000 mg/L to 45,000 mg/L. Similar ranges in salinities would be maintained under all possible futures through the year 2074. Because there would likely be no future problems with maintaining salinities and elevations in the SHC, the viability of this alternative would be at **low risk** relative to future inflows.

Alternative No. 6: No-Project

Under the risk-based inflow approach described above, it is expected that under Alternative No. 6, salinities in the year 2040 would be greater than 250,000 mg/L. As a result, the viability of this alternative would be **fatal** relative to maintaining salinities capable of supporting a fishery.

Chapter 5. Biology Issues

Introduction

The Salton Sea and adjacent land and wetlands have historically provided abundant habitat resources to a wide range of fish and wildlife species. However, the Sea has recently experienced water quality issues that have adversely affected the fishery and other resources. Future reductions in water inflow will exacerbate this situation until, ultimately, water quantity and quality conditions will adversely affect most of the biota currently supported by the Sea. Current projections indicate that in 50 years or less, the Sea will support only the most salt tolerant micro-organisms and once-abundant habitat resources will be gone (Cohen and Hyun, 2006). Resource agencies are evaluating mechanisms and approaches that would reduce the negative impacts of lost resources to wildlife using the Sea. This chapter addresses biology issues and provides an assessment of how anticipated No-Project conditions, and estimated conditions associated with five restoration strategies, would affect future habitat resources.

Snowy Plover.

Issues Overview

Habitat is a concept that requires an operational definition. Habitat provides resources for specific species, and, in the case of the Salton Sea, abundant habitat resources have supported abundant and diverse wildlife. For example, the abundance and diversity of avifauna (400+ bird species recorded with about 270 species observed on a regular basis [Cooper, 2004]) using the Sea and associated landscapes illustrates the area’s ability to provide resources and its value to such a wide range of species. This ability to provide resources to a diverse assemblage of birds, coupled with their high visibility, render birds an ideal assessment tool for evaluating potential changes in future resource abundance. Birds are, therefore, used in this assessment to define the landscape features or habitat types providing resources at risk, and as indicators of how successful future restoration strategies may be in providing habitat resources to area wildlife.

Not all habitat types currently providing resources would be affected by future reductions in water inflow to the Sea and associated changes in water quality.

Essentially, habitat types of interest include components of the Sea (shoreline, open water, islands, and constructed wetland complexes), and associated unmanaged wetlands (associated with the three rivers, major drains, and ephemeral pools that may develop in the exposed Seabed). Other types, such as freshwater marshes managed by wildlife agencies or agricultural fields providing food for numerous species, would not be directly affected by future changes in water management (DWR, 2006). These habitat types and the birds that use them are not addressed in this assessment.

Birds that use the habitat types that would be most affected by reduced water inflow and changes in water quality are generally known as semi-aquatic water birds, and can be grouped into several functional groups, such as fish-eating divers, shorebirds, long-legged waders, etc. (Shuford et al., 2000). The principal resources provided by habitat types at risk are food and cover (secure sites used for roosting, loafing, and or nesting). Principal food resources are fish and invertebrates; snags and small islands provide security (DWR, 2006). The habitat types of interest in this assessment and the bird groups that use them are identified in **Table 5.1**.

Table 5.1 Avifauna functional groupings associated with various habitat types present within and/or adjacent to the Salton Sea

Avifauna functional groups[1]	Shoreline[2]	Open water[3]	Islands and snags[4]	Wetlands[5]
Fish-eating divers	x	x	x	
Gulls, terns, and skimmers	x	x	x	
Invertebrate-eating divers	x	x		x
Diving ducks	x	x		x
Shorebirds	x			
Long-legged waders	x		x	x
Rails and moorhens	x			x
Dabbling ducks	x			x

[1] Groupings generally follow the descriptions provided by Shuford et al. (2000). The groupings imply that representatives occur in or use the indicated habitat types. An exception would be found in the last three groups (grey shaded) where individual species may use the delta areas of rivers, but most group use occurs in adjacent wetlands.

[2] Shoreline is operationally defined as the wetted surface area (acres) of the Sea from the edge of water to a depth of 6 feet.

[3] Open water is operationally defined as the wetted surface area (acres) of the Sea from a depth of 6 feet to the maximum depth.

[4] Islands and snags are used by some avian groups for nesting sites and/or roosting sites. These features are generally located at the north and south ends of the Sea.

[5] These wetlands occur along canals, drains, creeks, and other locations, and are not managed as habitat. Principal vegetation includes cattail-bulrush marshes and/or varying densities of salt cedar (tamarisk).

Both features that provide security, and sites that provide food, can be developed and operated to provide habitat resources for wildlife using the Salton Sea area. Food is the major issue confronting resource agencies and the relevant questions involve “how much” and of “what quality.” Current approaches generally look at bird use of existing habitat types to provide insight into future area requirements for habitat restoration features. For example, the shoreline habitat type is generally recognized as providing abundant food resources as defined by high bird use (Shuford et al., 2000; DWR, 2006). Recent estimates of the areal coverage of "shoreline," based on depth, range from about 6,000 acres (0-3 feet deep, DWR, 2006) to about 12,000 acres (0 to 6 feet deep, Reclamation, unpublished data). The area producing abundant food resources—again defined by bird use—increases to about 38,000 acres when a "nearshore" habitat type (water's edge to 1 kilometer offshore) is considered (DWR, 2006). One could infer that the area—or "how much"—needed to provide or replace this food resource ranges between 6,000 and 38,000 acres depending upon management objectives. Potential restoration strategies evaluated in this report address the question of "how much" through different sized marine lakes, or different sized SHC, or different combinations of the two food-producing concepts.

Addressing the question of "how much" food also requires an evaluation of "what quality." The question of food quality is important when addressing Salton Sea issues because of the presence of Se in agricultural waste water that would be used in restoration efforts. Se effects associated with avian reproductive impairment have been widely studied and extensively documented. In aquatic birds that feed on fish and/or invertebrates, accumulated Se can impair reproduction by affecting egg viability and/or producing deformities in developing embryos. Bioaccumulation is a concern because some species at the Salton Sea currently exhibit Se egg concentrations associated with reduced egg viability in other locations (Setmire et al., 1993). Consequences of these elevated Se concentrations have not been determined, but it is assumed that any increase in Se levels in area food chains would increase the risk of additional Se bioaccumulation for breeding birds. Because Se-induced reproductive impairment is dose responsive (Skorupa, 1998), an increased risk of Se bioaccumulation—to birds that may be currently on the threshold of experiencing reduced egg viability—should be avoided.

Objectives

Reclamation's principal objective in this study is to identify a restoration approach that retains the Salton Sea's historic habitat function of providing quality habitat resources:

- To an abundant and diverse assemblage of fish and wildlife species.
- At a level sustainable within the constrains of future water availability.

This assessment of restoration alternatives evaluates the acreages of habitat type developed—with a focus on shoreline and open water—and then attempts to characterize, to the extent possible, the risk of increased Se bioaccumulation in both fish-eating and invertebrate-eating birds that may be associated with features of each alternative management plan.

Assessment Methods

As presented in Chapter 4, the Sea will become smaller and more saline in the future. These changes will affect the surface area available (e.g., shoreline and open water) to produce food and also the ability (e.g., increasing salinity) of the reduced surface area to produce food. Although multiple variables are likely associated with the production of food (fish and invertebrates) and its use by birds, a simple approach of comparing habitat type (shoreline, open water, and wetlands) area, as modified by salinity and possibly Se risk, was used to evaluate effects on avian groups using the Salton Sea.

Area Determinations

The area of shoreline and open water habitats were determined for the marine lakes, residual Sea (brine basin), and SHC proposed for each alternative, including the No-Project Alternative. Different features would be developed at different times and, thus, would provide varying amounts of habitat resources. The actual future timing of events, including feature development associated with the alternatives, is unknown. However, for the purposes of analysis, four time periods were evaluated. Changes in acres of marine lakes, brine basins, and SHC were estimated for each period, and descriptions of conditions at the end of each period were developed. The following periods were evaluated:

- 1999–2006 (i.e., current conditions) (2006)
- 2007–2023 (2023)
- 2024–2040 (2040)
- 2041–2078 (i.e., the conclusion of the study period) (2078)

It was assumed that because of the time needed to complete analyses, obtain the necessary permits, secure funding, and complete design and construction, the various features of the alternatives would not become functional until 2024. Therefore, conditions under the first period (1996–2006) and second period (2007–2023) would be the same under all alternatives, including No-Project. Following a rapid reduction in inflow after year 2018, the Sea would begin a rapid reduction in surface area and increase in salinity.

It was assumed that during the third and fourth periods (2024–2040 and 2041–2078), the various features of the alternatives would be in place and functional. All alternatives would approach environmental equilibrium by year 2040. The residual Sea would continue its decline during these periods. During the third period (2024–2040), salinity concentrations within the brine basin would likely reach levels favoring brine flies and brine shrimp and would mark a significant change in the character of residual food chains.

Salinity concentrations, important in defining the type and relative abundance of food present for bird use, were estimated for each habitat type and time period. Nutrient levels are also important in determining food item abundance. The Sea is currently in a hypereutrophic condition and is expected to remain that way for some time. In this analysis of bird habitat resources abundance, nutrients were assumed to be non-limiting.

Selenium Concerns

Brine fly larvae.

Dilution is likely a significant process in reducing initial inflow Se concentrations (5-10 micrograms per liter [µg/L]) to observed Sea concentrations (1-2 µg/L). The Sea currently contains about 7.2 million acre-feet of water with an annual inflow of about 1.23 million acre-feet. When a large volume of water (the Sea) with a low concentration of some constituent receives a smaller flow of water with a higher concentration of that constituent, dilution occurs. Setmire et al. (1993) described the dilution process for sample sites at the mouth of the Alamo River. At these sites, total Se concentration in river water went from 6.35 µg/L to less than 2.4 µg/L in the interface mixing zone between the river and the Sea. Se species composition went from about 60 percent selenate to predominantly selenite.

Dilution alone cannot explain current Se concentrations in Sea water. Indeed, Schroeder and Orem (2000) have estimated that if Se were to have continued to accumulate within the water column, as have other constituents such as chloride, its concentration would have risen to about 400 µg/L. It is currently believed that anaerobic bacteria play a significant role in the removal of Se from the water column (Setmire et al., 1993). Schroeder et al. (2002) found no selenate in Sea water—even in the oxygenated surface water. Selenite composed about 33 percent of total Se in the upper 4 m, but no selenite was detected in deeper water. The bulk of Se entering the Sea is sequestered in bottom sediments in the elemental form as non-volatile organic selenides. Any change in future conditions that would alter the dilution functions and/or affect the anaerobic bacterial Se processing mechanisms currently in place should be carefully evaluated for increased Se concentrations.

For this study, the potential for increased risk of Se bioaccumulation in future food chains was evaluated qualitatively. The evaluation was based on the predicted depth, salinity, Se levels, and other factors of the alternative features. Five risk categories were identified:

- ***Low Risk***: Problems are evident but do not require mitigation measures
- ***Moderate Risk***: Problems are evident and may require mitigation
- ***Serious Risk***: Problems create significant threats—mitigation required
- ***High Risk***: Problems require extreme measures that may create problems
- ***Fatal***: No solution for problems currently exists

Summary of Conditions under No-Project Alternative

As recently as 1999, the Salton Sea provided abundant food and secure nesting, roosting, and resting sites for large numbers of birds. Several functional groups—primarily fish-eating and invertebrate-eating birds—used the habitat resources provided by the Sea's shoreline, open water, and islands and snags (**Table 5.1**). Rising salinity levels, along with water quality issues, further reduced the already declining fish populations between 1999 and 2006.

The description of the period 2006 to 2023, while presented here for the No-Project Alternative, would generally describe conditions under all alternatives. Therefore, during this period—under all alternatives—significant changes would occur in biota supported by the Sea and bird populations using the Sea and its habitat resources (Cohen and Hyum, 2006). An accelerated reduction in the Sea's elevation after the termination of mitigation water in 2017, with an accompanying accelerated increase in salinity, would change the structure of food chains historically supported by the Sea. Tilapia, pileworms, and most other macro-invertebrates that now populate the Sea's food chains and support the fish-eating and invertebrate-eating bird groups would decrease. In addition, secure sites (islands and snags) would be connected to land as water levels decrease and lose their habitat value. Currently, there are no known significant elevated land masses that would be exposed to create replacement habitat as the Sea recedes. Fish-eating divers and gulls, terns and skimmers—represented by pelicans, cormorants, terns, and others—would lose their food supply and nesting/roosting sites. Other groups, such as invertebrate-eating divers (e.g., eared grebes), shorebirds (e.g., snowy plovers), and diving ducks (ruddy ducks) would lose their traditional food items during this period and be forced to use brine flies and brine shrimp, or abandon the Sea. Some fish and some invertebrate communities would persist in the mixing zones and fresh water lenses at the mouths of the three rivers. However, the food biomass needed to support the abundance and diversity of avifauna historically supported by the Sea would not survive this period because of increasing salinity levels. Without a diverse prey base, the abundance and diversity of birds using the Sea would decline during this period.

Biological change in response to chemical and physical changes in the residual Sea would continue during the 2024–2040 period. For example, by the end of this period, salinity would exceed 250,000 mg/L, which is the level expected to impact brine flies and brine shrimp. Above this salinity, the Sea would be functionally devoid of macro-invertebrates. However, there is the potential for areas at the interface of the rivers and the Salton Sea that may support macro-invertebrates and possibly even fish. But before reaching this level of 250,000 mg/L, salinity would rise during the 2023–2040 period through levels that would provide optimum conditions for these two macro-invertebrates, and densities should reach maximum levels. Certain species within the functional groups identified in **Table 5.1** (e.g., eared grebes, ruddy ducks, and some shorebirds) may exploit this abundant food supply. Numbers of these birds using the Salton Sea during this period may be high. However, as salinity values exceed optimum levels for brine flies and brine shrimp, bird numbers would likely decline until both prey and the birds using them would reach low numbers.

Future Se levels in the residual Sea are a concern. If current anaerobic reduction mechanisms continue to function, then Se levels may remain similar to current levels. However, it is possible that Se concentrations in the residual Sea could increase for the following reasons:

- The residual Sea would be shallower than under current conditions and may be more prone to wind mixing. Mixing may re-suspend Se bearing sediments. Re-suspension may facilitate changes in Se speciation that result in increased concentrations within the water column.
- If additional mixing occurs, it may result in a more oxygenated system. More oxygen may reduce the effectiveness of anaerobic bacteria in removing Se from the water column.
- Sediments would be exposed as the Sea is reduced in size. Alternate wetting and drying of exposed sediments via drains, seepage, and/or dust mitigation may facilitate the formation of ephemeral pools with high Se levels.
- Agricultural drainage concentrations entering the Sea would increase as drainage volumes decrease. Concentrations of Se in the New and Alamo Rivers could increase to as high as 8 to 18 mg/L in the future with future conservation actions (Setmire, 2005).

Any increases in Se levels in the residual Sea, coupled with the assumed abundance of brine fly larva and brine shrimp during this period, create uncertainty regarding increased risk of Se bioaccumulation.

Finally, the period 2041–2078 would be marked by low resource abundance and low numbers of birds using the Salton Sea.

Summary of Conditions under Restoration Alternatives

An assessment of how best to replace habitat resources that would be lost in the future is actually an evaluation of concepts. In the present study, the principal concepts involve (1) large saline ("marine") lakes, (2) large SHC, and (3) combinations of marine lake and various sized saline complexes. The alternatives resulting from these concepts are assumed to provide varying quantities of food—represented here by acreage estimates for both shoreline and open water habitats—for marine lakes and/or SHC. Most alternatives also contain additional features (e.g., brine basins, sediment retention basins, conveyance channels) with primary functions other than providing habitat resources, but that would also provide invertebrate and/or fish prey items for area birds. Food produced by alternative features must, therefore, also be subject to a quality modification by salinity and/or potential Se levels that may be associated with alternative features in the future.

Several cautionary notes are in order when evaluating these alternatives. First, the current Sea supports a unique combination of physical, chemical, and biological components that provide both food for birds and deal with Se input by sequestering it in sediments. Although the eggs of some birds nesting at the Salton Sea exhibit Se levels associated with reduced egg viability in other studies, no major reproductive impairment issues have been identified in area birds to date. Note however, that all proposed alternatives—including No-Project—would alter the current combination of physical, chemical, and biological components in features by increasing or decreasing salinity levels and generally increasing Se concentrations. Major features and their associated concerns are as follows:

- Marine Lake—As discussed in other sections of this report, most marine lakes would likely experience salinity and/or nutrient problems. Salinity may be difficult to reduce to levels that would support a viable fishery in some lakes, and/or eutrophication issues may result in frequent fish kills. Food for fish-eating birds using such lakes may be limited. Invertebrates produced by marine lakes are assumed to contain Se levels similar or somewhat higher than current levels—if Se sequestering mechanisms in future marine lakes function as efficiently as in the current Sea.

- Residual Sea/Brine Pool—The residual Sea would be the dominant feature of all alternatives until about 2024. Existing food chains would disappear as salinity increases and be replaced for a time by brine fly larvae and brine shrimp. Although the residual Sea/brine basin would likely not produce food by the end of the third time period

(2024–2040) because of salinity levels greater than 250,000 mg/L. Optimum conditions for brine flies and brine shrimp would occur at some time during the period. This food resource may be so abundant for a time after 2024 that some birds may use the residual Sea rather than facilities constructed for their use. A proactive plan is needed that would address the potential for Se accumulation within this future food source supported by the residual Sea.

- SHC—These features are large constructed wetlands with varying salinities. The majority of these shallow wetland habitats would be less than 3 feet deep. SHC are described in more detail in Chapter 3. These constructed wetlands would use a mix of river, marine lake (or brine pool) water to mimic shallow shoreline with dispersed deep pools of open water for fish. As Se levels rise in the rivers, and water within the complexes is concentrated to increase salinities, Se concentrations would also increase. Unless some mechanism is used to reduce or eliminate Se in water used in the complexes, food chains that develop would experience increased Se levels.

- Sediment Retention Basins—These constructed freshwater wetlands receiving drain water could pose a risk for Se bioaccumulation in the food chains they would support (Setmire, 2005). The assumed shallow water and relatively low salinities would support vegetation that would rapidly develop into “marsh-like” conditions. These conditions would be attractive to several bird groups, including the federally listed Yuma clapper rail. Unless some mechanism is used to reduce or eliminate Se in water used in the basins, food chains that develop would experience increased Se levels.

- Other Wetlands—Other wetlands would develop in response to a receding Sea shoreline and/or in association with various alternative features. For example, ponded water on exposed Sea-floor sediments would present an opportunity for increased Se concentrations. Alternate wetting and drying—which would occur during dust mitigation actions—could result in high Se concentrations. Increased Se concentrations would then be available for incorporation into local food chains.

All of the proposed alternatives would provide some level of food for fish- and invertebrate-eating birds. Food abundance would vary, but all alternatives would include operational uncertainties and, therefore, would present some level of increased risk for Se bioaccumulation at levels higher than currently exhibited by area birds. These uncertainties are discussed below and summarized in **Table 5.2**. Note that **Table 5.2** addresses alternatives as fully operational and near equilibrium in the year 2040. Although **Table 5.2** lists salinity values for the residual Sea/brine pool as greater than 250,000 mg/L, this level would not likely

Table 5.2 Summary comparison of shoreline habitat, open water habitat, and food provided under restoration alternatives and No-Project Alternative in the year 2040

	Alternative No. 1 - Mid-Sea Dam with North Marine Lake			Alternative No. 2 – Mid-Sea Barrier with South Marine Lake			Alternative No. 3 – Concentric Lakes			Alternative No. 4 – North-Sea Dam with Marine Lake			Alternative No. 5 – Habitat Enhancement without Marine Lake			Alternative No. 6 – No-Project		
	Marine lake																	
	Shoreline habitat[1]	Open water habitat[2]	Food provided	Shoreline habitat[1]	Open water habitat[2]	Food provided	Shoreline habitat[1]	Open water habitat[2]	Food provided	Shoreline habitat[1]	Open water habitat[2]	Food provided	Shoreline habitat[1]	Open water habitat[2]	Food provided	Shoreline habitat[1]	Open water habitat[2]	Food provided
Acres	13,800	103,700	Inverts Fish	17,300	44,700	Inverts Fish	46,800	817	Inverts Fish	3100	16,400	Inverts Fish	No lake	No lake	No lake	No lake	No lake	No lake
Salinity (g/L)[3]	58[4]	58[4]	58[4]	34	34	34	20 to 45	20 to 45	20 to 45	26	26	26	No lake	No lake	No lake	No lake	No lake	No lake
Selenium	Increase possible	Increase possible	Increase possible	Increase possible	Increase possible	Increase possible	Increase possible	Increase possible	Increase possible	Increase possible	Increase possible	Increase possible	No lake	No lake	No lake	No lake	No lake	No lake
	Brine pool																	
Acres	No shoreline habitat (Salinity > 250)	No open water habitat (Salinity > 60)	No food	No shoreline habitat (Salinity > 250)	No open water habitat (Salinity > 60)	No food	No shoreline habitat (Salinity > 250)	No open water habitat (Salinity > 60)	No food	No shoreline habitat (Salinity > 250)	No open water habitat (Salinity > 60)	No food	No shoreline habitat (Salinity > 250)	No open water habitat (Salinity > 60)	No food	No shoreline habitat (Salinity > 250)	No open water habitat (Salinity > 60)	No food
Salinity (g/L)[3]	>250	>250	>250	>250	>250	>250	>250	>250	>250	>250	>250	>250	>250	>250	>250	>250	>250	>250
Selenium	No food	No food	No food	No food	No food	No food	No food	No food	No food	No food	No food	No food	No food	No food	No food	No food	No food	No food
	Saline habitat complex																	
Acres	12,800	3,200	Inverts	17,400	4,300	Inverts Fish	No complex	No complex	No complex	29,800	7,400	Inverts Fish	33,800	8,400	Inverts Fish	No complex	No complex	No complex
Salinity (g/L)[3]	20 to 150	20 to 150	20 to 150	20 to 150	20 to 150	20 to 150	No complex	No complex	No complex	20 to 150	20 to 150	20 to 150	20 to 150	20 to 150	20 to 150	No complex	No complex	No complex
Selenium	Increase probable	Increase probable	Increase probable	Increase probable	Increase probable	Increase probable	No complex	No complex	No complex	Increase probable	Increase probable	Increase probable	Increase probable	Increase probable	Increase probable	No complex	No complex	No complex

[1] Shoreline habitat is defined as habitat with depths of water between 0 and 6 feet with selenium in sediments less than or equal to 2.5 milligrams per kilogram (mg/kg) and salinity <= 250,000 mg/L.
[2] Open water habitat is defined as habitat with depths of water greater than 6 feet and salinity less than or equal to 60,000 mg/L
[3] Salinities are for mean possible future conditions as described in Chapter 4.
[4] Salinities for the Alternative No. 1 will exceed 60,000 mg/L under all possible inflow conditions less than mean possible future inflows (as described in Chapter 4) unless the marine lake is operated at elevations below than -238 feet

be reached until the latter part of the 2024–2040 period. Before reaching this salinity level, the residual Sea would provide optimum conditions for brine fly larvae and brine shrimp. If Se concentrations increase, this abundant food supply could result in increased Se bioaccumulation in birds using this resource.

Following is a discussion of potential benefits and uncertainties relative to each restoration alternative.

Alternative No. 1: Mid-Sea Dam with North Marine Lake

Potential Benefits

This alternative would provide about 13,800 acres of the shoreline habitat type in the marine lake component and another 12,800 acres of shoreline habitat within SHC (**Table 5.2**). About 103,700 acres of open water would be available within the marine lake and 3,200 acres within SHC. The total surface area the SHC in this alternative is 16,000 acres.

Uncertainties

Model simulations indicate that the marine lake may not support salinities that would support a viable fishery until late (after 2038) in the study period. The risk to fish-eating birds of increased Se bioaccumulation is assumed moderate—if Se sequestering mechanisms continue to efficiently function in the marine lake. Uncertainties surrounding the SHC, residual Sea/brine basin, sediment retention basins, and other constructed wetlands previously discussed, indicate the risk of increased Se bioaccumulation to invertebrate-eating birds is assumed serious.

Alternative No. 2: Mid-Sea Barrier with South Marine Lake

Potential Benefits

This alternative would provide about 17,300 acres of the shoreline habitat type in the marine lake component and another 17,400 acres of shoreline habitat within SHC (**Table 5.2**). About 44,700 acres of open water habitat type suitable for fish would be provided by the marine lake, and an additional 4,300 acres of open water habitat would be provided by saline complexes.

Uncertainties

The risk to fish-eating birds of increased Se bioaccumulation is assumed moderate—if Se sequestering mechanisms continue to efficiently function in the marine lake. Uncertainties surrounding the SHC, residual Sea/brine basin, sediment retention basins, and other constructed wetlands previously discussed, indicate the risk of increased Se bioaccumulation to invertebrate-eating birds is assumed serious.

Alternative No. 3: Concentric Lakes

Potential Benefits

No "SHC" are proposed for this alternative. However, the concentric lakes would likely function as "linear complexes" under this alternative, with similar habitat areas to those created in SHC. The concentric lakes would provide about 46,800 acres of the shoreline habitat type and about 817 acres of open water habitat (**Table 5.2**).

Uncertainties

This alternative would use river water (with increased future Se levels) and then concentrate it to reach desired salinity levels in the various lakes. Uncertainties surrounding the ring lakes, water management, and residual Sea/brine basin previously discussed, indicate the risk of increased Se bioaccumulation to both fish- and invertebrate-eating birds is assumed serious.

Alternative No. 4: North-Sea Dam with Marine Lake

Potential Benefits

This alternative would provide about 3,100 acres of the shoreline habitat type in the marine lake component and another 29,800 acres of shoreline habitat within SHC (**Table 5.2**). About 16,400 acres of open water suitable for fish would be provided by the marine lake, and an additional 7,400 acres of open water habitat would be provided by saline complexes.

Uncertainties

The risk to fish-eating birds of increased Se bioaccumulation is assumed moderate—if Se sequestering mechanisms continue to efficiently function in the marine lake. Uncertainties surrounding the SHC, residual Sea/brine basin, sediment retention basins, and other constructed wetlands previously discussed, indicate the risk of increased Se bioaccumulation to invertebrate-eating birds is assumed serious.

Alternative No. 5: Habitat Enhancement without Marine Lake

Potential Benefits

This alternative does not include a marine lake component, but would provide about 33,800 acres of the shoreline habitat type, and an additional 8,400 acres of open water habitat via constructed SHC (**Table 5.2**).

Uncertainties

The risk of increased Se bioaccumulation to fish-eating birds is assumed moderate. Uncertainties surrounding the SHC, residual Sea/brine basin, sediment retention basins, and other constructed wetlands previously discussed, indicate the risk of increased Se bioaccumulation to invertebrate-eating birds is assumed serious.

Alternative No. 6: No-Project

The conditions that would likely exist into the future for the residual Sea/brine basin have been previously described. As noted earlier, **Table 5.2** indicates that no food would be produced after salinity levels exceed about 250,000 mg/L. Because most fish except tilapia have disappeared, and tilapia will likely functionally disappear soon, the risk of increased Se bioaccumulation to fish-eating birds is assumed to be low under this alternative. However, before the residual Sea/brine basin loses its ability to support macro-invertebrates (salinity > 250,000 mg/L), it would support an abundant prey base of brine fly larvae and brine shrimp. Because of the uncertainties involved with future Se cycling in the residual Sea, the risk to invertebrate-eating birds of increased Se bioaccumulation is assumed serious.

Alternative Assessment

All of the proposed alternatives would provide some level of food resources for future bird populations using the Salton Sea area. In terms of the shoreline habitat type, Alternative No. 3, Concentric Lakes, would provide the largest area, with Alternative No. 2, Alternative No. 5, and Alternative No. 4 providing similar acreages, and Alternative No. 1 providing the smallest acreage (**Table 5.2**). Alternative No. 1, Mid-Sea Dam with North Marine Lake, would provide the largest open water area, followed by Alternative No. 2 and Alternative No. 4. Alternative Nos. 3 and 5 would provide limited open water when compared to the other alternatives (**Table 5.2**).

Although Alternative No. 3 would provide the largest area of the shoreline habitat type, and Alternative No. 1 would provide the largest area of open water, there are concerns for both of these approaches. Specifically, there are questions of salinity levels under Alternative No. 1 and the ability of this approach to provide a marine lake that would support a viable fishery within the study period. In addition, Alternative No. 3 would concentrate river water within the various ring lakes and thus increase the risk of Se exposure to birds (Setmire, 2005). The remaining alternatives—Alternative Nos. 2, 4, and 5—have potential of providing shoreline and open water resources if Se levels can be managed at safe levels. The uncertainties surrounding the risk for increased Se bioaccumulation at this stage of planning requires caution, and, thus, ratings for all alternatives range from moderate to serious.

There appear to be many unanswered questions concerning how best to provide adequate food resources for area wildlife, and how to ensure that food produced would not increase the risk of Se bioaccumulation in area food chains. These unanswered questions should be addressed before a large and irretrievable commitment of resources is dedicated to a long-term approach to restoration. For example, the U.S. Geological Survey is currently collecting data on a 100-acre experimental saline pool near the Alamo River Delta. This experimental pool is yielding valuable information on construction techniques, salinity levels, bird use, etc. An expanded version of this approach—in 200-to-500-acre-sized pools—should perhaps be considered for future implementation. Benefits may include a better understanding of:

- Water depths and salinities that maximize food production and bird use.
- Construction techniques that are efficient and cost effective in producing water depths that maximize food production and bird use.
- Mechanisms to safely deal with Se in water used for food production.

Such an approach would provide some habitat resources while improving our understanding of how future systems may operate. Such an approach would also maintain needed flexibility until a consensus approach can be developed. Further study and experimentation appears warranted.

Finally, the residual Sea would be the only source of substantial habitat resources until about 2024, when proposed plan features would become operational. Sometime during the 2006–2023 period, increasing salinity levels would eliminate existing food chains, and brine flies and brine shrimp would become the dominant food items in the Sea. Although these species may reach an impressive abundance, they will not support the numbers and diversity of avifauna found at the Sea in recent years. An experimental SHC approach would not only provide important information but may also provide needed habitat resources as resource agencies determine how best to address the questions of “how much” and of “what quality” resources are needed in the long-term.

Chapter 6. Environmental Factors Affecting Project Viability

This chapter summarizes information on environmental issues that could affect project viability. Some of this information was derived from a workshop held on July 26-27, 2005, to evaluate risks from proposed alternatives with respect to eutrophication, DO, and Se issues. Several reports (Amrhein, 2005; Amrhein and Anderson, 2005; Anderson, 2005; Horn and Holdren, 2005; Robertson, 2005 [see also Robertson and Schladow, in review; Robertson et al., in review]; Schladow, 2005; and Setmire, 2005), were produced for the workshop.

All of the alternatives currently under consideration, including No-Project, have potentially serious environmental consequences with respect to eutrophication, DO, Se, and fish and bird health. It is likely that some combination of treatment, mitigation, and/or active management will be required to minimize adverse environmental impacts of the project, regardless of which alternative is selected.

All configurations of a smaller Sea are projected to be more eutrophic than the current Sea, as existing nutrient loads enter smaller bodies of water and water conservation efforts further increase concentrations of nutrients and other pollutants entering the Sea. As a result, the remaining Salton Sea and created habitat features are likely to face problems with high algal productivity and subsequent low DO levels.

Se would be of increasing concern under all alternatives. Under all restoration alternatives, currently inundated sediments would be exposed, increasing the chances of Se oxidation, mobilization, and bioaccumulation in food chains. Se concentrations also are expected to increase as a result of shrinking receiving waters and rising concentrations in inflow waters resulting from water conservation measures. The extensive SHC created by most alternatives are also of concern with respect to Se.

An area of significant concern with respect to the viability of each of the restoration alternatives could be fugitive dust and exhaust emissions from construction and maintenance equipment and vehicles. It is expected that all alternatives (not including the No-Project Alternative) would result in emissions that exceed thresholds established by regulatory agencies. Both Imperial and Riverside Counties already hold status designations of "non-attainment" related to Federal and State of California PM_{10} air quality standards (DWR, 2006). Reclamation acknowledges that construction emissions could affect the timing and duration of construction and maintenance of any restoration alternative.

However, for the purposes of this study, it was assumed that the construction and maintenance of all the restoration projects could be permitted such that the timing and duration would not be affected.

Eutrophication

The Salton Sea has been eutrophic for many years. High productivity was responsible for the very large fish populations that were found in 1999 and 2000 (Reidel et al., 2002), but it also leads to periodic low DO concentrations caused by the decomposition of organic matter in the Sea and high sulfide levels created by bacterial sulfate reduction when oxygen levels drop.

Nutrient ratios indicate that P is the nutrient limiting algal growth in the Sea, and efforts to control eutrophication should concentrate on reducing P inputs; however, P concentrations in the Sea changed very little between 1968 and 1999 in spite of an increase in P loading of about 55 percent (Holdren and Montaño, 2002; Robertson et al., in review). The Sea did not significantly respond to the loading increases, indicating that proposed TMDL and other treatment options would have little impact unless total P loads are drastically reduced by 60 percent or more. Modeling results (Robertson, 2005; Robertson and Schladow, in review) indicate that P levels would increase under all proposed alternatives, and that eutrophication would be as bad, if not worse than under existing conditions unless significant P removal is achieved.

Walker (2006) proposed target inflow concentrations of 80 to 200µg/L to meet an in-lake P concentration of 35 µg/L that is consistent with TMDL goals. Achieving these targets would require 75 to 90 percent reductions in total P inflows. The technology exists for reducing P by these amounts, but implementation of BMPs, treatment wetlands, and other watershed measures are unlikely to meet TMDL goals in the absence of other, more advanced, treatment methods. The addition of treatment plants to remove P is likely to be required to reduce P loadings to the point where eutrophication is no longer a problem. Because of the volume of water involved, such treatment plants would need to be on the scale of the largest existing treatment plants in the United States.

The trophic state index (TSI) developed by Carlson (1977) is a relative expression of biological productivity in a lake. Use of the TSI permits comparisons among different lakes and also allows managers to track the progress of restoration projects. The TSI can be calculated from total P, chlorophyll *a* concentrations, and Secchi depth. Total P was used for this analysis because P is the limiting nutrient in the Salton Sea and because P models are more advanced than models for most other water quality variables. The total P TSI was calculated for existing conditions based on 1999 data (Holdren and Montaño, 2002) and for the proposed alternatives from P modeling conducted by Robertson (2005).

Increasing TSI values are indicative of increasing productivity. A TSI of less than 35 indicates oligotrophic conditions; a TSI between 35 and 50 indicates mesotrophic conditions; and a TSI greater than 50 indicates eutrophic conditions. Hypereutrophic, or excessively productive, lakes have TSI values greater than 70. Results for the Salton Sea summarized in **Table 6.1** indicate the Sea will progress from its current eutrophic state to a hypereutrophic state (TSI ≥ 70) for all alternatives, except Alternative No. 3, at high inflows, under the expected range of risk-based inflow volumes and resulting depths.

Table 6.1. Calculated TSI for Salton Sea alternatives

Alternative	Total P (µg/L)		TSI	
	Low Flow[1]	High Flow[2]	Low Flow[1]	High Flow[2]
Current Salton Sea (1999)	69		65	
Alternative No. 1: Mid-Sea Dam with North Marine Lake	94	95	70	70
Alternative No. 2: Mid-Sea Barrier with South Marine Lake	152	147	77	76
Alternative No. 3: Concentric Lakes	131	91	74	69
Alternative No. 4: North Marine Dam with Marine Lake	145	141	76	76
Alternative No. 5: Habitat Enhancement without Marine Lake[3]	131	98	74	70
Alternative No. 6: No-Project	N/A			

[1] Inflow = mean - one standard deviation

[2] Inflow = mean + one standard deviation

[3] Conditions in habitat ponds

The results in **Table 6.1** do not include any as yet unquantified reductions in P loadings that may occur through implementation of agricultural BMPs or construction of treatment plants to remove P from water flowing into the Sea. Using the target P inflows of 80 to 200 µg/L proposed by Walker (2006), the total P TSIs for the north marine lake under Alternative No. 1 would range from 55 to 63 (in-lake total P concentrations of 22 and 34µg/L, respectively). These values still indicate eutrophic conditions. Additional modeling would be required to predict the impacts of any such proposed reductions in P loading for other alternatives and inflow concentrations.

Selenium

Se is an important consideration for Salton Sea restoration alternatives because of the risk of bioaccumulation in fish and wildlife. The largest "step" in the bioaccumulation process occurs when Se concentrations go from parts per billion in water to parts per million in plants and invertebrates. As additional layers, or trophic levels, of fish and wildlife feed on the levels below, Se can reach concentrations resulting in reproductive impairment or death.

Se concentrations are expected to increase in both the Salton Sea and influent waters as conservation measures are implemented in future years. Cohen and Hyun (2006) predicted that expected changes in hydrodynamics and sediment resuspension could also dramatically reduce, or even eliminate, the Sea's current ability to sequester incoming Se, which would result in increases in Se concentrations in the Sea, in aquatic organisms, and in birds.

Se concentrations in the Alamo, New, and Whitewater Rivers are currently in the range of 2 to 6 µg/L (Holdren and Montaño, 2002), a level associated with high to high hazard risks of bioaccumulation (**Table 6.2**). These concentrations will increase in the future as conservation measures are implemented. IID (2002) projected that Se concentrations in river inflows could increase by up to 46 percent as a result of reductions in tailwater drainage and operational losses. A panel of experts convened by the Salton Sea Science Office in 2003 (Selenium and the Salton Sea, undated) projected that conservation, water transfers, and desalination could result in Se concentrations in the New and Alamo Rivers of 12 to 36 µg/L. Furthermore, concentrations in puddles on exposed playa could exceed 1,000 µg/L, a level far exceeding the concentrations found at Kesterson Reservoir. Finally, Setmire (2005) suggested that the flow in the New and Alamo Rivers would be composed almost entirely of subsurface drainwater after all tailwater and operational loss is eliminated and flow from Mexicali is significantly reduced. Under those conditions, Se concentrations in the Alamo River are expected to approach the median concentration of 28 ug/L found in sumps and gravity tile outlets throughout the Imperial Valley (Setmire et al., 1993; Setmire and Schroeder, 1998).

Risk levels are qualitative and loosely linked to Se concentrations in water and sediments. Se concentrations associated with various risk levels are summarized in **Table 6.2.**

Table 6.2 Selenium concentrations associated with risk levels for bioaccumulation

Risk level sediment	Concentration in water (µg/L)	Concentration in sediment (µg/g)
Low	≤ 1	≤ 1
Moderate	1-2	1-2.5
High	2-5	2.5-5
High hazard	> 5	> 5

The cycling of Se within the Salton Sea system involves a number of complex interactions among physical, chemical, and biological components. Some of these interactions are understood, and others are not. Thus, in order to conduct a viability assessment on the Se risk to aquatic birds, it was first necessary to make assumptions that establish boundaries for the Salton Sea system and its components of the future. These assumptions attempted to characterize parameters that may affect Se concentrations in future alternative components. The following assumptions were identified for this analysis:

- Se levels would increase in rivers and drains emptying into the Salton Sea (or future restoration features) as dilution water (tailwater) is reduced.
- A deep marine lake behind a mid-Sea dam—because of a smaller-cross sectional area and shorter fetch—would be less prone to sediment re-suspension and wind/wave mixing.
- A deep marine lake behind a mid-Sea dam would experience persistent stratification (Schladow, 2005).
- Bacterial reduction in the bottom sediments would continue for some time.
- Salinity concentrations would continue to increase until they reach a level that negatively affects existing primary producers.
- P would continue to increase from present conditions until a state of very low inflow is reached.
- Primary producers would continue to remove Se from the water column to a level of 1 to 2 µg/L, or somewhat higher, until salinity levels reach a level that disrupts and/or reduces the current assemblage of micro-organisms (including bacteria). This disruption would likely continue until salinity levels stabilize at a lower level.

It appears that biological uptake, with subsequent deposition, is currently sequestering most Se entering the Sea, resulting in Se concentrations <2 µg/L, and the anoxic conditions in the sediments prevent this Se from being oxidized and mobilized through the food chain. Although Se concentrations are expected to increase in water entering the Sea as water conservation measures are implemented, Se should remain low in the low-oxygen marine environments created.

For the shallower, SHC and concentric lakes with higher concentrations of DO created under Alternative Nos. 1, 2, 3, 4, and 5, the uptake and bioaccumulation of Se by primary producers would likely increase because of higher Se concentrations entering the system from tributaries and drains. In addition, it is reasonable to assume that increasing salinity in downstream SHC areas and concentric lakes would act to reduce the current assemblage of micro-organisms that play a key role in Se cycling in the Salton Sea. Such a disruption may lead to higher Se levels until salinity levels stabilize. This same disruption may occur in the marine lakes and brine pools. If such situations develop, they would translate into a high-risk level of increased Se bioaccumulation for aquatic birds.

Unless adequate mitigation can be provided, water entering SHC and concentric lakes may need to be treated to remove Se to make those areas safe for wildlife. Unfortunately, no current, proven technologies are available that are capable of treating the large volumes of water that will continue to enter the Sea. More research is needed to determine whether or not available processes are capable of providing the necessary treatment. As an alternative, additional mitigation habitat could be created to help compensate for damages to wildlife resulting from increased Se concentrations.

Estimates of the Se risk level to aquatic birds using the Salton Sea and components of future restoration alternatives are summarized **Table 6.3.**

Table 6.3 Estimates of future Se risk to fish-eating and invertebrate-eating birds under Salton Sea restoration alternatives and the No-Project Alternative

Alternative	Se risk level to aquatic birds	
	Fish-eating birds	Invertebrate-eating birds
Alternative No. 1: Mid-Sea Dam with North Marine Lake	Moderate	Serious
Alternative No. 2: Mid-Sea Barrier with South Marine Lake	Moderate	Serious
Alternative No. 3: Concentric Lakes	Serious	Serious
Alternative No. 4: North Sea Dam with Marine Lake	Moderate	Serious
Alternative No. 5: Habitat Enhancement without Marine Lake	Moderate	Serious
Alternative No. 6: No-Project	Low[1]	Serious

[1] Assumes no fishery would exist in the future.

Fishery Sustainability

Maintaining a marine fishery is a goal of all alternatives, except Alternative Nos. 5 and 6, but salinities are expected to reach at least 80,000-100,000 mg/L under all alternatives during the transition from the current Sea to a new equilibrium state. This salinity spike would eliminate the existing sport fishery and require the establishment of a new fishery once equilibrium is achieved. The loss of the fishery is also likely to cause at least a temporary relocation of fish-eating birds.


Recent fish kill.

Under existing conditions, low DO concentrations appear to be the major factor adversely impacting the Salton Sea fishery. Low DO levels have led to massive, periodic fish kills. With eutrophication expected to increase, DO would continue to be of major concern under all alternatives. Increasing salinity, temperature fluctuations, and increases in Se concentrations may also adversely impact the Salton Sea fishery in the future.

A DO risk assessment model (Horn and Holdren, 2005) shows that there is a potential for DO levels to drop below 4 mg/L in the upper 3 m of the water column over 60 percent of the Sea's surface on any given night during the summer under current conditions. Similar results were predicted under most of the alternatives, indicating that low DO concentrations would continue to be a problem for fish in the Sea.

Hydrodynamic and thermodynamic modeling conducted by University of California-Davis was used to evaluate the hydrodynamics of the Salton Sea under various alternatives involving bisecting the Sea with a dam (Schladow, 2005). This modeling indicated that reducing the size of the Sea under various alternatives could result in intense and persistent thermal stratification for water depths greater than 10 m (33 feet). The main consequence of this stable stratification is that the Sea would switch from a polymictic system, i.e., with several mixing events per year, to a monomictic system, i.e., mixed for a relatively brief period in the winter. As a result of this stability and the expected continuing eutrophication, the hypolimnium of the Sea would be anoxic for most of the year. With the expected, extensive anoxia, H_2S and NH_3 would build up to unprecedented levels because of the lack of mixing.

Hydrodynamic and Thermodynamic Modeling: The field of hydrodynamics deals with the study of fluids in motion through the application of the physical laws pertaining to the conservation of mass, momentum, and energy. The field of thermodynamics is associated with the branch of physics that studies the effects of changes in temperature, pressure, and volume in physical systems. The models applied by the University of California at Davis combine hydrodynamic and thermodynamic principals. These models were used to evaluate changes in the Salton Sea that might occur as a result of implementation of Restoration Alternatives (Schladow, 2005).

The predicted rapid breakdown of the stratification would lead to a sudden redistribution of anoxia, H_2S, and NH_3 throughout the water column and to gaseous NH_3 and H_2S to the air. The effect of this could be an annual die off of most fish in the Sea and serious odor problems. There are also potential human health impacts, including headache and nausea, as well as more serious problems for sensitive individuals. Sediment re-suspension studies (Anderson, 2005) supported the results of the hydrodynamic model. Mixing is affected by lake morphometry; a sediment transport model developed by Hakanson (1982) indicated sediment transport and resuspension would be curtailed by those alternatives that divide the current Salton Sea.

Results presented by Amrhein (2005) indicate that the Sea currently generates about 75,000 to 78,000 metric tons of sulfide per year, resulting in a calculated sulfide concentration of 7.5 mg/L. At this concentration, sulfide oxidation alone could consume 14.5 mg/L of DO when the Sea mixes each year. This concentration is far higher than DO saturation levels in the Sea. Although this calculation is based on limited information, the results support the possibility that all oxygen could be eliminated by the predicted annual mixing events.

An analysis by Ruane (2006) found that oxygen demands in the Salton Sea were the largest reported in that author’s experience, which includes study of more than 110 large reservoirs. Oxygen demands in the Sea originate from decomposition of organic matter (algae) in the water column. When there is sufficient organic matter to consume all available oxygen during the decomposition process, bacterial processes then consume sulfate and nitrate, producing H_2S and NH_3. Salton Sea sediments contribute additional oxygen demand that could continue to be exerted even if algal growth was reduced in the future by controlling nutrient loadings to the Sea, although sediment oxygen demand would decrease over time in the absence of additional inputs of organic material.

Ruane (2006) calculated the total oxygen demands for the hypolimnion of a south marine lake alternative using the assumptions that the hypolimnetic volume was 1,600,000 acre-feet. This value corresponds to a thermocline originating at 4 m, which is typical of levels observed during the monitoring program and is also consistent with the thermocline depth predicted by Schladow (2005). The calculated total daily DO demands for the hypolimnion of the Sea ranged from 6.9 to 9.5 mg/L per day over the ranges of observed data and assumptions made, which equates to a daily oxygen demand of 15,000 to 20,600 tons that would have to be satisfied by external means to prevent the possibility of fish kills under future conditions. These results depend upon the thermocline depth and hypolimnetic volume, but not on the location of the marine lake.

Five main approaches could be used to reduce risks associated with low DO levels in the Salton Sea: (1) reduce nutrient inputs to a level that would lower algal productivity to acceptable levels, (2) avoid deep water to improve the efficiency of wind mixing, (3) mechanically circulate Sea water to improve reoxygenation, (4) use aeration/oxygenation/ozonation to directly increase DO concentrations, and (5) pump water out of the Sea and treat it by ozonation/oxygenation before returning the treated water to the Sea. Each of these approaches potentially has serious limitations and flaws.

Viability of Alternatives Relative to Environmental Factors

None of the current alternatives appear to be free of environmental concerns. In general, environmental conditions are likely to deteriorate, regardless of which alternative is selected. There are significant concerns for all alternatives with respect to increasing Se concentrations and requirements for dust abatement.

In addition to loss of the Sea’s fishery during the transition period when salinities will spike at 80,000 to 100,000 mg/L, the new equilibrium state for all alternatives including marine lakes (Alternatives Nos. 1, 2, and 4) is expected to be hypereutrophic, and low DO concentrations are expected without significant, and possibly unattainable, nutrient reductions from the watershed. Eutrophication and low DO levels, high Se concentrations, and fluctuating temperatures and salinities are potential problems in the SHC and concentric lakes created under Alternatives Nos. 1 thru 5.

Establishment of a viable fishery would be difficult under all alternatives with open water. All of the alternatives have significant adverse viability impacts. An additional alternative that could adapt to changing conditions and new information as the restoration proceeds should be considered. **Table 6.4** summarizes alternative viability study results. This table identifies variability in these results where appropriate. A summary of potential viability concerns for each alternative follows.

Table 6.4 Alternative viability assessment summary[1]

Alternative	Se risk to fish-eating breeding birds	Se risk to invertebrate-eating breeding birds	Hydrodynamic/ stratification risk	Eutrophication risk	Fishery sustainability risk
Alternative No. 1: Mid-Sea Dam with North Marine Lake	Moderate risk	Serious risk	Serious to high risk	Moderate risk	In Sea –Serious to High Risk: Salinity, DO, H_2S, NH_3 In Ponds – Moderate to Serious Risk: DO, temperature extremes
Alternative No. 2: Mid-Sea Barrier with South Marine Lake	Moderate risk	Serious risk	Low risk	Moderate to serious risk	In Sea –Serious to High Risk: DO, temperature extremes, salinity variations In Ponds – Moderate to Serious Risk: DO, temperature extremes
Alternative No. 3: Concentric Lakes	Serious risk	Serious risk	Low risk	Low to moderate risk	Moderate to Serious Risk: DO, temperature extremes
Alternative No. 4: North Sea Dam with Marine Lake	Moderate risk	Serious risk	Low risk	Moderate to serious risk	In Sea – Moderate to Serious Risk: DO, temperature extremes In Ponds – Moderate to Serious Risk: DO, temperature extremes
Alternative No. 5: Habitat Enhancement w/o Marine Lake	Moderate risk	Serious risk	Low risk	In ponds moderate risk	In Ponds – Moderate to Serious Risk: DO, temperature extremes
No-Project	Low risk	Serious risk	Low risk	Low risk	Fatal: Salinity

[1] Risk classified according to the following categories:

Fatal: Nothing can be done to alleviate the problems and issues

High risk: Problems can be dealt with by taking extreme measures that would likely result in other significant problems

Serious risk: Problems create significant threats that may be tolerable with significant mitigation measures in place

Moderate risk: Problems are evident and potentially significant and may require mitigation measures

Low risk: Problems are evident but would not require immediate mitigation measures

Alternative No. 1: Mid-Sea Dam with North Marine Lake

Under Alternative No. 1, the possibility of prolonged stratification, major die-offs of aquatic life, and salinity levels that would be too high to support a viable fishery would exist under the risk-based inflow approach. Eutrophication and hypolimnetic oxygen depletion are expected. The level of risk of stratification is uncertain and is shown in Table 6.4 as being from serious to high in nature. Existing modeling studies indicate that this risk could be reduced if operating water depths in the marine lake were reduced below 10 m (33 feet) (Schladow, 2005) which would correspond to an operating water surface elevation of -245 feet. Temperature fluctuations in the SHC also would be greater than those currently experienced, which could further limit the establishment of a viable fishery. Areas of potential concern with respect to Se for Alternative No. 1 include conveyance channels, 16,000 acres of created SHC, and the brine pool. The 4,000 acres of treatment wetlands on the New and Alamo Rivers included for

P removal are also of concern, as the same processes that remove P could also concentrate Se. Reclamation is currently studying Se issues at existing New and Alamo Rivers wetlands projects. These studies will provide additional insight into potential concerns relative to the concentration of Se in SHCs.

Approximately 103,800 acres of lake playa could be exposed under Alternative No. 1, and it is estimated that 70 percent of this acreage would require dust mitigation by 2040. Reclamation modeling indicates that there may not be sufficient quantities of brine available to use for the treatment method proposed under Alternative No. 1 for AQM.

Alternative No. 1 includes treatment plants to remove P if watershed measures do not remove enough P to reduce eutrophication. The SSA proposed this alternative and the treatment plant but has not provided designs. There is uncertainty that this treatment may or may not produce the desired results and, as such, there exists significant risk of eutrophication.

While Alternative No. 1 also includes ozonation to address DO problems, the amount of treatment proposed may be several orders of magnitude too low to solve the problem. Therefore, there is uncertainty that the ozonation process would be effective.

The treatment plants proposed by the SSA in Alternative No. 1 have not been proven for conditions existing at the Salton Sea. Even if they were to work, the plants would be as large as the biggest treatment plants in the United States.

Alternative No. 2: Mid-Sea Barrier with South Marine Lake

The marine lake in Alternative No. 2 is expected to have hypereutrophic conditions with occasional, severe oxygen depletion. Temperature fluctuations also would be greater than those currently experienced, which could further limit the establishment of a viable fishery. Furthermore, it is expected that it would be difficult to maintain a constant salinity under low inflow conditions in the south Sea formed by the barrier, which could create additional challenges for establishing a viable fishery. Areas of potential concern with respect to Se for Alternative No. 2 include conveyance channels, 21,700 acres of created saline habitat, and the brine pool. Under mean risk-based inflows, approximately 73,600 acres of lake playa could be exposed under Alternative No. 2, and it is estimated that 70 percent of this acreage would require dust mitigation by 2040.

Alternative No. 3: Concentric Lakes

The concentric lakes in Alternative No. 3 are expected to be shallow enough to be subjected to frequent mixing, but some oxygen depletion could still occur during the summer months as a result of the expected hypereutrophic conditions. Temperature fluctuations also would be high under this alternative, creating additional problems for establishment of viable fishery. Se is of particular concern for Alternative No. 3 because each of the lakes would form large shallow water habitats directly receiving and concentrating New and Alamo River water. Se concentrations are expected to be greater than 5 µg /L in each lake. These levels would create significant threats that may be tolerable with significant mitigation measures in place. Under mean risk-based inflows, approximately 65,000 acres of lake playa would be exposed under Alternative No. 3, and it is estimated that 70 percent for this acreage would require dust mitigation by 2040.

Alternative No. 4: North-Sea Dam with Marine Lake

Hypereutrophic conditions with occasional, severe oxygen depletion are also expected to occur under Alternative No. 4. Temperature fluctuations also would be greater than those currently experienced, which could further limit the establishment of a viable fishery. Areas of potential concern with respect to Se for Alternative No. 4 include conveyance channels, 37,200 acres of created saline habitat, and the brine pool. Under mean risk-based inflows, approximately 91,800 acres of lake playa could be exposed under Alternative No. 4, and it is estimated that 70 percent of this acreage would require dust mitigation by 2040.

Alternative No. 5: Habitat Enhancement without Marine Lake

No marine lake is associated with Alternative No. 5, and any fishery would be restricted to rivers, conveyance channels, and deep pools within the SHC. The shallow depths, expected eutrophic conditions, and fluctuating temperatures in these complexes would further limit creating a fishery. Areas of potential concern with respect to Se for Alternative No. 5 include conveyance channels, 42,200 acres of created saline habitat, and the brine pool. Under mean risk-based inflows, approximately 81,200 acres of lake playa could be exposed under Alternative No. 5, and it is estimated that 70 percent of this acreage would require dust mitigation by 2040.

Alternative No. 6: No-Project

Alternative No. 6, the No-Project Alternative, has no marine lake or created habitat, and has significant environmental concerns. Areas of potential concern with respect to Se for Alternative No. 6 include exposed sediments, river channels, and the brine pool. Under mean risk-based inflows, approximately 92,200 acres of lake playa could be exposed under Alternative No. 6, and it is estimated that 70 percent of this acreage would require dust mitigation by 2040.

Chapter 7. Costs of Alternatives

Reclamation coordinated closely with the State of California DWR and the Salton Sea Authority in developing the alternatives presented in this report. Consequently, both the State and Reclamation have analyzed alternatives that are conceptually similar, yet have some differences. Variation between agencies in approaches to risk, uncertainty, complexity, and other factors contribute to differences in designs and costs. While Reclamation's design and cost estimating criteria and guidelines may be different than those used by other agencies and this may lead to different design conclusions and project costs, Reclamation makes no judgment relative to methods, assumptions, and criteria used by others.

It was Reclamation's intention to provide the highest quality design and cost estimates within the constraints of funding, schedule, and available information. Available knowledge of geologic conditions, in particular, was limited.

These factors should be taken into consideration when comparing costs of alternatives presented in this summary report to those presented in DWR's draft PEIR and to reports prepared by other organizations.

Table 7.1 displays appraisal level estimates of subtotal construction and implementation costs of all alternatives, including the No-Project Alternative, using embankment designs that meet Reclamation's design criteria and guidelines. **Table 7.2** presents appraisal level annual recurring costs of all the alternatives. All appraisal level cost estimates are expressed in 2006 price levels for comparison purposes.

The costs of all alternatives are based on very limited geologic and geotechnical data that were obtained through exploration in years 2003 and 2004. Significant design uncertainties exist as a result of the limited amount of site information. Uncertainties also exist relative to constructability, seismic performance, static performance, and construction costs. These uncertainties can only be reduced by conducting significant geologic and geotechnical design data collection programs.

Specific schedules that take into account the construction duration of each alternative feature have not been developed. Without consideration of construction durations, cost escalation during construction cannot be properly evaluated. The appraisal level cost estimates provided in this chapter do not include funds for escalation during construction and the time leading up to construction. Escalations during construction are expected to be a very significant dollar amounts given the size and cost magnitude of the various restoration alternatives presented here.

Table 7.1 Alternatives and Associated Component Construction Costs [1]

Alternative Components	Alternative No. 1A: Mid-Sea Dam with North Marine Lake using Sand Dam Design with Stone Columns	Alternative No. 2A: Mid-Sea Barrier with South Marine Lake using Sand Dam Design with Stone Columns	Alternative No. 3A: Concentric Lakes using Sand Dam Design with Stone Columns [3]	Alternative No. 4: North-Sea Dam with Marine Lake using Sand Dam Design with Stone Columns	Alternative No. 5: Habitat Enhancement without Marine Lake	Alternative No. 6: No-Project
1. Mid-Sea Dam	$2,210,287,846					
2. West and East Perimeter Dikes	$543,400,979					
3. South-Sea Dam	$954,557,582					
4. Mid-Sea Barrier		$605,723,577				
5. Three Concentric Lake Dikes			$6,754,900,211			
6. Concentric Lakes - Habitat Islands and Deep Areas			$181,119,163			
7. Concentric Lakes - Lake Cell Divider Structures			$44,346,843			
8. North Sea Dam				$4,519,967,738		
9. Earthen Dikes for Habitat Ponds	$215,568,000	$292,364,100		$501,195,600	$568,560,600	
10. Habitat Ponds - Habitat Islands and Deep Areas	$246,651,333	$334,514,933		$573,455,600	$650,532,267	
11. Water Conveyance Features	$314,915,017	$201,680,735	$799,914,684	$193,488,011	$272,282,161	$58,896,420
12. Water Treatment Facilities	$218,000,000					
13. Air Quality Mitigation - via Water Vegetation Features	$762,930,000	$540,960,000	$477,750,000	$674,730,000	$596,820,000	$677,670,000
14. Air Quality Mitigation - via Other Features	$152,586,000	$108,192,000	$95,550,000	$134,946,000	$119,364,000	$135,534,000
Subtotal Construction Costs[2]	**$5,618,896,757**	**$2,083,435,345**	**$8,353,580,901**	**$6,597,782,949**	**$2,207,559,028**	**$872,100,420**
Unlisted Items: 10%	$581,103,243	$216,564,655	$846,419,099	$702,217,051	$192,440,972	$87,899,580
Total Contract Costs	$6,200,000,000	$2,300,000,000	$9,200,000,000	$7,300,000,000	$2,400,000,000	$960,000,000
Contingencies: 25%	$1,500,000,000	$600,000,000	$2,300,000,000	$1,800,000,000	$600,000,000	$240,000,000
Total Field Costs	$7,700,000,000	$2,900,000,000	$11,500,000,000	$9,100,000,000	$3,000,000,000	$1,200,000,000
Non-Contract Costs: 20%	$1,500,000,000	$600,000,000	$2,500,000,000	$1,900,000,000	$600,000,000	$200,000,000
Total Project Implementation Costs	**$9,200,000,000**	**$3,500,000,000**	**$14,000,000,000**	**$11,000,000,000**	**$3,600,000,000**	**$1,400,000,000**

[1] Costs presented are for alternatives using embankment designs that meet Reclamation design criteria and standards.

[2] Includes mobilization costs estimated at 5 percent.

[3] Total project implementation costs assuming four concentric lakes for Alternative No. 3A is $17,800,000,000

Table 7.2 Summary of Annual Reoccurring Costs of Restoration Alternatives ($ million)

Alternative	Annual Operations, Maintenance, and Energy (OM&E) Costs	Annual Replacement Costs	Annual Operations, Maintenance, Energy, and Replacement (OME&R) Costs	Annual Risk Costs [2]	Annual Operations, Maintenance, Energy, Replacement, and Risk (OMER&R) Costs
Alternative No. 1A: Mid-Sea Dam with North Marine Lake using Sand Dam Design with Stone Columns	148	87	235	5	240
Alternative No. 2A: Mid-Sea Barrier with South Marine Lake using Sand Dam Design with Stone Columns	71	62	133	3	136
Alternative No. 3A: Concentric Lakes using Sand Dam Design with Stone Columns [1]	64	55	119	1	120
Alternative No. 4: North-Sea Dam with Marine Lake using Sand Dam Design with Stone Columns	89	77	166	6	172
Alternative No. 5: Habitat Enhancement without Marine Lake	79	68	147	7	154
Alternative No. 6: No-Project	87	77	164	0	164

[1] Costs shown are for three concentric lakes as required under mean possible future inflow conditions.

[2] Risk costs are defined as the annualized cost of repairing structures calculated from estimated annualized probabilities of failure (from major seismic events) and from estimates of how much of a structure would have to be repaired as a result of the failure.

The following sections of this chapter describe the various components of the appraisal level cost estimates**.**

Total Project Implementation Costs

The estimating process for alternative features involved application of models and equations to determine major construction material quantities and placement requirements. Unit prices per physical quantity were developed and then applied to physical quantities to develop the subtotal construction cost estimates. Unit prices included estimates of initial mobilization of contractor personnel and equipment to the project site during start-up.

Some appraisal level cost estimates for other less costly features were developed in a different manner. For example, the construction costs for the AQM features relied heavily on estimates presented by the State of California in its Salton Sea Ecosystem Restoration Program Draft Programmatic Environmental Impact

Report (DWR, 2006). The construction costs for the water treatment facilities in Alternative No. 1 were based on estimates developed by the SSA. These treatment plant estimates were not verified by Reclamation and they could be significantly understated.

In accordance with the Reclamation's cost estimating guidelines, a 10-percent allowance, based upon engineering judgment, was added to subtotal construction costs to cover unlisted items of work that would appear in the specifications and would be required for a fully finished feature. The sum of subtotal construction costs and unlisted items is termed "contract costs", as shown in **Table 7.1**.

A 25-percent allowance for "contingencies", based upon engineering judgment, was added to contract costs to address the differences between actual and estimated quantities, unforeseeable difficulties at the site, possible minor changes in plans, and other uncertainties. As shown in **Table 7.1**, the sum of contract costs and contingencies equals "total field costs."

"Non-contract costs" were estimated to be 20 percent of the total field costs. This allowance was based on review of non-contract costs from past large Reclamation projects. Non-contract costs reflect some or all of the following items: services facilities, investigations and studies including environmental compliance, design data collection, final designs and specifications, permits, construction engineering and management, and other general expenses.

The sum of total field costs and non-contract costs is equal to the "total project implementation costs", which are the total estimated costs of putting any of the alternatives fully in service. As shown in **Table 7.1**, these costs range from a low of $1.4 billion for the No-Project Alternative (Alternative No. 6) to a high of $14.0 billion for Alternative No. 3A, expressed in 2006 prices.

Costs provided in **Table 7.1** reflect application of embankment designs to the alternatives that would meet Reclamation's general design criteria and guidelines as listed in **Table 3.7**. **Attachment A** at the back of this report presents subtotal construction and implementation costs for the alternatives using embankment designs that would not meet Reclamation's general design criteria and guidelines as follows:

- Alterative No. 1B: Mid-Sea Dam with North Marine Lake – Original SSA alignment using SSA rockfill design. This alternative includes 12,000 acres of saline habitat complex.
- Alternative No. 2B: Mid-Sea Barrier with South Marine Lake using sand dam design without stone columns.

Table 7.3 Summary of Restoration and Air Quality Mitigation Project Implementation and OMER&R Costs ($ million)

Alternative	Restoration project implementation costs	AQM project implementation costs	Total project implementation costs	Annual restoration OMER&Risk costs	Annual AQM OM&R costs	Total OMER&R costs
Alternative No. 1A: Mid-Sea Dam with North Marine Lake using Sand Dam Design with Stone Columns	7,600	1,600	9,200	56	184	240
Alternative No. 2A: Mid-Sea Barrier with South Marine Lake using Sand Dam Design with Stone Columns	2,400	1,100	3,500	5	131	136
Alternative No. 3A: Concentric Lakes using Sand Dam Design with Stone Columns [1]	13,000	1,000	14,000	5	115	120
Alternative No. 4: North-Sea Dam with Marine Lake using Sand Dam Design with Stone Columns	9,700	1,300	11,000	9	163	172
Alternative No. 5: Habitat Enhancement without Marine Lake	2,400	1,200	3,600	10	144	154
Alternative No. 6: No-Project	0	1,400	1,400	0	164	164

[1] Costs shown are for three concentric lakes as required under mean possible future inflow conditions.

- Alternative No. 3B: Concentric Lakes using sand dam design without stone columns.
- Alternative No. 3C: Concentric Lakes using Geotube® embankment design (as proposed by the Imperial Group).

Alternative No. 1B uses the SSA's rockfill embankment design which includes the use of geocomposite filters. Use of geocomposite filters would likely result in constructability problems and unreliable filter performance.

Alternative No. 2A includes stone columns to reduce seismic risk; Alternative No. 2B does not include stone columns. These two sets of costs provide for an understanding of the costs associated with reducing seismic risk.

Costs provided in **Table 7.1** and in **Attachment A** for the Concentric Lakes Alternative Nos. 3A, 3B, and 3C assume the need for three concentric lakes as described in Chapter 3. Footnotes are provided in both **Table 7.1** and **Attachment A** that show implementation costs of four concentric lakes as proposed by the Imperial Group. Alternative No. 3A uses an embankment design that includes stone columns and, as such, would provide for reduction of both static and seismic risks. Alternative No. 3B does not include stone columns and would carry with it seismic risks that would not occur in Alternative No. 3A, which does include stone columns. Alternative No. 3C involves use of Geotubes® as proposed by the Imperial Group. Constructing concentric lake dikes using Geotubes® would result in significant seismic, static, and constructability problems. These three sets of costs for the Concentric Lakes Alternatives provide an understanding of the costs associated with reducing static and seismic risk.

Annual Operation, Maintenance, Energy, Replacement, and Risk Costs

Annual operations, maintenance, energy, replacement, and risk (OMER&R) costs (**Table 7.2**) were developed by Reclamation at a relatively low level of detail because those costs for the restoration alternatives, incremental to the No-Project Alternative, are small relative to initial project implementation costs. Costs were included for staff, office space, vehicles, materials, and pumping energy. Reclamation relied on information from DWR's Salton Sea Ecosystem Restoration Program Draft PEIR (DWR, 2006) for operation and replacement costs of AQM features. Finally, for Alternative No. 1, only, Reclamation relied on an estimate for operation of the water treatment facilities prepared by the SSA. These treatment plant costs were not verified by Reclamation and they could be significantly understated.

The Salton Sea is located in an area with a history of earthquakes of sufficient magnitude to cause significant damage to the constructed features of the various alternatives, i.e., the dams, dikes, barriers, habitat islands, conveyance facilities, and treatment facilities. Repair and replacement costs for each of these features were estimated to range from 10 to 50 percent of original project implementation costs, depending on the type of structure and how it was designed. No damage from potential seismic activity was assumed for the AQM features. The annual probability of failure was estimated for each of the facilities susceptible to earthquake damage for all alternatives. The annual probability of failure for each potentially earthquake-damaged feature was multiplied by the estimated repair and replacement costs for that feature to derive the "annual risk cost" associated with its location in an active seismic area. For the Concentric Lakes Alternative with Geotubes® (No. 3C) an additional annual risk cost was considered for repair and replacement of significant portions of the dikes due to expected foundation piping and erosion problems (static risk problems).

The annual operation, maintenance, replacement, and energy costs were added to the annual risk cost for each alternative to derive the total OMER&R costs, as shown in **Table 7.2**. These costs are lowest for Alternative No. 3A and highest for Alternative No. 1A.

Summary of Restoration and Air Quality Mitigation Costs

AQM costs would be incurred whether or not any of the restoration features are constructed, as playas are exposed over time. As noted previously, the No-Project Alternative consists entirely of this cost. AQM costs for all alternatives were estimated using construction costs consistent with DWR's Salton Sea Ecosystem Restoration Plan. Construction costs for mitigation using water-efficient vegetation were assumed to be $14,000 per acre. Construction costs for mitigation using other methods was $7,000 per acre. **Table 7.3** presents implementation costs of restoration features and AQM features separately. OMER&R cost data for each alternative are also summarized in **Table 7.3,** divided between restoration features and AQM. The values presented in **Table 7.3** for the Concentric Lakes Alternatives assume the need for three lakes, as discussed in Chapters 3 and 4. Only three lakes would be required under mean possible future inflows. It is assumed the State of California will manage AQM in coordination with landowners and other stakeholders as may be applicable by Federal and State laws, regulations, ordinances, and legal agreements.

Chapter 8. Economic Analyses

Conceptual Overview

Federal standards for planning and economic evaluation of water resource projects are contained in the 1983 *Economic and Environmental Principles and Guidelines for Water and Related Land Resources Implementation Studies*, commonly referred to as the P&Gs. In terms of economic analysis, the P&Gs establish two accounts to facilitate the evaluation and display of the effects of alternative plans: national economic development (NED) and regional economic development (RED). As implied, the NED account shows effects on the entire national economy, while the RED account shows the regional (or local) income and employment effects. Most "multiplier" effects, which occur as dollars initially spent in the regional economy are successively re-spent, are considered to be transfers from other locations in the Nation and are not counted as NED benefits.

The P&Gs establish that the beneficial and adverse effects of all alternative plans should be measured incrementally against the most likely future condition without a plan -- the No-Project Alternative. To the extent possible, the economic analysis quantified NED benefits and costs for a 72-year period of analysis, 2006–2077. This period of analysis was selected because the 75-year project period for the existing Salton Sea Ecosystem Restoration Program ends in 2077. In accordance with the P&Gs, quantifiable benefits and costs over this period of analysis were converted to 2006 present worth values using the fiscal year 2006 Federal discount rate of 5.125 percent. Any economic effects beyond the period of analysis have minimal value in present worth terms.

The present worth costs presented in this chapter differ from the implementation costs shown in Chapter 7. Present worth analysis requires the conversion of all cash flows to a common point in time—the present. As such, it requires consideration of the time value of money, and all future cash flows are discounted back to the present. Comparison of the equivalent worth of competing alternatives allows comparison of alternatives on the basis of economics. This type of analysis is normally prepared when conducting Reclamation feasibility studies, and the process is followed to the best degree possible in this study.

For the purposes of comparing cost of alternatives as designed and estimated by other agencies, such as the DWR and the SSA, care should be taken to determine what types of costs they are reporting. Most likely they are not performing present worth analyses and are presenting implementation costs as presented in **Table 7.1** of this report.

National Economic Development (NED) Costs

From a national perspective, all costs potentially incurred for the Salton Sea restoration alternatives and the No-Project Alternative are relevant without respect to whether those costs are incurred by the Federal Government, the State of California, local governmental agencies, or private citizens. In this study, NED costs consist of initial implementation costs for construction and program development, plus recurring annual operation, maintenance, energy, replacement, and risk (OMER&R) costs, as described and displayed in Chapter 7.

All NED costs were adjusted for time of occurrence and converted to present worth values in year 2006 dollars, as shown in **Table 8.1**. For purposes of this analysis, it was assumed that project implementation costs would begin to be expended in year 2008 and would be expended in equal annual increments. It was further assumed that construction of restoration features for any of the alternatives would be completed in year 2024, and AQM construction costs would be incurred through 2040. Under this schedule, prorated OMER&R costs for AQM would begin in 2009, but OMER&R costs for restoration features would not begin until 2025, the first year after those features are complete.

The incremental NED costs of each alternative, over and above those of the No-Project Alternative, also are shown in **Table 8.1**. NED costs are only provided for embankment design concepts that have been determined to meet Reclamation’s design criteria and guidelines as described in Chapter 3. NED costs in **Table 8.1** for the Concentric Lakes Alternative (Alternative No. 3A) represent costs for three concentric lakes as required under mean possible future inflow conditions.

The present worth project implementation costs are less than the project implementation costs displayed in **Table 7.1** to represent the fact that project costs would be expended over time, and, due to interest accumulation, the amount needed in 2006 would be less than if all costs were expended in that year. The present worth OMER&R costs in **Table 8.1** are more than the OMER&R costs in **Table 7.1** because **Table 7.**1 displays costs for only one year, and **Table 8.1** displays the present worth of the total amount for the 72-year period of analysis.

NED Benefits

The potential environmental improvements at the Salton Sea, as compared to the No-Project Alternative, represent the basis for NED benefits for each alternative. Although there are risks and uncertainties, each of the alternatives might prevent further environmental degradation in varying degrees. These risks and uncertainties involve future inflows, biology, and environmental viability issues as presented in Chapters 4, 5, and 6 of this report.

Table 8.1 NED costs of alternatives, present worth basis, expressed in 2006 millions of dollars using 5.125% discount rate

Alternative	Project implementation costs	OMER&R costs	Total	Incremental to No-Project Alternative
Alternative No. 1A: Mid-Sea Dam with North Marine Lake using Sand Dam Design with Stone Columns	5,500	1,900	7,400	5,400
Alternative No. 2A: Mid-Sea Barrier with South Marine Lake using Sand Dam Design with Stone Columns	2,000	1,100	3,100	1,100
Alternative No. 3A: Concentric Lakes using Sand Dam Design with Stone Columns [1]	8,600	1,000	9,600	7,600
Alternative No. 4: North-Sea Dam with Marine Lake using Sand Dam Design with Stone Columns	6,600	1,400	8,000	6,000
Alternative No. 5: Habitat Enhancement without Marine Lake	2,000	1,300	3,300	1,300
Alternative No. 6: No-Project	600	1,400	2,000	0

[1] Values shown are for three concentric lakes as required under mean possible future inflow conditions.

Economists typically distinguish between use values and nonuse values in addressing benefits to be gained from enhancement of environmental resources. Use values refer to the values derived by individuals who physically “use” the resource; in the case of Salton Sea, these are the recreation visitors who come to the Sea. Nonuse values relate to the values ascribed by other individuals who may never visit or otherwise “use” the resource. Some people may derive satisfaction, or value, from potential habitat improvements at the Salton Sea, both for their own sake and for future human generations. However, as explained later in this chapter, it was not possible to compute dollar estimates of nonuse value for the Salton Sea alternatives considered in this study.

Recreation Benefits

Although recreation visitation at the Salton Sea has diminished from historical highs, current visitation is still significant, estimated at approximately 340,000 visits annually. The most popular activities include bird-watching, fishing, boating, camping, picnicking, and hunting. The largest single recreation attraction is the Salton Sea State Recreation Area, followed by the Sonny Bono Salton Sea NWR, and the Wister Unit of the Imperial Wildlife Area. Recreation also occurs at a number of unmanaged public and private access points around the Sea. Based on a number of studies across the West, the average value for primary recreation activities was estimated be about $63 per visit, or $21.4 million total annually.

Under the No-Project Alternative and all restoration alternatives, the present worth of recreation is expected to significantly decline, as compared to the current level.

Under the No-Project Alternative, there would be large reductions in surface elevation and area of the Sea. It is estimated that even under the restoration alternatives, environmental degradation would occur at the Sea for the next 18 years in the same pattern as under the No-Project Alternative, until facilities and programs are in place and the process of restoration begins. Therefore, under such a future, because benefits are measured against the No-Project Alternative, there would be no recreation benefits realized in that time period.

All recreation benefits for the restoration alternatives would be realized in the years after the Sea begins to recover, when they are worth much less than current value in present worth terms. Given the significant risk and uncertainty associated with alternatives and the distant time frame involved, recreation benefits were not estimated individually for each of the alternatives. However, under an assumed recovery period with restoration, the present worth of NED recreation benefits would be about $106 million. These benefits are far less than the present worth of incremental NED costs for any of the restoration alternatives, which range from $1.1 to $7.6 billion, as presented in **Table 8.1**.

Nonuse Environmental Benefits

Reclamation acknowledges that the Salton Sea has non-use environmental benefits. The benefits of Salton Sea environmental enhancements may be higher to some individuals across the Nation who never visit the Sea than to the individuals who do. A common technique used to determine nonuse values is "contingent valuation," a rather complex and lengthy survey process in which individuals are asked to express their willingness to pay for enhancements. It is important in this technique to be specific about the nature of the environmental improvements, and it is desirable to quantify the improvements in physical terms. There are significant risks and uncertainties concerning the quantity of future inflows, quality of habitat, and associated water quality conditions to be achieved under each of the alternatives. Due to a lack of funding and adequate time, a site-specific contingent valuation survey was not conducted. If a survey had been conducted that presented to the participants the high uncertainty of success associated with any of the alternatives, it is likely that respondents would have returned relatively low willingness to pay values. A survey would have to clearly identify these uncertainties. The fact that restoration alternatives have continued to evolve through the study would have further complicated a survey process.

Without a dollar measure of nonuse benefits, it is not possible to complete the benefit-cost analysis of alternatives contemplated by the P&Gs. However, with such high NED costs and the potential that survey responses could result in low willingness to pay values, it is not clear that that any of the restoration alternatives would have NED benefits that exceed NED costs.

As a means to analyze the worth of alternatives in a relative sense, a cost effectiveness technique was employed that considered risk and uncertainty. Cost effectiveness cannot be used to identify whether the NED benefits of any or all of the alternatives exceed the NED costs, but it can be used to assess the relative cost between alternatives of creating habitat acres whereby it is assumed that habitat acres are proportionate to the economic benefits.

Cost Effectiveness and Risk

For the cost effectiveness analysis for the Salton Sea, the incremental NED cost of a restoration alternative was divided by the number of habitat acres (combined open water and shoreline habitat) developed by the alternatives by the year 2040, resulting in a derived “dollars per acre” value. Habitat acres serve as a “proxy” for environmental improvement benefits; in other words, it is assumed that habitat acres are proportionate to the economic benefits, had the latter been quantified. With substantial risks associated with each alterative this approach must be tempered with consideration of risk, and the potential variability in these risks, in an attempt to minimize costs per acre while at the same time minimizing risks. Without consideration of risk, alternatives with lower costs per acre could be viewed more favorably than other alternatives with higher costs per acre. Risk factors considered are as follows:

- Se risks to fish-eating birds
- Se risks to invertebrate-eating birds
- Hydrodynamic / stratification risks
- Eutrophication risks
- Fishery sustainability risks
- Future inflow risks

The risks for each of these factors are qualitatively identified in Chapters 4 and 6.

Figure 8.1 displays the results of the cost effectiveness and risk evaluation for the Salton Sea. Both NED costs and habitat acres are incremental to the No-Project Alternative. (There are no productive habitat acres in 2040 under the No-Project Alternative.) Composite risks are not quantified numerically, but are displayed in **Figure 8.1** as low, moderate, serious, or high. The relative composite risks shown are an average of all the risks listed above and represent an index of risk to be used for comparison purposes. Some viability risks shown in **Table 6.4** are shown as ranges. The variability in composite risks shown in **Figure 8.1**

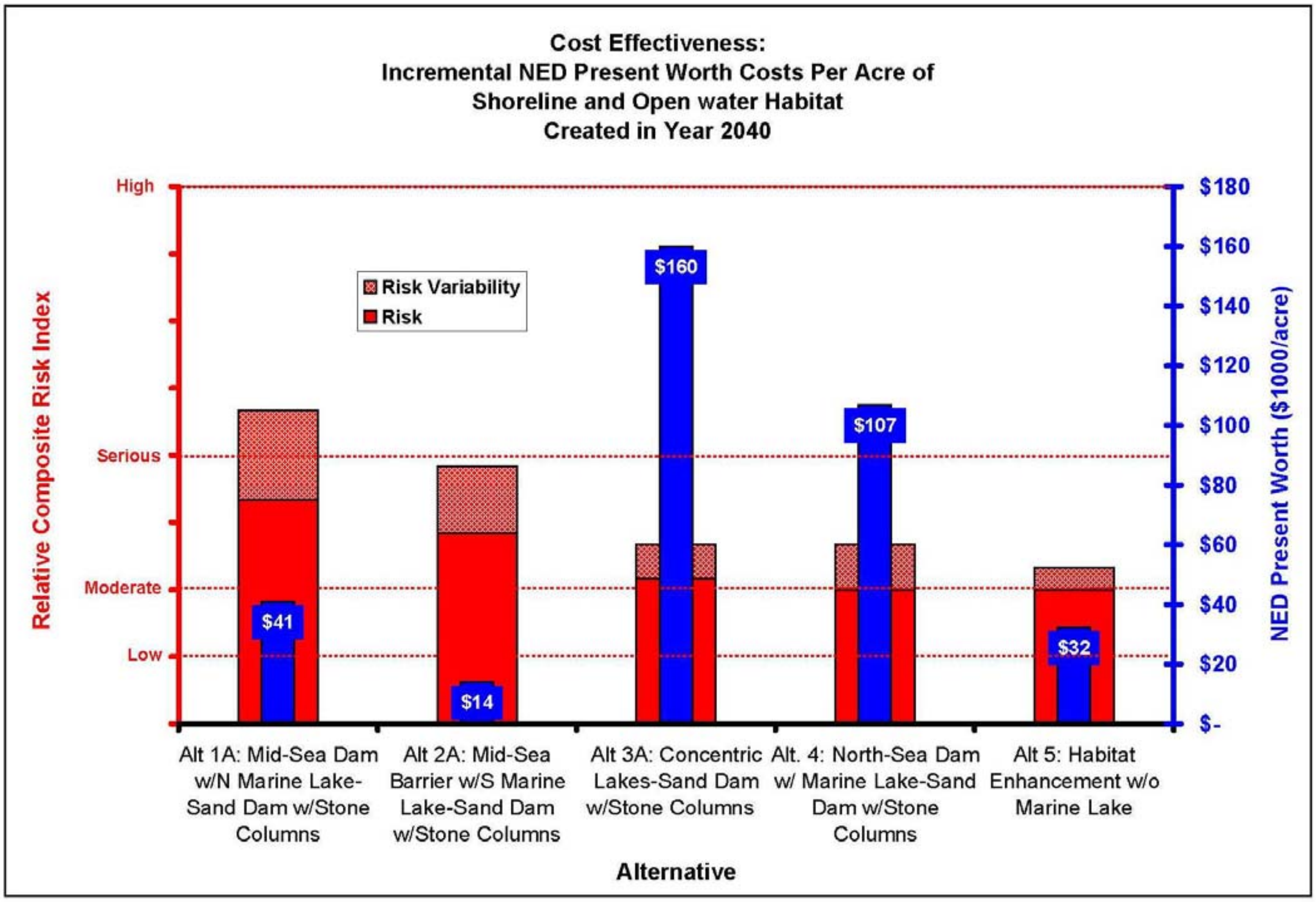


Figure 8.1 Cost effectiveness (NED present worth costs per acre of shoreline and open water habitat created in year 2040).

are in a lighter color of red. The mid-Sea barrier alternative (No. 2A) minimizes the costs per acre of habitat created without consideration of risk and would appear to be the most cost effective. However, the risks associated with this alternative are higher than for all other alternatives, except Alternative No. 1. Of the alternatives that offer less risk than Alternative No. 2A, Habitat Enhancement without Marine Lake (Alternative No. 5), has the next lowest cost and is the alternative that has the least risk. In consideration of both costs and risks, Alternative No. 5 minimizes both risk and costs as a means for providing shoreline and open water habitat. The composite risks index for this alternative is **moderate,** which would indicate that “on average” problems would potentially be significant and may require mitigation. When looking at specific risks listed in **Table 6.4,** it is clear that Se risks to breeding birds and fishery sustainability problems would be serious under this alternative, which implies that these problems would create significant threats that may be tolerable with significant mitigation measures in place.

Regional Economic Development (RED)

The preceding discussion dealt with the NED account. At the regional level, any of the restoration alternatives would cause positive economic output, as compared to the No-Project Alternative. There are three potential sources of these regional effects: recreation visitor expenditures, induced economic growth, and project construction and operation expenditures. Of these, construction expenditures is considered to be the most significant and is the only impact evaluated in dollar terms.

It was assumed that because the No-Project and the restoration alternatives would result in the same pattern of environmental degradation for the next 18 years until restoration facilities and programs are operational, there will be no differences in recreation expenditures or in residential and commercial activity around the Sea in that time frame. As previously noted, recreation visitation will increase after year 25 as the Sea recovers, as compared to No-Project. To the extent that the increased visitation comes from individuals outside the region, and they spend money for food, lodging, gasoline, and other travel-related items, then RED effects (income and employment) would occur.

Similarly, to the extent that the Sea starts becoming a more aesthetically pleasing location to reside and work after year 18, and any increased residential and commercial development near the Sea would not have occurred elsewhere in the region, there would be a positive impact on the regional economy. Growth has recently been occurring around the Sea, but it is likely due to the availability of affordable housing for service workers in the relatively more expensive greater Palm Springs area.

Property values could diminish from current levels until restoration begins, and increase after that. Because there is no incremental impact on property values for nearly two decades, with the restoration alternatives compared to the No-Project, these values were not estimated.

The main near-term RED effect between the restoration alternatives and the No Project Alternative would be the considerable construction expenditures that occur as soon as one of the alternatives is implemented.

The modeling package used in this study to assess the regional economic effects of construction of each alternative is IMPLAN (IMpact Analysis for PLANning). IMPLAN is an economic input-output modeling system that estimates the effects of economic changes in an economic region.

IMPLAN data files were compiled for the study area from a variety of sources, including the U.S. Bureau of Economic Analysis, the U.S. Bureau of Labor, and the U.S. Census Bureau. This analysis uses 2003 IMPLAN data for California's

Imperial and Riverside Counties. The total of these two counties comprises the study area for the RED analysis.

The expenditures associated with each of the alternatives were placed into categories that represent different sectors of production in the economy. The expenditures that are made inside the study region were considered in the regional impact analysis. Expenditures made outside the two-county area were considered “leakages” and would have no impact on the local economy.

Because of the enormous scale of the restoration alternatives, it was assumed that local suppliers and contractors would be able to supply only a small portion (1 percent) of the necessary materials, equipment, and expertise. Construction of the restoration alternatives would involve major construction companies that do not have a presence within the study area. Therefore, the RED study assumed that the workforce associated with these major construction companies would temporarily move to the region and spend their wages inside the area during the construction period. In contrast to the restoration features, 50 percent of the water efficient vegetation AQM expenditures (for AQM projects) take place in the region because of the large number of irrigation related suppliers and service companies within the region. The analysis also assumed that 30 percent of the other AQM expenditures would take place within the region.

This analysis also assumed that the vast majority of the construction expenditures would be funded from sources outside the two-county study area. Money from outside the region that is spent on goods and services within the region would contribute to regional economic impacts, while money that originates from within the study region is much less likely to generate regional economic impacts. Spending from sources within the region represents a redistribution of income and output rather than an increase in economic activity.

For the purpose of this study, the total implementation costs less non-contract costs were used to measure the overall regional impacts. These overall impacts would be spread over the construction period and would vary year-by-year proportionate to actual expenditures.

RED Results

Regional economic impacts, incremental to the No-Project Alternative, for each restoration alternative that includes embankment design concepts that have been determined to be acceptable relative to Reclamation’s design criteria and guidelines are shown in **Table 8.2**. Impacts shown in **Table 8.2** for the Concentric Lakes Alternative (Alternative No. 3) are representative of developing three concentric lakes as required under mean possible future inflow conditions.

Table 8.2 Regional economic impacts from construction of each alternative, incremental to No-Project Alternative, compared to the economy of Imperial and Riverside Counties

Alternative	Employment [1] (number of jobs)		Output [2] (millions $)		Income [3] (millions $)	
	Total	Percent of the total regional economy	Total	Percent of the total regional economy	Total	Percent of the total regional economy
Regional Economy	771,690		75,488		16,306	
Alternative No. 1A: Mid-Sea Dam with North Marine Lake using Sand Dam Design with Stone Columns	22,767	3%	2,302	3%	760	5%
Alternative No. 2A: Mid-Sea Barrier with South Marine Lake using Sand Dam Design with Stone Columns	4,819	1%	485	1%	151	1%
Alternative No. 3A: Concentric Lakes using Sand Dam Design with Stone Columns [4]	35,493	5%	3,590	5%	1,171	7%
Alternative No. 4: North-Sea Dam with Marine Lake using Sand Dam Design with Stone Columns	27,250	4%	2,756	4%	903	6%
Alternative No. 5: Habitat Enhancement without Marine Lake	5,258	1%	528	1%	165	1%

[1] Employment is measured in the number of jobs.

[2] Output represents the value of industry production.

[3] Income is the value of total payroll (including benefits) for each industry in the region plus income received by self-employed individuals located within the region.

[4] Values shown are for three concentric lakes as required under mean possible future inflow conditions.

The employment, output, and income generated from each alternative's expenditures are compared to the overall regional economy. The majority of the employment, output, and income impacts are due to the expenditures of the wages earned by the workforce involved in the construction project. Employment is measured in the number of jobs. Output represents the dollar value of industry production. Income is the dollar value of total payroll (including benefits) for each industry in the region plus income received by self-employed individuals located within the region.

Chapter 9. Preliminary Discussion of Restoration Study Findings

Substantial risk and uncertainties are associated with all the restoration alternatives proposed in this study. These risks are directly associated with a lack of data and/or uncertainty involving the description, implementation, and subsequent performance of each of the proposed alternatives. Risk must be considered in economic analyses to determine the most favorable method of replacing lost habitat (primary objective) at the Salton Sea. Following is a discussion of risks, uncertainties in the costs of the alternatives, cost effectiveness, and considerations for the future.

Risks to Alternatives

A comparison of alternative viability risks and costs for creating habitat for each of the restoration alternatives is presented in **Figure 8.1**. This chart contains information for alternatives with embankment design concepts that have been determined to be meet Reclamation's design criteria and guidelines as described in Chapter 3. The relative risk comparison was developed by averaging risks associated with inflows and environmental factors that are discussed in Chapters 4 and 6. Viability risks are presented in detail in **Table 6.4**. The following risks were considered in the development of the comparison chart:

- Se risks to fish-eating birds
- Se risks to invertebrate-eating birds
- Hydrodynamic / stratification risks
- Eutrophication risks
- Fishery sustainability risks
- Future inflow risks

Alternative No. 1: Mid-Sea Dam with North Marine Lake

Alternative No. 1 offers the highest risk of the action alternatives. This alternative is proposed by the SSA. The water surface in the marine lake would need to be allowed to fluctuate with inflow. Limited fluctuations were considered in evaluating this alternative. The alternative was evaluated assuming an operating water surface elevation in the lake of -238 feet, which is 8 feet lower than the elevation originally proposed by the SSA. Operating at a constant elevation of -230 feet would require a guaranteed minimum water supply. All alternatives were modeled using the risk-based approach to inflows as described in Chapter 4. Model results for Alternative No. 1 indicate that in 2040 that mean future salinity would be 58,000 mg/L (see **Figure 4.4**), which is very close to the 60,000 mg/L salinity threshold for a sustainable fishery. After construction is completed in 2024, salinity in the marine lake would not fall below 60,000 mg/L until year 2038. A fishery would not be potentially viable until after this time. The early start features described in the discussion of SHCs in Chapter 3 would be necessary to maintain a viable fishery prior to 2038. With an operating water surface elevation of -238 feet, the salinity threshold of 60,000 mg/L would be exceeded in year 2040 in more than half of the possible future inflow conditions unless the lake elevation was dropped further below -238 feet. If future inflow conditions are significantly above mean possible estimates then the operating elevation of the marine lake could be higher and potentially at a level consistent with the SSA's target of -230 feet.

The alternative could pose serious to high risks associated with thermal stratification and associated H_2S and NH_3 problems. The alternative could also pose serious Se risks to invertebrate eating breeding birds, with potentially moderate risk of eutrophication problems (see **Table 6.4**).

Alternative No. 2: Mid-Sea Barrier with South Marine Lake

Alternative No. 2 offers the second highest risk of the action alternatives. The serious to high composite risk shown in **Figure 8.1** for this alternative is the result of potentially high risks to the fishery from DO problems, temperature extremes, and salinity variations. The alternative could also pose serious Se risks to invertebrate eating breeding birds, with potentially serious risk of eutrophication problems (see **Table 6.4**).

Alternative No. 3: Concentric Lakes

Alternative No. 3 offers the higher risk than Alternative No. 5. The moderate to high composite risk shown in **Figure 8.1** for this alternative is the result of potentially serious risks to the fishery from DO problems and temperature extremes. The alternative could also pose serious Se risks to invertebrate eating breeding birds, with potentially moderate risk of eutrophication problems (see **Table 6.4**).

Alternative No. 4: North-Sea Dam with Marine Lake

Alternative No. 4 offers similar risk to Alternative No. 3. This alternative provides for a marine lake on the north end of the Sea that would receive only Whitewater River inflows. Large habitat enhancements would be provided on the south end of the Sea through construction of SHC. Maintaining a fishery in the marine lake could pose potentially serious risks from DO problems and temperature extremes. This alternative could also include serious Se risks to invertebrate eating breeding birds, with moderate to serious risk of eutrophication problems (see **Table 6.4**).

Alternative No. 5: Habitat Enhancement without Marine Lake

Alternative No. 5 offers the lowest risk of the action alternatives. This alternative provides for habitat enhancement without a marine lake. The habitat enhancements would be provided through construction of SHC on a very large scale that could exceed historic shoreline habitat values. This alternative could pose serious Se risks to invertebrate eating breeding birds, with a potentially moderate risk of eutrophication problems (see **Table 6.4**).

Discussion of Cost of Alternatives

Table 7.1 displays appraisal level estimates of construction and initial implementation costs for each alternative. **Table 7.2** presents recurring operational costs of all alternatives, including the No-Project Alternative. The costs of all alternatives are based on very limited geologic and geotechnical data that were obtained through exploration in years 2003 and 2004. Significant design uncertainties exist as a result of the limited amount of site information. These design uncertainties, in turn, create uncertainties regarding embankment constructability, seismic performance, static performance, and construction costs. These uncertainties can only be reduced by conducting additional significant geologic and geotechnical design data collection programs.

Specific schedules that take into account the construction duration of each alternative feature have not been developed. Without consideration of construction durations, cost escalation during construction cannot be properly evaluated. The appraisal level cost estimates provided in **Figure 7.1** do not include costs for escalation during construction. Escalation during construction is expected to be a very significant dollar amount given the size and cost magnitude of the various restoration alternatives presented here.

Cost Effectiveness and Risk

As a means to analyze the worth of alternatives in a relative sense, a cost effectiveness technique was employed that considered risk and uncertainty. Cost effectiveness cannot be used to identify whether the NED benefits of any or all of the alternatives exceed the NED costs, but it can be used to assess the relative cost between alternatives of creating habitat acres whereby it is assumed that habitat acres are proportionate to the economic benefits.

The cost effectiveness analysis and risk evaluation was performed, and the results are presented in Chapter 8. This evaluation shows that Alternative No. 2 (Mid-Sea Barrier with South Marine Lake) minimizes the costs per acre of habitat created without consideration of risk. However, the risks associated with this alternative are higher than for all other alternatives, except Alternative No. 1. Of the alternatives that offer less risk than Alternative No. 2A, Habitat Enhancement without Marine Lake (Alternative No. 5), has the next lowest cost and is the alternative that has the least risk. Alternatives No. 3A and 4 also offer lower risk than Alternative 2A but with costs per acre of habitat that are 5 and 3 times costs per acre for Alternative 5, respectively.

In consideration of both costs and risks, Alternative No. 5 (Habitat Enhancement without Marine Lake) minimizes both risk and cost as a means for providing replacement shoreline and open water habitat at the Salton Sea. Alternative No. 5 would still provide for significant problems. The composite risks index for this alternative is moderate, indicating that "on average" problems would potentially be significant and could require mitigation. Selenium risks to breeding birds and fishery sustainability problems could be serious under this alternative. This implies that these problems could create significant threats that may be tolerable with significant mitigation measures in place. With additional study, mitigation measures could be developed that may offset these potential threats. The size of the SHC studied in Alternative No. 5 was based on maximizing use of gentle slopes around the Sea and not upon a complete understanding of habitat values associated with SHC.

Considerations for the Future

Due to extreme costs and the substantial engineering, physical, and biological uncertainties and associated risks associated with all five action alternatives considered in this report, implementation of such alternatives would be speculative. All of the action alternatives considered in this report have been estimated to cost between $3.5 and $14 billion. There are many risks and uncertainties. However, given the negative impacts associated with doing nothing (No-Project Alternative), future consideration could be given to restoration efforts at the Sea that could incorporate a more informed and less risky approach focused on restoring historic wildlife benefits. Such an approach could focus on developing, studying, and monitoring relatively small parcels (250 to 500 acres per phase) of SHC in an adaptive and flexible, yet progressive, manner. This concept could be called a Progressive Habitat Development Alternative (PHDA).

A PHDA could be a successional and phased approach to developing habitat. Each phase could include construction of between 200 and 500 acres of saline habitat complex, in which engineering designs and wildlife management criteria and strategies could be derived from a previous phase. During each phase, continuous detailed evaluations could be obtained concerning water quality, habitat values and use, biologic issues, and engineering performance. Then, information from these evaluations could be used to refine the designs and adaptive strategies for the next phase of complexes. The design of management strategies for the first phase could be based on what is being learned at the existing 100-acre shallow habitat pilot project currently being studied cooperatively by the United States Geological Survey and Reclamation.

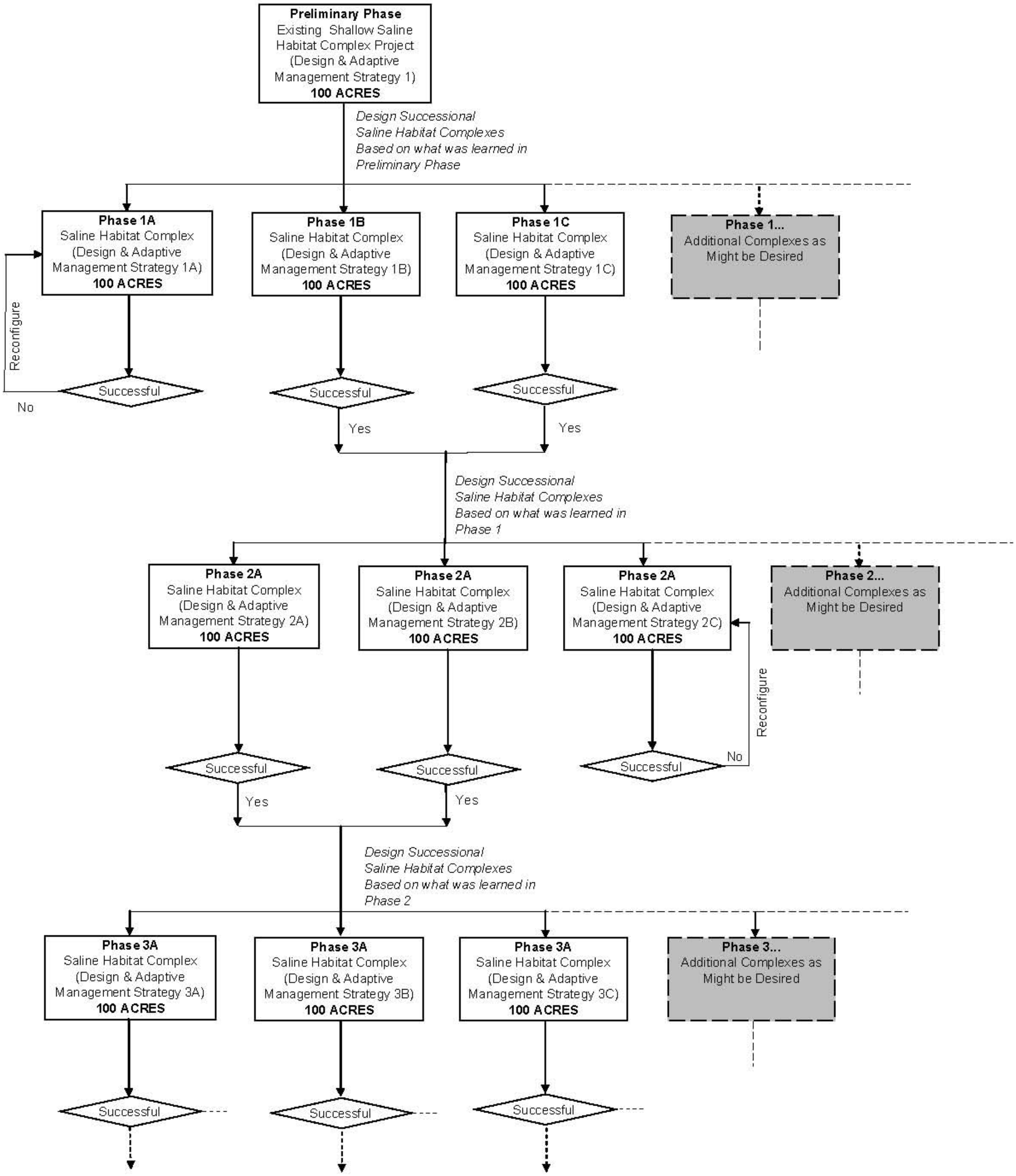
PHDA could be implemented by committing to an initial 2,000 acres during the first 7 to 10 years assuming phased construction of 300 acres per year. PHDA habitat areas could continue to be added beyond those constructed in the first 7 to 10 years up to what is determined to be historic values at the Sea. The total scope of the build out would be dependent on what actual habitat values were observed from previous studies. **Figure 9.1** is a diagram displaying an example of a successional construction strategy of SHC, with each phase using lessons learned from previous phases of development.

The PHDA concept would need to be refined based on information being collected at the existing 100-acre complex in order to determine an accurate cost estimate for a successional project of 2,000 acres. However, the cost of implementing such a project can be estimated on the basis of appraisal level estimates that have been compiled for SHC incorporated in alternatives evaluated for this study. **Table 9.1** lists appraisal level PHDA implementation and annual operation, maintenance, energy, and replacement costs assuming an initial project of 2,000 acres.

In **Table 9.1** costs have been divided between PHDA feature implementation costs and AQM costs. The AQM costs shown coincide with those listed for the No-Project Alternative in **Table 7.2**. It is assumed the State of California will manage AQM in coordination with landowners and other stakeholders as may be applicable by Federal and State laws, regulations, ordinances, and legal agreements. Estimated implementation costs (in 2006 dollars) for the 2,000 acres are $150 million. Annual operation, maintenance, energy and replacement costs would be $0.2 million per year once the 2,000 acres were completed.

Table 9.1 Summary of Progressive Habitat Development Alternative (2,000 acres) and AQM Project Implementation and OME&R Costs ($million)

Alternative	PHDA implementation costs	AQM project implementation costs	Total project implementation costs	Annual PHDA OME&R costs	Annual Air quality mitigation OME&R costs	Total OMER costs
Progressive Habitat Development up to 2,000 acres	150	1,400	1,550	0.2	164.3	164.5



Design and construct additional phases until 2000 acres is achieved.
Each phase will include refined adaptive management strategies.

Figure 9.1 Progressive Habitat Development Alternative Conceptual Diagram.

References

Adams, W.J., K.V. Brix, M. Edwards, L.M. Tear, D.K. DeForest, and A Fairbrother, 2003. Analysis of field and laboratory data to derive selenium toxicity thresholds for birds. Environmental Toxicology and Chemistry 22:2020–2029.

Amrhein, C., 2005. Rationale for a smaller “marine lake” at the Salton Sea, Report prepared for the Bureau of Reclamation, August 2, 2005.

Amrhein, C. and M.A. Anderson, 2005. Salton Sea Sediment and Water Oxygen Demands. Report prepared for the Bureau of Reclamation Eutrophication/Selenium Viability Workshop, July 25-27, 2005.

Anderson, M.A., 2005. Predicted Sediment Distribution and Resuspension in Proposed Alternatives for the Salton Sea. Report prepared for the Bureau of Reclamation Eutrophication/Selenium Viability Workshop, July 25-27, 2005.

Bennett, J., 1998. Biological effects of selenium and other contaminants associated with irrigation drainage in the Salton Sea area, California 1992–1994. Department of the Interior National Irrigation Water Quality Program. Information Report No. 4, Washington, DC.

Black, G.F., J. St. Amant, and K.R. Anderson, 1985. The Salton Sea Sport Fishery, Region 5 Informational Bulletin, 0010-5-1985, Department of Fish and Game, The Resources Agency, State of California. May 1985. 43 pp.

Carlson, R.E., 1977. A trophic state index for lakes. Limnol. Oceanogr. 22:361–369.

Cohen, J.P., 2000. Saving the Salton Sea: researchers work to understand its problems and provide possible solutions. BioScience 50:295–301.

Cohen, M.J. and K.H. Hyun, 2006. Hazard: the future of the Salton Sea without a restoration project. Pacific Institute. 54 pp.

Cooper, D.S. 2004. Salton Sea avifauna—a global perspective. Audubon California.

Costa-Pierce, B.A. and R. Riedel, 2000. Final Report on Fish Biology and Fisheries Ecology of the Salton Sea. 2000. Mississippi-Alabama Sea Grant Consortium, Ocean Springs, Mississippi, and Gulf Coast Research Laboratory, Institute of Marine Sciences, University of Southern Mississippi, Ocean Springs, Mississippi. April 28. 47 pp.

Crayon, J.J., S. Keeney, and R.A. Schrag, 2005. The Salton Sea Fisheries: The Good, the Bad, and the Unexpected. Presented at the Salton Sea Centennial Symposium, Celebrating a Century of Symbiosis among Agriculture, Wildlife, and People, 1905–2005, San Diego, California, March 30–April 1, 2005.

Dahl, T. E., 1990. Wetlands Losses in the United States 1780s to 1980s. U.S. Department of the Interior, Fish and Wildlife Service, Washington, DC. 21 pp.

DWR, 2005. “Salton Sea Ecosystem Restoration Study, Conceptual Design for In-Sea Rock Barriers,” Interim Report, Working Draft No. 3, March.

DWR, 2006 (Appendix H-2). “Salton Sea Ecosystem Restoration Program PEIR, Appendix H-2: Hydrology Development and Future Hydrologic Scenarios.”

DWR, 2006. Salton Sea Ecosystem Restoration Program, Final Draft Technical Memorandum. Task Order No. 17. Task 1: Identify and Outline Measures to Control Playa Emissions. March.

DWR, 2006. Salton Sea Ecosystem Restoration Program PEIR.

Fan, T.W.-M., S.J. The, D.E. Hinton, and R.M. Higashi, 2002. Selenium biotransformations into proteinaceous forms by foodweb organisms of selenium-laden drainage waters in California. Aquatic Toxicology In Press.

Gilmer, D.S., M.R. Miller, R.D. Bauer, and J.L. LeDonne, 1982. California’s Central Valley Wintering Waterfowl: Concerns and Challenges. Trans. North. Am. Wild. and Nat. Resour. Conf. 47:441–452.

Glantz, M.H., 1999. “Sustainable development and creeping environmental problems in the Aral Sea region,” pp. 1–25 in Glantz, M.H. (ed.), Creeping Environmental Problems and Sustainable Development and in the Aral Sea Basin. Cambridge: Cambridge University Press, 304 pp.

Hakanson, L., 1982. Lake bottom dynamics and morphometry: the dynamic ratio. Water Resources Research. 18: 1444–1450.

Hamner, W.M, R.W. Gilmer, and P.P. Hamner, 1982. "The Physical, Chemical, and Biological Characteristics of a Stratified, Saline, Sulfide Lake in Palau." Limnology and Oceanography, Vol. 27, No. 5 (September 1982), pp. 896–909.

Hayhoe K, D. Cayan, C.B. Field, P.C. Frumhoff, E.P Maurer, N.L. Miller, S.C. Moser, S.H. Schneider, K.N. Cahill, E.E. Cleland, L. Dale, R. Drapek, R.M. Hanemann, L.S. Kalkstein, J. Lenihan, C.K. Lunch, R.P. Neilson, S.C. Sheridan, and J.H. Verville, 2004. Emissions Pathways, Climate Change, and Impacts on California.

Heinz, G.H., 1996. Selenium in birds. Pages 447–458 in Beyer, W.N., G.H. Heinz, and A.W. Redmon-Norwood, Eds. Environmental Contaminants in Wildlife. CRC Press, Inc. New York, New York. 494 pp.

Holdren, G.C., and A. Montaño. 2002. Chemical and Physical Characteristics of the Salton Sea, California. Hydrobiologia 473:1–21.

Horn, M.J., and C. Holdren. 2005. Salton Sea Restoration Project, Feasibility Study – Phase 1, Viability Assessment of Fishery Sustainability- Dissolved Oxygen. Technical Memorandum 8220-05-15, U.S. Department of the Interior, Bureau of Reclamation, Denver, Colorado.

IID, 2002. Imperial Irrigation District Water Conservation and Transfer Project, Final Environmental Impact Report/Environmental Impact Statement, dated June 2002 (incorporates Draft EIR/EIS), issued by IID.

IID, 2002 (Appendix F). "Imperial Irrigation District Water Conservation and Transfer Project: Final Environmental Impact Report/Environmental Impact Statement, Appendix F – Salton Sea Accounting Model."

IID, 2002. Imperial Irrigation District Water Conservation and Transfer Project, Final Environmental Impact Report/Environmental Impact Statement. State Clearinghouse Report No. 99091142, October, 2002.

IPCC, 2001. Climate Change 2001: Synthesis Report, Summary for Policymakers.

Jehl, J.R., 1988. Biology of the Eared Grebe and Wilson's Phalarope in the Nonbreeding Seasons: Study of Adaptations to Saline Lakes. Studies in Arian Biology, No. 12.

Pacific Institute, 2006. Hazard: "The Future of the Salton Sea With No Restoration Project." Available at: http://www.pacinst.org/reports/saltonsea/index.htm

Reclamation, 1974. "Federal/State Feasibility Report, Salton Sea, California," Volume 1, Appendix C – Geology, April, 1974.

Reclamation, 2003a. "Guidelines for Achieving Public Protection in Dam Safety Decision Making," June 15, 2003.

Reclamation, 2003b. Salton Sea Project. Status Report. U.S. Department of the Interior, Bureau of Reclamation, Lower Colorado Region, Boulder City, Nevada. January 2003.

Reclamation, 2003c. "Part 417: Regional Director's Final Determination and Recommendations: Imperial Irrigation District, Calendar Year – 2003."

Reclamation, 2005. Salton Sea Restoration Project. Fiscal year 2005 appraisal level study reports. Denver, Colorado.

Reclamation and Salton Sea Authority, 2004. Salton Sea Salinity Control Research Project: Research Conducted at the Salton Sea Test Base.

Reclamation and State of California, 1974. Salton Sea Project Feasibility Report.

Redlands Institute - University of Redlands, 2003, "Salton Sea Digital Atlas."

Riedel, R., L. Caskey, and B.A. Costa-Pierce, 2002. Fish Biology and Fisheries Ecology in the Salton Sea, California. Hydrobiologia 473:229–224.

Robertson, D.M., 2005. Empirical Modeling of the Response in the Eutrophication of the Salton Sea to Various Alternatives. Report prepared for the Bureau of Reclamation Eutrophication/Selenium Viability Workshop, July 25-27, 2005.

Robertson, D.M., and S.G. Schladow. In Review. Response in the Water Quality in the Salton Sea to Changes in Phosphorus Loading: An Empirical Modeling Approach. Submitted to Hydrobiologia.

Robertson, D M., S.G. Schladow, and G.C. Holdren. In Review. Long-term Changes in the Phosphorus Loading to and Trophic State of the Salton Sea. Submitted to Hydrobiologia.

Ruane, R.J., 2006. Scientific Note for the Development of Dissolved Oxygen Demands and a Concept-Level Oxygenation Diffuser System for South Lake of the Salton Sea. Report prepared for the Bureau of Reclamation, September 24, 2006.

Schladow, S.G., 2005. One-Dimensional Hydrodynamic and Thermodynamic Modeling of a Modified Salton Sea under Future Inflow Conditions. Report prepared for the Bureau of Reclamation Eutrophication/ Selenium Viability Workshop, July 25-27, 2005.

Schroeder, R.A., and W.H. Orem, 2000. Nutrient dynamics in the Salton Basin—implications from calcium, uranium, molybdenum, and selenium. Presentation, Spring 2000, Annual Meeting of American Geophysical Union, Washington, DC.

Schroeder, R.A., W.H. Orem, and Y.K. Kharaka, 2002. Chemical evolution of the Salton Sea, California: nutrient and selenium dynamics. Hydrobiologia 473:23–45.

Selenium and the Salton Sea, Undated. Report from a meeting of 13 selenium experts convened by the Salton Sea Science Office, March 11, 2003, Sacramento, California.

Setmire, J.G., R.A. Schroeder, J.N. Densmore, S.L. Goodbred, D.J. Audet, and W.R. Radke, 1993. Detailed study of water quality, bottom sediment, and biota associated with irrigation drainage in the Salton Sea area, California, 1988–90. U.S. Geological Survey Water-Resources Investigations Report 93-4014.

Setmire, J.G., and R.A. Schroeder, 1998. Selenium and salinity concerns in the Salton Sea area of California. In Frankenberger W.T., Jr. and R.A. Engberg (eds.), Environmental Chemistry of Selenium, Marcel Dekker, Inc., New York•Basel•Hong Kong, pp. 205–221.

Setmire, J.G., 2005. Selenium Risk Evaluation of Salton Sea Restoration Alternatives. Report prepared for the U.S. Bureau of Reclamation Eutrophication/Selenium Viability Workshop, July 25-27, 2005.

Shuford, W.D., N. Warnock, and K.C. Molina, 1999. The avifauna of the Salton Sea: a synthesis. Point Reyes Bird Observatory Baseline Recon Studies.

Shuford, W. David, N. Warnock, K.C. Molina, B. Mulroony, and A.E., Black, 2000. “Avifauna of the Salton Sea: Abundance, Distribution, and Annual Phrenology.” Contribution No. 93 of Point Reyes Bird Observatory. Final Reports for EPA Contract No. R826552-01-0 to the Salton Sea Authority.

Shuford, W. David, N. Warnock, K.C. Molina, and K.K. Strum, 2002. “The Salton Sea as Critical Habitat to Migratory and Resident Waterbirds.” Point Reyes Bird Observatory, 4990 Shoreline Highway, Stinson Beach, California 94970. Available at: <saltonsea.ca.gov/ltnav/library.html>.

Skorupa, J.P., 1998. Selenium poisoning of fish and wildlife in nature: lesions from twelve real-world examples. Pages 315–354 in Frankenberger, W.T. Jr., and R.A. Engberg, Eds. Environmental Chemistry of Selenium. Marcel Dekker, Inc. New York. 713 pp.

Sutton, R., 2000. Salton Sea desert pupfish movement study. Report for the Salton Sea Authority. Bureau of Reclamation.

Sykes, G., 1937. The Colorado Delta. American Geographical Society Special Publication No. 19. Baltimore: Lord Baltimore Press. 193 pp.

Walker, W.W., Jr., 2006. SSA's Plan for Revitalizing the Salton Sea to Support Recreational Uses. Report prepared for the Salton Sea Authority, March 22, 2006

URS Corporation, “Preliminary In-Sea Geotechnical Investigation, Salton Sea Restoration Project, Riverside and Imperial Counties, California,” 2003.

Attachment A

Table A-1 Alternatives and Associated Component Subtotal Construction Costs and Implementation Costs for Alternatives with Embankment Designs that Do Not Meet Reclamation Design Criteria and Guidelines

Alternative Components	Alterative No. 1B: Mid-Sea Dam with North Marine Lake – Original Salton Sea Authority alignment using SSA rockfill design	Alternative No. 2B: Mid-Sea Barrier with South Marine Lake using sand dam design without stone columns	Alternative No. 3B: Concentric Lakes using sand dam design without stone columns [2]	Alternative No. 3C: Concentric Lakes using Geotube® embankment design (as proposed by the Imperial Group) [2]
1. Mid-Sea Dam	$1,042,379,866			
2. West and East Perimeter Dikes	$687,199,238			
3. South-Sea Dam	$883,674,869			
4. Mid-Sea Barrier		$414,728,079		
5. Three Concentric Lake Dikes			$5,208,686,051	$1,711,029,675
6. Concentric Lakes - Habitat Islands and Deep Areas			$181,119,163	$181,119,163
7. Concentric Lakes - Lake Cell Divider Structures			$37,593,185	$8,987,800
8. Earthen Dikes for Habitat Ponds	$161,676,000	$292,364,100		
9. Habitat Ponds - Habitat Islands and Deep Areas		$334,514,933		
10. Water Conveyance Features	$314,915,017	$201,680,735	$617,309,280	$202,783,291
11. Water Treatment Facilities	$218,000,000			
12. Air Quality Mitigation - via Water Vegetation Features		$540,960,000	$477,750,000	$477,750,000
13. Air Quality Mitigation - via Other Features	$6,578,000	$108,192,000	$95,550,000	$95,550,000
Subtotal Construction Costs[1]	**$3,314,422,990**	**$1,892,439,847**	**$6,618,007,679**	**$2,677,219,928**
Unlisted Items: 10%	$285,577,010	$207,560,153	$681,992,321	$222,780,072
Total Contract Costs	$3,600,000,000	$2,100,000,000	$7,300,000,000	$2,900,000,000
Contingencies: 25%	$1,000,000,000	$500,000,000	$1,800,000,000	$800,000,000
Total Field Costs	$4,600,000,000	$2,600,000,000	$9,100,000,000	$3,700,000,000
Non-Contract Costs: 20%	$900,000,000	$500,000,000	$1,900,000,000	$700,000,000
Total Project Implementation Costs	**$5,500,000,000**	**$3,100,000,000**	**$11,000,000,000**	**$4,400,000,000**

[1] Includes mobilization costs.

[2] Total project implementation costs assuming four concentric lakes for Alternative No. 3B is $14,000,000,000 and Alternative No. 3C is $5,400,000,000

Table A-2 Summary of Annual Reoccurring Costs of Restoration Alternatives($ million) for Alternatives with Embankment Designs that Do Not Meet Reclamation Design Criteria and Guidelines

Alternative	Annual Operations, Maintenance, and Energy (OM&E) Costs	Annual Replacement Costs	Annual Operations, Maintenance, Energy, and Replacement (OME&R) Costs	Annual Risk Costs	Annual Operations, Maintenance, Energy, Replacement, and Risk (OMER&Risk) Costs
Alterative No. 1B: Mid-Sea Dam with North Marine lake – Original Salton Sea Authority alignment using SSA rockfill design	53	0.3	53	Not Estimated	Not Estimated
Alternative No. 2B: Mid-Sea Barrier with South Marine Lake using sand dam design without stone columns	71	62	133	6	139
Alternative No. 3B: Concentric Lakes using sand dam design without stone columns [1]	64	55	119	30	149
Alternative No. 3C: Concentric Lakes using Geotube® embankment design (as proposed by the Imperial Group) [1]	66	55	121	13	134

[1] Costs shown are for three concentric lakes as required under mean possible future inflow conditions.