# 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.

Reclamation recognizes that any site-specific evaluation and/or alternative implementation would require consultation with the U.S. Fish and Wildlife Service, the Torres Martinez Nation, and others to ensure consistency with other missions and land uses.

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 report to those presented in DWR's Salton Sea

Ecosystem Restoration Program draft programmatic environmental impact report (PEIR) and to reports prepared by other organizations.

The drains that flow directly into the Salton Sea are potential habitat for the desert pupfish. In the future, IID will provide for connectivity among the direct-to-sea drains in areas on the south end of the Salton Sea; this will be required as mitigation for the IID-San Diego water transfer project. These mitigation requirements are not directly reflected in any of the alternative depictions presented in this chapter. However, it is recognized that future implementation of any of these alternatives would need to address these mitigation actions.

## 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

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.


**Saline habitat complex.**

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.

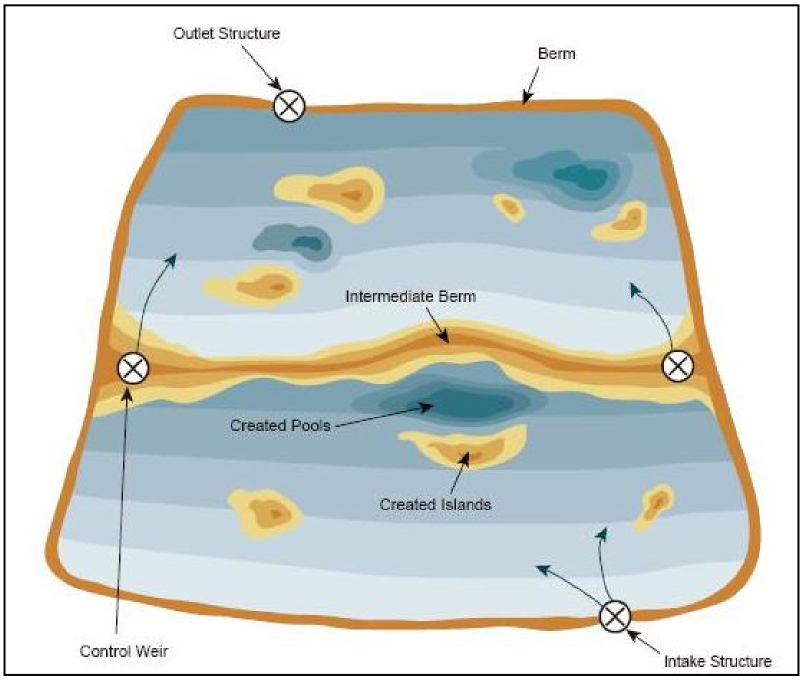


**Figure 3.1 Cell in a typical SHC.**

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 completion of project construction the Sea is expected to experience environmental degradation involving the complete loss of the fishery and the collapse of the invertebrate food base. In order to provide some replacement habitat, 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 Projects

Each alternative (including No-Project) includes an AQM project for control of emissions from exposed playa areas. The AQM project 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 by implementing the following four steps:

1. Restrict access. Minimize disturbance of natural crusts and soil surfaces in future exposed shoreline areas.

2. Research and monitoring. Research effective and efficient dust control measures for exposed pla ya, and monitor surrounding air quality.

3. If monitoring results indicate exposed areas are emissive, create or purchase offsetting emissions reductions.

4. To the extent that offsets are not available, implement direct emissions reductions at the Sea. Implement dust control on emissive parts of the exposed playa.

All of the alternatives contain AQM components related to this 4-step process. It is assumed the State of California will manage AQM in coordination with landowners and other stakeholders. For the No Project Alternative, AQM for the IID-San Diego water transfer project would be implemented by IID in coordination with California State regulating agencies.

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 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 for comparison purposes in **Tables 7.3 and 7.4** 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 4.4** 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.

### Air Quality Mitigation Measures

Under the approach used by DWR in the PEIR, emissive areas would be stabilized using one or more methods (tool box), including water-efficient vegetation, surface wetting, water spreading, event-driven irrigation, or dry measures, such as gravel cover, chemical treatment, tillage and sand fences or other wind breaks.  Vehicular and pedestrian access to all potentially emissive areas would be controlled to limit surface disturbance.  The tool box of dust control measures would remain open to change, and all potentially feasible dust control measures would continue to be evaluated until significant questions regarding dust control on Salton Sea playa have been resolved.

AQM performance criteria have been defined based on the fundamental requirement that the measures used must have been proven effective for similar applications (both in character and scale), to the maximum extent practicable. The AQM  performance criteria are as follows:

- Must be effective and reliable
- Must be feasible and cost-effective
- Must be consistent with other project features and objectives

AQM measures identified to date and recommended for implementation are subdivided into permanent and temporary categories.  Temporary measures would be applied when and where permanent approaches are not feasible (e.g., areas that have not yet been sufficiently dewatered to allow construction to begin).

Permanent measures include access control, water-efficient vegetation (salt and drought tolerant shrubs or grasses) and stabilization with brine (wetting and replenishment of salt on unstable surfaces to create a stable salt crust). These measures would require an estimated 1 foot of irrigation per year. Water-efficient vegetation may also require subsurface drainage. Temporary measures include access control, sand fences (or other linear sand capture features) and surface treatment (chemical treatment and stabilization).

Implemented AQM measures would be monitored for their effectiveness, and the overall AQM program would be adaptively managed.

### Air Quality Monitoring

Under the approach taken by DWR in the PEIR, all AQM areas would be monitored. The goals of monitoring are to:

- Focus dust control on significant areas and sources
- Gradually improve the understanding of the locations and intensities of playa emissions potential
- Gradually improve the effectiveness and efficiency of control

Monitoring initially would be more intensive and focused on determining whether an area requires immediate dust control. Regardless of designation for dust control, initial intensive monitoring will transition to a less intense phase to ensure all areas remain non-emissive over the long term.

## 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 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

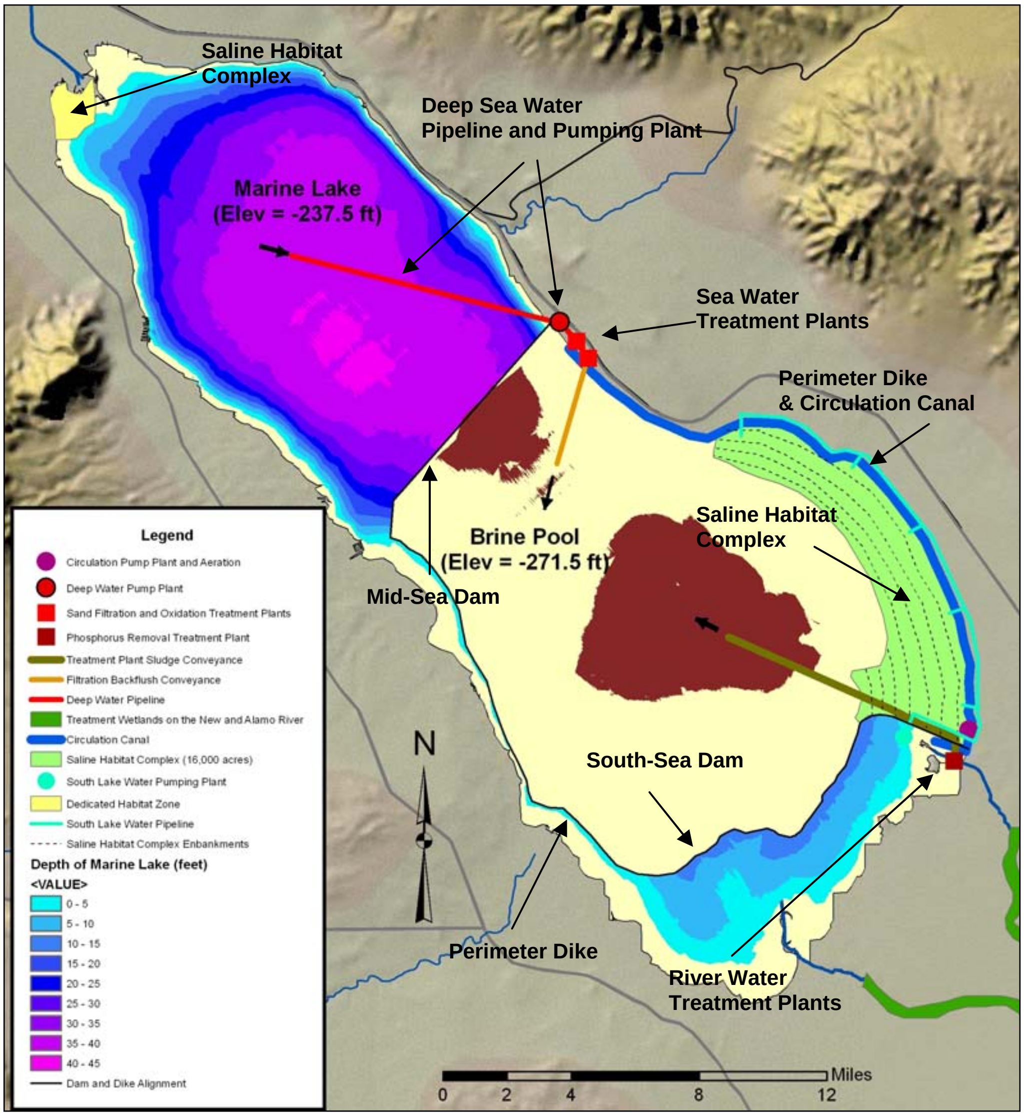


**Figure 3.2 Alternative No. 1: Mid-Sea Dam with North Marine Lake (SSA Alternative).**

**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 |

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.

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 embankment design 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.

> ***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. **Tables 7.3 and 7.4** of this 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 estimates presented in **Tables 7.3 and 7.4** 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. Reclamation evaluated the rockfill embankment concept and determined it would not meet Reclamation's

> ***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, stabilized, 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.

## 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.

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.

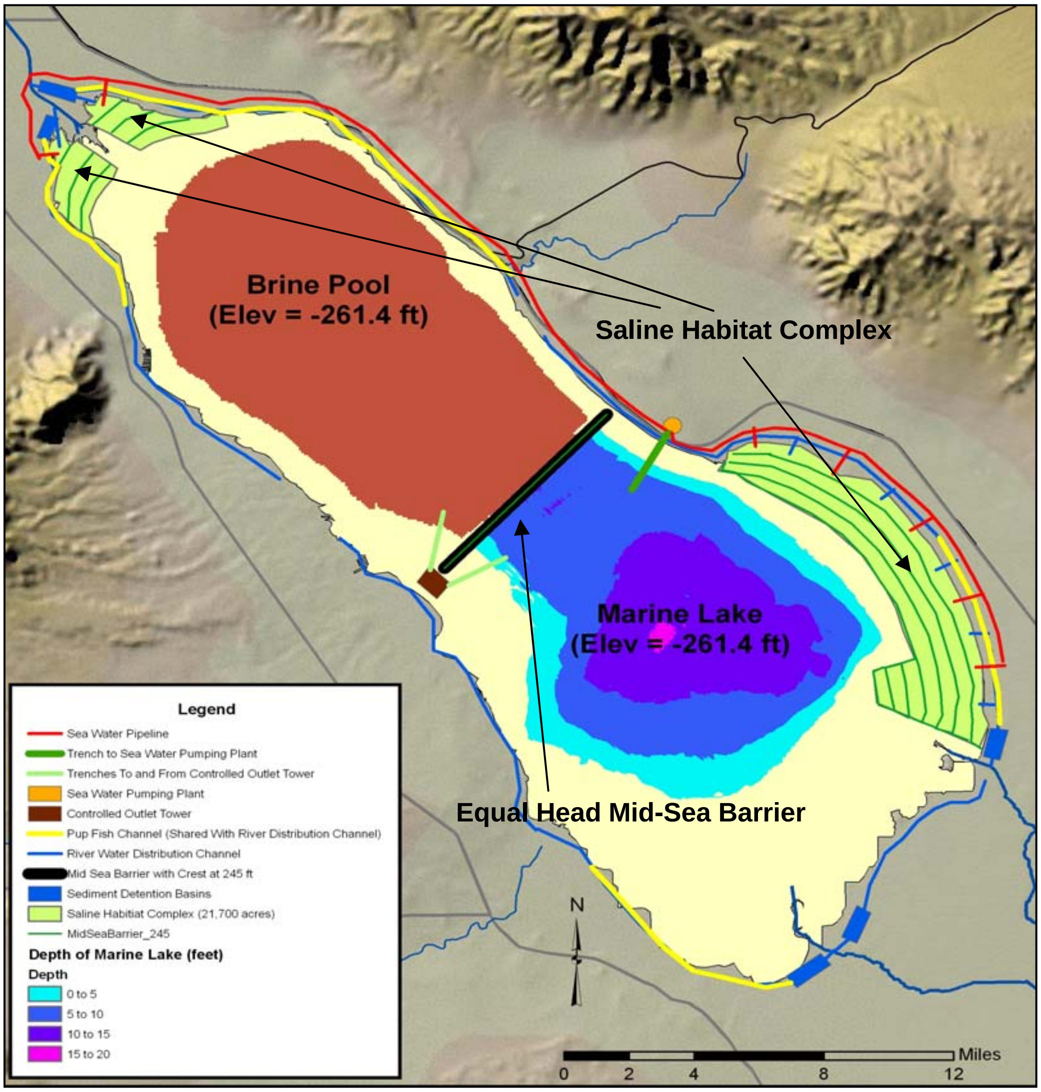


**Figure 3.3 Alternative No. 2: Mid-Sea Barrier with South Marine Lake.**

**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 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 **Table 7-4**.

## 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.

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. Up to 20 feet in depth, these pools could support a sustainable fishery. Outside of the deep areas, the maximum lake depth would be 6 feet.

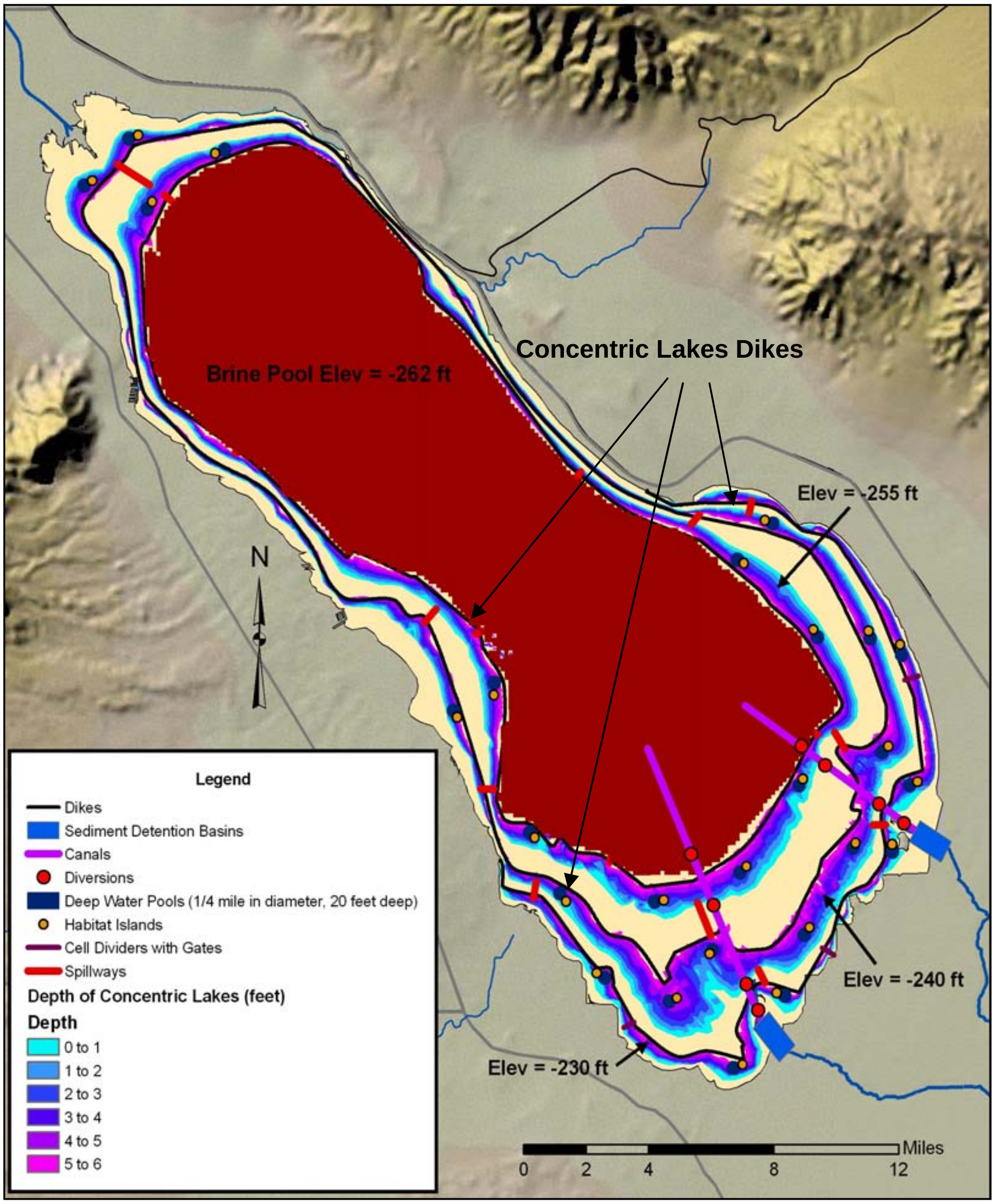


**Figure 3.4 Alternative No. 3: Concentric Lakes.**

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.

**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.

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 **Table 7-4**.  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.

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 design 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.

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.

The 19,500-acre lake was designed to reduce as much as possible the requirement to achieve acceptable salinity levels without dependence on long detention times in the marine lake. Smaller lakes would require evapoconcentrating salt without making releases from the lake for many years, which would result in the concentration of contaminants.

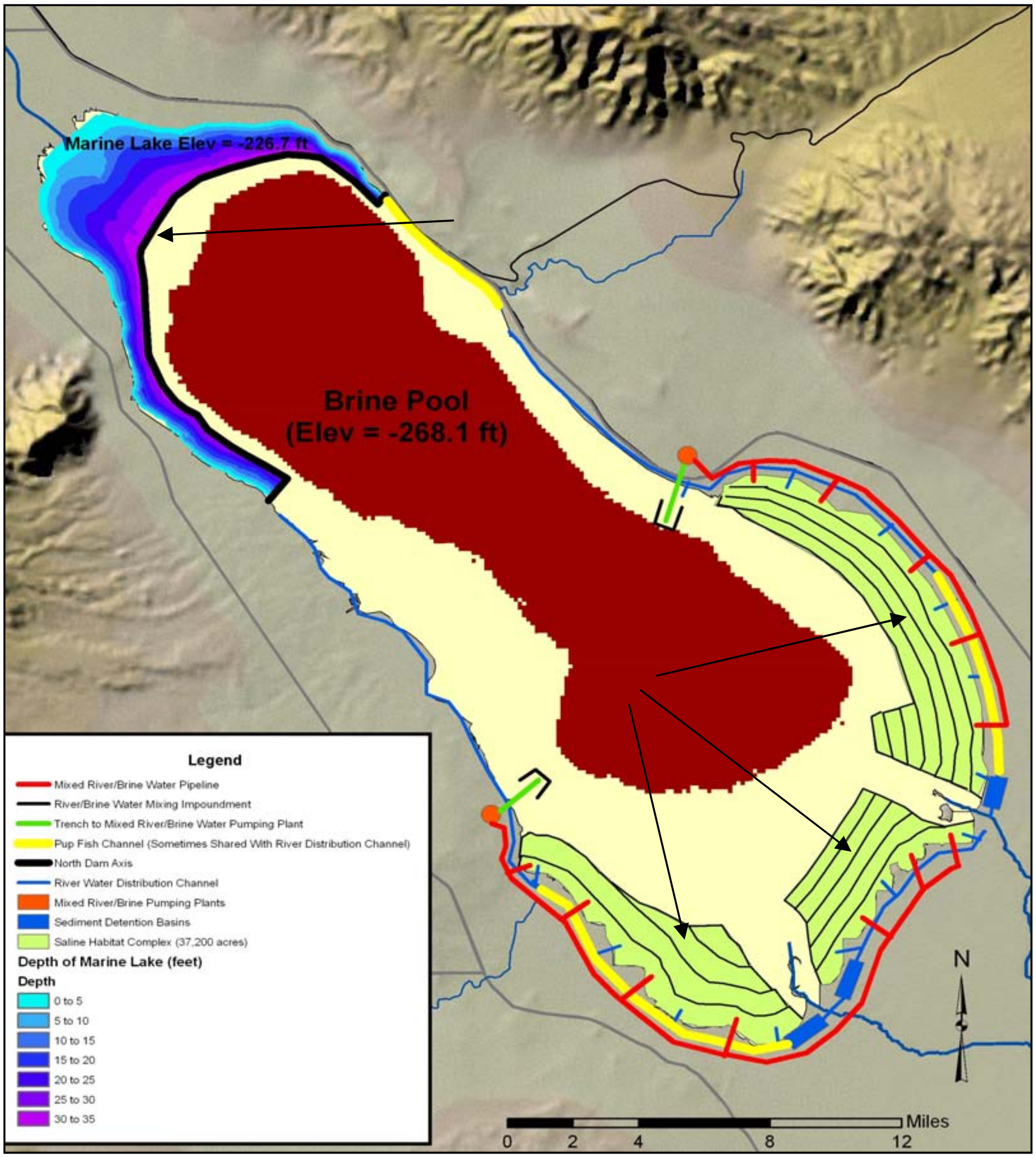


**Figure 3.5      Alternative No. 4:  North-Sea Dam with Marine Lake.**

**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 |

# 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** 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.

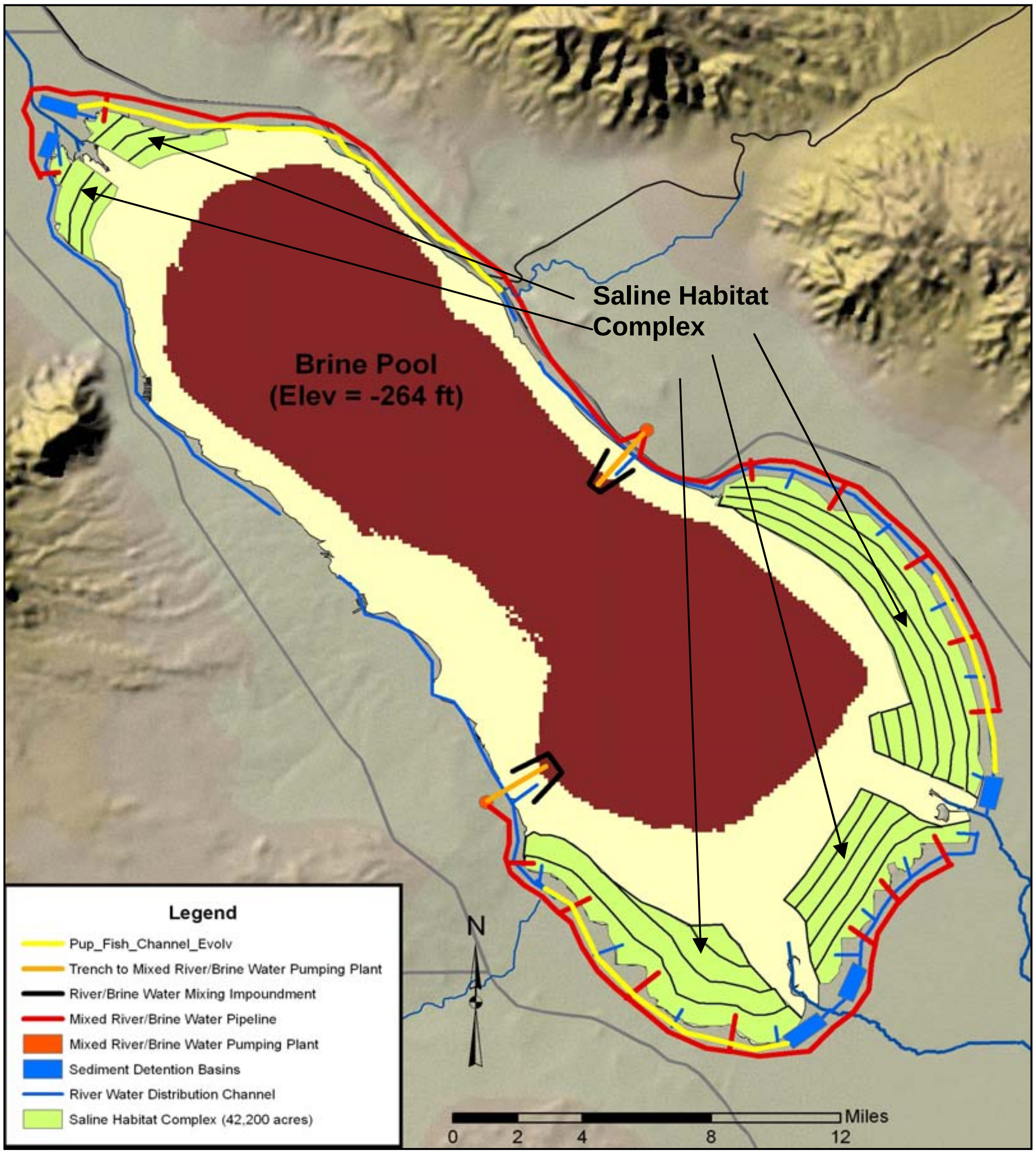


**Figure 3.6 Alternative No. 5: Habitat Enhancement Without Marine Lake.**

**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 |

## 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.

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 and all other alternatives include:

- 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.

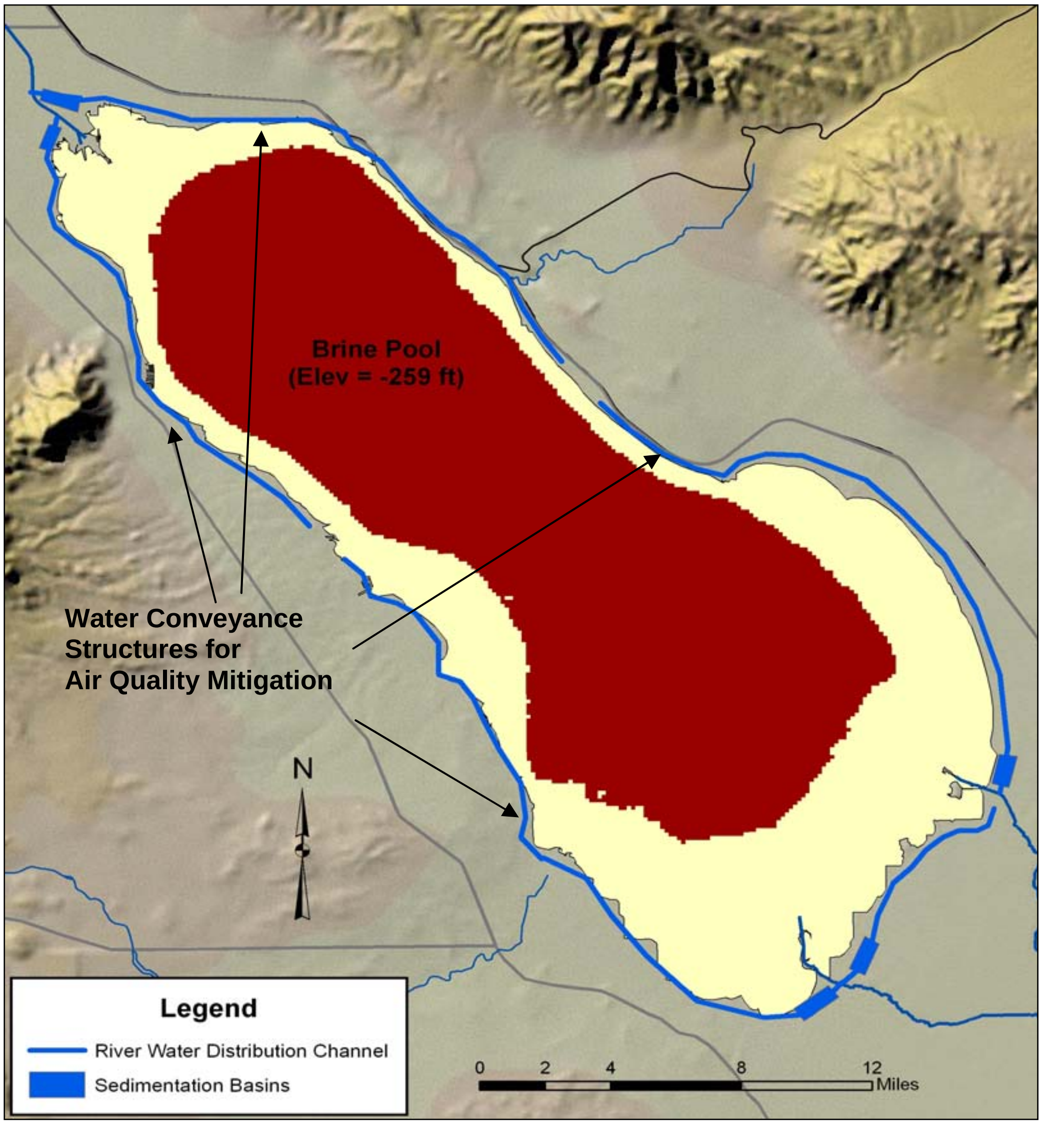


**Figure 3.7  Alternative 6:  No-Project.**

**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 |

- 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 consistent with Reclamation's Dam Safety Program and to meet Reclamation's general design criteria and Public Protection Guidelines (Reclamation, 2003) where applicable. Volume 2 of this report, entitled "Embankment Designs and Optimization Study," contains details about the development of dam, barrier, and habitat pond embankment designs. Volume 2 of this report also presents information related to constructability, risks, and costs.

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

Reclamation's Dam Safety Program is authorized under the Reclamation Safety of Dams Act of 1978 (P.L. 95-578). The Act provides for action to be taken when it is determined that a structure presents an unacceptable risk: "In order to preserve the structural safety of Bureau of Reclamation dams and related facilities, the Secretary of the Interior is authorized to perform such modifications as he determines to be reasonably required." To determine the risks associated with its structures, Reclamation has established procedures to analyze data and assess the condition of its new and existing structures. Reclamation has established a risk-based framework to meet the objectives of its program, the Dam Safety Act, and the Federal Guidelines. Risk-based procedures are used to assess the safety of new and existing Reclamation structures. Addressing risks in a technically consistent and timely fashion is an important part of sustaining the public's trust in Reclamation to construct and manage facilities in the best interest of the nation.

Reclamation is responsible for about 370 storage dams and dikes that form a significant part of the water resources infrastructure in the western United States. A high level of national safety and stewardship of public assets is expected of Reclamation as an agency specifically entrusted to manage a large inventory of dams. The greater the inventory of dams and the time of exposure, the more difficult it becomes to ensure that the agency will not experience a dam failure. Reclamation has developed guidelines to assist in the management of risk associated with its existing dam inventory and in considering new structures. These guidelines for public protection are published in the following document:

> Bureau of Reclamation, June 2003, *Guidelines for Achieving Public Protection in Dam Safety Decisionmaking*

Reclamation's guidelines focus on two assessment measures of risks related to Reclamation structures: (1) the estimated probability of dam failure and (2) the potential life loss consequences resulting from the unintentional release in the event of failure. The estimated annual probability of failure guideline addresses agency exposure to dam failure. As a water resource provider, Reclamation must maintain and protect its dams and dikes that store water. The second measure addresses the potential life loss component of societal risk. Protection of human life is of primary importance to public agencies constructing, maintaining, and/or regulating civil works.

Within these guidelines, it is specified that to ensure a responsible performance level across the inventory of Reclamation's dams, it is recommended that decisionmakers consider taking action to reduce risk if the estimated annual probability of failure exceeds 1 chance in 10,000.

For dam safety decisionmaking, risk of life loss is measured as the product of the probability of dam failure and the estimated consequences (life loss) associated with that failure. This product is the expected annualized life loss at a given dam for a given loading condition and is referred to as the estimated annualized risk of life loss.

In cases of small populations at risk (such as at the Salton Sea), the guidelines related to annual probability of failure serve as a limit of exposure. With an annual probability of failure equal to 1 chance in 10,000 (0.0001) and a loss of life of one person, the annualized risk of life loss would be 1 times 0.0001, which is equal to 0.0001 lives per year. This is analogous to a probability of life loss of 1 chance in 10,000. Reclamation guidelines specify that the justification to reduce risk of life loss diminishes as estimated annualized life loss risk becomes smaller than 0.001. These same guidelines also specify that the justification to reduce risk increases as the annualized risk of life loss exceeds 0.001.

In cases of small populations at risk (as at the Salton Sea), it is the annual probability of failure that drives the need to reduce risk. A zero loss of life at the upper probability of failure limit of 1 in 10,000 would result in unacceptable risk. The only way to achieve compliance with Reclamation guidelines under such circumstances is to ensure that the annual probability of failure of any embankment at the Salton Sea is below 1 in 10,000. This would be true regardless of whether or not the embankments are classified as significant or high hazard structures.

## 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 numerous embankment design options, including 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.

For each restoration alternative, the estimated APF and ALL values were compared with Reclamation's PPG. Structures with estimates that exceed either one of the following would be considered unacceptable:

- APF greater than $1 \times 10^{-4}$ (1E-04)
- ALL greater than $1 \times 10^{-3}$ (1E-03)

**Table 3.7** presents the risk analysis results for each of the restoration alternatives considered in this report.

**Table 3.7 Salton Sea Restoration Study: Embankment Risk Analysis Summary**

| Alternative Description | Estimated Annualized Probability of Failure (APF) | Estimated Annualized Loss of Life (ALL) |
|---|---|---|
| Alternative No. 1: Mid-Sea Dam with North Marine Lake (sand dam with stone columns) | | |
| Mid-Sea Dam | 3.8 E-06 | 7.6E-06 |
| Perimeter Dikes | <3.8E-06 | 0.0E+00 |
| South-Sea Dam | 1.0E-04 | 1.0E-04 |
| Alternative No. 2A: Mid-Sea Barrier with South Marine Lake (with stone columns) | ≤3.8E-06 | 0.0E+00 |
| Alternative No. 2B: Mid-Sea Barrier with South Marine Lake (without stone columns) | >1.0E-02 | 0.0E+00 |
| Alternative No. 3A: Concentric Lakes (with stone columns) | 1.0E-04 | 0.0E+00 |
| Alternative No. 3B: Concentric Lakes (without stone columns) | >1.0E-02 | 0.0E+00 |
| Alternative No. 3C: Concentric Lakes (with Geotubes®) | >1.0E-03 | 0.0E+00 |
| Alternative No. 4: North-Sea Dam with Marine Lake (with stone columns) | ≤3.8E-06 | 7.6E-06 |
| Alternative No. 5: Habitat Enhancement Without Marine Lake | 1.0E-02 | 0.0E+00 |

### *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 (7 feet to 16 feet) in the foundation beneath the south-Sea dam and the concentric ring dikes in the southern Sea.

Reclamation's sand dam with stone columns design provides for partial failure without compromising the structure as a whole. Incorporation of stone columns to improve seismic resistance is not the major cost item in the embankment designs. The stone columns account for 10, 9, and 25 percent of the subtotal construction costs for Alternative Nos. 1A, 2A, and 3A, respectively.

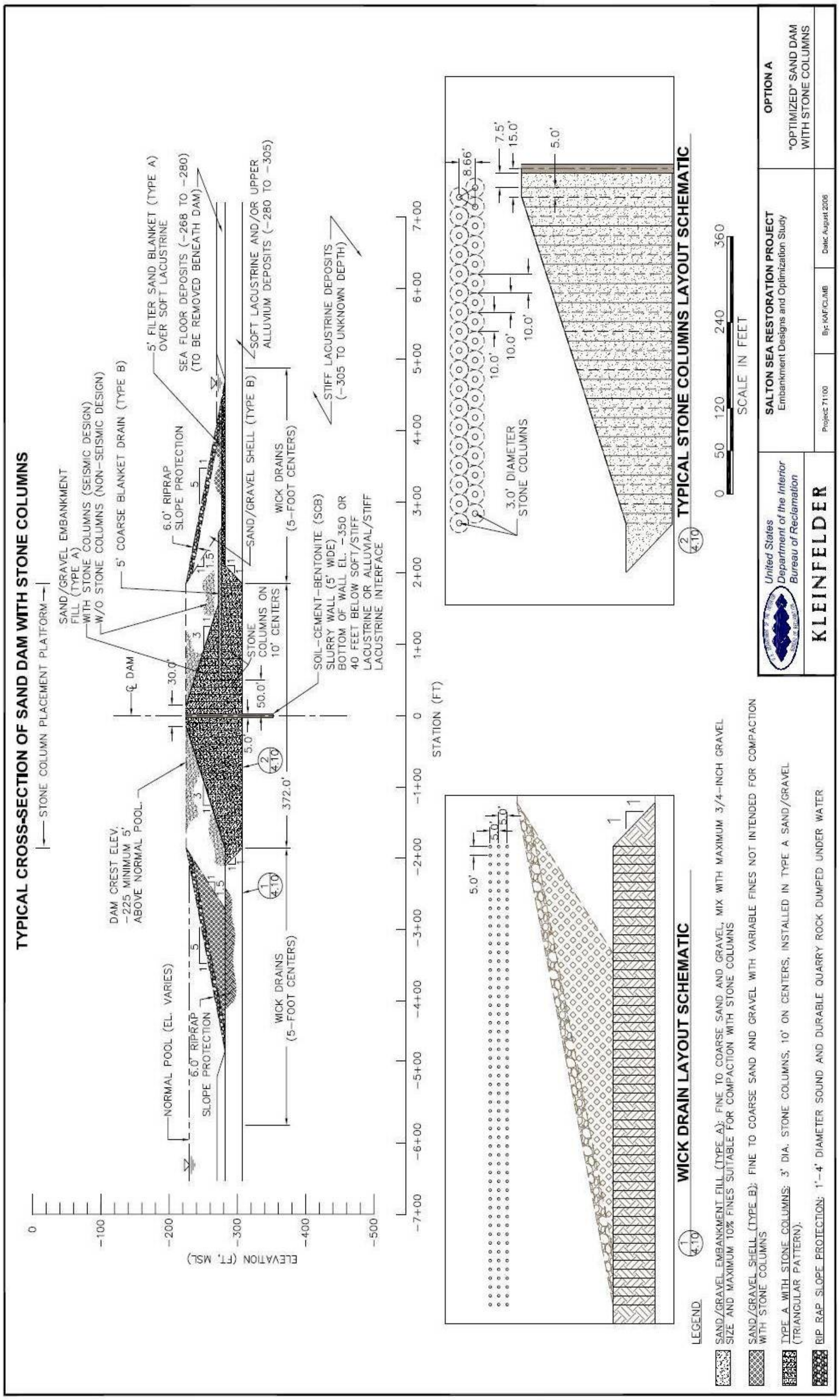


**Figure 3.8 Typical cross-section of sand dam with stone columns.**

### *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 **Table 7-4**.

### *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.

### *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.

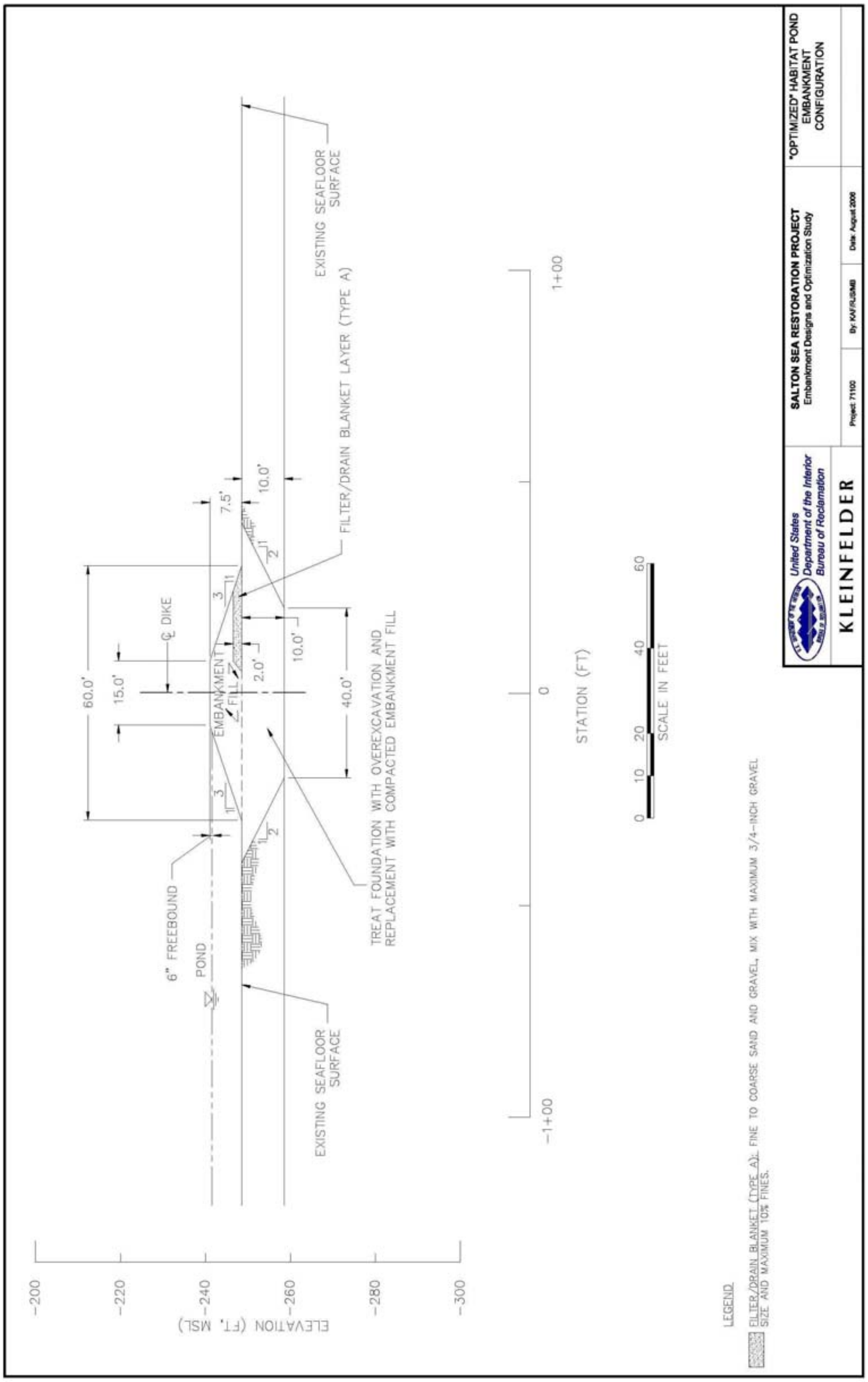


**Figure 3.9 Typical cross-section of habitat embankment.**

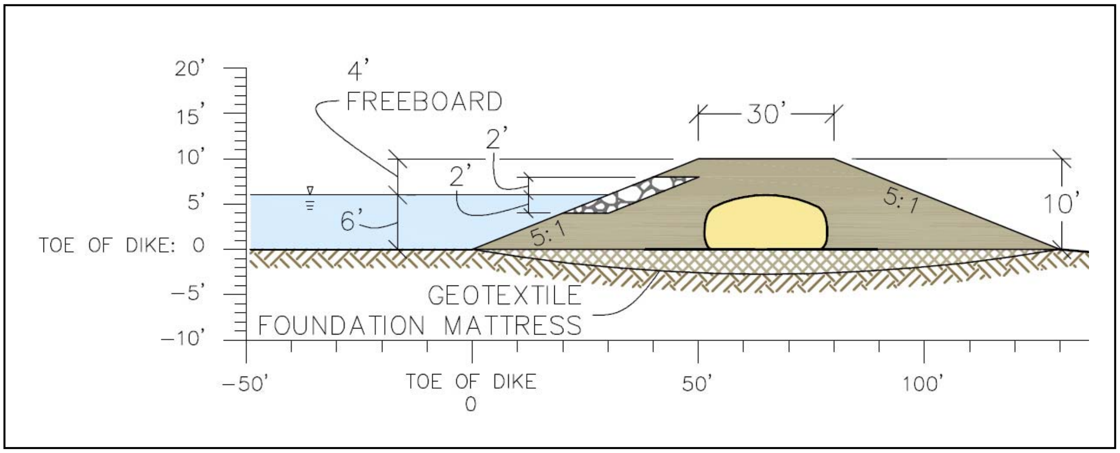


**Figure 3.10 Typical Geotube® design.**

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. **Table 7.3** 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.

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.

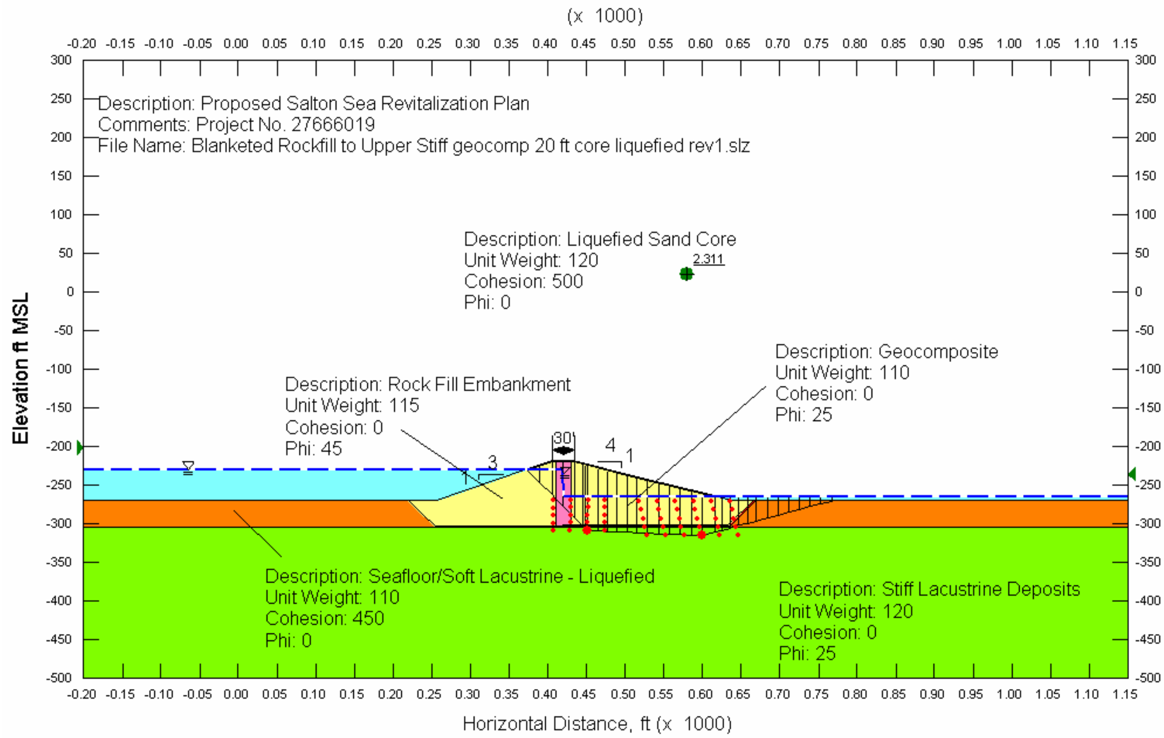


**Figure 3.11 Typical cross-section of the SSA rockfill embankment.**

## Comparisons to Design Criteria and Guidelines

**Table 3.8** 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)
- 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)

**Table 3.8 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 | |

Costs are presented in Chapter 7 for the alternatives that meet Reclamation's requirements. **Tables 7.3 and 7.4** provide cost estimates for the alternatives that do not meet Reclamation's requirements.