Salton Sea Alternatives

Preappraisal Report

DRAFT

U.S. Department of the Interior
Bureau of Reclamation
Lower Colorado Region
Boulder City, Nevada

October 2, 1998

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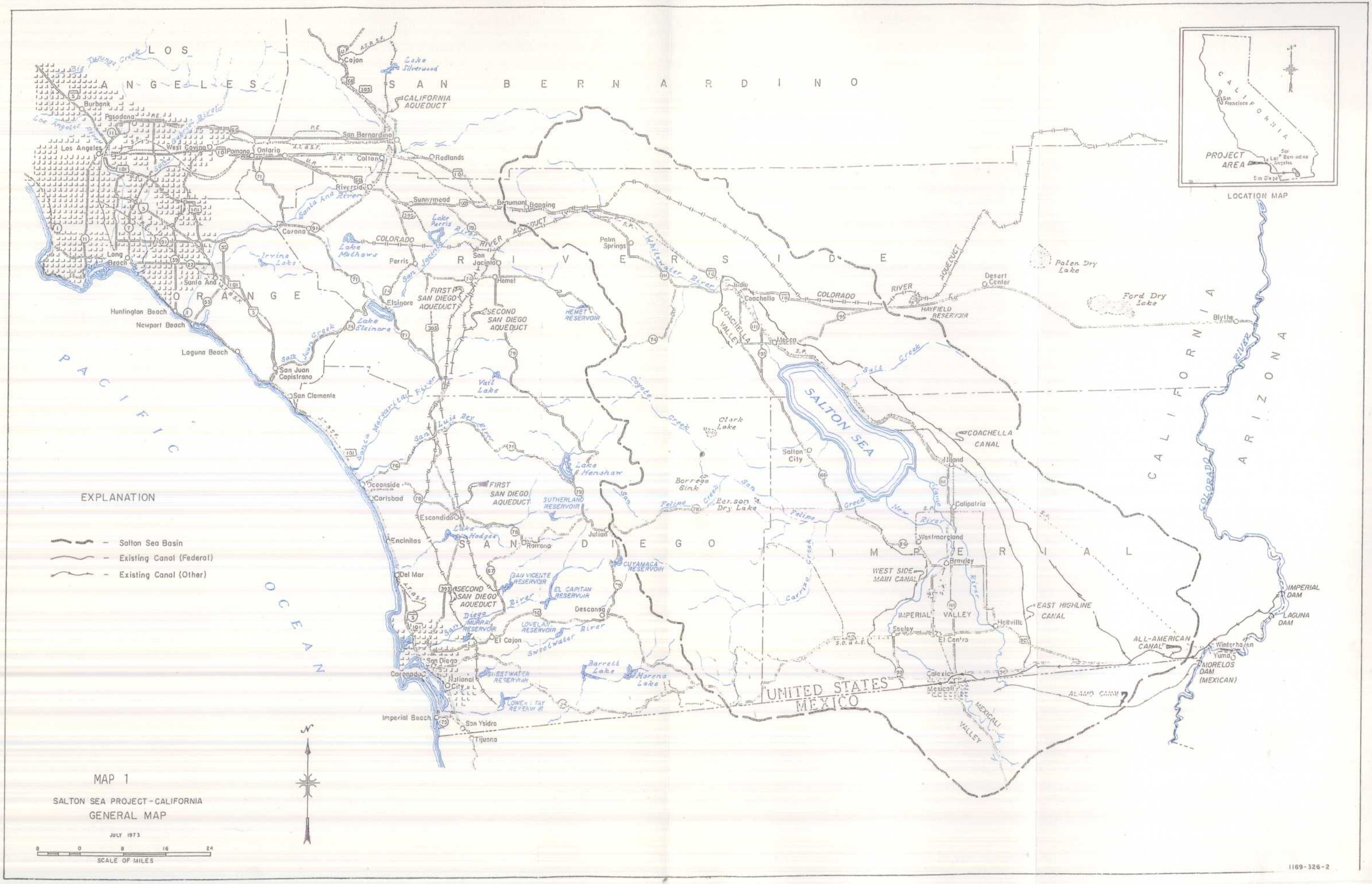
LOCATION MAP
CALIFORNIA
PROJECT AREA
San Francisco
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San Diego
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SAN BERNARDINO
RIVERSIDE
ORANGE
SAN DIEGO
IMPERIAL
CALIFORNIA
ARIZONA
PACIFIC OCEAN
UNITED STATES
MEXICO
SALTON SEA
CALIFORNIA AQUEDUCT
COLORADO RIVER AQUEDUCT
FIRST SAN DIEGO AQUEDUCT
SECOND SAN DIEGO AQUEDUCT
COACHELLA CANAL
EAST HIGHLINE CANAL
WEST SIDE MAIN CANAL
ALL-AMERICAN CANAL
ALAMO CANAL
IMPERIAL DAM
LAGUNA DAM
MORELOS DAM (MEXICAN)
HAYFIELD RESERVOIR
HEMET RESERVOIR
SUTHERLAND RESERVOIR
CUYAMACA RESERVOIR
SAN VICENTE RESERVOIR
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MURRAY RESERVOIR
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SWEETWATER RESERVOIR
LOWER OTAY RESERVOIR
COACHELLA VALLEY
IMPERIAL VALLEY
MEXICALI VALLEY
Lake Silverwood
Lake Perris
Lake Mathews
Irvine Lake
Lake Elsinore
Vail Lake
Lake Henshaw
Lake Hodges
Barrett Lake
Morena Lake
Clark Lake
Palen Dry Lake
Ford Dry Lake
Borrego Sink
Borrego Dry Lake
Los Angeles River
San Gabriel River
Santa Ana River
San Jacinto River
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Salt Creek
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Banning
Corona
Long Beach
Santa Ana
Huntington Beach
Newport Beach
Laguna Beach
San Juan Capistrano
San Clemente
Perris
San Jacinto
Hemet
Elsinore
Palm Springs
Indio
Coachella
Mecca
Desert Center
Blythe
Salton City
Niland
Calipatria
Westmoreland
Brawley
Imperial
Seeley
El Centro
Holtville
Calexico
Mexicali
Winterhaven
Yuma
Oceanside
Carlsbad
Escondido
Encinitas
Del Mar
Ramona
Julian
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El Cajon
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Coronado
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Imperial Beach
San Ysidro
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Existing Canal (Other)
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Summary

The preappraisal level alternatives presented in this report were identified to reduce salinity in Salton Sea (Sea), to maintain an acceptable water surface elevation, and to be of proven technology. Estimated implementation costs are presented for use in future screening of these alternatives. No conclusions have been made about the desirability of retaining any alternative for further consideration.

Purpose and Need

Salton Sea is in the Salton Sea basin, which extends from Palm Springs, California, on the north to near the Gulf of California on the south. The Sea is about 35 miles long and 15 miles wide. At its current elevation of about -227 feet mean sea level (m.s.l.) (1996), the Sea has a maximum depth of 51 feet, with an estimated surface area of 240,000 acres (376 square miles). The lowest elevation it has reached has been approximately -278 feet m.s.l.

The Salton Sea has an average annual volume of approximately 7.5 million acre-feet. Annual inflows of approximately 1.3 million acre-feet contribute about 5 million tons of additional salt.

Purpose

The purpose of this study is to develop alternatives that would reduce salinity to no more than 40 parts per thousand (ppt) and to maintain a water surface elevation in the Sea of about -232 m.s.l., using proven technology.

Since water has been imported for irrigated agriculture, the water surface level of the Sea has risen steadily to its present level of approximately -227 feet m.s.l. Because no natural outlet for this largest manmade water body exists, salinity concentrations also have risen to about 44 ppt—about 25 percent higher than average ocean salinity of 35 ppt.

High water surface elevations and salinity have contributed to declines in land, recreation, economic, and ecological values.

Authority

This study was conducted under an agreement between the Salton Sea Authority, a joint powers authority established under California law, and the Bureau of Reclamation. Over the past 25 years, many proposals have been suggested for managing salinity of the Sea; however, to ensure inclusion of all possible solutions to the salinity and water surface elevation problems of the Sea, media announcements and public meetings during 1998 were used to invite submission of new alternatives.

Scope of Study

The alternatives developed and presented in this report were based on fulfilling three criteria:

- Achieving and maintaining a target salinity level of up to 40 ppt
- Achieving and maintaining a water surface elevation of -232 m.s.l.
- Using a proven technology that does not involve research

The Science Subcommittee, established by the Secretary of the Interior, is examining the needs of the biological habitat and many other important science-related issues of the Sea. Therefore, biology is outside the scope of this report.

Alternatives

Many alternatives, representing a wide variety of solutions, were considered during this study and in a previous study (draft September 1997). After evaluation of all alternatives submitted for consideration, 33 alternatives were selected for presentation in this document, costs were developed, and an initial analysis of the potential success was determined using the Salinity Model. This document presents the results of that analysis.

The alternatives described in this report are presented in three categories:

- Pump-out/pump-in alternatives
- Desalinization plants and solar pond alternatives
- Diked impoundment alternatives

Table S-1 presents the preappraisal costs for the Salton Sea alternatives, as well as a limited description of the alternatives.

The main report provides additional details of the alternatives to be further analyzed, and it provides an analysis (using a salinity model) of the potential success of various representative alternatives.

Identification of a preferred alternative would be dependent on many factors. The environmental effects of all reasonable alternatives would need to be analyzed to select an alternative that would bring the greatest overall benefit to the area. In addition, biological, chemical, and pathogenic studies would have to be performed to provide assurance that correcting the salinity and elevation problems of the Sea would also minimize mortality events and maintain a safe environment for migratory and resident wildlife. These studies would contain sufficient detail to secure construction financing and complete State and Federal environmental compliance processes.

Table S-1.–Preappraisal costs for the Salton Sea alternatives

Pump-out / Pump-in Alternatives

No.	Pump-out Discharge (k ac-ft/yr)	Pump-out To	Pump-in Discharge (k ac-ft/yr)	Pump-in From	Construction Field Cost ($M)	Energy Costs Annual ($M)	Other OM&R Annual ($M)	Total OMR&E Annual ($M)	Total Present Worth ($M)
1.346 M ac-ft/yr Drainage inflow – Reach 40 ppt salinity in 15 years									
1	700	Camp Pendleton	600	Camp Pendleton	3,500	478	8	486	10,314
2	700	Gulf of California	600	Gulf of California	3,300	42	0.7	43	3,902
3	700	Hyperion	600	Hyperion	4,700	359	6	365	9,813
4	250	Point Loma	153	Point Loma	1,500	153	5	158	3,717
5	250	Hyperion	153	Hyperion	1,850	117	4	121	3,548
6	250	Gulf of California	153	Yuma [3]	1,150	12	0.5	13	1,328
7	250	Palen Lake	153	Point Loma	2,682	119	678	797	13,859
8	250	Palen Lake	153	Hyperion	2,852	116	678	795	13,992
9	250	Gulf of California	153	Point Loma	1,450	70	3	73	2,468
10	250	Gulf of California	153	Hyperion	1,550	56	2	59	2,370
1.346 M ac-ft/yr Drainage inflow – Reach 40 ppt salinity in 30 years									
11	400	Camp Pendleton	303	Camp Pendleton	2,100	262	6	268	5,861
12	400	Gulf of California	303	Gulf of California	2,100	26	0.6	26	2,466
13	400	Hyperion	303	Hyperion	2,800	199	5	203	5,653
14	170	Point Loma	73	Point Loma	1,050	94	5	99	2,437
15	170	Hyperion	73	Hyperion	1,250	73	4	77	2,326
16	170	Gulf of California	73	Yuma [3]	800	9	0.4	10	935
17	170	Palen Lake	73	Point Loma	1,807	71	462	533	9,277
18	170	Palen Lake	73	Hyperion	1,887	65	462	526	9,264
19	170	Gulf of California	73	Point Loma	980	38	2	40	1,546
20	170	Gulf of California	73	Hyperion	1,050	32	2	34	1,522
1.346 M ac-ft/yr Drainage inflow – Reach 43 ppt salinity in 90 years									
21	100	Camp Pendleton			420	39	2	41	1,001
22	100	Gulf of California			470	6	0.4	7	564
1.000 M acre-ft/yr Drainage inflow – Reach 40 ppt salinity in 30 years									
23	205/120	Gulf of California	405/345	Yuma [3]	1,300	7	0.3	8	1,406

Desalinization Plants and Solar Pond

No.	Discharge (k ac-ft/yr)	Description	Construction Field Cost ($M)	Energy Costs Annual ($M)	Other OM&R Annual ($M)	Total OMR&E Annual ($M)	Total Present Worth ($M)
1.346 M ac-ft/yr Drainage inflow – Reach 40 ppt salinity in 30 years							
24	110	Desalt plant & brackish pipe to the Gulf	932	47	17	64	1,822
25	94	Solar pond, desalt plant & brackish pipe to Gulf	1,006	14	18	32	1,453

Dikes

No.	1997 Report Alternative No.	Surface Area Of Dike (mi^2)	Description	Construction Field Cost ($M)	Energy Costs Annual ($M)	Other OM&R Annual ($M)	Total OMR&E Annual ($M)	Total Present Worth ($M)
26	1	50	Dike	840	9.7	352	361	5,908 [2]
27	2	40	Dike	660	9.7	351	361	5,722 [2]
28	3	127	Dike	700	9.7	796	806	11,996 [2]
29	4	47 Total	Two Ponds	1,100	9.7	352	361	6,167 [2]
30	5	25/127	East / North Ponds	1,250	9.7	797	806	12,555 [2]
31	2*	40	Earthquake Design [1]	1,950	9.7	351	361	7,012
32	6	30	Dike only	610	- -	- -	-	610 [2]
33	7	30	Dike only	610	- -	- -	-	610 [2]

New Combination Alternatives

No.	Description	Construction Field Cost ($M)	Energy Costs Annual ($M)	Other OM&R Annual ($M)	Total OMR&E Annual ($M)	Total Present Worth ($M)
34	Salt Pond / Shipping Channel / Canals / Desalting Facility					
35	Gulf of California Pump-in / Pump-out / Diking / Treating Inflows					
36	Phased Approach -- Ph.1: Salt Stabilized, Ph.2: Pump-in					
37	In-Sea Concentrator / Pipeline	1,748	64	3	67	2,690
38	Out-of-Sea Concentrator / Pipeline					

Costs do not include cost of obtaining water or cost reductions for pumping cut backs..

[1] Similar to No. 2 but designed to withstand earthquakes.

[2] Costs do not include cost of repairing dike failures caused by earthquakes.

[3] See Chapter 5, "Pump-in Sources" for availability of water.

Chapter 1

Purpose and Need

Designs of the preappraisal level alternatives presented in this report were based on the ability of the alternatives to reduce salinity in the Salton Sea (Sea), to maintain an acceptable water surface elevation in the Salton Sea, and to use proven technology. Costs are presented for information in future screening. No conclusions are presented regarding whether or not the alternatives should be retained for further consideration.

Purpose and Scope of Study

The purpose of this study is to develop alternatives that would reduce salinity to no more than 40 parts per thousand (ppt) and to maintain a water surface elevation in the Salton Sea to about -232 mean sea level (m.s.l.), using proven technology.

The Salton Sea problems are many and complex because the Sea is an integral part of a dynamic hydrologic system. The physical problems of the Sea are directly related to the characteristics of inflow, to hydrologic factors in the basin, and to the geometry of the basin and the Sea. The salinity concentration and the water level problems will be discussed in this document.

Because of Salton Sea's present physical, chemical, and biological characteristics, the Sea falls short of its potential contribution toward national, regional, and local needs for recreation opportunity, wildlife conservation, and community enhancement. These characteristics are discussed in other documents and are outside the scope of this report.

Description of the Area

Located at the bottom of the Salton Sea basin, the Salton Sea has a surface elevation of about -227 feet m.s.l. (1996) and an estimated surface area of 240,000 acres (376 square miles [mi^2]). The Sea is about 35 miles long and 15 miles wide. At its current elevation, the Sea has a maximum depth of 51 feet, with its lowest elevation at approximately -278 feet m.s.l. The

Salton Sea has a volume of approximately 7.5 million acre-feet. Annual inflows of approximately 1.3 million acre-feet contribute about 5 million tons of additional salt.

The Salton Sea basin is a below-sea-level topographic depression extending from Palm Springs, California, on the north, to near the Gulf of California, on the south. This area has, in the recent geologic past, undergone cycles of filling with water and evaporating as the Colorado River made radical course changes (Waters, 1983). Lake Cahuilla, the most recent predecessor to the Salton Sea, at one time had a surface elevation slightly above sea level. The last filling of Lake Cahuilla has been dated at 300 to 500 years ago (Colorado River Board of California, 1992).

Between the time of the evaporation of Lake Cahuilla and the recent formation of the Salton Sea, the area was similar to the bare desert, characteristic of present-day basins east of the Sea.

The Salton Sea basin comprises more than 500,000 acres of agricultural land (updated from the 1974 report—Interior and Resources Agency of California [RAC]). Because there is no outlet from the basin, evaporation is the only escape for water that enters it. High temperatures and low humidity contributed to rapid evaporation of the water that occasionally filled Lake Cahuilla, leaving a salty crust on the basin floor. Those same factors are at work on today's Salton Sea, resulting in approximately 5.5 feet of evaporation per year.

History

The modern-day Salton Sea, often referred to as the largest manmade water body in California, was formed in late 1905 as the result of a break in a temporary levee along the Colorado River (Interior and RAC, 1974). For a period of about 16 months after the breach, the Colorado River flowed into the below-sea-level depression, then known as the Salton Sink, filling it to a depth of more than 80 feet above its lowest elevation.

Since that time, the water level in the Sea has been seeking a balance between the harsh desert forces that extract water by evaporation and inflows of water from surface and subsurface sources. For a time following closure of the break in the levee, water levels declined rapidly as evaporation greatly exceeded inflow. A minimum level was reached in the 1920s, after which the level of the Sea once again began to rise, due, in major part, to importation of water for agriculture. Since then, maximum elevations were reached only to be exceeded in following years. The level of the Sea has been steadily rising since the emergence of agriculture in the area to a current elevation of approximately -227 feet m.s.l.

During the course of historical changes in the Sea's water balance, its salinity has also changed. At the time of the levee break, the salinity of the Sea was about that of the Colorado River, but because of evaporative concentration and redissolution of lakebed salt deposits, the salinity began to rise as water levels fell toward the minimum level of the 1920s.

Subsequently, as water was imported for irrigation, salt loads from irrigation drainage and return flows added salt to the water body. As agriculture expanded and water importation increased, not only did the Sea's water level increase, but salinity also rose steadily, eventually surpassing that of average ocean salinities. Today, the Sea's salinity has reached its highest historical level of approximately 44 ppt, or a level about 25 percent greater than that of the ocean.

Land ownership is typically in a checkerboard pattern, with sections alternating between Federal and private ownership. Much of the north shore is owned by the Torres-Martinez Desert Cahuilla Indians. The northeast shoreline has been leased to California for use as the Salton Sea State Recreation Area.

In 1924 and 1928, the President of the United States executed Public Water Reserve Order Numbers 90 and 114, respectively, for withdrawal of lands located in and surrounding the Salton Sea. The Public Water Reserve consists of 123,360 acres of public land lying below an elevation of -220 feet. These lands were designated as a repository to receive and store agricultural, surface, and subsurface drainage waters (appendix F, Currie et al., 1988). The State of California designated the Sea for this same purpose in 1968.

Land, recreational, and ecological values associated with the Sea have declined over the last decade, due, in large part, to the rising salinity and surface elevation. The desire to regain those values to the largest extent possible has prompted the investigations documented in this report.

Salinity Concentration Problems

For the last 25 years, the problem that has had the most attention has been salinity. That problem has become more pressing over the past 10 years as salinity concentrations have surpassed that of the ocean. Measurements indicated that the salt concentration at the end of 1995 was about 44 ppt, which is 9 ppt higher than average ocean salinity. An estimated 5 million tons of salt flow into the Sea each year and are left behind as the water evaporates. This rate of salt inflow causes an increase in salinity of about 0.51 ppt each year, provided the volume of water in the Sea remains unchanged.

Ideally, for the saltwater species of fish and other aquatic life in the Sea, a salinity level equivalent to ocean water, around 35 ppt, should prevail. However, biologists regard a salinity level of between 33 ppt and 37 ppt as adequate. With increasing salinity, survival of the fish in the Sea is in jeopardy. The limited reproductive success of some organisms has placed physiological stresses on the fishery food chain, as well as fish eggs, larvae, and adult fish. At some level, one or more of the links will finally break. At this point, the fishery will gradually or suddenly be lost, depending on the link that is broken first.

High salinity also tends to discourage recreational use of the Sea for body contact sports, such as swimming and water-skiing. In general, highly saline water can be irritating to the eyes and skin.

Higher salinity also causes increased corrosion of boats and other recreational equipment. With increasing salinity, there has been a gradual decline in water-related recreational use of the Sea. Figure 1 presents historical changes in the Sea's salinity and elevation.

Water Level Problems

In addition to salinity, a second major problem is water level fluctuation. The Sea's elevation is a balance between inflow and evaporation, and it normally fluctuates within 1 foot during a given year. In the history of the Sea, the elevation rose quickly to its highest point of close to -200 feet m.s.l. during its formation and then fell to around -250 feet m.s.l. until the introduction of agriculture to the area in the early 1920s. Since that time, it has steadily increased to its present height of approximately -227 feet m.s.l. Changes in inflow to and evaporation from the Sea have caused continually changing water levels during much of the Sea's existence.

Water level fluctuations are a serious problem as conditions of inflow and evaporation change. Both the Coachella Valley Water District and the Imperial Irrigation District, the irrigation districts in the area, have had legal action brought against them for damages to shoreline property because of inundation. Water level fluctuations are disruptive to using the Sea and adjoining land.

The gentle slopes of the land under and around the Sea cause a significant change in the shoreline with a relatively insignificant change in water level. Shoreline developments are being flooded as the water level rises, and changes in water level affect both private and public facilities. As the water

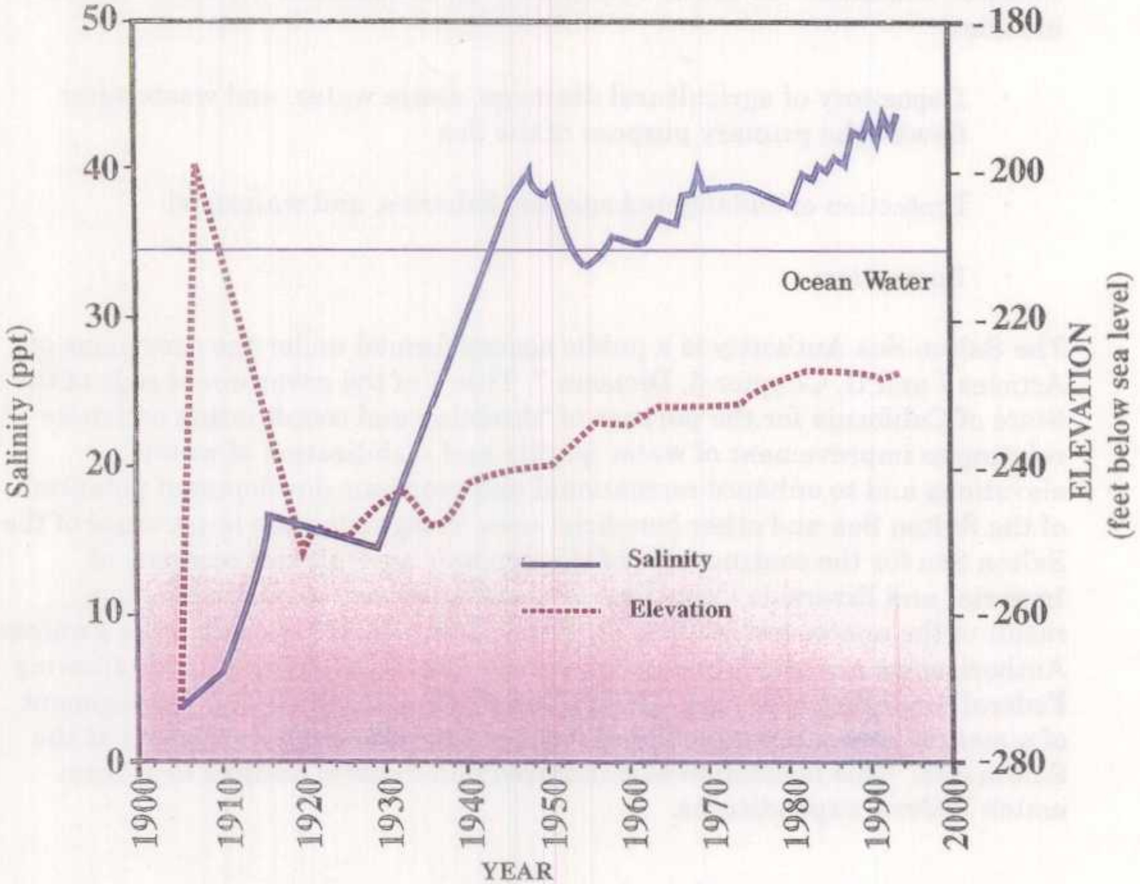


Figure 1.—Historical salinity and elevation through time.

level increases, there are additional costs in levee construction and maintenance. Millions of dollars have been spent trying to solve these issues alone. In addition, agricultural drainage would be adversely affected by water levels higher than those presently prevailing.

Authority

Local authority to pursue remedies to problems facing the Salton Sea comes from the formation of the Salton Sea Authority (Authority) by a Joint Powers

Agreement on June 2, 1993. This agreement between the Coachella Valley Water District, Imperial Irrigation District, Imperial County, and Riverside County established the Authority as a recognized State agency. The Authority was formed to work with California State agencies, Federal agencies, and the Republic of Mexico to develop programs that would continue beneficial use of the Salton Sea. In the agreement, "beneficial use" includes:

- Depository of agricultural drainage, storm water, and wastewater flows—the primary purpose of the Sea
- Protection of endangered species, fisheries, and waterfowl
- Recreation

The Salton Sea Authority is a public agency formed under the provisions of Articles I and II, Chapter 5, Division 7, Title 1 of the government code of the State of California for the purpose of "directing and coordinating activities relating to improvement of water quality and stabilization of water elevations and to enhance recreational and economic development potential of the Salton Sea and other beneficial uses, recognizing the importance of the Salton Sea for the continuation of the dynamic agricultural economy of Imperial and Riverside Counties." Federal authority to participate is a result of the enactment of Title 11, Public Law 102-575, Reclamation Projects Authorization and Adjustment Act of 1992, dated October 30, 1992, allowing Federal expenditure of up to $10 million for "investigation and development of a method or combination of methods" to address salinity problems at the Salton Sea. This legislation also required non-Federal entities to at least match Federal expenditures.

Participants

The principal participants in this appraisal evaluation are the Authority and the Bureau of Reclamation (Reclamation). The Salton Sea Planning and Research Agreement (Agreement) has been executed between these two agencies. This Agreement describes the relationships among the parties, the responsibilities of the parties, cost-sharing arrangements, and the framework for accomplishing study activities. At least 50 percent of the study cost is borne by the non-Federal participants; the remainder is provided by Reclamation.

A Technical Advisory Committee (TAC) has been established to provide technical advice to the Salton Sea Authority. The TAC is composed of staff from the individual Authority member agencies who have knowledge of the Sea and have the ability to work together to address its problems.

Reclamation and the Authority work with the TAC to develop study tasks and ensure that the study progress meets the needs of the Authority. While the TAC membership is limited to member agencies of the Authority, representatives from Reclamation, DWR, California Department of Fish and Game, Coachella Valley Association of Governments, Imperial Valley Association of Governments, Southern California Association of Governments, and California State Secretary of Resources are invited to participate as *ex officio* members.

Program managers working for Reclamation and the Authority are responsible for developing work plans, schedules, and budgets; monitoring the development and completion of the planning and research activities; and providing direction to the development of planning and research activities.

Relationship to Other Projects

The problem of salinity of the Salton Sea and a desire to correct it was recognized first in the mid-1960s. In response to this recognition (Interior and RAC) jointly completed reconnaissance and feasibility studies that investigated the options available to manage the Salton Sea. Study results were reported in 1969 and 1974, respectively. The 1974 study recommended that an in-Sea evaporation pond be pursued. A draft environmental impact statement was completed on the proposed 50-mi^2 evaporation impoundment, but construction of the project never began due to a lack of funding.

In April 1986, the Resources Agency of California created the Salton Sea Task Force at the prompting of the California Department of Fish and Game. This group, consisting of representatives from Federal, State, and local governmental agencies, was formed to investigate practical solutions and associated funding mechanisms to address the problems of high water surface elevations and salinity concentrations of the Salton Sea. The State of California also hired a consultant to complete certain studies and act as a staff resource to the task force. Reclamation and DWR participated on the task force, which was dissolved after the Authority was formed.

In September 1997, a *Salton Sea Area Study Alternative Evaluation Appraisal Report, Final Draft* (1997 report), was published in cooperation with the Salton Sea Authority, the California Department of Water Resources, and the Bureau of Reclamation. This report presented results of a study to identify and evaluate 54 alternatives submitted for consideration to improve the physical, chemical, and biological conditions of the Salton Sea.

The 1997 report included a two-fold process. Four criteria were developed to eliminate those alternatives which had no realistic potential for correcting the problems of the Sea, and 20 evaluation criteria were developed and applied to rank those remaining alternatives that met the elimination criteria.

Chapter 2

Alternative Development Process

The preappraisal level alternatives are designed to reduce the salinity of the Salton Sea and maintain an acceptable water surface elevation. It is not known at what salinity level the Sea will become unproductive. Interim or phased projects may be considered for development that arrest salinity increases, do not preclude long term solutions, and do not increase water elevation levels.

Reducing salinity and maintaining the Sea level, alone, will not ensure a good biological habitat. However, the current biological habitats in the Sea will cease if the salinity of the Sea continues to rise. The Science Sub-Committee, established by the Secretary of the Interior, is examining the needs of the biological habitat and many other important science-related issues of the Sea. Therefore, biology is outside the scope of this report.

Additional geologic work is beyond the scope of this report but was considered in these designs based upon the information in the 1974 report. The 1974 report does contain much geologic information, including field investigations, sampling, and laboratory testing data. Seismic activity in the Salton Sea area is very high and is an important consideration in final designs.

Salinity, as used in this report, is a measure of the concentration of total dissolved solids (TDS) in water. Salts are inorganic compounds of metals, such as sodium, calcium, magnesium, and potassium and bases such as carbonates, sulfate, and chloride. Soluble salts will dissolve into metallic and basic ions when exposed to water. Salinity values are commonly given in parts per million (ppm), parts per thousand (ppt), and milligrams per liter (mg/L). The values of ppm and mg/L are essentially equal. There are a thousand more ions in 1 ppt than in 1 ppm. This report uses mostly parts per thousand because of the large quantities of ions in the waters discussed.

The reader should keep in mind that ocean water has a salinity concentration of 35 ppt, and the Salton Sea currently has a salinity concentration of 44 ppt. However, at this time, the overall effects of salinity on the fishery are not known. The questions of what effect salinity has on the aquatic habitat has been given to the Science Sub-Committee for analysis and recommendations.

Public Involvement

While a number of alternatives were identified during previous studies, it was important that any new ideas be included in the alternatives being evaluated. Opportunity was given to companies, universities, individuals, and the general public to suggest alternatives for solving challenges of the Sea.

A public discussion was opened on ideas and suggestions for management of the Sea in the form of two public workshops hosted by the Salton Sea Authority Board's TAC in August and September 1995. The public was again invited to propose solutions during summer 1998 at three public meetings. The TAC, along with *ex officio* members, was there to listen, discuss, and record alternatives proposed by the public. Notice of these meetings was given in Imperial and Coachella Valley newspapers and posted in local libraries in accordance with the California Government Code Section 54950 (Ralph M. Brown Act), governing open meetings. (All meetings of the Authority and TAC also fall under the Act.) In addition to ideas and suggestions presented in the workshops, written submissions were accepted with the understanding that all the alternatives submitted to the TAC would be considered on their technical and economic merit.

Development Process

One consideration in selecting a management alternative is that a drop in elevation could also cause developments to be left at a considerable distance from a receding shoreline. There is also a correlation between salinity and elevation such that any increase in the Sea's volume is accomplished by inflow from a less saline water source which dilutes the existing salt concentration. Also, any decrease in volume is by evaporation, which raises the salinity by concentrating the salt in the remaining water.

Rising water surface elevations also can disrupt historic flow patterns and contribute to access problems at marinas. Deposition of sediment and barnacles in channels that provide access to boat slips and docking facilities can require increased maintenance to keep those channels open. In some cases, these problems have resulted in denied access altogether.

The development process, therefore, involved designing alternatives that meet the three criteria. These criteria were applied to all submitted alternatives. An alternative must have the ability to:

- Reduce salinity to not more than 40 ppt
- Control water surface elevation to -232 m.s.l.
- Use proven technology

Alternatives that did not meet all criteria may be dropped from further consideration and are described later in this report.

Target Salinity: 40 ppt

Salinity management targets have been established at levels that protect the existing fishery in the Salton Sea. The Sea currently supports a fishery of marine species (that is, corvina, sargo, and bairdiella) transplanted to the Sea when the salinity concentrations rose too high to support freshwater species. The Sea's fishery is important to the region from both environmental and economic viewpoints. For example, fish are important biologically to fish-eating birds and other animals found around the shore of the Salton Sea, and the wildlife in the region attracts fisherman, hunters, and naturalists, providing economic growth to the area. Furthermore, the Water Quality Control Plan for the Colorado River Basin (California Regional Water Quality Control Board, 1994) designates warm-water aquatic habitat as a beneficial use, and its water quality objective for salinity relates to sustenance of aquatic life.

For the existing fishery to be maintained, a salinity range of 35 to 40 ppt has been determined acceptable. The criteria identified for these alternatives was selected to meet a salinity concentration of no more than 40 ppt. This salinity concentration would stabilize the fishery at the existing conditions of the Sea. As a comparison, ocean water is approximately 35 ppt; Salton Sea water, at the time of this report, is approximately 44 ppt. This salinity would allow fish species currently found in the Sea to spawn, thereby complying with Water Quality Control Plan for the Colorado River Basin requirements for protecting beneficial uses of the Sea.

Target Water Surface Elevation: -232 feet m.s.l.

Many considerations determine a target water surface elevation of the Salton Sea. Private and commercial property owners are concerned with the Sea's elevation because of its direct effect on property values and on future construction projects along the shore. Because the Sea is a repository for agricultural drainage, the Sea's elevation is important to agricultural interests. The Sea's elevation is also important to the biota of the area. Birds, such as the endangered Yuma clapper rail, depend on wetland habitat around the margins of the Sea for breeding, and many hundreds of acres of wildlife refuge have been inundated by rising Sea levels. State and Federal agencies must also plan for potential flood conditions. History has shown that rapid flooding occurs regularly in the area, and the Sea is a repository for storm runoff. Finally, the Sea's target water surface elevation is closely connected to its target salinity concentration. The removal of water from the Sea as a means of removing salt can result in dramatic changes in water surface elevation. The elevation management target and ability to regulate water surface elevation may ultimately determine the salinity management option selected for implementation.

The water surface elevation of the Sea is currently about -227 feet m.s.l. The Sea's elevation fluctuates about 1 foot per year based on Imperial Irrigation District elevation data for the past 9 years. In 1994, for example, the Sea's elevation ranged from between -227.75 to -226.75 feet m.s.l. and from -227.8 to -227.2 m.s.l. from November 1994 to February 1995.

While current shoreline damage resulted from high water surface elevations, much lower levels could also cause damage. A large drop in Sea elevation could adversely affect shoreline development, including marinas, the Salton Sea State Recreation Area, commercial enterprise, and residential developments. Large drops in elevation would also expose large areas of land that were Sea bottom and degraded biomatter. Some people feel that this would become a health hazard when made airborne by wind. As a method of balancing between excessively high and low levels, a target elevation range of -232 feet m.s.l. was established.

Maintaining the water surface elevation of the Sea within the target range is certainly of interest, but uncertainties of future flows into the Sea make it difficult to determine an alternative's effect on the Sea's elevation. As a result, the elimination of an alternative due to its inability to achieve and maintain the target elevation is used only on those alternatives that have no ability to control the water surface elevation of the Sea.

Proven Technology

Because of the short timeframe allowed for applying the alternative, the technology employed in the alternative must be currently available and proven in similar situations. The goal of the development process was to design alternatives with the best chance of success. To further the design process, only alternatives that could present data demonstrating the involved technology's effectiveness were considered. An alternative's technology could be demonstrated by data gathered in a full-scale application, prototype, or lab results, but all data necessary for evaluation had to be available. By definition, this eliminated all research proposals.

Salinity Model

An operational model was developed for the Salton Sea by Richard Thiery for use by the Salton Sea Authority (Thiery, 1998). The model is a workbook or spreadsheet model created using the Microsoft Excel spreadsheet program. For the most part, the model uses simple mass balance arithmetic to calculate changes in elevation and salinity in response to annual estimates of inflow and evaporation with pump-in and pump-out alternatives. Worksheets were developed to evaluate water exchange (pump-out/pump-in) alternatives with the Sea and several in-Sea evaporation pond configurations containing 48, 85, and 143 square mile surface areas based on total Sea area at -227-foot elevation.

Elevation-area and elevation-capacity relationships were developed for each of the alternative configurations. New area and capacity relationships would need to be developed for any new in-Sea evaporation pond configuration. One worksheet was developed to evaluate variable areas as desired by the model operator; however, the area and capacity relationships are general and do not represent actual conditions. The original model was provided to Reclamation and was evaluated by the Technical Service Center (TSC) for applicability to this preappraisal study. It was concluded that the original model could be used in alternative evaluations.

Evaporation Rates

The evaporation rate from water surfaces is a function of energy exchange at the water surface and the salinity concentration of the water body. The energy relationship was handled by using average annual energy conditions for the Sea area and developing a relationship for the Sea based on salt concentration in ppt. This resulted in an annual Sea evaporation rate of 66 inches of water at a salinity concentration of 44 ppt. It was reduced to 56.1 inches at a salinity of 200 ppt. This evaporation relationship was programmed into the model. As salinity in the Sea or salt concentrations varied, the appropriate evaporation rate was calculated and used in evaporation calculations.

Precipitation Rate

The original version of the model did not account for direct precipitation to the Sea water surface and was not available for use in evaluating the pump-in and pump-out alternatives. Mr. Thiery added precipitation as a model input in version 1.1 of the model, which also contained a worksheet that would hold the Sea elevation constant and let the in-Sea evaporation pond elevation vary independent of the Sea for one impoundment configuration (143-square-mile surface area). The average annual precipitation rate used in version 1.1 of the model was 2.80 inches per year. To be consistent in all model calculations, precipitation to the Sea was not used. However, it was determined that if precipitation was input to the worksheets, the Sea water surface elevation in the model would increase approximately 3 feet in 100 years. The total increase depends on the Sea and evaporation pond salinity concentrations.

Drainage to the Sea

The current drainage to the Sea is estimated to be 1,346,000 acre-feet annually from all sources, including the Alamo, New, and Whitewater Rivers and other drainages discharging directly to the Sea. The estimated salinity concentration of this drainage is 2.8 ppt and was used in all alternative evaluations using current conditions. The maximum Sea salinity concentration rose to 91 ppt at the end of 100 years under these baseline conditions.

Water conservation activities are planned in the Sea drainage area and are expected to reduce the drainage inflow from 1,346,000 acre-feet annually to 1,000,000 acre-feet annually over the next 10 years. For evaluation of the water conservation alternatives, an additional 20,000 acre-feet were removed from the inputs for each of the first 9 years. The remaining 166,000 acre-feet were removed in year 10 to reach a total inflow of 1,000,000 acre-feet per year, a reduction of 346,000 acre-feet. It was assumed that an associated 300,000 tons of salt also would not drain into the Sea. This reduction was prorated as the drainage was prorated with 12,000 tons being removed each year for 9 years and the remaining 192,000 tons removed in the tenth year. The rest of the time, the drainage inflow to the Sea was 1.0 million acre-feet at a salinity concentration of 3.5 ppt. These changes were programmed into the water exchange worksheet to determine required pumpage.

The in-Sea evaporation impoundment worksheets were programmed with the salinity concentration and water surface elevation at the end of year 9 as initial conditions for each of the drainage quantities. This was done because it was assumed that it would take at least 9 years to design and construct effective salinity control measures. Under this assumption, the Sea would increase in salinity for the first 9 years in the water exchange scenarios before pumping started.

Salinity and Sea Elevation Goals

The salinity goals for the alternatives in the model were to keep the salinity concentration from exceeding 50 ppt and to reduce the Sea's salinity concentration to 40 ppt in 15 or 30 years after the control measure was initiated. The salinity target would be accomplished by pumping quantities of Sea water out and disposing of it in evaporation ponds or the ocean. Water with lower salinity concentrations could also be pumped into the Sea to help meet the salinity target. Usually, both pump-out and pump-in were required to meet the target of maintaining the Sea at -232 feet m.s.l.

All pump-in/pump-out alternatives could be made to meet the targets by balancing the pump-out and pump-in volumes of water. The ocean water pump-in alternative required large volumes of water to meet the target salinity. For example, 700,000 acre-feet of pump-out and 600,000 acre-feet of pump-in were required to meet the target salinity concentration of 40 ppt in 15 years. Under this scenario, the elevation target was met in simulation year 42.

The 30-year salinity target was met with 400,000 acre-feet of pump-out and 303,000 acre-feet of pump-in of ocean water. The ocean water used had a salinity concentration of 35 ppt. The target water surface elevation of -232 m.s.l. was met in simulation year 47. With ocean pump-in water, the Salton Sea salinity could not be lowered to 35 ppt. The minimum salinities (100 year) were 35.4 ppt and 36 ppt, respectively, for the two ocean water examples above. Other pump-in/pump-out alternatives could have the Sea salinity go below 35 ppt and the target elevation if pumping was not properly balanced.

Model Behavior

The model has some unique behavior characteristics that occur, such as the case described above for ocean water pump-in conditions. The Sea salinity will approach the pump-in water salinity asymptotically if large enough quantities are pumped for a long enough period of time. Pump-in water with low salinities (4 ppt), such as from Yuma (Tucson, Arizona), discussed later, had to have both the pump-out and pump-in quantities reduced to prevent the Sea salinity from going below this 35-ppt target, the salinity of the ocean.

The difference between the final pump-in and pump-out quantities needs to be balanced with the evaporation rate and the drainage volume to the Sea after the target salinity is reached to maintain the Sea at the target elevation. The ocean example given above, with 1,346,000 acre-feet of annual drainage, required between 97,000 and 100,000 acre-feet less water pumped in than pumped out to meet the -232-foot target elevation. The two examples had final elevations of -232.3 and -232.1 m.s.l., respectively.

The model operation results showed that the most effective way to reach the target salinity was to pump as much water as possible from the Sea as quickly as possible. This should be started as soon as the pump-out system can be designed and constructed. The maximum pump-out design capacity needs to be balanced with the later steady pumping rate to minimize infrastructure and pumping costs. Also, the pump-in flow can be delayed from start of pump-out. This may be delayed until the most appropriate source is determined. It should start at the appropriate time to balance the evaporation, pump-in, and pump-out to the Sea target water surface elevation and prevent significant drops in elevation prior to reaching the target salinity. Once the target salinity is reached, then the inputs and outputs need to be set at reduced pumping rates to maintain both the target elevation and salinity.

The results of the model analysis—the success of the alternatives to meet the salinity and water surface elevation goals—are discussed in chapter 9.

Cross-Reference Table to 1997 Report

All alternatives presented in the 1997 report have been reconsidered using the three criteria stated above. Some are discussed in detail in later chapters, and others have been considered for elimination from further consideration because they could not lower salinity concentrations, could not maintain the water surface elevation at the desired levels, or did not use a proven technology.

Table 1 lists the alternatives considered in the 1997 report and provides a cross-reference location to that alternative's discussion in this document.

Table 1.—List of alternatives and cross-reference location

54 original alternatives	Location in this report
Diked Impoundments	Page
1. 50 square miles, south end	27
2. 40 square miles, south end	27
3. 127 square miles, north end	27
4. 47 square miles, in-Sea evaporation basin	30
5. Phased impoundment	30
6. 30 square miles with pumping to Palen Lake	30
7. 30 square miles with maximum pumping	30
13. 190 square miles, plastic curtain	74
14. Various sized impoundments—plastic curtain	74
Pump-Out	
8. Onshore evaporation ponds	71
9. Enhanced evaporation/solar pond/power	72
10. Dry lakebed (Palen, Clark, or Ford)	48,51
11. Pipe to Pacific Ocean/Camp Pendleton	48-51
12. Navigable waterway/Mexicali seaport	73
15. Canal/dam to base of Chocolate Mountains	74
16. Diked impoundment to Gulf of California	74
17. Frontier Aquadyne enhanced evaporation	75
18. Solar still desalt/Colorado River replenish	75
19. SNAP technology	76
20. Aquaculture/evaporation ponds	76
21. Pump to Gulf of California (415K acre-feet)	56
22. Pump to Laguna Salada/Gulf of California (415K acre-feet)	56
23. Pumped storage canal to Gulf of California	76
24. Solar membrane distillation	77
25. Disposal of reject stream to Yuma	77
Combination	
26. Impound/evaporation pond/pipe to Gulf of California/Yuma Desalting Plant	77
27. Impound/power generation/wetlands	78
28. Freshwater shore/pumped storage/wetlands	78
29. Solar power/pumped storage/wetlands with Laguna Salada disposal	79
30. Move Yuma Desalting Plant to Sea	79
31. Poplar tree constructed wetlands	80
32. Special pretreatment reservoirs	80
33. U.S. Filter-New River desalting	80
34. Groundwater pump for selenium management	81
Water Imports	
35. Freshwater blending—Calexico	81
36. Replenish—Colorado River surplus	81

Other	Page
37. Venturi Air Pump	82
38. Foraminifera studies (research)	82
39. Potential use study ponds (research)	82
40. Injection well salt disposal	83
41. Air diffusion/ultraviolet ozone system	83
42. Surface aeration	83
43. Gravel berm	83
44. Sea water filtration	84
45. Enzyme-activated removal	84
46. Power/freshwater cogeneration	84
47. Water conservation	85
48. Drainage water reuse or blending	85
49. Pulsed plasma	85
50. Hydropower/filtration system resort	85
51. Slow sand reverse osmosis filtration	86
52. Electrochemical extraction	86
53. Mexican cleanup of New River	87
54. Land speed racetrack	87

Chapter 3

Costs of the Alternatives

Costs included in this report are comparative costs. They should only be used to compare the relative differences in costs among the alternatives.

The costs shown as construction field costs were based on estimated quantities. Minor items were handled by adding a percentage (15 percent) of the overall cost. The total construction field cost also includes contingencies of 25 percent.

The costs do not include the expense of purchasing water to be delivered to the Salton Sea. A cost may be charged for water other than ocean water. Pumping plant costs (capital and OM&R) were determined using computer programs and equations developed for planning estimates. Program input included head (pressure), discharge flow, and other factors.

The alternative designs assumed the presence of electrical transmission lines and energy prices typical of the local area. These are current energy costs and not marginal energy costs. The rate used was $0.0725 per kilowatthour (kWh), which is an average of the following rates:

Winter:
- Offpeak: $0.037 per kWh (37 mills)
- Onpeak: $0.103 per kWh (103 mills)

Summer:
- Offpeak: $0.037 per kWh (37 mills)
- Onpeak: $0.113 per kWh (113 mills)

Operation, maintenance, and replacement (OM&R) costs include those for operating and maintaining the pumping plants and replacing components as required. OM&R costs do not include energy costs.

Present worth calculations are based on a project life of 100 years and annual interest of 7.125 percent. The design assumes that salt removal is an ongoing event throughout the project life. The estimator assumed that trucks would haul the salt to the ocean. Salt trucked to the ocean would be mixed with ocean water, dissolved, and discharged through a dispersion pipe into the ocean; therefore, the salt would not stockpile over the 100-year period.

Table 2.—Preappraisal costs for the Salton Sea restoration

Pump-out / Pump-in Alternatives

1.346 M ac-ft/yr Drainage inflow – Reach 40 ppt salinity in 15 years

No.	Pump-out Discharge (k ac-ft/yr)	Pump-out To	Pump-in Discharge (k ac-ft/yr)	Pump-in From	Construction Field Cost ($M)	Energy Costs Annual ($M)	Other OM&R Annual ($M)	Total OMR&E Annual ($M)	Total Present Worth ($M)
1	700	Camp Pendleton	600	Camp Pendleton	3,500	478	8	486	10,314
2	700	Gulf of California	600	Gulf of California	3,300	42	0.7	43	3,902
3	700	Hyperion	600	Hyperion	4,700	359	6	365	9,813
4	250	Point Loma	153	Point Loma	1,500	153	5	158	3,717
5	250	Hyperion	153	Hyperion	1,850	117	4	121	3,548
6	250	Gulf of California	153	Yuma [3]	1,150	12	0.5	13	1,328
7	250	Palen Lake	153	Point Loma	2,682	119	678	797	13,859
8	250	Palen Lake	153	Hyperion	2,852	116	678	795	13,992
9	250	Gulf of California	153	Point Loma	1,450	70	3	73	2,468
10	250	Gulf of California	153	Hyperion	1,550	56	2	59	2,370

1.346 M ac-ft/yr Drainage inflow – Reach 40 ppt salinity in 30 years

No.	Pump-out Discharge (k ac-ft/yr)	Pump-out To	Pump-in Discharge (k ac-ft/yr)	Pump-in From	Construction Field Cost ($M)	Energy Costs Annual ($M)	Other OM&R Annual ($M)	Total OMR&E Annual ($M)	Total Present Worth ($M)
11	400	Camp Pendleton	303	Camp Pendleton	2,100	262	6	268	5,861
12	400	Gulf of California	303	Gulf of California	2,100	26	0.6	26	2,466
13	400	Hyperion	303	Hyperion	2,800	199	5	203	5,653
14	170	Point Loma	73	Point Loma	1,050	94	5	99	2,437
15	170	Hyperion	73	Hyperion	1,250	73	4	77	2,326
16	170	Gulf of California	73	Yuma [3]	800	9	0.4	10	935
17	170	Palen Lake	73	Point Loma	1,807	71	462	533	9,277
18	170	Palen Lake	73	Hyperion	1,887	65	462	526	9,264
19	170	Gulf of California	73	Point Loma	980	38	2	40	1,546
20	170	Gulf of California	73	Hyperion	1,050	32	2	34	1,522

1.346 M ac-ft/yr Drainage inflow – Reach 43 ppt salinity in 90 years

No.	Pump-out Discharge (k ac-ft/yr)	Pump-out To	Pump-in Discharge (k ac-ft/yr)	Pump-in From	Construction Field Cost ($M)	Energy Costs Annual ($M)	Other OM&R Annual ($M)	Total OMR&E Annual ($M)	Total Present Worth ($M)
21	100	Camp Pendleton			420	39	2	41	1,001
22	100	Gulf of California			470	6	0.4	7	564

1.000 M acre-ft/yr Drainage inflow – Reach 40 ppt salinity in 30 years

No.	Pump-out Discharge (k ac-ft/yr)	Pump-out To	Pump-in Discharge (k ac-ft/yr)	Pump-in From	Construction Field Cost ($M)	Energy Costs Annual ($M)	Other OM&R Annual ($M)	Total OMR&E Annual ($M)	Total Present Worth ($M)
23	205/120	Gulf of California	405/345	Yuma [3]	1,300	7	0.3	8	1,406

Desalinization Plants and Solar Pond

1.346 M ac-ft/yr Drainage inflow – Reach 40 ppt salinity in 30 years

No.	Pump-out Discharge (k ac-ft/yr)	Description	Construction Field Cost ($M)	Energy Costs Annual ($M)	Other OM&R Annual ($M)	Total OMR&E Annual ($M)	Total Present Worth ($M)
24	110	Desalt plant & brackish pipe to the Gulf	932	47	17	64	1,822
25	94	Solar pond, desalt plant & brackish pipe to Gulf	1,006	14	18	32	1,453

Dikes

No.	1997 Report Alternative No.	Surface Area Of Dike (mi^2)	Description	Construction Field Cost ($M)	Energy Costs Annual ($M)	Other OM&R Annual ($M)	Total OMR&E Annual ($M)	Total Present Worth ($M)
26	1	50	Dike	840	9.7	352	361	5,908 [2]
27	2	40	Dike	660	9.7	351	361	5,722 [2]
28	3	127	Dike	700	9.7	796	806	11,996 [2]
29	4	47 Total	Two Ponds	1,100	9.7	352	361	6,167 [2]
30	5	25/127	East / North Ponds	1,250	9.7	797	806	12,555 [2]
31	2*	40	Earthquake Design [1]	1,950	9.7	351	361	7,012
32	6	30	Dike only	610	-	-	-	610 [2]
33	7	30	Dike only	610	-	-	-	610 [2]

New Combination Alternatives

No.	Alternative	Construction Field Cost ($M)	Energy Costs Annual ($M)	Other OM&R Annual ($M)	Total OMR&E Annual ($M)	Total Present Worth ($M)
34	Salt Pond / Shipping Channel / Canals / Desalting Facility					
35	Gulf of California Pump-in / Pump-out / Diking / Treating Inflows					
36	Phased Approach – Ph.1: Salt Stabilized, Ph.2: Pump-in					
37	In-Sea Concentrator / Pipeline	1,748	64	3	67	2,690
38	Out-of-Sea Concentrator / Pipeline					

Costs do not include cost of obtaining water or cost reductions for pumping cut backs.

[1] Similar to No. 2 but designed to withstand earthquakes.

[2] Costs do not include cost of repairing dike failures caused by earthquakes.

[3] See Chapter 5, "Pump-in Sources" for availability of water.

Table 2 shows the costs of the alternatives that were determined to meet the three evaluation criteria previously discussed. The table includes not only construction costs but also energy, operation, maintenance, and replacement costs. Chapters 4, 5, and 6 describe the items included in these costs and their derivation. Please remember the designs and costs are for relative comparison among the alternatives.

As stated, table 2 shows the costs for complete pipeline systems. Figure 2 illustrates field costs as a function of discharge. It shows individual pipelines flowing in only one direction.

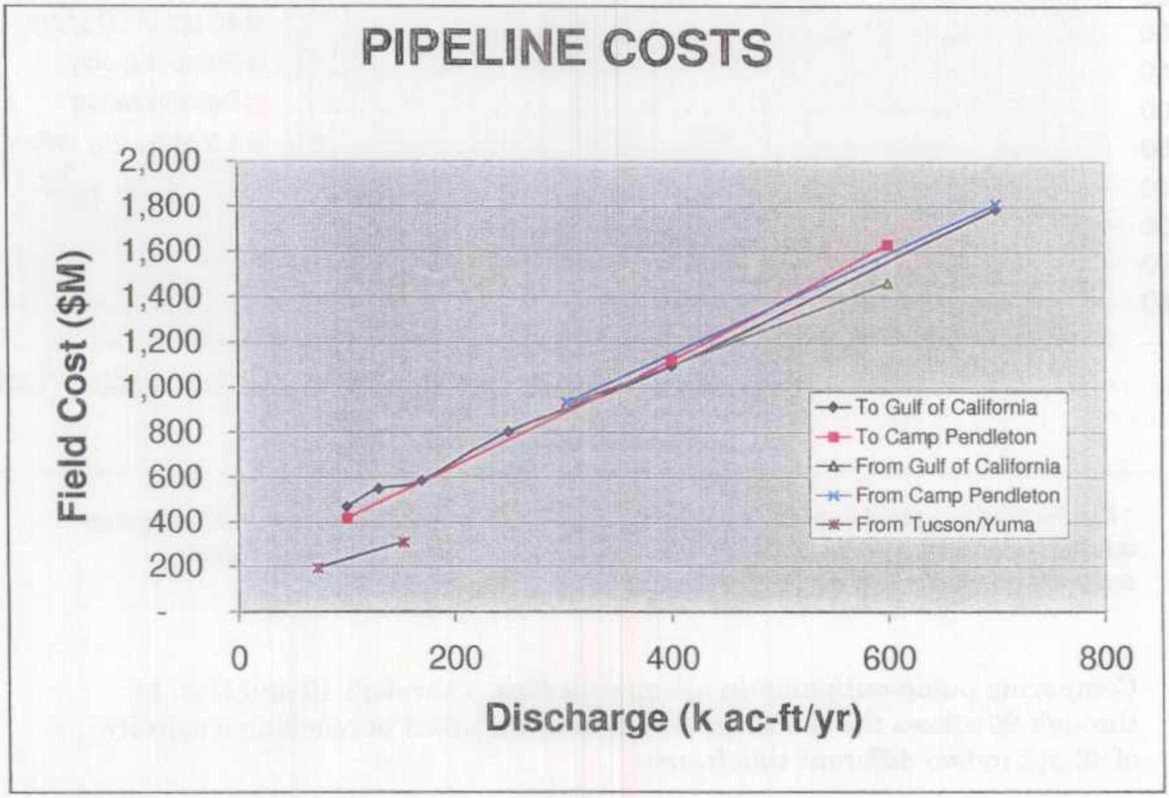


Figure 2.—Pipeline field costs as a function of discharge flowing in one direction.

It may be difficult to understand how the costs of a particular alternative (from table 2) compare with other alternatives. Figure 3 shows all alternatives' complete costs—field costs versus annual costs. Figure 4 shows the same information, but only for the alternatives with lower costs.

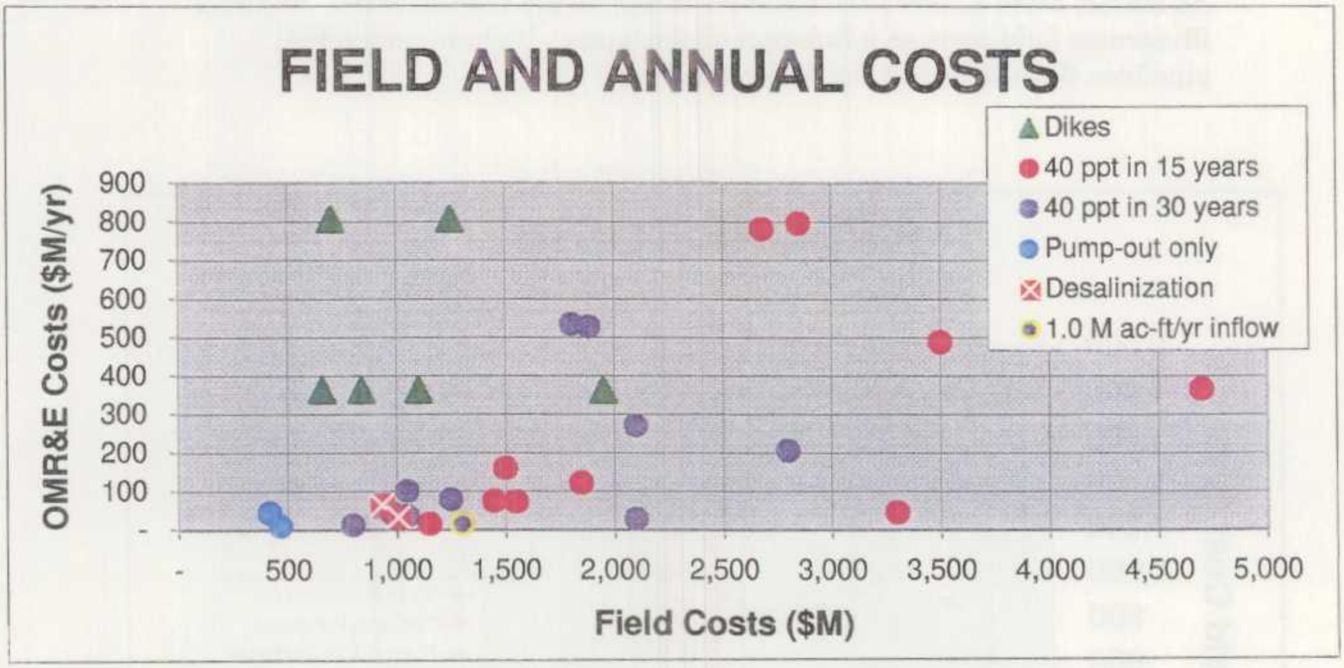


Figure 3.—Construction field costs are displayed on the horizontal axis and the annual costs of operation, maintenance, repair, and energy on the vertical axis. Pump-out/pump-in pipelines are shown as circular dots.

Comparing pump-out/pump-in alternative Nos. 1 through 10 and Nos. 11 through 20 allows the reader to understand the effect of reaching a salinity of 40 ppt in two different timeframes.

Figure 5 (Cost of Salinity) compares the cost of reaching various salinity concentrations in 30 years. This curve is based on inflow of 1 million acre-feet per year, 2.8-inch-per-year precipitation, and a pump-in salinity of 4 ppt.

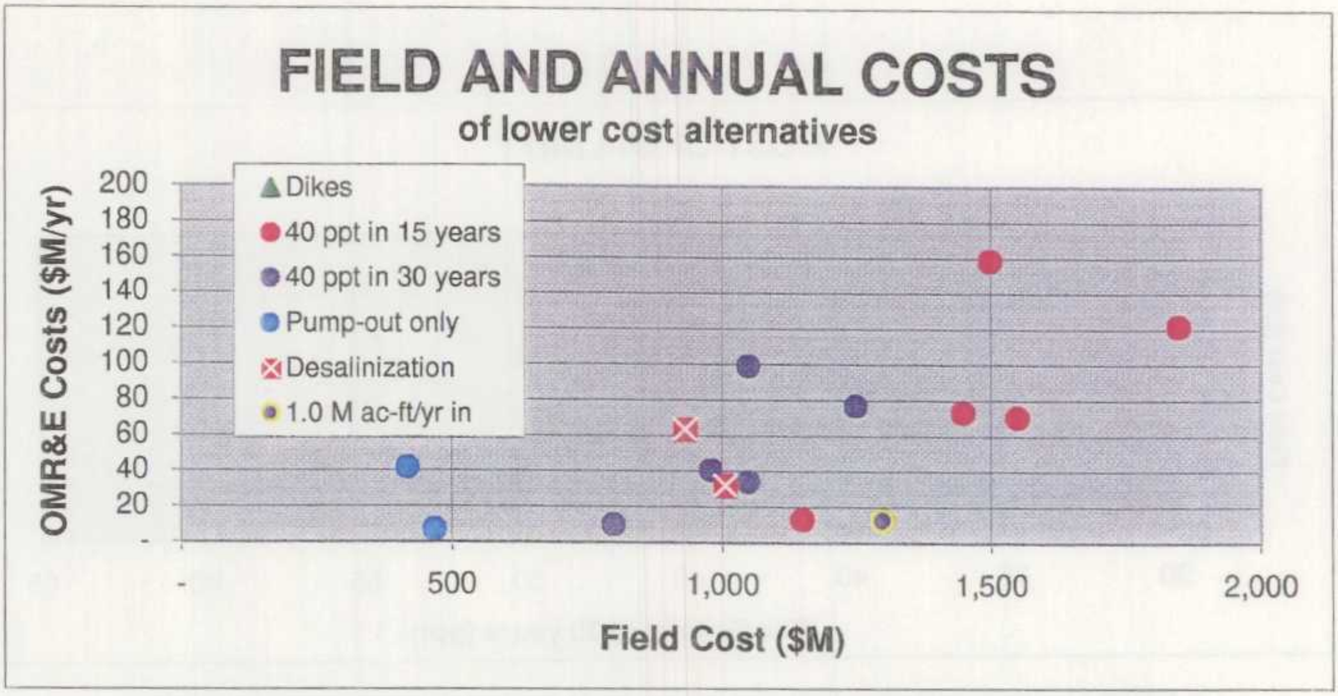


Figure 4.—The same field costs and operation, maintenance, replacement, and energy costs as in figure 3 are displayed on the horizontal and vertical axis, but only for the lower cost alternatives—a small portion of those in figure 3.

The curve is also based on a pipeline going to and from either Camp Pendleton or the Gulf of California. The costs are approximate but accurate enough to portray the cost of reaching various salinity levels in 30 years from the end of construction. The lower the salinity concentration to be achieved, the higher the cost would be to achieve that level of salinity under these circumstances.

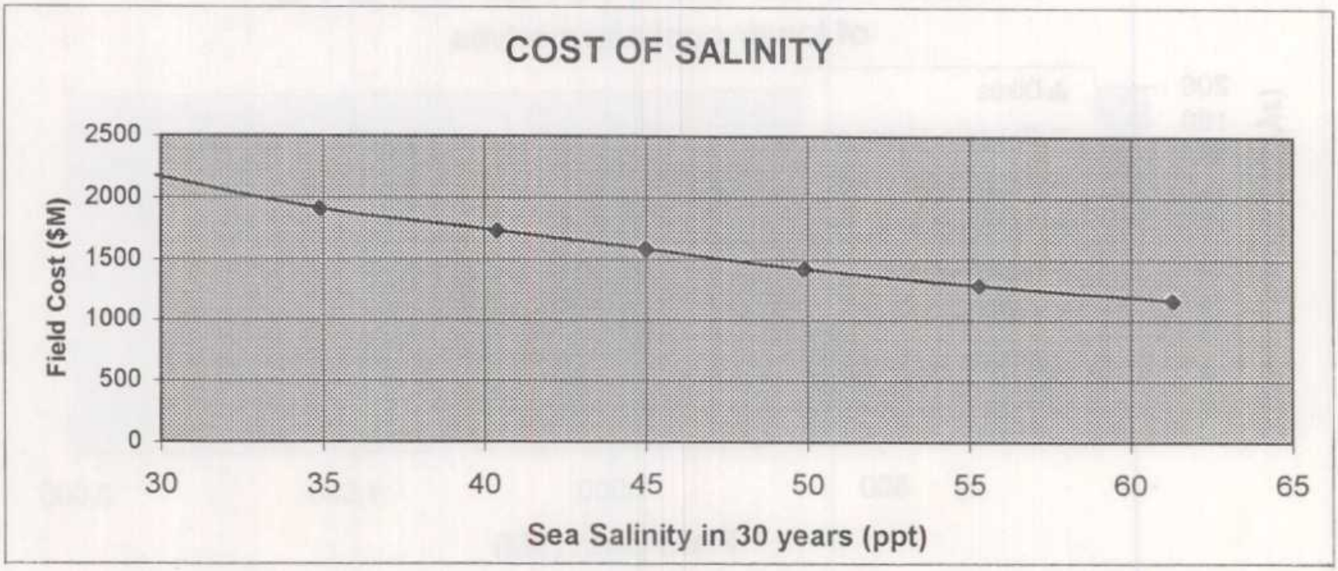


Figure 5.—The construction field cost decreases as the target salinity increases. This illustrates the relationship based on a fictitious pipeline going to and from the Gulf of California or Camp Pendleton. Other parameters are discussed in the text.

Chapter 4

Diked Impoundment Alternatives

This section provides background on and discussion of the alternatives that involve diked impoundments in the Salton Sea. Managing salinity with a diked impoundment is based on the concept of providing the Sea with an outlet into an evaporation pond—an impoundment within the Sea itself. Under this concept, the main body of the Sea is separated from an evaporation pond by an earthen dike.

Description of the Concept

The diked impoundment concept is based upon water flowing into the impoundment pond area carrying a heavy salt load, while inflow to the main body of the Sea from the Alamo River, New River, and other sources carries a smaller salt load, thereby decreasing the salt concentration of the main body of the Sea. Over the years, a number of in-Sea impoundment proposals have been made (Interior and Resources Agency of California, 1969 and 1974; Aerospace Corporation, 1971; Coachella Valley Water District, undated report and *Salton Sea Area Study – Alternative Evaluation Appraisal Report*, September 1997). Variations of the diked impoundment concept continue to emerge. Detailed engineering and geologic studies, dialogue with local residents, and water conservation developments in Imperial Valley would, in all likelihood, result in further adjustments in impoundment size, location, configuration, and design.

Unless inflows to the Sea decrease in volume, an in-Sea impoundment would change the elevation of the Sea very little. Although the surface area of the main body of the Sea would be reduced by the impoundment, the total surface area of the Sea would be essentially unchanged. Some minor changes in elevation would occur because evaporation rates in the impoundment and the main body of the Sea would be affected by salinity and temperature changes that would occur as the main body became less saline and the impoundment became more saline. Surface evaporation rates decline as salinity increases because the vapor pressure of the water decreases in proportion to its salt content.

In a diked impoundment alternative, one or two inlet structures in the dike separating the main body of the Sea from the evaporation pond would allow water to flow from the Sea into the impoundment. The length of time required for the main body of the Sea to reach some predetermined salinity level would depend on the size of the impoundment and, thus, the amount of water flowing between the Sea and the impoundment. If a target salinity level in the main body of the Sea is set higher than the impoundment system's natural equilibrium level, flow into the impoundment would eventually have to be reduced or salt could be pumped back from the evaporation pond to the Sea to maintain it at the target.

While water in the main body of the Sea would become less saline until it reaches an equilibrium level, water in the impoundment would become more saline over time. Salt concentrations would eventually reach saturation, at which point precipitation as a solid would occur. Precipitated salts would occupy volume in the impoundment, but impacts on elevation and useful project life would be relatively small, except in the case of small or shallow impoundments.

In those small impoundment cases, impounded water would reach salt-saturated levels relatively quickly, and impoundment volumes would be small enough that salt buildup could noticeably affect project life. The lifespan of the impoundment configuration that is selected would be affected by the rate of inflow. Decreased inflow rates would result in a longer effective life due to deposition of less salt.

Background

The data available for this design and estimate work consisted of two reports: (1) the 1997 *Salton Sea Area Study, Alternative Evaluation Appraisal Report* (1997 report), already mentioned above, and (2) the April 1974 *Federal-State Feasibility Report, Salton Sea Project, California* (1974 report), including volumes 1, 2, and 3 (Interior and RAC, 1974), which contain the appendices to the report. The second report includes the cost estimate work done on the alternatives considered in 1974 and also presents the geologic and geotechnical data developed from field and laboratory investigations conducted in 1972.

The 1972 field and laboratory investigations included seven drill holes around the southern part of the Sea, boring logs for the drill holes, samples from the Sea floor sediments, standard penetration testing of the Sea floor sediments, field vane shear testing of the sediments adjacent to two drill holes, physical properties testing of the samples recovered, laboratory vane shear testing in one or both ends of the samples, about 60 hand sediment-penetration holes and visual classifications of the sediment penetrated, and estimates of the thickness of the very soft material (called "sludge" in the preappraisal design estimate worksheets).

Diked Impoundment Alternatives

The diked impoundment alternatives presented in this report assume that the Sea would be separated from the impounded pond(s) by earth dikes—structures that have water at essentially equal elevations on both sides, thus no pressure-head differential. The diked impoundment alternatives and alignments used in the current study are the same as those developed in the 1974 report and in the 1997 report. The seven diked impoundment alternatives have ponds with surface areas of 30 mi^2 (with pump-out required), 40 mi^2, 47 mi^2, 50 mi^2, and 127 mi^2; the first four ponds are at the south end of the Sea, and the 127 mi^2 pond is at the north end. There is also a "Phased Pond" alternative that involves a 25-mi^2 pond along the "East Bay" of the south end of the Sea as phase 1 and a 127-mi^2 pond diked off in the north end of the Sea as phase 2. Phase 2 is assumed to be the same pond and dike as in the 127-mi^2 alternative. The last alternative is an earthquake-resistant Sea dike with the 40-mi^2 pond configuration for use as a cost comparison. The 47-mi^2 pond alternative actually consists of two ponds—one at the "East Bay" location and the other at the southwest area of the Sea.

The diked impoundment alternatives (figures 6 and 7) are identified in the same sequence as the 1997 report and briefly described as follows.

1. **50-mi^2 Pond at South End**

   This diked impoundment pond has a surface area of 50 mi^2 and is completely encircled by the dike at the south end of the Sea. The dike includes a deep-water segment, two intermediate-water segments, and a shallow-water segment along the southern shore side. One or two inlet structures to allow Sea water into the pond are located along the deep-water section of the dike.

2. **40-mi^2 Pond at South End**

   This diked impoundment pond has a surface area of 40 mi^2 and is completely encircled by the dike. The dike includes a deep-water segment, two intermediate-water segments, and a shallow-water segment along the southern shore side. One or two inlet structures to allow Sea water into the pond are located along the deep-water section of the dike.

3. **127-mi^2 Pond at North End**

   This diked impoundment pond has a surface area of 127 mi^2 that is created by diking off the north end of the Sea. The dike includes a deep-water segment in the middle and two intermediate-water segments at the ends connecting the dike to the Sea shore. One or two inlet structures to allow Sea water into the pond are located along the deep-water section of the dike.

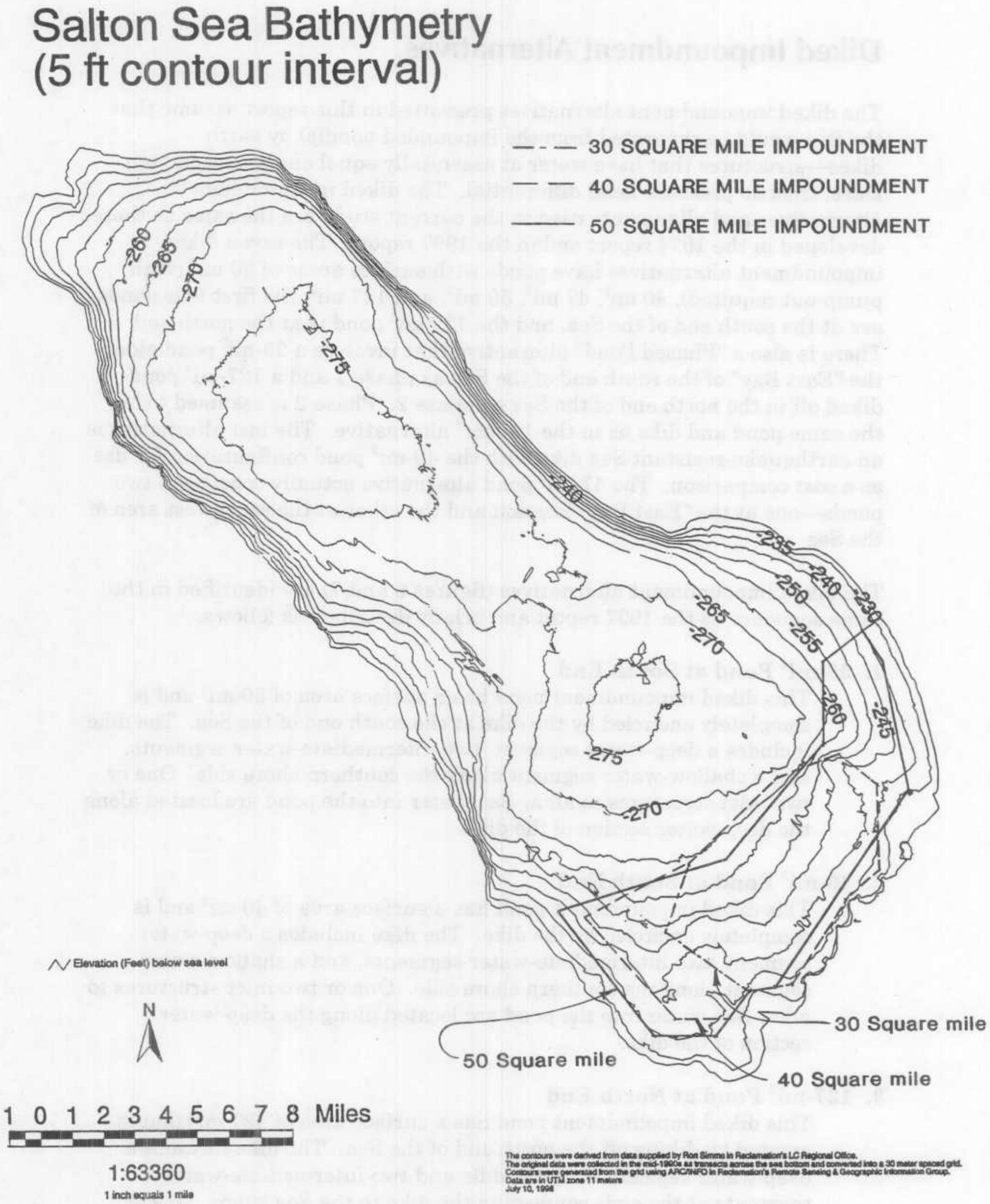


Figure 6.—Location of 30-, 40-, and 50-square-mile impoundments.

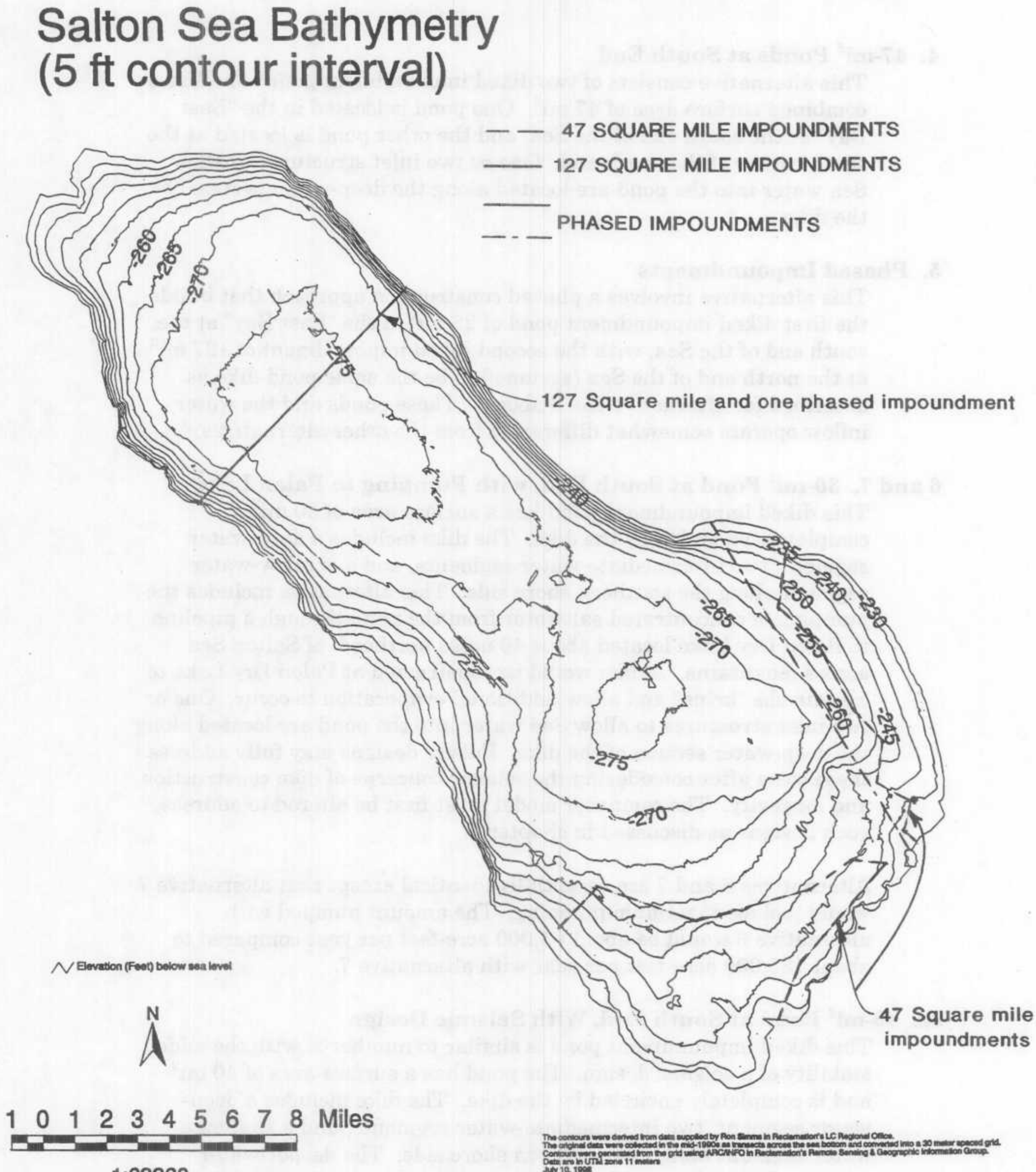


Figure 7.—Location of 47- and 127-square-mile and phased impoundments.

4. 47-mi² Ponds at South End

This alternative consists of two diked impoundment ponds and has a combined surface area of 47 mi². One pond is located in the "East Bay" at the south end of the Sea, and the other pond is located at the south corner of the south end. One or two inlet structures to allow Sea water into the pond are located along the deep-water section of the dike.

5. Phased Impoundments

This alternative involves a phased construction approach that builds the first diked impoundment pond of 25 mi² in the "East Bay" at the south end of the Sea, with the second diked impoundment of 127 mi² at the north end of the Sea (assumed to be the same pond dike as described for alternative No. 3 above). These ponds and the water inflow operate somewhat differently from the other alternatives.

6 and 7. 30-mi² Pond at South End, with Pumping to Palen Lake

This diked impoundment pond has a surface area of 30 mi² completely encircled by the dike. The dike includes a deep-water segment, two intermediate-water segments, and a shallow-water segment along the southern shore side. This alternative includes the pumping of concentrated saltwater from the pond through a pipeline to Palen Dry Lake located about 40 miles northeast of Salton Sea across mountains. A dam would be constructed at Palen Dry Lake to contain the "brine" and allow additional evaporation to occur. One or two inlet structures to allow Sea water into the pond are located along the deep-water section of the dike. Future designs may fully address these costs after considering the seismic concerns of dike construction and longevity. The computer model must first be altered to address such designs as discussed in chapter 9.

Alternatives 6 and 7 are essentially identical except that alternative 7 would include maximum pumping. The amount pumped with alternative 6 would be about 65,000 acre-feet per year compared to about 135,000 acre-feet per year with alternative 7.

2a. 40-mi² Pond at South End, With Seismic Design

This diked impoundment pond is similar to number 2, with the added stability of a seismic design. The pond has a surface area of 40 mi² and is completely encircled by the dike. The dike includes a deep-water segment, two intermediate-water segments, and a shallow-water segment along the southern shore side. The deeper-water portion of the dike would be designed and constructed to remain stable under seismic (earthquake) loading. The deep-water and intermediate-water dike segments would be constructed in the dry, using cellular cofferdams encircling several segments of the dike embankment alignment as construction progresses along the dike alignment. The Sea water would be pumped out of the encircled segments to allow construction of the reconstructed foundation and the embankment in the dry. The shallow-water dike segment would be constructed in the same dump-into-the-Sea manner as assumed in the static dike design approach. One or two inlet structures to allow Sea water into the pond are located along the deep-water section of the dike.

The diked impoundment alternatives vary somewhat in the manner that water flowing into the Sea from the Alamo, New, and Whitewater Rivers and other sources is allowed to flow into the Sea around the diked impoundment(s) or is directed into a pond. In the cases of alternative Nos. 1, 2, 4, 6, and 2a, the inflowing fresh (less salty) water is allowed to flow into the Sea and is not allowed into the pond. In the cases of alternative Nos. 3 and 5, some of the fresh water flows into the impoundment pond. One operation and maintenance (O&M) type cost item relates to the inflowing fresh water and its load of sediment. The near-shore dikes required for alternative Nos. 1, 2, 4, 6, and 2a will produce calm-water estuaries from the current mouths of the rivers to the Sea. The rivers' load of sediment will fall to the bottom in the calm water, resulting in an O&M need to periodically dredge the estuaries.

Static Dike Design

The Sea water surface elevation used in this study was elevation -227, which is 5 feet higher than the Sea level in the 1974 report. This study assumes that the water surface elevation in the pond is 2 feet lower than the Sea level on the other side of the dike. These designs assume that some kind of geomembrane or less pervious material would need to be installed within the dumped or placed and compacted sand and gravel dike embankments to prevent mixing of Sea and pond waters after the pond water becomes much more saline.

Based on Reclamation's *Design Standards* (1987), achievement of a static stability safety factor of 1.3 was selected for these Sea dike designs. This factor of safety criteria would not normally be addressed in a preappraisal design, but the Sea floor sediment data in the 1974 report indicate that much of the Sea-bottom sediment was very weak "fat clay" (CH classification) material, similar to the bottom sediment encountered in the 1950s during the construction of the railroad embankment across the Great Salt Lake in Utah.

Based on a report of the railroad embankment's design, analysis, design changes, and construction (Casagrande, 1964), and this study's limited stability analyses, a Sea dike cross section was developed to estimate the dike quantities and costs for the various alternatives. The dike cross section for the alignment through the deeper part of the Sea includes the excavation of a 25-foot-deep trench to remove the weak upper foundation sediment. The trench extends out 70 feet beyond the base of the embankment from the dike toe along both sides of the dike to create a stable foundation for the dike. The trench is backfilled with the same dumped sand and gravel material the dike is made from. Figure 8 shows two dike cross sections. The first cross section shows firm sediment elevation at -270 with a 432 foot-wide sand and gravel base. The second shows the firm sediment elevation at -280 with a 492-foot-wide sand and gravel base. These different foundation elevations reflect the variable Sea-bottom elevation along the deeper dike alignment.

With the basic dike cross section determined, the work to estimate dike embankment quantities involved varying the water depth and the related embankment height. The water depth/embankment height variations were grouped—shallow, intermediate, and deep. The dike embankment cross sections were quantified for each of these groups. The areas for each of the following activities (i.e., foundation excavation) or materials were determined—sludge dredging/excavating, dredging/excavating the upper weak foundation material along the deeper dike section, dumped sand and gravel embankment, placed and compacted (upper) embankment, and placed riprap. The activity or material areas were then multiplied by the appropriate dike lengths for each water depth/dike height for each of the different pond-size alternatives. This approach toward dike material quantification and cost estimating was not the method used in either the 1974 report or the 1997 report.

The foundation beneath the Sea is judged to be weak, largely unconsolidated fat clay and silty sand material based on the information presented in the 1974 report. This will lead to settlement of the dike embankment as initially constructed, with the rate of settlement (consolidation) decreasing over time. The amount of dike settlement that should be anticipated has not been evaluated, but it has been assumed in this study to be about 3 to 5 feet. Further, it has been assumed that this dike settlement will occur over a period of 50 years, with an O&M requirement to place additional dumped sand and gravel fill on the dike crest and on both dike slopes every 5 to 10 years, totaling 3 to 5 feet. The total dike volume added over the 50-year period has been annualized, and its annual O&M cost has been included in the estimates for each of the diked impoundment alternatives.

It should be noted that based on the information presented in the report titled "A Value Engineering Evaluation of Salton Sea Alternative Dike Structures," dated August 1995, the preferred dike embankment construction involved dumped sand and gravel earthfill. The report judged

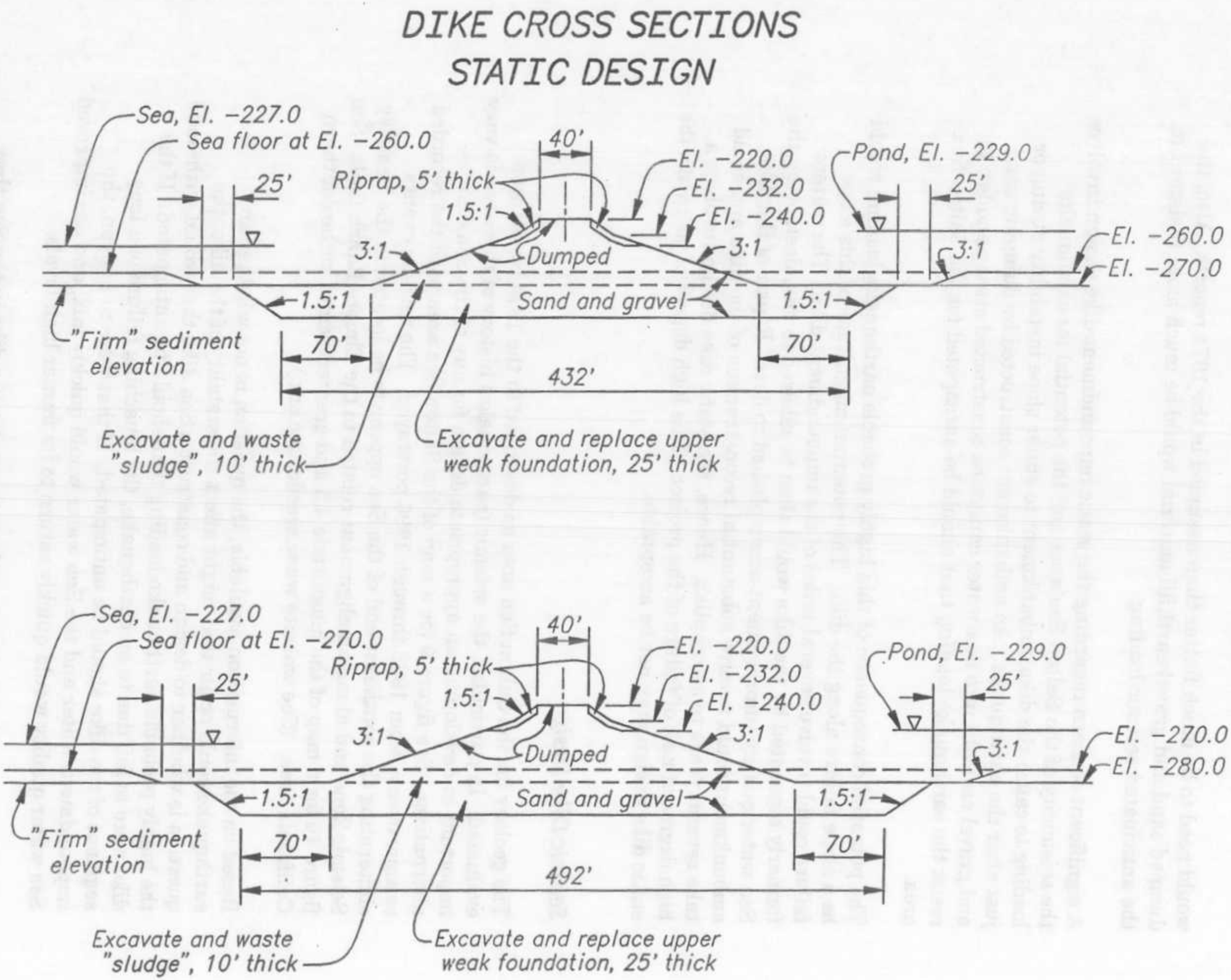


Figure 8.—Cross sections show different foundation elevations in Sea bottom.

would need to be much flatter than assumed in the 1974 report). Also, the dumped sand and gravel earthfill material would be much more resistant to the anticipated seismic loading.

A significant concern regarding the static impoundment dike design involves the seismicity of the Salton Sea area and the potential for earthquake loading to cause the dike embankment to suffer slope instability during or just after the earthquake. An embankment constructed by dumping sand and gravel earthfill into Sea water cannot be constructed strong enough to resist the earthquake loading that should be anticipated for the Salton Sea area.

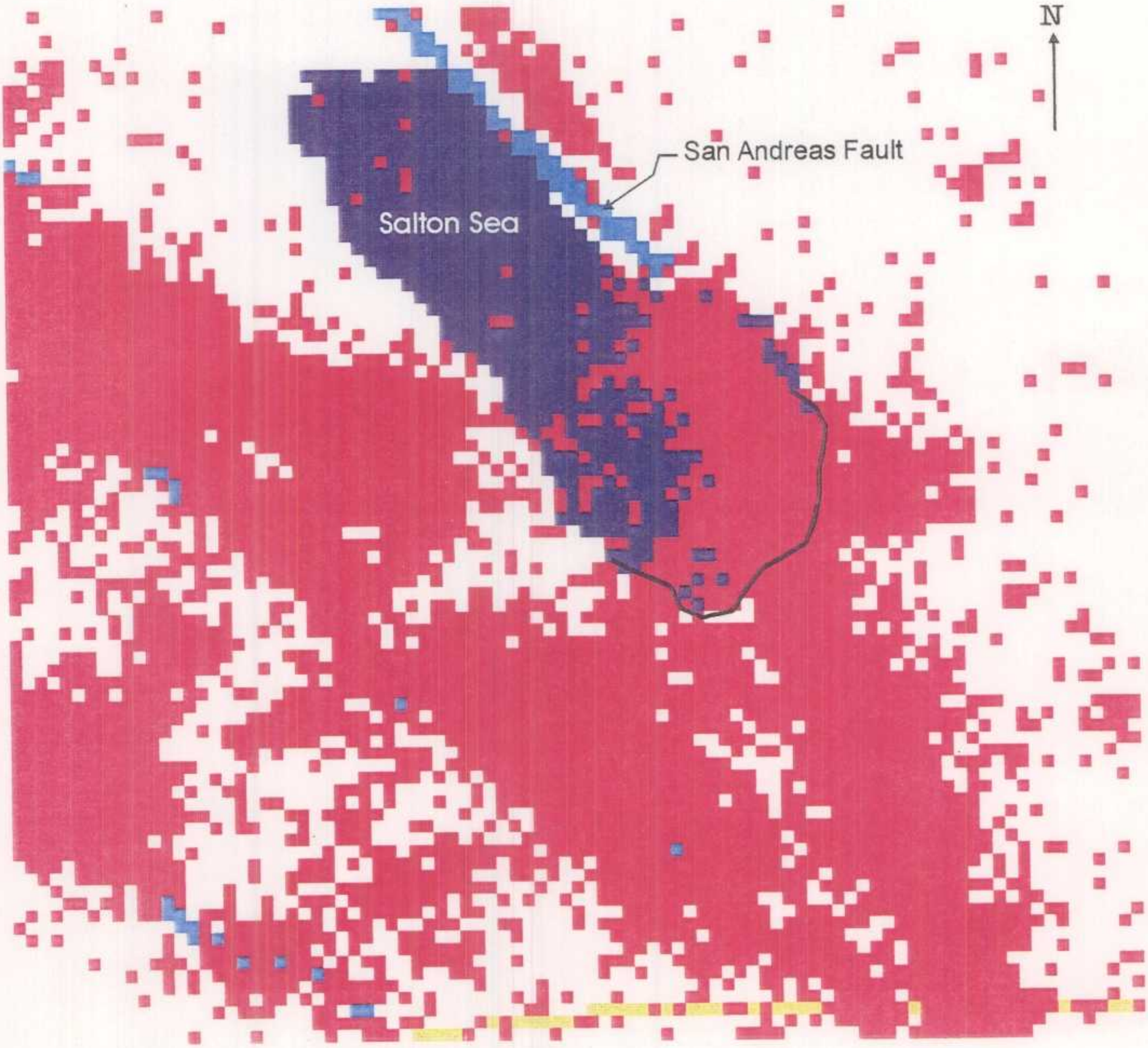
The potential consequence of this highly probable earthquake loading would be a slope failure along the dike. The potential magnitude of this slope failure could involve several miles of the impoundment dike. The waters formerly separated by the dike would then be allowed to mix, destroying the Sea water quality improvement accomplished to date. Repair of the dike embankment could involve substantial reconstruction of the dike and could take several years to accomplish. Hence, the static dike design involves a high degree of risk of failure of the project. This high degree of risk with the static dike design may not be acceptable.

Seismic Dike Design

The geology for the Salton Sea area as described in the 1974 report was evaluated. In particular, the seismic (earthquake) history of this area is very important in developing an appropriate design for any of the Sea dike alternatives. See figure 9 for a map of the Salton Sea area with the recorded seismic events from 1932 through 1996 portrayed. The seismic events obliterating the southeast end of the Sea appear to be located in the Brawley Seismic Zone and along an alignment related to the Elmore Ranch fault. See figure 10 for a map of the magnitude 4.5 and greater events in the southern California area. (See website www.scecdc.scec.org.)

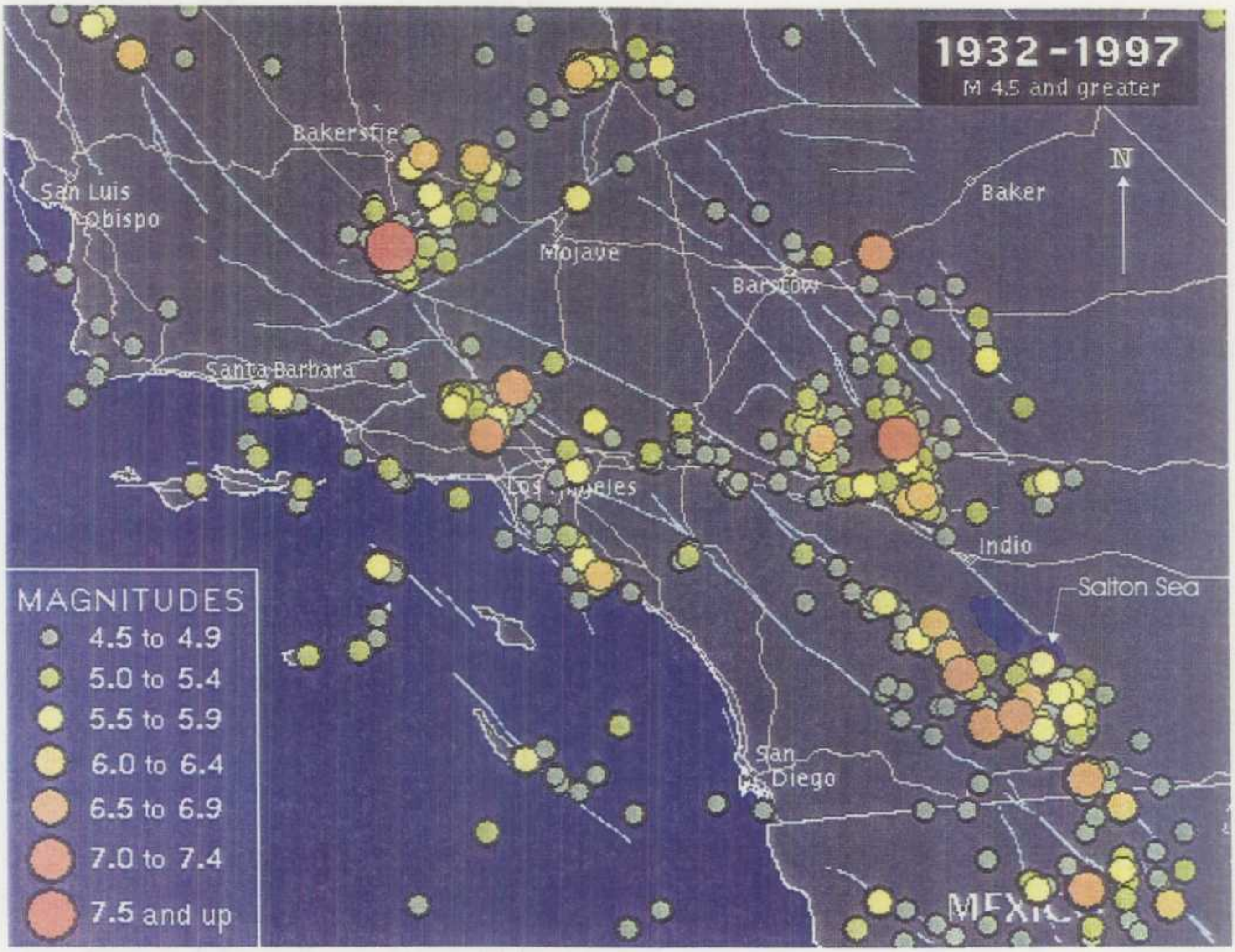
Based on the information available, the question is not whether an earthquake could occur that might affect the stability of the dike; the question is whether to design and construct a Sea dike that would withstand the highly probable earthquake loading that should be anticipated. If the dike were to fail due to an earthquake, the breaching failure of a long segment of the dike should be anticipated. If that were to happen, the impoundment water and the Sea water would quickly mix, and the improved Sea water quality would quickly return to its former high levels.

Therefore, the critical concern is how to construct a dike in the Sea that would be stable under the anticipated magnitude of earthquake loading.



The map shows the epicenters of all recorded seismic events that have occurred in southern California in the years from 1932 through 1996. Each quake is represented by a single red pixel (many overlap). Plotted for reference on the background are the surface traces of the major faults in the area (shown as light blue-green lines—the most prominent being the San Andreas Fault, which runs from the lower right corner to the upper left corner of the map) and the major area highways (shown in yellow).

Figure 9.—Salton Sea area with recorded seismic events.



Above is a map of southern California upon which are plotted all the epicenters of earthquakes greater than or equal to magnitude 4.5 that have been instrumentally recorded since 1932, when the first catalogs of such records began. (Some symbols of smaller quakes and aftershocks are hidden due to overlap.) A small number of cities and towns are labeled for reference. Shown, too, are major highways (in tan) and the surface traces of major faults (in greenish-blue). As with the map of historic southern California earthquakes, the magnitudes given by the scale are generally moment magnitudes for earthquakes above magnitude 6, and local magnitudes for most earthquakes below magnitude 6.

Figure 10.—Map of earthquakes in southern California with a magnitude 4.5 and greater.

This type of problem is commonly addressed by California engineers, but not on a project of this size that is constructed in water. One approach that might ensure the ability of the constructed dike to withstand earthquake loading would be to build the dike in the dry with the embankment sand and gravel material properly compacted to a density high enough to withstand the earthquake loading. Also, the existing upper foundation sediments would need to be improved beyond the 25-foot-deep trench approach presented for the static design case.

To build the deeper dike in the dry, the dike site would need to be unwatered (the Sea water removed). A system of large cellular cofferdams forming large rings around segments of the dike alignment could be constructed and the Sea water pumped out. There would need to be at least three segments of ringed cofferdams to allow a leapfrog progression of dike construction to proceed. Each of the three cofferdam segments would be about 800 feet wide (perpendicular to the dike alignment) and about 2,000 feet long. The cofferdam cells would need to be able to withstand loading by Sea water up to 50 to 60 feet deep plus 5 or 10 feet for waves. The cofferdams would be constructed from cellular cofferdam sheet piling embedded 15 or 20 feet into the Sea floor sediment. The interior of the cell would be backfilled with sand or sand and gravel for stability. The cells would be interconnected to form a rectangular ring (800 feet by 2,000 feet) around the dike segment to be unwatered. Dike construction inside two to three segments would be going on at any given time. A dike cross section for the earthquake design is shown in figure 11, and the Plan earthquake design is shown in figure 12.

After the segment of the dike was completed, the segment would be removed, and the cofferdams and sheetpiling would be taken apart and pulled out of the Sea floor for reuse on the next segment to be constructed along the dike alignment. The Sea water would flood the formerly unwatered segment up to the end wall of the next segment down the alignment. This cellular cofferdam unwatering would start at/near the Sea shore at one end of the deeper dike segment and would end at the other shore. Access to the cofferdam segment via the dike crest would be required for hauling dike materials. It may not be possible to pull the sheetpiles along higher dike locations, requiring the sheetpiles to be cut off flush with the dike slope. Replacement of these sheetpiles would be required.

Because of the weak foundation, especially under earthquake loading, the upper portion of the foundation would be excavated as was done for the static dike design, and the trench would be backfilled with roller-compacted concrete (RCC) or soil-cement (SC) made from the same sand and gravel material as the embankment. The RCC/SC material would form a mat or pad 25 feet thick that would be a stable base for the overlying dike

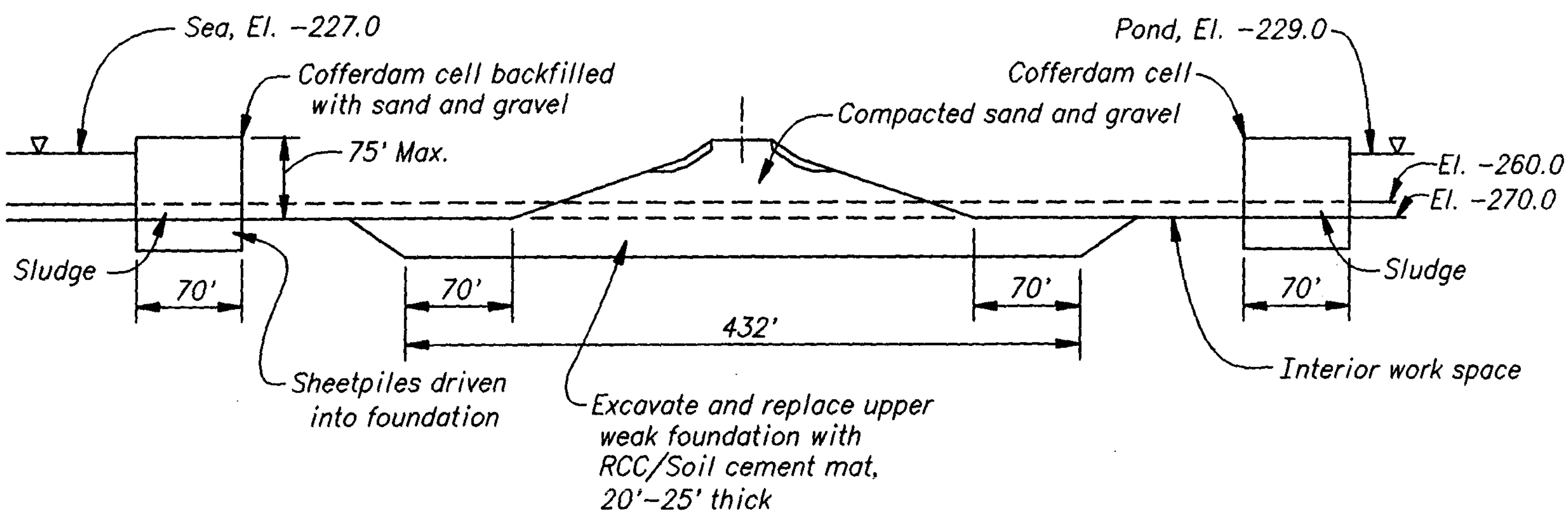


Figure 11.—Cross section showing earthquake design.

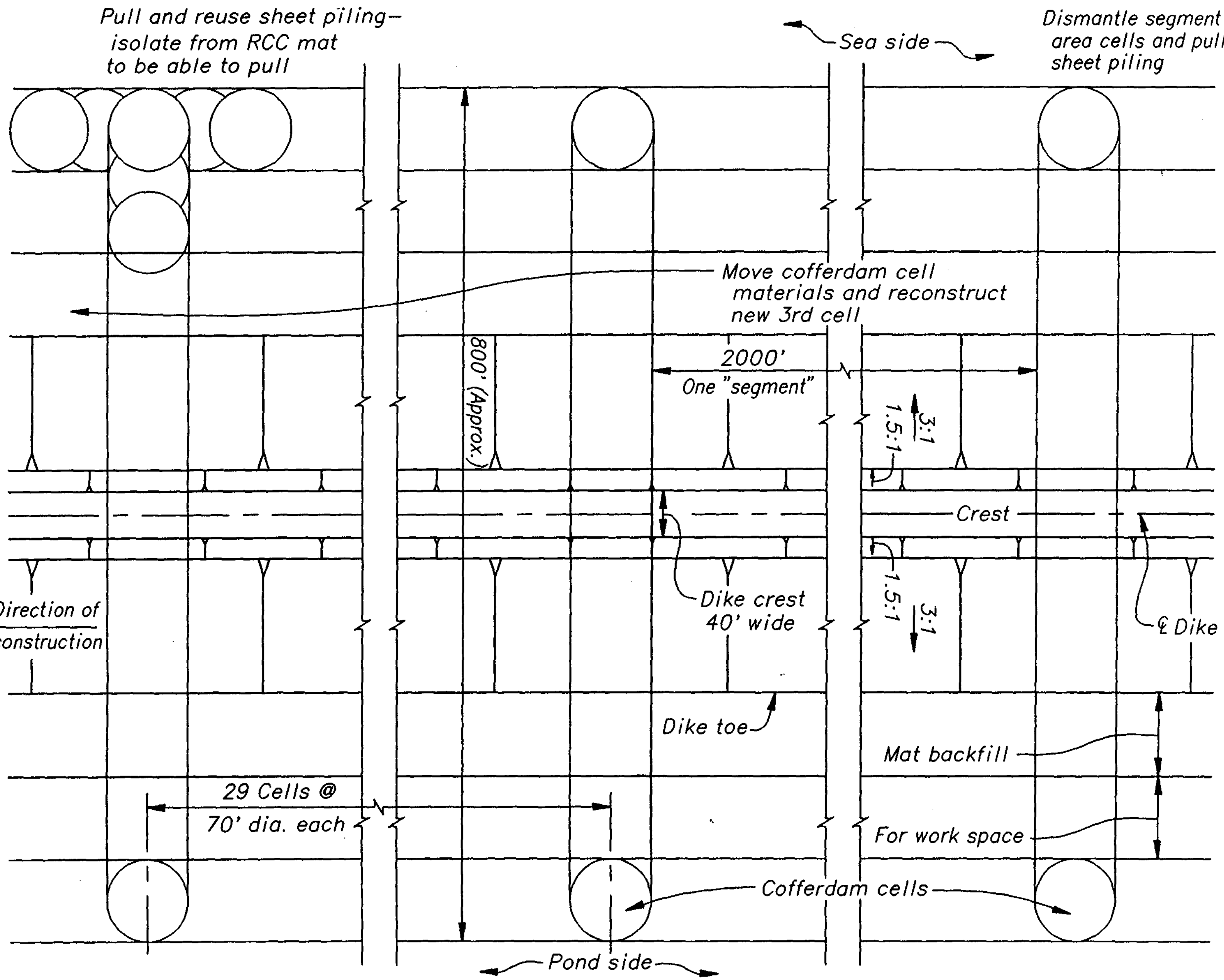


Figure 12.—Sketch shows plan earthquake design.

embankment. The dike embankment would be constructed in the dry on top of the RCC/SC mat base. The dike sand and gravel fill would be placed in 1-foot lifts and compacted to a very high density.

This earthquake-resistant dike using cellular cofferdams for unwatering would be constructed only along the "intermediate" and "deep" sections of the 40-mi^2 pond dike. The shallow, near-shore sections of the dike would not be constructed using that system; they would use the "static" dike design/ construction approach instead. The seismic dike design includes estimates of the quantities of cofferdam sheetpile materials, the work process, the pumping of Sea water to unwater the work site, the power required, and costs for the work involved.

Earthfill Material Sources

As described in the 1974 report, the sand and gravel for constructing the dike embankment would be obtained from the alluvial deposits (Qal) east of the Salton Sea, above the Coachella branch of the All-American Canal. Sand and gravel borrow sites located on either the Chocolate Mountain Gunnery Range or the Camp Dunlap Artillery Range should be available for use by the Government. This material would be hauled 5 to 15 miles to the access end of the dike and then along the constructed dike, using trucks and existing highways. Likewise, appropriate riprap would be quarried from the Chocolate Mountains located northeast of the canal.

Dike Construction Schedule

The time required to construct any of the dike embankments was estimated in the 1974 report at about 2-1/2 years. That schedule for all the alternatives assumes that construction of the larger pond and longer dike alternatives would be accomplished by more construction activity during the same period of time; this report makes the same assumption. However, the seismic dike alternative and its cellular cofferdam unwatering construction would be a far more complicated construction process. The time required for its construction could easily take twice as long (5 years) as the static dike alternatives, depending on the amount of construction activity possible within the cellular cofferdam segment areas.

Chapter 5

Pump-Out / Pump-In Alternatives

The pump-out/pump-in alternatives are those that pump water from the Salton Sea to distant locations and then pump water to the Sea from other locations, in various combinations. Pumping water out removes salt laden water and thus reduces the amount of salt and salinity in the Sea. Using other pipelines, water is then pumped into the Sea. This fresher water decreases the Sea's salinity—in essence, diluting the salinity of the Sea. Some alternatives do not pump water into the Sea. These designs maintain the Sea's water surface elevation by balancing the pumped outflow and pumped inflow with evaporation and natural inflow.

While the salinity and water surface elevation depend on the natural inflow and evaporation, they also depend on the quantity and quality of the water pumped into the Sea. These alternatives assume an average inflow of 1.346 million acre-feet per year entering the Sea from surrounding areas, such as irrigation return flows, rivers, precipitation, and groundwater.

The options studied were not limited to the discrete alternatives presented in the 1997 report. Several of the 1997 alternative elements were incorporated into the 1998 alternatives. Without being limited to the 1997 designs, mixing and matching of various routes and being able to modify the criteria allowed additional preappraisal designs.

All ideas were not fulfilled, and designers did not completely design all ideas. If an alternative was not feasible from a technical perspective, that information is stated.

Salinity and Water Surface Level Interaction

To understand the interrelationship of the salinity concentration and water surface levels, the reader should first look at these as qualities in a natural lake. Most natural lakes have inlets and outlets. Waters entering the lake normally include natural sources (such as groundwater, rivers, and creeks) and manmade sources (such as pipelines and canals). Another water source is precipitation. Water leaves the lake through rivers, diversions, and evaporation.

Water and salts (and pollutants) enter the lake at various concentrations. Water and salts (and pollutants) flow out of the lakes in the rivers with concentrations of salt equal to the concentrations in the lake. Water also exits the lake, without the salts, through evaporation. Therefore, the salinity of the lake is a function of the difference in concentrations of salts coming into and leaving the lake. Some lakes, such as the Great Salt Lake and the Salton Sea, do not have natural outflows. Evaporation is the only means for water to leave the lake. Salt concentrations would continue to increase in such lakes.

The water surface elevation of a lake is also a function of the inflows and outflows. Topography is also a factor. Lakes that have rivers flowing out of them would have a lake elevation the same as the water surface elevation of the river. However, if a lake does not have a river to limit its elevation, then the lake level is a function of the evaporation rate. As the water surface elevation of the lake rises, the surface area usually increases, which, in turn, increases the area from which water can evaporate. Eventually, the lake surface elevation would reach an equilibrium so that the water flowing into the lake equals the water leaving the lake by evaporation. The lake levels would vary as the inflows and the rates of evaporation change. Such variations can be daily, seasonal, or long term.

From the information provided, one can conclude that the salinity of a lake without natural outflows would increase (or decrease) with time, and the water surface would stabilize, depending on the current inflows and evaporation rates.

The Salton Sea is not much different from natural lakes. The waters come from precipitation, natural rivers, groundwater, and irrigation. It has a very high rate of evaporation, but it does not have any rivers flowing out of it. Left to current conditions, the salt concentrations would continue to increase, and the water surface level would eventually stabilize (within normal variations) at a level slightly higher than it is now.

Design Considerations

Some of the items considered in designing the pump-in/pump-out alternatives are discussed in the following sections and include pipeline design, type of pipe, possibility of power recovery, and how saline water reacts with pipelines.

Pump-Out / Pump-In Water Conveyance Functions

We can think of the Salton Sea in the terms described above. The Salton Sea water conveyance systems would either replace or augment the water of the Sea in a way that rivers and streams replace or augment the water of natural lakes. The conveyance system that pumps water from the Sea simulates the rivers that flow from the natural lakes. Depending on the amount of water continually pumped out of the Sea, the salinity and the water surface level would stabilize within its variations. The salinity level could eventually be reduced to the salinity level of the inflows. The water surface elevation could be much lower than it is now.

The conveyance system that brings water into the Salton Sea serves to increase or maintain the water surface elevation higher than what the surface would be without it. It also dilutes the salt concentration. While diluting the salt concentration in the Sea is one goal, it also then dilutes the salt concentrations leaving through the pump-out conveyance system, requiring a larger capacity system to remove a given amount of salt.

This difficulty quickly leads to the conclusion that if water would be pumped into the Sea, then it is more economical to pump out as much water as possible before beginning to pump the fresher water into the Sea. The total amount that can be pumped out before pumping in begins is a function of how low the water surface elevation can be dropped.

Water Import Assumptions

Certain assumptions were made before the alternative designs began. Some sources of water were not available to consider as possible import sources. The designs for the alternatives could not use water from the Colorado River. The Colorado River waters are fully allocated, including groundwater that flows into the Colorado River. The stipulation also excluded boundary groundwaters that flow into Mexico and groundwaters that, if tapped, would cause water to flow from Mexico into the United States.

However, legislation pending before Congress would provide for the delivery of floodflows from the Colorado River to the Salton Sea under some circumstances. Diversion into the All-American Canal for delivery directly to the Salton Sea of floodflows in the Colorado River that are required by the Water Control Manual for Flood Control, Hoover Dam and Lake Mead, Colorado River, NV-AZ, adopted February 8, 1984, and which would pass to Mexico in excess of the amount required to be delivered pursuant to the Mexican Water Treaty and Minute 242 thereunder may be made available to carry out the purpose of this Act. The volume of water diverted pursuant to this subsection shall be limited to the excess capacity of the All-American Canal to carry such floodflows after, and as, it has been used to meet existing obligations.

The alternative designs also could not use groundwater and surface water within the Salton Sea basin. Such waters already flow into the Sea. Ground and surface waters from other States were also off limits. Wastewater from other regions or States, however, could be used.

Power Recovery Potential

Hydropower development should be considered when designing new pipelines. Although this is not the time to study the feasibility of producing hydropower on this system of pipelines, some sites do appear to be prime hydropower sites.

The feasibility of producing hydropower at a particular site depends on several things, including power rates, the type of plant and plant characteristics, discharge, and head. The amount of energy a hydropowerplant can produce is the product of the discharge, head, unit weight of the water, and the efficiency of the plant.

Possible power revenues depend not only on the current market, but also on the type and characteristics of the plant. The requirements of the power grid would vary greatly during the day. Plants that take a long time to reach full generating capacity produce most of the base power—coal-fired powerplants are a good example. Run-of-the-river hydropowerplants can also provide such energy. Grid operators must also provide power above this base load. For a coal-fired plant to meet these daily peaks, it would have to run continually at high enough output to meet the maximum loads, and excess energy would be wasted.

An optimum system would have system output follow the system requirements. A plant must be able to come on-line quickly to provide this peaking power if it is not to burn off the energy. Hydropower can meet these peaking plant requirements, provided that the plant characteristics are appropriate. Many high-head hydropowerplants can do this. Peaking plants can charge much more for the energy they produce than baseline plants.

The time in which a hydropowerplant can come on-line to produce energy is closely related to the surges produced in the penstocks. A plant coming on-line or going off-line too quickly produces great surges. Using surge tanks and designing the pipeline for higher than standard heads can counteract these surges. Both of these add to the plant cost.

The pipelines would flow continually in this design. Flow durations other than this would require larger pipes if the yearly discharge remains constant. Fluctuation of the discharge to supply peaking daytime power would require larger pipes.

The pipes are designed for static head. Greater surges require stronger pipes. A more complete design would include pipes large enough to allow the water to flow over the given distance and burn up the head through friction. Any head used for power production at full flow would require larger pipes.

Future, higher level designs should consider power generation. Run-of-the-river powerplants may be a viable option.

Saline Water Concerns

Saltwater can cause many problems with water conveyance features, such as pipelines, tanks, pumps, and inlets. The ions in the saltwater can greatly accelerate corrosion of steel and metallic surfaces.

Scaling is another major concern. Ocean water and Sea water are extremely "hard." Hard waters deposit calcium and magnesium on the surfaces they contact. Pipelines may become completely clogged even when hardness values are much less than at Salton Sea.

Other salts may precipitate out of the water and become a problem. The salts may be abrasive to the linings. Water in the conveyance system would be subjected to both temperature and pressures changes. The interaction of temperature and pressure must be fully understood before final design.

Most of these problems can be solved. Corrosion, scaling, and abrasion would not harm some polymer coatings. These coatings are quite expensive, and the costs for them have been included in the cost estimate.

Pipelines Only Design

The pump-in/pump-out preappraisal alternatives were designed using only pipelines. Other features could be used to convey water and may be appropriate. Pipelines were used in these designs only to decrease the time required for the design. It is highly unlikely that selection of a particular scheme or route would be affected by using only pipelines in the design. It would be prudent to analyze the feasibility and cost of canals and tunnels in a future analysis to aid in making the best choice.

Canals generally have lower capital construction costs than do pipelines, but their maintenance costs are higher. Canals must maintain a constant slope. The ground surface initially looks favorable for canal construction in the area where other canals already exist. There is a possible problem with geologic faults, however. A canal that crosses a fault may drop to an elevation that would render several miles of canal useless. This problem is particularly important where grabens are present, such as in the Salton Sea. Grabens are geologic blocks, bound by faults on two long sides, that have dropped relative to the surrounding geologic formations. A pressure pipeline, on the other hand, may need only to be repaired at the points of fracture.

Tunnels are more expensive to construct, per linear foot, than either canals or pipelines. Some redeeming qualities, though, are that tunnels are not as winding as canals and pipelines, which may give better hydraulic properties. Tunnels go under mountains, not over them as pipelines do; consequently, the number of pumping plants needed may be decreased, dramatically reducing energy requirements. Tunnels are usually much more environmentally acceptable than pipelines and canals and have shorter routes.

Type of Pipe

The type of pipe is not important at this level of design. It is important that a type of pipe be available that would satisfy design assumptions. These designs are based on using steel pipe with a polymer lining. In the size range of these designs, the pipe is available in any diameter and could easily accommodate the design pressures. In general, the pipe was sized to convey water at 5-foot-per-second velocity with pressure heads not greater than 500 feet of water. A pressure head of 100 feet was added to allow for surges. Pumping plants were designed for about 400 feet of head (lift).

Discarded Components

Some components were found to have problems that were obviously too costly to overcome.

Evaporation Lakes and Ponds. Clark Lake is a dry lakebed west of the Salton Sea. Past studies indicated this could be a location to place an evaporation lake. The area of the dry lake is much smaller than is required for such an operation. The area required engulfed Borrego Springs, population (1990) of 2,244, a State Wilderness Area, and a few landing strips. Three dams would be required for larger areas, one of which would be 560 feet high and more than 10 miles long. Designers deemed this site unsuitable.

The possibility of placing evaporation ponds in the Chocolate Mountains, which is now a military range, was also considered. The area is not very suitable because of the topography. Flat topography lends itself to constructing evaporation ponds. Steeper topography requires higher dikes. Large, one dam evaporation ponds become very expensive in steep topography. Although the cost of pipelines would be less for the Chocolate Mountain site than the Palen Lake site, the cost of dams would be higher and the cost of removing salt would be the same as at the Palen Lake site.

Groundwater for Salton Sea Restoration. Obtaining water from wells was studied in depth, was discarded, and is discussed in this section.

The criteria for locating a groundwater source to use to restore the Salton Sea were that the:

- Groundwater must be within the State of California
- Must not already be allocated to others
- Must not be tributary to the Colorado River or the Salton Sea

Aquifer Systems. Much of Southern California Desert physiographic area—the portion of southern California east of the Peninsular Ranges, the Transverse Ranges, and the Sierra Nevada—contains basin fill deposits consisting of sand, gravel, silt, and clay of continental origin. These sediments are saturated with water and are considered a principal aquifer within the State. The area is sparsely populated, and these aquifers have not been extensively developed. Recharge is largely limited by low rainfall (less than 6 inches per year) for much of the region. Locally, recharge by runoff from streams that originate in the high mountain occurs in isolated areas (U.S. Geological Survey, 1985).

For this subappraisal level assessment, it is prudent to treat recharge as insignificant. As such, any groundwater development would be a "mining operation" where the aquifers are depleted forever. Widespread groundwater development of aquifer systems in Arizona with similar geologic and hydrologic conditions has produced large, continuous declines demonstrating low recharge. Decisionmakers should consider the low recharge when searching for additional water sources.

Water Demands. Preliminary modeling efforts show that the volume of water required depends on the quality of the water. The tabulation below gives water volumes required to meet objectives in the two timeframes for selected concentrations.

Water required to meet objectives

TDS (mg/L)	Water volume (af/yr) Meet objectives in 15 years	Meet objectives in 30 years
925	100,000	NA
4,000	153,000	73,000
35,000	700,000	400,000

Previous Studies. Steinemann (1989) evaluated the quantity and quality of groundwater from the basin fill aquifers in the Southern California Desert as a potential supply of powerplant cooling water. The principal quantity criterion was that the aquifer could supply 30,000 acre-feet per year for 30 years from a well field. Of the 142 basins in the Southern California Desert initially identified by Koehler and Ballog (1979), only the basins listed in table 3 were deemed "suitable" to supply powerplants.

Table 3.—Basins capable of supplying 30,000 acre-feet annually for 20 years

Basin	Area (mi^2)	Storage (10^6 acre-feet)	Depth (feet)	Saturated thickness (feet)	Well yield Average (gpm)	Well yield Maximum (gpm)	TDS concentration Average (mg/L)	TDS concentration Range (mg/L)
Middle Amargosa Valley	1,300 620	18 8.6	100 CA	900 only	2,500	3,000	1,600	566 - 4,600
Soda Lake Valley	590	4-9.3	8-76	400	1,100	1,700	1,600	297 - 3,330
Caves Canyon Valley	100	2	0-200	?	990	1,990	?	622 - 2,680
Chuckwalla Valley	870	15	?	?	1,800	3,900	2,100	274 - 8,150
Calzona-Vidal Valley [1,2]	310	3.5	250	500	100	to 1,800	?	502 - 1,400
TOTAL		33.1 - 38.4						

[1] Basin is probably hydraulically connected to the Colorado River.
[2] Two separate basins in the work of Koehler and Ballog.

Although the magnitude and duration of the demand for the Salton Sea far surpass those required for a powerplant, Steinemann's work provides an ideal basis for rapid assessment of the potential for groundwater as a possible supply to restore the Sea.

Storage Volume *vs.* Usable Volume. The total volume of water in aquifer storage can never be completely removed. The fraction that can be removed depends on many factors, with the economics of installing wells and pump lifts probably controlling. Inconclusive data from the California DWR (1975) suggests that the usable volume of groundwater ranges from 10 to 50 percent of the total volume of water in storage.

Assuming the usable volume is 25 percent (probably high), the total usable volume of water in storage, excluding the Chuckwalla and Calzona-Vidal Valleys, which are probably hydraulicly connected to the Colorado River (Wilson and Owen-Joyce, 1994), is:

Basin	Usable storage (10^6 acre-feet)
Middle Amargosa Valley (California only)	2
Soda Lake Valley	1 - 2.3
Caves Canyon Valley	.25
Total	3.2 - 4.5

Aquifer Life. In the absence of significant recharge, extracting all usable storage from the four basins combined would sustain pumping from less than 10 years to more than 100 years. Actual values are presented in the tabulation below:

Demand (acre-feet per year)	Usable storage, (af) $6.9x10^6$ ---- Aquifer life ---- (yr)	Usable storage, (af) $8.2x10^6$ ---- Aquifer life ---- (yr)
73,000	94.5	112.3
100,000	69.0	82.0
153,000	45.1	53.6
400,000	17.3	20.5
700,000	9.9	11.7

Most basins (136 of 142) were excluded from the original screening for reasons such as lack of information, inadequate water quality, and inadequate water supply. The State (California DWR, 1987) estimates that more than 410 million acre-feet of water may be found in groundwater storage within the Southern California Desert. This estimate is about 10 times the volume of the 5 basins found to be suitable by Steinemann. Assuming a usable storage of 25 percent for the remainder of the area, if wells were drilled throughout the entire Southern California Desert and appurtenant pipelines were constructed, the desert could supply restoration needs for from 100 to 1,000 years.

Pipelines to convey water from these locations would have a total distance of 575 miles. Many more miles of pipelines would be required to collect water from individual wells.

Pipeline Routes

Pipelines to and from the Salton Sea encounter various terrain. In all but the pipeline from Yuma, pumps must lift the water over elevations higher than Salton Sea elevation. These lifts vary from 82 feet m.s.l. to 3636 feet m.s.l. All pipelines flowing to the ocean from the Salton Sea must overcome the 227 feet the Sea is below ocean level.

At this preappraisal level of study, it is common practice to obtain the pipeline length by multiplying the straight-line distance between the two ends by some factor. The actual routes were determined in these designs, thus ensuring the maximum pumping heads were found. Final design routes may be different.

Routes to the Pacific Ocean would encounter the coastal mountain ranges. The assumption was also made that routes would not go through Mexico. The two lowest passes that exist between Mexico and northeast of Los Angeles mark the location of the high points of these pipelines.

Each route location is shown in figure 13 and has its own advantages and disadvantages.

> San Diego, California, Point Loma Wastewater Treatment Plant (WWTP) – The route to Point Loma WWTP in San Diego travels over a pass one-half mile northwest of San Felipe at 3636 m.s.l. in the Laguna Mountains. The route would take the pipeline through approximately 30 miles of cities. Much of the route in San Diego would be under city streets. Tunnels would likely be economical to reduce energy and construction costs in the mountains, if incorporated into future designs. The route favors energy recovery from flow in each direction.

Pacific Coast south of LAX airport, Hyperion WWTP – The route to the Hyperion WWTP is over a high point of 2630 m.s.l., a mile west of Beaumont. While much of this route is through cities, it follows existing utility corridors. This route does not favor tunneling or energy recovery.

Pacific Ocean – The route to Camp Pendleton, a Marine base at Oceanside, California, is the same east of the mountains as the Point Loma route. It crosses over the same 3636 m.s.l. pass. The routes separate on the west side of the mountains. Little of this route is in cities. Energy recovery is very favorable on this route for flow in each direction. Later designs would probably find that tunnels are very beneficial in reducing both energy costs and, possibly, construction costs.

Gulf of California – The route to the Gulf of California requires little pumping to go over the high point in Mexico of 82 feet m.s.l. This route has very gradual slopes and favors neither tunnels nor energy recovery. Because of energy losses in the pipe, this route does require that the flow velocities be less than the 5 feet per second used on all the other pipelines.

Yuma – Yuma, Arizona, is the destination for water from the potential Tucson Desalination Plant. This project would then pick up water in Yuma. The route (and cost) is for a pipeline from Yuma to the Salton Sea with gravity flow. Pumps would probably not be required. The route follows existing canal rights-of-way, does not favor energy recovery, and should not require any tunnels.

Palen Dry Lake – The route from the Salton Sea to Palen Dry Lake lies through the Chocolate Mountains and between the Eagle Mountains and the Chuckwalla Mountains, and the route reaches an elevation of 1680 m.s.l. before dropping down into the Chuckwalla Valley. Palen Dry Lake lies at 427 m.s.l. Both tunnels and energy recovery may be possible.

Pump-In Sources

To understand the number of possibilities for conveyances of the project, the reader must understand the pump-in sources, pump-out locations, and the routes. Remember that the flow capacities required for both pump-out and pump-in depend not only on the time desired to reach salinity and water surface elevation goals, but also on the salinity of the imported water. The main part of the pump-in/pump-out design is based on obtaining water from one of five sources.

San Diego, Point Loma WWTP – Point Loma is a wastewater treatment plant in San Diego, California, on the tip of a peninsula within the city. This water has a salinity of 1.75 ppt and has an estimated usable discharge of 268,000 acre-feet per year, which is greater than required.

Pacific Coast, Hyperion WWTP – Hyperion WWTP is located on the Pacific coast, south of LAX airport in Los Angeles. This new tertiary plant's effluent has a salinity of 0.925 ppt with an estimated discharge of 470,000 acre-feet per year, which is greater than needed. The design of this plant envisioned the water would be used to irrigate golf courses, parks, and other similar locations. This Hyperion water would cost $7.50 per acre-foot. Los Angeles has a water right of refusal in that the city of Los Angeles has the first option to use the water before it leaves the city.

Pacific Ocean – The pump-in water can come from the Pacific Ocean at various locations between Los Angeles and the Mexican border. Ocean water generally has a salinity of 35 ppt.

Gulf of California – Water coming from the Gulf of California would have a salinity similar to the ocean, but the salts may differ slightly from ocean water.

Yuma, Arizona – The city of Tucson is considering building a desalination plant to decrease the level of salts in the water coming from the Central Arizona Project. At 4 ppt, the effluent of this plant is considered salty when compared with fresh water. It is quite fresh when compared with the water in the Salton Sea. One of the routes considered by the Tucson project conveys the effluent to the Gulf of California via Yuma. Instead of flowing into Mexico, the effluent could flow to the Salton Sea for use in this project. Other cities in the Southwest may also need such repositories in the future with estimated flows of up to 200,000 acre-feet per year. The estimated available water from only the Tucson project, which includes water from Phoenix, is 67,000 acre-feet per year, which does not meet the estimated needs. Water from other sources would also be needed.

The Yuma Desalting Plant also rejects similar effluent but with a salinity of 10 ppt. Future alternative designs may wish to consider using this effluent as a source of water for the Salton Sea. This water may be intermittently available.

Excess flows — Some Colorado River water that is declared excess about every third or fourth year may be available as a source. The amount of water and the reliability of the supply have not been determined. Several complex issues exist. First, the majority of the water is unused Upper Basin State allocations. This water could be available for a few years or until the States use all of their allocations. Second, all users of Colorado River water, including excess flows, must have a contract with the Secretary of the Interior.

The requesting user needs are added to the bottom of the priority list that exists when his request is made for excess flows. Those at the top of the list may use all of the excess flows, leaving no water for those at the bottom of the list. Third, the infrastructure required to convey and store the water may have to be quite large. Floodflows, in particular, can be difficult to capture when a large volume moves through the system in a short time span. If significant quantities of surplus water were added to the Sea in a given year, this would add to problems of the surface elevation fluctuation. Such floodflows could be diverted and temporarily stored in a reservoir, allowing a smaller system for moving this water to Salton Sea.

Pump-Out Locations

The pump-out location designs were completed for conveyance systems to remove water from the Salton Sea to five locations. Three of these locations are the same locations discussed above as pump-in sources—Point Loma WWTP, Hyperion WWTP, and the Gulf of California. Another location is the Pacific Ocean off the coast of Camp Pendleton. These locations provide for final disposal, which would require a pipeline to be extended into the ocean and a diffuser attached to the end of it to ensure proper salt dispersal for the ocean environment.

Another location—Palen Dry Lake—that could be used as an evaporation lake is northeast of the Sea. Salt from this evaporation lake would have to be removed to another location at some future time.

The Yuma Desalting Plant's bypass drain was considered and deemed inappropriate. This drain flows to the Santa Clara Wetlands in Mexico. It is currently conveying water that has a salinity of 3.2 ppt. Previous studies have indicated salt concentrations greater than 6.0 ppt are unhealthy to cattails. For this reason, water in the drain must have salinity levels below 6.0 ppt. This precludes using the drain to convey water from the Salton Sea, which has a salinity greater than 40 ppt.

The bypass drain was considered to convey intermittent flows, which would require constructing a turnout at the wetlands. Canal operators estimated that 100 cubic feet per second (ft^3/s) of Salton Sea water could flow down the canal 50 percent of the time. The cycle would have to be about 2 weeks long. A flow of 50 ft^3/s is much less flow than any of the alternatives currently require. For this reason, and the salinity problem, using the bypass seems impractical. If an alternative in future designs uses lower flows than the current alternatives, then the bypass canal should again be considered.

Evaporation Ponds at Palen Dry Lake

The design of the evaporation pond is discussed here. The preappraisal design of the evaporation ponds at Palen Dry Lake used some potentially costly assumptions about the requirements of this site. Geologic investigations would provide data that may change the design and associated costs considerably. The question is whether or not the lakebed should be lined. During feasibility design and thereafter, the design must be sufficient to ensure that the lake would not leak saltwater and pollute the groundwater. The geology contained in the 1974 report indicates that the site contains much fat clay. If this clay exists throughout the site, the lakebed probably would not require lining. Lining would be required, however, where such a barrier does not exist. It was assumed that 25 percent of the lakebed would require lining. This lining would consist of a welded high density polyethylene geomembrane, with clay lining below and a protective soil layer above.

Another potentially costly question, discussed at the beginning of chapter 3, is whether the salt removed must be eventually removed to the ocean. The design assumes that it is hauled to the ocean. There, a pumping plant would mix the salt with ocean water before it would be piped to a diffuser at the end of a pipeline. The exact timing of the salt removal and an associated extra pond were priced as a percentage addition.

An appropriate Palen Dry Lake dam design was provided. Subsequent investigations may determine that a series of lagoons would serve the intended purpose better than a dam.

The lakebed area is the minimum required in meeting the evaporation needs from the Salton Sea.

Complete Designs

The team designed 23 complete alternatives of the pump-in/pump-out options. Figure 13 (previously shown) illustrates all routes, and table 4 shows all the pertinent engineering data about pipeline length, elevation achieved, and discharge flows and pipe sizes.

Table 4.—Pipeline length and maximum elevation

Route	Length	Maximum elevation (feet)	Term elevation (feet)
Los Angeles – Hyperion	165	2630	0
Pacific Ocean – Camp Pendleton	113	3,636	0
San Diego – Point Loma	126	3,636	0
Gulf of California	136	82	0
Palen Lake	49	1,680	427
Yuma	79	180	120

Pipeline discharge and pipe size

Discharge (acre-feet per year)	Discharge (ft^3/s)	Basic pipe diameter (inches)
73,000	101	61
100,000	138	72
130,000	180	81
153,000	211	88
170,000	235	93
200,000	276	101
250,000	345	113
300,000	414	124
303,000	419	124
400,000	553	143
500,000	691	160
600,000	829	175
700,000	967	189

Earlier in chapter 3, table 2 presented the cost data. Construction Field Cost is the cost to construct the facilities in the field. This includes all the contingencies. The Energy Costs column indicates the annual cost of obtaining energy required by the pumps. The Other OM&R column lists the total cost for operation, maintenance, replacement, and energy of equipment over the life of the project. While much of the design is based on constant operation, the present worth values are based on a 100-year life.

As noted above, future designs may reduce the costs for the Point Loma and Camp Pendleton alternatives.

Viewing the table and map allows the reader to understand most of the individual designs. The following provides highlights of some of the major features shown in table 2 and provides other information not included in the tables.

Design Nos. 1 through 10 reach a salinity of 40 ppt in 15 years from construction completion.

Design Nos. 1, 2, and 3 require the greatest flows into and out of the Salton Sea. Greater flows are required because the alternative design uses ocean water to replenish the Sea in the shortest time. Design Nos. 1 and 3 also use the most energy of the 23 designs.

Design Nos. 4, 5, 9, and 10 pump water in from wastewater treatment plants and pump water out into the ocean or gulf. Their construction costs are similar. The energy costs for Design Nos. 4 and 5 are much higher than for Design Nos. 9 and 10 because the latter requires much less head to pump to the Gulf of California than over the mountains.

Design No. 6 receives water from Yuma. This water is the effluent of the proposed reverse osmosis plant in Tucson. A question exists regarding if and when the plant would be built. The alternative design assumes that the water would be available at Yuma at the end of construction. The pipeline travels downhill on a gradual slope from Yuma to the Salton Sea. If hydraulics were the only concern, a canal could replace this pipeline. This is the least costly alternative regarding both construction and energy if the salinity goal is reached in 15 years.

Design Nos. 7 and 8 receive water from wastewater treatment plants and pump water out from the Salton Sea to Palen Dry Lake, where evaporation separates the water from the salt. The costs for the lake liner and dam were prorated from Design Nos. 17 and 18. The required reservoir is the more technically challenging, probably requiring moving several miles of interstate highway and Federal highway. The table does not include these costs. A small town would also have to be moved. The extremely high OM&R cost comes from the high operating costs of removing the salt to the ocean. These designs have the highest total present worth costs.

Design Nos. 11 through 20 closely relate to Design Nos. 1 through 10. These designs require less water to reach the salinity level in twice the time (30 years). The previous comments for Design Nos. 1 through 10 are essentially the same as for Design Nos. 11 through 20, with the exception of Palen Dry Lake. Design Nos. 17 and 18 are probably technically feasible, and cost estimates were prepared to preappraisal precision and accuracy. The costs for Design Nos. 1 through 10 are about 1.6 times the costs for Design Nos. 11 through 20 and are consistent with the change in flow rates.

Design Nos. 21 and 22 are totally different from the first 20 designs. They only pump water out of the Salton Sea. They have the lowest construction costs of any of the alternative designs, and their energy costs are among the lowest. This should be expected because the flows are relatively low and they require only pipes leading away from the Sea. These low costs are associated with a major drawback. The designs reduce the salinity in the Sea very slowly, which is discussed in detail in chapter 2 in the Salinity Model section. Figure 14 illustrates how this concept affects salinity. Pumping out only 69,000 acre-feet per year would eventually have the pump-out salt load equal the current salt load entering the Salton Sea.

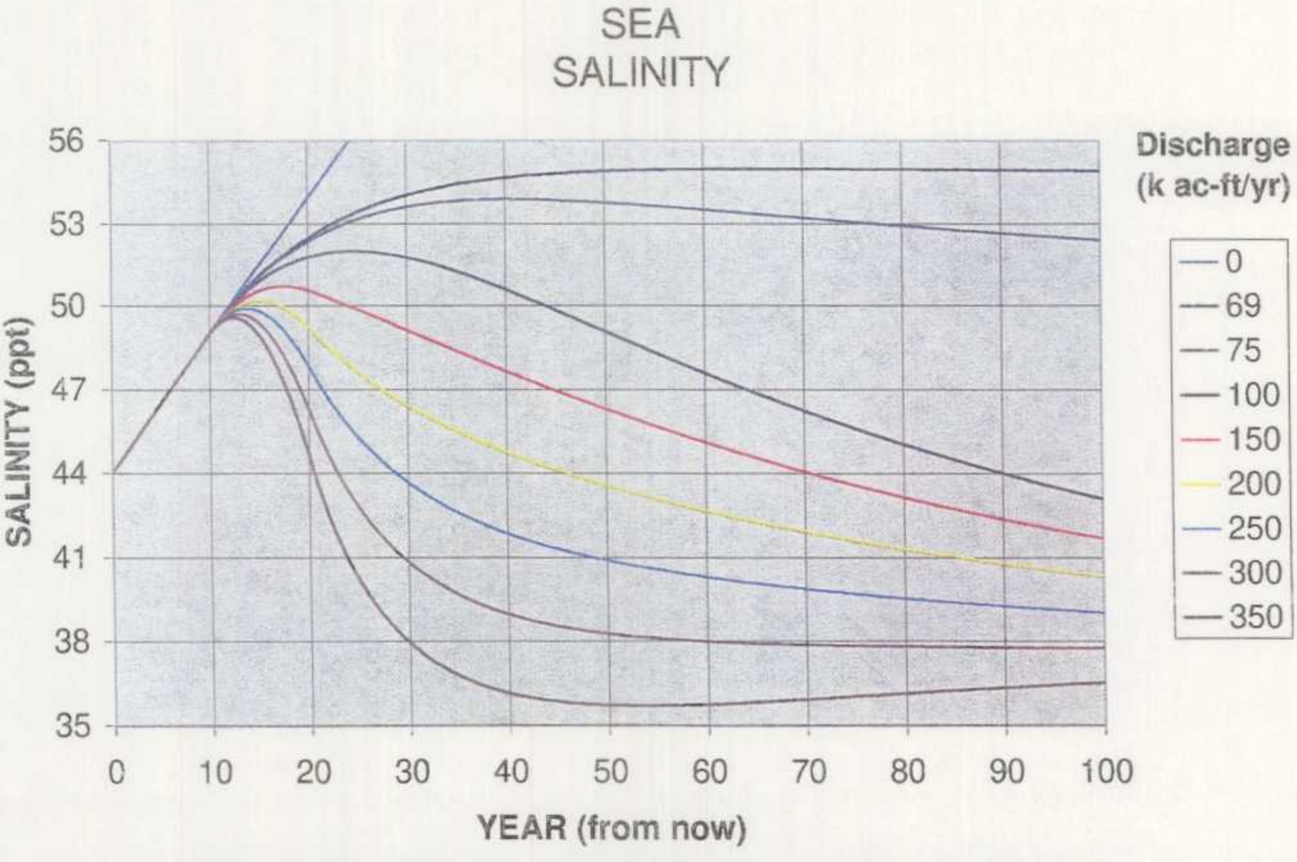


Figure 14.—Sea salinity at various pump-out rates in various years in the future.

Similar Designs

Two alternatives discussed in the 1997 report are very similar to the new pump-out/pump-in alternatives. Alternative 21 is similar to the new alternative 22. While the route for the 1997 alternative 21 travels to the west, along Laguna Salada, for preappraisal level designs, these routes are the same.

The 1997 alternative 22 pumps water out of the Salton Sea to Laguna Salada and pumps water in from the Gulf of California. Six of the new alternatives use ocean water to refresh the Salton Sea. Four of the new alternatives pump water out to a dry lakebed. The discharge quantities of alternative 22 would be similar to the ocean water alternatives, and the dry lakebed would have the same problems as Palen Dry Lake.

Chapter 6

Water Treatment Alternatives

Reverse Osmosis Desalting Plant With Pump-Out / Pump-In

The proposed project would be a combination of two basic proven technologies as shown in figure 15, a reverse osmosis desalting plant with pump-in to the Sea and a pump-out system to one of the locations discussed under the pump-out alternative in chapter 5. The pump-out system would be put into operation first, and the desalting plant/pump-in system would be put into operation years later, after the elevation criteria has been reached, because the desalting plant is only needed to maintain the salinity and elevation once the target elevation has been reached.

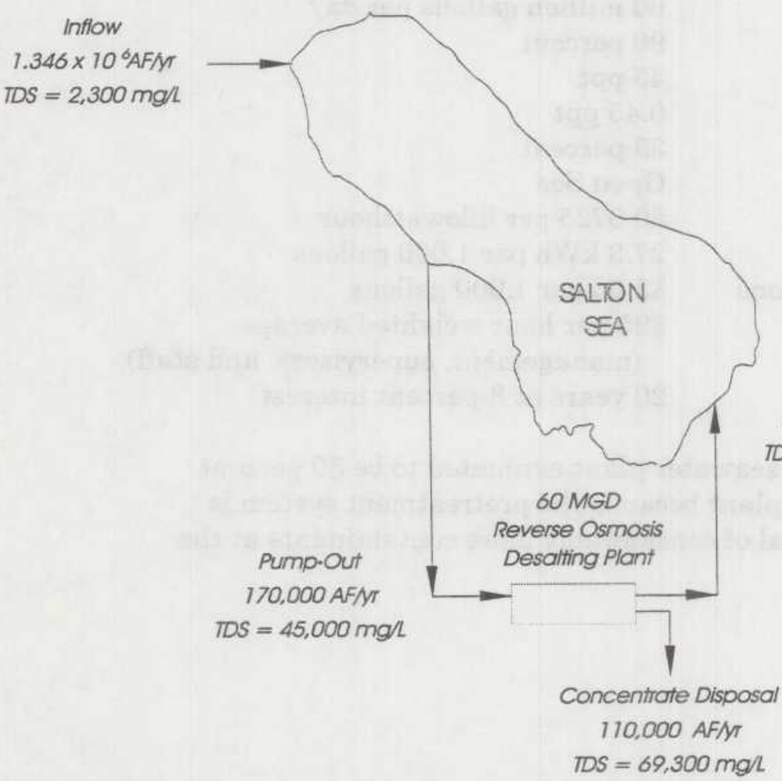


Figure 15.—Reverse osmosis desalting plant with pump-in/pump-out.

Analyses

A conceptual design study was accomplished extrapolating the performance and cost data for a similar seawater reverse osmosis plant in the Arabian Gulf having a feed water with TDS of 45 ppt (Shields et al., 1996). The desalting plant would have a feed water flow rate from the Salton Sea of 170,000 acre-feet per year and an average TDS of 45 ppt. Because of the high TDS, the recovery ratio is not likely to exceed 35 percent. On this basis, the desalting plant would provide a freshwater pump-in rate back to the Salton Sea of 60,000 acre-feet per year at a TDS of approximately 0.45 ppt and a concentrate reject flow of 110,000 acre-feet per year at a TDS of 69.3 ppt. The costs and size of plant may possibly be reduced further by blending the product waterflow to match the higher TDS of other pump-in alternatives, but this was not included in this initial study. For the alternative that was studied, the pump-out system for the concentrate flow would have to be designed for a flow rate of 110,000 acre-feet per year.

A summary of the assumptions and results of this conceptual design study are as follows:

Assumptions

Desalting plant capacity	60 million gallons per day
Availability	90 percent
Feed water TDS	45 ppt
Product TDS	0.45 ppt
Recovery ratio	35 percent
Intake	Open Sea
Energy costs	$0.0725 per kilowatthour
Energy per 1,000 gallons	27.8 kWh per 1,000 gallons
Energy cost per 1,000 gallons	$2.03 per 1,000 gallons
Average labor cost	$25 per hour weighted average (management, supervisors, and staff)
Capital amortization	20 years at 8-percent interest

1998 dollars

Capital cost of Salton Sea seawater plant estimated to be 50 percent higher than Arabian Gulf plant because the pretreatment system is expected to require removal of considerably more contaminants at the Salton Sea

Results

Total construction capital cost	\$435 million

Labor — The estimated staffing required for the 60-million-gallon-per-day plant is as follows:

Managers	1
Supervisors	3
Operators	20
Mechanics	11
Lab technicians	2
Office workers	2

Total workforce	39 staff days per day
Total annual O&M cost	
Energy cost	\$39.90 million per year
Labor	\$2.85 million per year
Consumables, maintenance, and membrane replacement	\$13.65 million per year
Total	\$56.4 million per year
Product water produced per year	1.97×10^{10} gallons per year (about 60,000 acre-feet per year)
Total water cost	
Cost per 1,000 gallons	\$5.11 per 1,000 gallons
Cost per acre-foot	\$1,665 per acre-foot

Pilot Plant

This alternative would require that a desalting pilot plant be built and tested with a number of pretreatment systems and reverse osmosis membranes be tested to determine the most cost-effective way to desalt the Salton Sea water and whether or not this alternative is cost effective when compared to the other pump-in alternatives. The possible pretreatment systems that could be tested are a conventional pretreatment system, a membrane bioreactor system, a membrane pretreatment system consisting of a microfiltration or ultrafiltration system, a slow sand system, and/or combinations of each.

It is estimated that the capacity of the pilot plant would be 6 to 24 gallons per minute; the cost of the desalting system would be approximately \$300,000; the lease of four pretreatment systems would be approximately \$50,000 each, for a total of \$200,000; other miscellaneous components would be approximately $50,000; and the labor would be approximately $400,000 over a 2-year period. Adding contingencies, the estimated cost would be about $1.2 million for the pilot plant.

It is estimated that it would take 1 year to design and build the pilot plant and 1 to 2 years to test it. This could be done without compromising the schedule of the overall Salton Sea project because the pump-out phase could be built first and the desalting plant/pump-in phase could be put into operation years later, after the elevation criteria has been reached.

Salinity and Elevation of the Sea

The Salton Sea computer model was run for this alternative, and the results are shown in figure 16 for this 60,000-acre-foot-per-year pump-in rate and 170,000-acre-foot-per-year pump-out rate. This alternative represents No. 24 on table 2. An explanation of the graph is found in chapter 9.

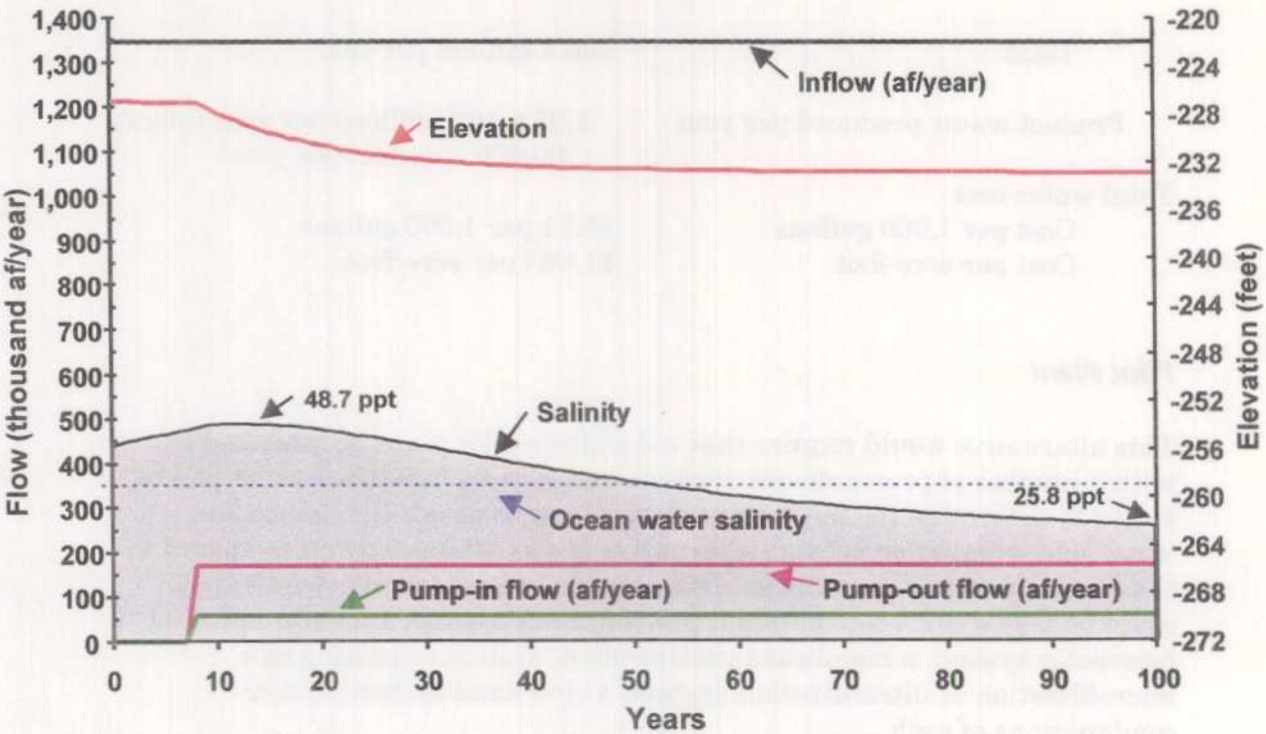


Figure 16.—Salinity model results of reverse osmosis desalting plant with 170,000-acre-foot pump-out and 60,000-acre-foot pump-in at 0.45 ppt with 1.346-million-acre-foot drainage inflow at 2.8 ppt.

Conclusion

As shown herein, this alternative uses proven technologies and satisfies the salinity target and elevation target criteria.

Solar Salt Gradient Pond / MED Desalting Plant With Pump-In / Pump-Out

The solar salt gradient pond/multiple effect distillation (MED) desalting plant proposal was included as a part of alternative 9 which included both a power system and a desalting system with a solar pond in the September 1997 report. It used technologies first proposed by Ormat Turbines (Yavne, Israel) in 1980 and was updated numerous times from 1980 to 1989 by and for numerous agencies, including Ormat Technical Services, Inc. (Sparks, Nevada); Meyer Resources, Inc. (Davis, California); Imperial Irrigation District (Imperial, California); County of Imperial (El Centro, California); and the Coachella Valley Water District (Coachella, California).

Based on a more recent report published in November 1991, Ormat Turbines, Ltd., has since concluded that low efficiency electric powerplants, such as the organic rankine powerplant, will not compete with conventional high temperature, high efficiency powerplants driven by fossil fuels unless fuel costs should increase. Therefore, the powerplant would not be cost effective when compared to grid power available locally at $0.0725 per kilowatthour, so is not a proven technology for this application. However, in the same report, they conclude that a solar salt gradient pond with an enhanced evaporation system (EES) may be cost effective for use with an MED desalting plant and have proposed a solar salt pond desalting plant to be built near Elait, Israel. This plant has yet to be built but is still being considered.

As a result, the Salton Sea studies were updated again in August 1998, assuming just a desalting system in combination with a solar pond and a pump-in/pump-out system.

Proposal Description

The proposed project includes a combination of several proven technologies as shown in figure 17, an MED desalting system with pump-in to the Sea, a solar salt gradient pond system that provides heat and cooling water to the desalting system, and a pump-out system to one of the locations discussed under the pump-out alternatives in chapter 5. An enhanced evaporation system (EES) would be used for initial filling of the solar pond. The

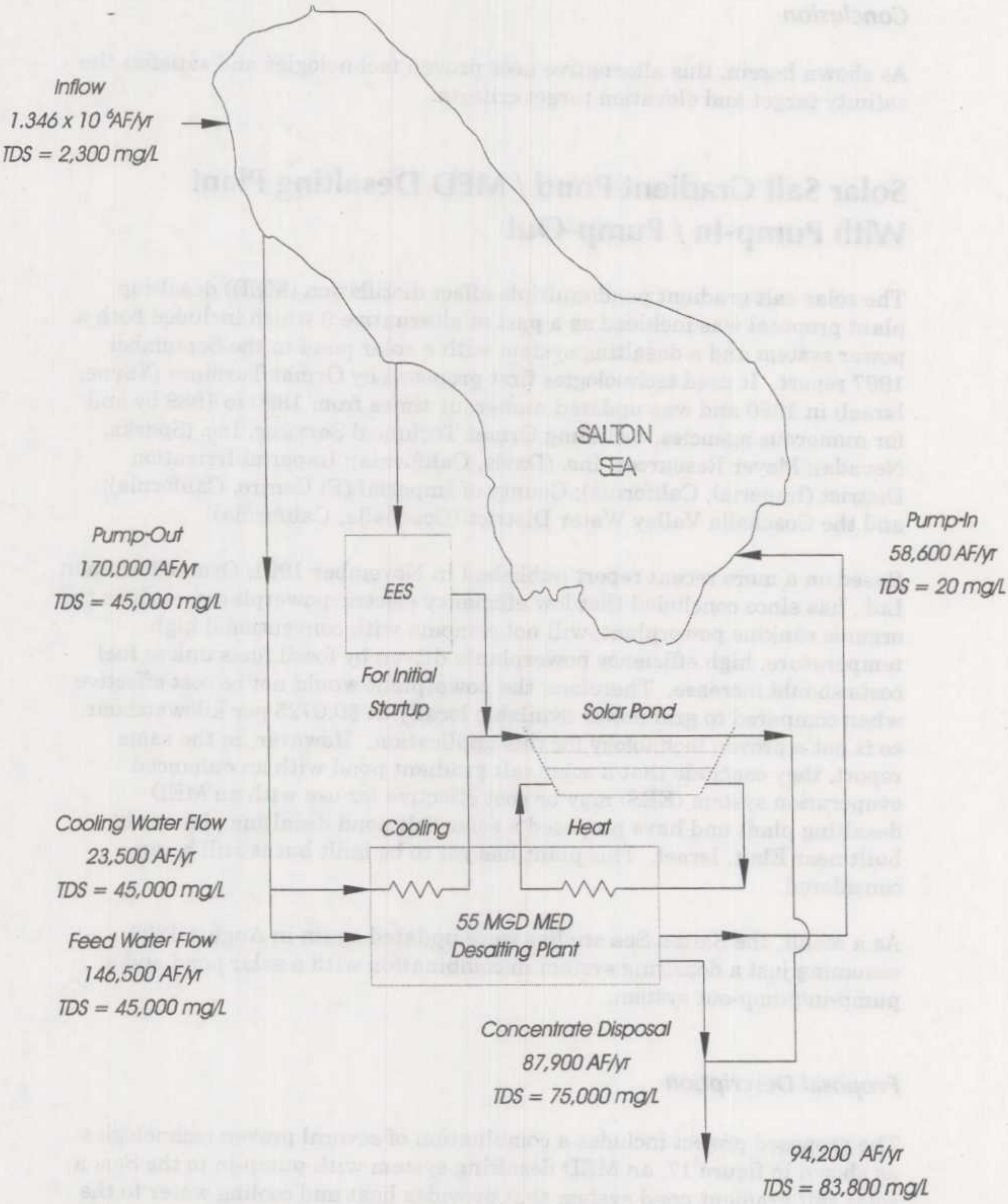


Figure 17.—Solar salt gradient pond/MED desalting plant with pump-in/pump-out.

pump-out system would be put into operation first, and the desalting plant/pump-in system would be put into operation years later, after the elevation criteria has been reached, because the desalting plant is only needed to maintain the salinity and elevation once the target elevation has been reached.

The use of a solar salt gradient pond is a proven technology, as a large 60-acre solar pond has been operated successfully in Israel over a number of years, and a 1-acre solar pond has been operated successfully by the University of Texas at El Paso with the Bureau of Reclamation for more than 10 years. Both have also operated solar ponds successfully with desalting plants and powerplants.

The Ormat EES is also a proven technology, which has been used in a commercial saltworks in Israel and would be used to expedite the initial filling of the solar pond lower heat storage zone. Once the desalting plant is operating, the EES is no longer required for the solar pond because the main flash chamber of the desalting plant can produce the required makeup brine for the solar pond. The EES pond can be designed to be converted to a solar pond once it is no longer needed for the initial filling. The EES technology can also be used alone with other pump-out options to reduce the volume of brine before it is pumped, so the size and cost of the pipeline would be less, or it can be installed to reduce the size of evaporation ponds if used at the final disposal site for the pump-out alternatives. It is reported that the EES

Analyses

A conceptual design study was accomplished extrapolating the performance and cost data (Ormat 1991) for a similar solar salt gradient pond and MED sea water desalting system that has been proposed to be built in Israel.

It was assumed that the Salton Sea desalting plant would have a feed water flow rate from the Salton Sea of 170,000 acre-feet per year and an average TDS of 45 ppt. Approximately 23,500 acre-feet per year will be needed for the desalting plant cooling waterflow and for flushing the surface of the solar pond, leaving a desalting plant feed water flow of 146,500 acre-feet per year. Because of the high TDS, the recovery ratio is not likely to exceed 40 percent. On this basis, the desalting plant would provide a product water pump-in rate back to the Salton Sea of 58,600 acre-feet per year at a TDS of approximately 0.020 ppt and a concentrate reject flow of 87,900 acre-feet per year at a TDS of 75 ppt. The water for flushing the surface of the solar pond would be added to this flow, giving a total flow of 94,200 acre-feet per year at a TDS of 83.8 ppt for pump-out to the site selected under the pump-out alternatives.

A summary of the assumptions and results of this conceptual design study are as follows:

Desalting plant capacity	55 million gallons per day
Availability	95 percent
Feedwater TDS	45 ppt
Product TDS	0.020 ppt
Recovery ratio	40 percent
Intake	Open Sea
Solar pond surface area	3,403 acres (5.3 mi^2)
Number of solar ponds	120 "U"-shaped ponds
Solar pond liners	2 clay and plastic liners
Enhanced evaporation system pond area	23.5 acres
Energy costs	\$0.0725 per kWh
Energy per 1,000 gallons	5.56 kWh per 1,000 gallons
Total energy costs	\$7.7 x 10^6 per yr
Other O&M costs	\$17.8 x 10^6 per yr
Total O&M costs	\$25.5 x 10^6 per yr
Total capital construction cost	\$551 x 10^6
1998 dollars (assuming no change since November 1991 report)	
Contingencies	20 to 30 percent (economy of scale)
Capital amortization	20 years at 8-percent interest
Total water cost	
Cost per 1,000 gallons	\$4.27 per 1,000 gallons
Cost per acre-foot	\$1,391 per acre-foot

Pilot Plant

As mentioned, the use of a solar salt gradient pond with a desalting plant is a proven technology by Ormat Turbines, Inc., in Israel and at the Bureau of Reclamation solar pond test facility in El Paso, Texas, on a small scale. However, a large pilot plant would have to be designed and built over a 2-year period of time, then tested for a 2-year period of time to determine the required pretreatment, performance, and cost using Salton Sea water before it would be known whether a full-scale solar pond desalination plant would be cost effective compared to a conventional reverse osmosis desalting plant for the Salton Sea.

To be able to scale up to a 55-million-gallon-per-day production plant, it is estimated that the capacity of the pilot plant would have to be 1 million gallons per day with 62 acres of solar ponds and a small enhanced evaporation system. On this basis, it is estimated that the cost of the pilot plant would be approximately $12 million, and the labor over a 2-year test period of time would be approximately $600,000. Adding contingencies, the estimated pilot plant cost would be approximately $15 million.

Salinity and the Elevation of the Sea

The Salton Sea computer model was run for this alternative, and the results are shown in figure 18 for this 58,600-acre-foot-per-year pump-in rate and 170,000-acre-foot-per-year pump-out rate. This alternative represents No. 25 on table 2. An explanation of the graph is found in chapter 9.

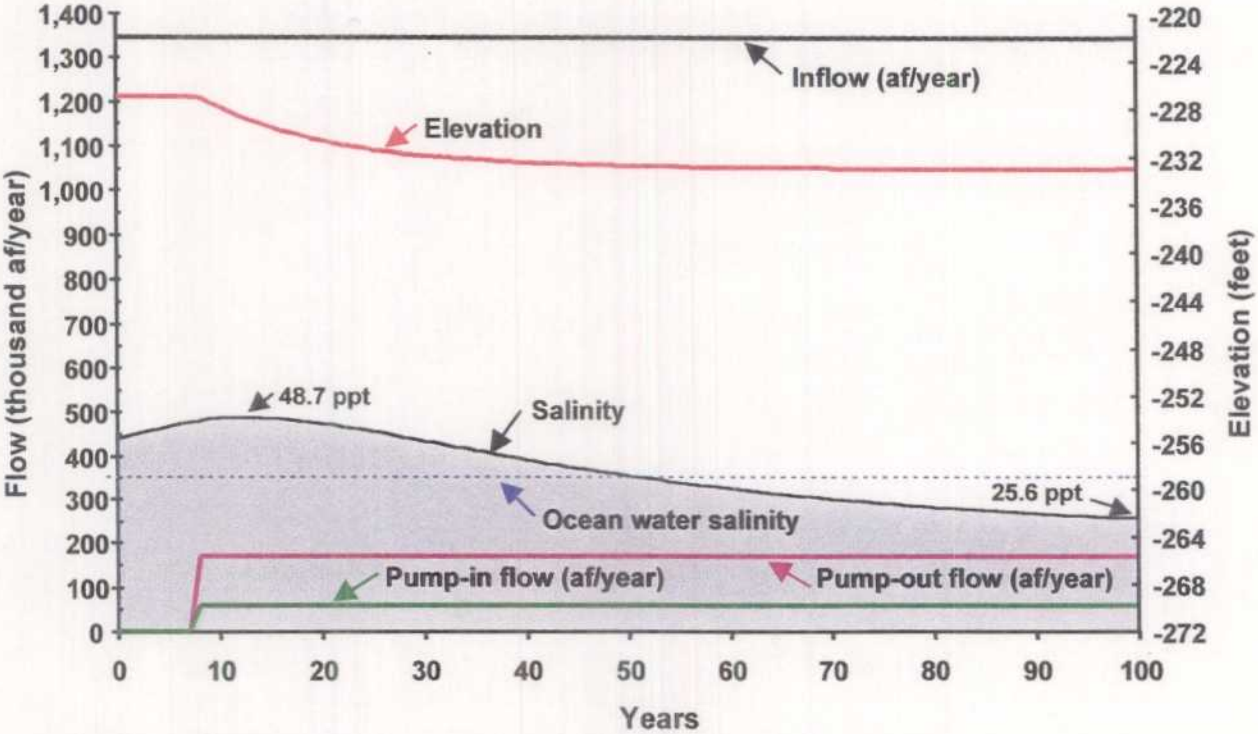


Figure 18.—Salinity model results of solar salt gradient pond/MED desalting plant with 58,600-acre-foot desalted replacement water at 20 ppm with 1.346-million-acre-foot drainage inflow at 2.8 ppt.

Conclusion

As shown herein, this alternative uses proven technologies and satisfies the salinity target and elevation target criteria.

Chapter 7

New Combination Alternatives

Salt Pond / Shipping Channel / Canals / Desalting Facility

This proposal was prepared by Metcalf and Eddy, San Diego, California, dated September 8, 1997, and sent to Los Alamos National Laboratory at the request of Mr. Patrick Quinlan of Congressman George Brown's office. This alternative is to construct a navigable canal between the Gulf of California and the Salton Sea.

This proposal is essentially a pump-out/pump-in scheme using ocean water (alternatives 2 and 12 on table 2 and in chapter 8) with costly facilities added that provide enhancements not related to desalting the Salton Sea. The alternative appears possible at this low level of design. This should not be taken to mean that all facilities have been noted and that the stated operation is complete.

One difference between this alternative and the other alternatives of this study is that it uses canals. The current pre-appraisal design did not. This report discusses using canals (see chapter 5, Pump-Out/Pump-In), which have a high probability of reducing costs.

With time, the assumptions that any study uses to estimate the future Sea salinity would change. The assumptions the Metcalf and Eddy proposal used would yield better results than the assumptions that the remainder of this report used.

While the current low level of design pays little attention to detail, the high point on the profile is usually important. The Metcalf and Eddy proposal indicates the high point of this particular route would be at an elevation of 82 feet m.s.l. Topographic maps indicate this elevation to be closer to 140 feet m.s.l. This would increase the required excavation over what the proposal uses. Other pump-out/pump-in alternatives use a different route that does have a maximum elevation of 82 feet m.s.l.

The diking and desalinization plant that the proposal uses would be similar to dikes and plants discussed elsewhere in this report and would also have similar problems and costs. The proposal also contradicts itself, as it states that a desalting plant would be built to provide drinking water to MWD and others, and then later states that the desalinated water would flow into the Salton Sea to maintain its level. If the desalted water is not put into the Sea, the desalting plant portion of the proposal does nothing to improve the salinity of the Sea.

The pump-out canal will discharge into the large canal section during low tides only. The timing and operation of the canal between the Salton Sea and the point of discharge is critical and should be investigated completely. The volumes of water transfer in the locks and the timing of this transfer are also critical.

Gulf of California Pump-In / Pump-Out / Diking / Treating Inflows

This proposal was faxed, dated August 10, 1998, to the Salton Sea Authority by U.S. Filter. It includes a combination of diking to control salinity concentration, pumping to and from the Gulf of California to stabilize elevation and treating the agricultural inflows. No quantities were provided for evaluation, and specific information was not provided. However, this proposal is very similar to alternatives discussed in Chapter 5, Pump-Out/ Pump-In and alternative 33 in the September 1997 report, proposed earlier by U.S. Filter.

As discussed in chapter 2, page 14, large quantities of water, requiring large infrastructure, are needed to reduce the salinity of the Sea. Information provided indicates that a desalting plant or nanofiltration plant would be built on the Alamo River to provide recycled water for agriculture and other purposes. This would reduce the inflow of relatively fresh water to the Salton Sea, making the salinity problem worse.

This proposal meets the criteria of salinity control, elevation stabilization, and proven technology, but it would be one of the most expensive alternatives.

Phased Approach—Phase One: Salt Stabilized, Phase Two: Pump-In Later

This proposal was submitted by Mr. Don Cox of Imperial Irrigation District at the public scoping meeting held in July 1998.

The goal of phase one is to stabilize the salinity of the Sea without dikes or brine ponds that might cause environmental concern. This would be economical and environmentally benign. It would take a 66-inch pipe, a pump, and a place to take the water. If needed, the 60-tons of salt per acre-foot of water could be concentrated to 200 tons of salt per acre-foot of water to reduce transportation costs. It appears that pumping 75,000 acre-feet per year out of the Sea would equal the salt load flowing into the Sea, which is included in the 1.346 million acre-feet per year. The 75,000 acre-feet of water pumped out of the Sea would not be a large enough quantity to cause secondary problems. This plan would be the quickest and simplest to implement, and time is certainly important. It would keep the Sea from deteriorating and allow the time to do the scientific studies for the final phase. In addition, the work would not be wasted as it would provide the outlet needed for any long-term solution. The outlet water going to Yuma is just one example of where the water might go.

Phase one is similar to Design Nos. 21 and 22 discussed on page 56. See these designs to understand the effect of this alternative. Phase two at a later date would receive water from one of the various sources discussed in "Pump-In Sources" on page 49.

Salt Concentrating Ponds

David Butts of DSB Engineering suggested using salt concentrating ponds in his report to the Salton Sea Authority, dated October 1995. The two alternatives that came from this report would use ponds to concentrate Sea water, through evaporation, prior to pumping. Concentrating the flow means pumping less water, requiring smaller pipes and less pumping energy. There is a small increase in head caused by change in kinematic viscosity and unit weight of the water. Table 2 shows these costs of the in-Sea concentration Alternative 37.

Alternative 38 is very similar to Alternative 37 but would use evaporation ponds on land near the Sea. Both Alternatives 37 and 38 are kindred to Alternative 9, and their cost can be compared to see the economics of concentrating the flows. They pump out 100,000 acre-feet per year from Point Loma. The ponds concentrate the pump-out discharge salinity from 44 ppt to 138 ppt and flow from 25,000 acre-feet per year to 100,000 acre-feet per year.

These alternatives use evaporation ponds with a minimum surface area of 45 square miles. Lower discharges or lower concentrations would require smaller ponds.

Chapter 8

Alternatives Considered for Elimination

Originally, four elimination criteria were developed to narrow the list of 54 alternatives to those alternatives that matched project requirements. These criteria were discussed and approved at an Authority workshop on October 19, 1995. Since that time, a decision was made not to use the $10 million OMR&E per year cost criteria for this analysis. The remaining three criteria were used to evaluate the original list of 54 alternatives plus any new alternatives received.

The proposal must meet the three criteria established:

- Achieve and maintain target salinity level of 40 ppt in the Salton Sea
- Achieve and maintain Salton Sea target water surface elevation to -232 m.s.l.
- Use proven technology and not involve research

Original 54 Alternatives

Some of the alternatives (cross-reference table on page 17) have partial solutions that may be used in conjunction with another alternative. Many of the alternatives have good ideas but lack a definitive plan or design, quantities, and costs. For reasons described earlier, Colorado River water is not available as a source to dilute Salton Sea water. The following alternatives could be considered for elimination because they were incomplete or did not meet one or more of the three criteria established. The number of the alternatives correspond to the number of the alternatives in the 1997 report.

Alternative 8 Onshore Evaporation Ponds

Included in the September 1997 report, this proposal was examined in the Reclamation and RAC report, Salton Sea Project, California, Federal-State reconnaissance report (1969, and in the final report in 1974). It was also included in the Aerospace Corporation report, Salinity Control Study, Salton Sea Project, Report No. ATR-71 (S990)-5 (1971).

This alternative would involve pumping Sea water into evaporation ponds onshore where the water would be evaporated, leaving behind saline residue. Saline water would be removed from the Sea until the desired salinity was reached. At this point, pump-out would continue at a lower rate so that salts removed by pump-out each year would equal the annual inflow of salts. Eventually, the evaporation ponds would fill with salts, and disposal would be necessary. The southeastern shore of the Sea, between Bombay Beach and Red Hill, would be a potential location for onshore evaporation ponds.

In the initial stages of this proposal, a total of 400,000 acre-feet of water would be pumped each year. Evaporating this quantity of water would require nearly 70,200 acres.

The amount of land required for evaporation ponds is judged unacceptable, and the alternative would not maintain the water surface elevation of the Sea.

Alternative 9 Enhanced Evaporation/Solar Pond Power Generation

Included in the September 1997 report, this proposal uses technology first proposed by Ormat Turbines (Yavne, Israel) in 1980. It was updated numerous times from 1980 to 1989 by and for numerous agencies, including Ormat Technical Services, Inc. (Sparks, Nevada); Meyer Resources, Inc. (Davis, California); Imperial Irrigation District (Imperial, California); County of Imperial (El Centro, California); and the Coachella Valley Water District (Coachella, California).

The proposed project included a combination of a number of technologies: an EES and a crystallization pond to reduce the volume of the brine prior to pump-out and to provide concentrated brine for the solar pond; a lined solar salt gradient pond system; and a low temperature organic rankine electric powerplant. A deep injection well was also proposed or a pipeline for pump-out disposal along the railroad right-of-way to the Yuma Desalting Plant Main Outlet Drain Extension.

Based on a more recent report (Ormat, 1991), Ormat Turbines, Ltd., has since concluded that low efficiency electric powerplants, such as the organic rankine powerplant, cannot compete with conventional high temperature, high efficiency powerplants driven by fossil fuels unless fuel costs should increase. Therefore, the powerplant would not be cost effective when compared to grid power available locally at $0.0725 per kilowatthour, so is not a proven technology for this application. However, in the same report, they conclude that a solar salt gradient pond with an EES may be cost effective for use with a multi-effect distillation (MED) desalting plant and have proposed a solar salt pond desalting plant to be built near Elait, Israel. This plant has yet to be built but is still being considered.

As a result of these more recent studies, this alternative uses proven technologies, but the power generation portion of the proposal would not be cost effective compared to purchasing local grid power at $0.0725 per kilowatthour. Deep well injection also would not be a reliable method for providing long-term disposal of large quantities of brine.

The use of a solar salt gradient pond desalting plant is a proven technology by Ormat Turbines, Inc., in Israel and at the Reclamation solar pond test facility in El Paso, Texas, on a small scale. However, a large pilot plant would have to be designed and built over a 2-year period of time, then tested for a 2-year period of time using Salton Sea water before it would be known whether a full-scale solar pond desalination plant would be cost effective compared to a conventional reverse osmosis desalting plant. As a result, this alternative, with an EES, is included as one of the subalternatives under the Water Treatment Alternative herein.

The Ormat EES is a proven technology which has been used in a commercial saltworks in Israel and can be used alone with other pump-out options to reduce the volume of brine before it is pumped, so the size and cost of the pipeline would be less, and the size and cost of evaporation ponds would be less at the final disposal site, because it is reported to reduce the size of the evaporation ponds by 5 to 10 times. In an earlier unpublished study by Reclamation, the cost was estimated to be $105 to $204 per acre-foot of pump-out water processed to dry salt in 1989 dollars.

Alternative 12 Navigable Waterway / Mexicali Seaport

Included in the September 1997 report, this project was documented in the Meyer Resources, Inc. (Currie, et al., 1988) *Problems and Potential Solutions at Salton Sea* (December 1988) and *Summary Analysis of Authorities and Responsibilities Associated with the Salton Sea* (December 1988). The proposal was also mentioned in the Dangermond and Associates report, *Strategies for the Restoration and Enhancement of the Salton Sea* (July 1994), and it was also discussed in the Coachella Valley Water District report, *The Salton Sea* (undated).

This alternative failed to satisfy the target salinity requirement of achieving and maintaining 40 ppt. None of the references provided any detailed information on a seaport or navigable waterway between the Gulf of

California and the Sea. However, a new alternative was received after the scoping meetings which does have more detail. It is being reviewed and is part of chapter 7, New Combination Alternatives.

Alternative 13 190 mi² - Plastic Curtain

Included in the September 1997 report, this was proposed by Mr. Gerald Martin in a paper titled "Salton Sea Barrier Curtain Project," dated August 1995. This proposal would divide the Sea in half with a high-density polyethylene dam or curtain. The curtain separates the Sea into an evaporation section and a fresher water section.

This alternative did not use proven technology.

Alternative 14 Various Sized Impoundments - Plastic Curtain

Included in the September 1997 report, this was proposed by Mr. Gerald Martin in February 1992 and revised in April 1992 and August 1995. This proposal used a high-density polyethylene dam or curtain to create isolated areas within the Sea which would serve as evaporation ponds.

This alternative did not use proven technology.

Alternative 15 Canal / Dam to Base of Chocolate Mountains

Included in the September 1997 report, this proposal was received by the TAC from Mr. Seth Arnold, North Shore, California, in response to a public workshop held on August 31, 1995. The proposal used the concept of constructing a canal/dam system, with gates, to transport Sea water to the base of the Chocolate Mountains in order to provide an outlet for the Sea. Very little data was provided, making it difficult to understand how the proposal would work.

This proposal failed to satisfy the salinity target and elevation target criteria.

Alternative 16 Diked Impoundment to Gulf of California

Included in the September 1997 report, this proposal was proposed by Mr. Horace McCracken, Sunwater Solar, Inc., in February 1986, in January 1994, and in 1995. This proposal used a 40-mi² diked impoundment at the south end of the Sea to concentrate Sea water by evaporation before it would be pumped by solar power to a height sufficient to allow it to flow by gravity in a canal to the Gulf of California.

The solar power is not reliable or cost effective. The use of discarded tires in the construction of the dike is unproven technology. There are some features in this proposal which are contained in other alternatives. (See chapter 5, Pump-Out/Pump-In Alternatives.)

Alternative 17 Frontier Aquadyne Enhanced Evaporation

Included in the 1997 report, this proposal was made by Frontier Aquadyne, Inc. It uses a low temperature brine concentrator to process the pump-out brine so that a cake salt is the output for disposal. This is not a proven technology for this application. In addition, Aquadyne is currently in default on a research contract to build and test a similar system for the Bureau of Reclamation. In an earlier unpublished study by Reclamation, the cost was estimated to be $3,910 per acre-foot of pump-out water processed to dry salt in 1989 dollars, if the tests of the technology proved successful. The system has been built and installed at Reclamation's El Paso solar pond test site, but is yet to be tested because of lack of funding. Thus, it is an unproven technology when compared to the Ormat Turbines, Inc., enhanced evaporation system.

Alternative 18 Solar Still Desalting / Colorado River Water Replenishment

Included in the 1997 report, this proposal was made by Environmental Enhancing Technologies (Daniels, 1990). It uses an enhanced solar still to produce and sell potable water and/or return it to the Sea, plus evaporation ponds to dispose of the concentrated flow and to reclaim and sell salt. Fresh water is also replenished from the Colorado River.

According to an unpublished study by the National Renewable Energy Laboratory (NREL), solar stills are not cost effective for large desalination plants when compared to conventional reverse osmosis desalination plants, so they are an unproven technology for large-scale plants (NREL, 1991).

Earlier information provided by the Western Salt Company concluded that the quality of the salt from the Salton Sea is so poor that it would have no market value. There also is no fresh water for replenishment available from the Colorado River, as proposed.

Alternative 19 SNAP Technology Enhanced Evaporation Tower

Included in the 1997 report, this proposal was submitted by Professor Dan Zaslavsky and the Technion, Israel, Institute of Technology. It uses a large, 3,300-foot tower structure to produce electricity and desalt water from the Sea. This alternative did not use a proven technology.

Alternative 20 Aquaculture / Evaporation Ponds

This alternative was proposed by Dov Grajcer, Ph.D., and Ms. Becky Broughton, Aquafarms International, in *Concept Strategy Commercializing Control of Salinity in the Salton Sea - Salton Sea Aquaculture Facilities* (1994).

This proposal used saltwater aquaculture facilities to raise fish in ponds created with water pumped from the Sea. Water from the fish rearing ponds would be disposed of by transferring it into evaporation ponds. Initially, a benchmark facility consisting of one 200-acre fish pond, one 400-acre evaporation pond, and 40 acres of support structure would be built to raise tilapia, a fish commonly produced in the area. The final stage of the plan called for 70 or more saltwater aquaculture facilities of similar composition and size, each using 2,000 to 4,000 acre-feet of Sea water per year.

About 45,000 acres of land (70 by 640 acres) would be needed for the facilities and evaporation ponds. There was no mention of how the water would be transported to the fish farms. In addition, the proposal did not include evaporation from the fish ponds in calculating the overall water usage for the system, which would total nearly 240,000 acre-feet per year. Evaporation would eventually result in large quantities of salt accumulation, which was proposed to be trucked out and disposed of in the Pacific Ocean. If 80,000 pounds or 40 tons of salt, were to be removed via truck, 225,000 truck trips would be required every year, or 617 truck trips every day, 365 days a year.

Although this alternative would reduce the salinity concentration, it would do nothing to maintain the water surface elevation.

Alternative 23 Pumped Storage Canal to Gulf of California

Included in the September 1997 report, this proposal was developed by Dangermond and Associates, Inc., for Riverside County and the Coachella Valley Water District. It was documented in the report, *Strategies for the Restoration and Enhancement of the Salton Sea* (July 1994). This proposal combined two main concepts—a pumped-storage power generation facility and a large canal/pipeline linking the Sea with the Gulf of California.

The pumped-storage power generation facility should be considered for elimination because the topography is very unfavorable for producing power. See "Power Recovery Potential" section in chapter 5. The canal/pipeline concept has some similarities to a new alternative, which is part of chapter 7, New Combination Alternatives.

Alternative 24 Solar Membrane Distillation

Included in the September 1997 report, this proposal was discussed in a letter from the National Water Research Institute to Ms. Roberta Burns. It uses a solar heated membrane distillation system to desalt the Sea water. It has been tested only on a small scale and has not been shown to be as cost effective for large-scale plants when compared to conventional reverse osmosis desalting plants, so it is an unproven technology.

Alternative 25 Disposal of Reject Stream to Yuma

Included in the September 1997 report, this proposal was presented in the Meyer Resources, Inc., report, *Summary Analysis of Authorities and Responsibilities Associated with the Salton Sea* (December 1988). The alternative included construction of a pipeline from the Salton Sea to Yuma to dispose of brine in the existing drain that empties into the Gulf of California. The existing drain was built to dispose of brine generated by operation of the Yuma Desalting Plant.

This proposal was a brine disposal option only. This proposal failed to satisfy both the salinity target and elevation target criteria but could be used with an alternative needing a disposal component. (See chapter 5, Pump-Out/Pump-In Alternatives.)

Alternative 26 Impoundment / Evaporation Pond / Pipeline to Gulf of California / Yuma Desalting Plant

Included in the September 1997 report, this alternative appeared in the Dangermond and Associates, Inc., report, *Strategies for the Restoration and Enhancement of the Salton Sea*, Sacramento, California (1994). It uses a combination of several alternatives discussed in the report, including a diked impoundment adjacent to the south shore, an onshore conventional lined evaporation pond, and a pump-out pipeline to transport concentrated brine either to the Gulf of California or the Yuma Desalting Plant Main Outlet Drain Extension brine discharge canal.

This alternative uses proven technologies. However, use of conventional evaporation ponds requires large areas and large O&M costs. This proposal also was only a brine disposal option. It thus fails to satisfy both the salinity target and elevation target criteria but could possibly be used with an alternative needing a disposal component. (See chapter 5, Pump-Out/Pump-In Alternatives.)

Alternative 27 Impoundment / Wetlands / Enhanced Evaporation/ Solar Pond, Power Generation, and Desalting System

Included in the 1997 report, this proposal appeared in the Dangermond and Associates, Inc., report, *Strategies for the Restoration and Enhancement of the Salton Sea.* It uses a combination of several options discussed in the report, including a diked impoundment adjacent to the south shore; constructed wetlands near the mouths of Alamo, New, and Whitewater Rivers; and an Ormat EES, a solar salt gradient pond with a power system, and a desalting system. The method of pump-out or final disposal of the concentrated brine or raw salt is not discussed, so this alternative failed to satisfy the salinity target and elevation target criteria.

As discussed in the evaluation of alternative 9, a solar salt gradient pond powerplant would not be cost effective when compared to grid power available locally at $0.0725 per kilowatthour, so it is not a proven technology for this application.

The impoundment, enhanced evaporation systems, and solar pond desalting systems are proven technologies which could be used in combination with other alternatives. The solar salt gradient pond and desalting system would require a large pilot plant. Design and construction would require a 2-year period of time and testing for 2 years to verify that it would be cost effective using Salton Sea water compared to a conventional reverse osmosis desalting plant before constructing a full-scale solar pond desalting plant.

Alternative 28 Impoundment / Freshwater Shoreline / Solar Pond Power Generation and Desalting System / Pumped Storage / Wetlands

Included in the September 1997 report, this proposal appeared in the Dangermond and Associates, Inc., report, *Strategies for the Restoration and*

Enhancement of the Salton Sea. It uses a combination of several alternatives discussed in the report, including diked impoundments, constructed wetlands, or solar salt gradient pond with a power system and a desalting system.

As discussed in alternative 9, a solar salt gradient pond powerplant would not be cost effective when compared to grid power available locally at $0.0725 per kilowatthour, so is not a proven technology for this application. An EES is not included in this alternative, so it would require a large area of conventional evaporation ponds to concentrate the brine for the solar salt gradient pond desalting system, which is not likely to be cost effective.

The remaining portions of the proposal cannot meet the salinity target and elevation target alone, but could possibly be used with another alternative.

Alternative 29 *Impoundment / Solar Pond Powerplants / Pumped Storage / Wetlands / Pump-Out to Laguna Salada*

Included in the September 1997 report, this proposal appeared in the Dangermond and Associates, Inc., report, *Strategies for the Restoration and Enhancement of the Salton Sea*. It uses a combination of several alternatives discussed in the report, including diked impoundment, solar salt gradient pond powerplants in the United States and Mexico, and constructed wetlands.

As discussed in alternative 9, a solar salt gradient pond powerplant would not be cost effective when compared to grid power available locally at $0.0725 per kilowatthour, so is not a proven technology for this application. An EES is not included in this alternative, so a large area of conventional evaporation ponds would be required to concentrate the brine for the solar salt gradient pond desalting system, which is not likely to be cost effective.

The remaining portions of the proposal could possibly be used with another alternative.

Alternative 30 *Move Yuma Desalting Plant to the Sea*

Included in the 1997 report, this alternative was proposed by Mrs. Iver Watkins, Salton Sea Beach, and Mr. Alex Michaels of Alex Michaels Company during the public workshops held in September and October 1995. It proposed moving the Yuma Desalting Plant to desalt the Salton Sea water. The Yuma Desalting Plant must be maintained in a ready reserve mode so that it can be used when required to meet the agreement signed with Mexico. All of the desalting plant, including all of the conventional pretreatment system, high pressure pumps, and the membrane desalting system, are built to remove the salt from relatively low salinity brackish water with a TDS of 3 ppt, so the systems are completely different from what would be required to desalt the Salton Sea, which is a highly concentrated Sea water with a TDS of 44 ppt. It would thus cost more to move and modify the system than it would cost to build an entirely new plant designed specifically for the Salton Sea salinity.

Thus, the Yuma Desalting Plant is not available, and its pretreatment and desalting systems are not a proven technology applicable to the Salton Sea salinity. It cannot meet the Salton Sea salinity target and the elevation target criteria as currently built.

Alternative 31 Poplar Tree Constructed Wetlands

Included in the September 1997 report, this idea was proposed by Mr. Neil J. Maxwell, Salton Sea Beach, in the August 1995 public workshop by letter dated August 11, 1995. This proposal used a stand of poplar trees planted in such a way that nitrates contained in the inflow to the Sea would be removed by flowing water through the trees.

This proposal primarily addressed concentrations of nitrates. It did not address salinity of the Sea. This proposal failed to satisfy the target salinity requirement of achieving and maintaining 40 ppt.

Alternative 32 Special Pretreatment Reservoirs

Included in the September 1997 report, this alternative was proposed by Mr. Tim Bloom, Diversified Scientific Technologies, Rancho Mirage, California, in a workshop on August 15, 1995. It uses percolation pretreatment reservoirs to capture water before it enters the Sea in order to remediate inflow pollution. No information is provided on what the pretreatment is or how it would work.

It does not meet the Salton Sea salinity target criteria or the elevation target criteria and does not use a proven technology.

Alternative 33 U.S. Filter Corporation—New River Desalting

Included in the 1997 report, this alternative was proposed by Mr. Eldon Gill of Lobland-Waring, Palm Desert, California, in a commentary solicited for the Salton Sea Symposium (undated). It uses a nanofiltration system to treat the inflow to the Sea. Nanofiltration would improve the inflow water quality but would remove very little salt from the inflow. Treating just the inflow also would not reduce the salinity to targeted levels, and it would not control the surface elevation.

Therefore, this alternative does not meet the salinity target or the elevation target criteria.

Alternative 34 Groundwater Pump for Selenium Management

Included in the September 1997 report, this concept was proposed by Hydrologic Consultants, Inc., Davis, California, in *Proposal to Plan and Operate a Pilot Program for the Management of Selenium by Groundwater Pumping*, dated December 8, 1995. In this proposal, selenium would be managed by pumping groundwater from a deep aquifer that underlies those areas that presently produce high selenium concentrations in drainage water flows.

This alternative did not achieve and maintain the target salinity of 40 ppt or provide any elevation control. Also, it is uncertain whether this pumping proposal would work because of clay layers that are dispersed throughout the Valley.

Alternative 35 Freshwater Blending

Included in the 1997 report, this alternative was proposed by Mr. J. Wendell Graves of Brawley, California, at one of the public workshops in 1995. It proposed pumping New River water to a storage reservoir at 30 feet above sea level. Salton Sea water and fresh water from an unnamed source would be blended with the New River water, and the blended water would flow back to the Sea. As proposed, this alternative would not remove salt from the Sea. This alternative, therefore, does not meet the salinity target or the elevation target criteria.

Alternative 36 Replenishment by Colorado River Surplus

Included in the 1997 report, this alternative appeared in the Meyer Resources, Inc., *Problems and Potential Solutions at the Salton Sea* for the RAC (December 1988). It proposed diverting the excess water during wet years from the Colorado River directly to the Sea to reduce the salinity level. Availability of water is unreliable. (See section on "Excess Flows" in chapter 5.) This proposal would improve salinity only temporarily and could not permanently satisfy the salinity target. Elevation control also would not be possible.

This alternative, therefore, does not meet the salinity target and the elevation target criteria.

Alternative 37 Venturi Air Pump

Included in the September 1997 report, this proposal was submitted in a letter, dated January 1990, written by Burke Hensley and Son, Banning, California. This alternative proposed the use of venturi action to pull air into tributary inflow and oxygenate the water to stimulate the natural purification process.

This proposal failed to satisfy the salinity target and elevation target criteria.

Alternative 38 Foraminifera Studies (Research)

Included in the September 1997 report, this alternative was proposed by Dr. Richard Casey, representing Ocean Research International of San Diego at the August 1995 workshop. This proposal suggested acquiring sediment samples from the Sea to evaluate the microscopic forms of life with shells (foraminifera) which have been preserved in this sediment.

This alternative was a research proposal. It failed to achieve and maintain the target salinity of 40 ppt and would not address elevation.

Alternative 39 Potential Use of Study Ponds

Included in the 1997 report, this alternative was submitted by Dr. Richard Casey, Float, Inc., and Ocean Research International, San Diego, California, in a letter dated June 10, 1995. It proposed installing floating platforms and plastic floating liners to create several ponds and plastic floating canals to dilute the Sea water in the ponds to run experiments of fisheries, aquaculture, recreation, and wildlife. It was a proposal for conducting research and does nothing to control salinity or water surface elevation of the Sea.

Therefore, this alternative does not meet the salinity target and elevation target criteria.

Alternative 40 Injection Well Salt Disposal

Included in the September 1997 report, this proposal was first made by Aerospace Corporation in *Salinity Control Study Salton Sea Project* (Goldsmith, 1971) and resubmitted by Mr. Michael Duffey of Holtcille, California, in 1995. This proposal would inject Sea water into high-salinity geothermal resource areas.

Requirements for pretreatment prior to injection were unknown. No attempt was made to predict geologic formations or difficulties in drilling wells. Injecting a high solids brine would be extremely expensive because of the resultant injection well plugging. This alternative had too many unknowns to determine if it would work.

Alternative 41 Air Diffusion / Ultraviolet Ozone System

Included in the September 1997 report, this alternative was proposed in a letter by Mr. Bill Ryan Free of Winterhaven, California (June 19, 1991) and by Ms. Elaine Thompson and Mr. John N. Hinde representing Air Diffusion Systems of St. George, Utah, in a letter dated September 28, 1995. This proposal would use a diffused air and ultraviolet ozone system installed on the Sea's floor to oxygenate and recirculate water, eliminating toxic substances and restoring its natural balance.

This proposal failed to satisfy the target salinity requirement of achieving and maintaining 40 ppt.

Alternative 42 Surface Aeration

Included in the September 1997 report, this letter dated June 19, 1991, to the Department of the Interior from Mr. Bill Ryan Free of Winterhaven, California, provided hand-drawn sketches of concepts for improving conditions of the Sea but did not contain a narrative description. The sketch implied that aeration fountains would be built into the Sea, and the quality of the water would be improved through oxygenation.

Very little information was provided. This proposal failed to satisfy the salinity target and elevation target criteria.

Alternative 43 Gravel Berms

Included in the September 1997 report, this proposal was given in an oral presentation by Mr. Sergio Garcia in the August 1995 public workshop. This alternative proposed building gravel berms at several points along tributaries to the Sea to serve as coarse filters to remove large solid matter.

This proposal failed to achieve and maintain the target salinity of 40 ppt and did not address elevation.

Alternative 44 Sea Water Filtration

Included in the September 1997 report, this proposal was made by Mr. Richard Goralczyk of the Zitelli Trust, Palm Springs, California, in a report to Mr. Phillip Meyer, dated January 18, 1990. The technology in this proposal used a free energy source which would cause chemicals to separate from one another and from the Sea water.

This alternative did not use proven technology.

Alternative 45 Enzyme-Activated Removal

Included in the 1997 report, this alternative was proposed by Mr. Clay Thorne, Thorneco Environmental Technologies, Payson, Arizona, in the "Treatability Study Report for Thorneco, Inc., Enzyme-Activated Cellulose Technology," dated February 1992 by PRC Environmental Management, Inc., for the U.S. Environmental Protection Agency. It proposed to use an enzyme-activated cellulose treatment technology to remove specific metals and inorganic and organic compounds. Very little information is provided on tests reported to have been made on small systems. The removal of these metals and inorganic and organic compounds also would not control the salinity or elevation of the Sea.

Therefore, this alternative does not meet the salinity target and the elevation target criteria and does not use a proven technology.

Alternative 46 Power / Freshwater Cogeneration

Included in the 1997 report, this alternative was proposed by Mr. Frank DiCola, Cogeneration Partners of America, Cheery Hill, New Jersey, in a letter dated January 28, 1992. It proposed to use a gas-fired turbine cogeneration system in combination with a thermal distillation desalting system to produce power and fresh water. Previous studies have shown that when using high cost fossil fuels in the United States, thermal distillation desalting systems are not cost effective when compared to sea water reverse osmosis desalting systems, so it is not a proven technology for this application.

Alternative 47 Water Conservation

Included in the September 1997 report, this proposal was contained in Imperial Irrigation District's *IID/MWD Water Conservation Program Impacts to Salton Sea* (May 1989) and in a Colorado River Board of California publication, *Report to the California Legislature on the Current Condition of the Salton Sea and the Potential Effects of Water Conservation* (April 1992). This proposal would use water conservation programs to help reduce the amount of water used for irrigation, thereby reducing inflows to the Sea.

This would decrease the water surface elevation and increase the salinity level. This proposal failed to satisfy the salinity target and elevation target criteria.

Alternative 48 Drainage Water Reuse or Blending

Included in the September 1997 report, this proposal was made by Mr. J.D. Rhoades, U.S. Department of Agriculture, in at least 10 publications dating from 1977 to 1996. This proposal suggested collecting agricultural drainage water for reuse on salt-resistant crops.

This proposal failed to achieve and maintain the target salinity of 40 ppt.

Alternative 49 Pulsed Plasma

Included in the 1997 report, this alternative was proposed by AURIX, Inc., of El Cajon, California, in the article "Pulsed Power Discharge Wastewater Treatment Technology" (undated). It proposed to use a pulsed plasma discharge wastewater treatment technology, which would reportedly remove metals and toxic substances and cause most dissolved and suspended solids in the water to settle. Additional research would be required to verify these claims, and a water treatment system by itself without pump-out would not control the salinity and elevation of the Sea.

Therefore, this alternative does not meet the salinity target and the elevation target criteria and does not use a proven technology for this application.

Alternative 50 Hydropower / Filtration System / Resort

Included in the 1997 report, this alternative was submitted by Mr. Steven Queen of Rancho Cucamonga, California, in a letter dated March 7, 1994. It proposed to use a combination of solar cells and fuel cells to pump water up through a vapor desalting chamber into storage tanks where it flows down through a hydroturbine and static pressure reverse osmosis desalting system. The entire system is enclosed within a large 150-foot tower.

Because this alternative is based only on a conceptual sketch with no analyses or test data, this alternative is not a proven technology.

Alternative 51 Slow Sand Reverse Osmosis Filtration

Included in the 1997 report, this alternative was proposed by Mr. C. Brent Cluff in a number of technical papers from 1990 through 1992. It proposes the use of slow sand filtration and/or nanofiltration as a pretreatment system for a reverse osmosis desalting system to remove salt from the Salton Sea. This method of pretreatment will be considered along with other methods of pretreatment under the Water Treatment Alternative, Reverse Osmosis Desalting Plant with Pump-In/Pump-Out. It will also require pilot plant testing along with the other methods of pretreatment. It is a proven technology, at least in some applications.

This is only a pretreatment alternative, which by itself does not meet the salinity target and the elevation target criteria, but could possibly be used with the Water Treatment, Reverse Osmosis Desalting Plant with Pump-In/Pump-Out alternative.

Alternative 52 Electrochemical Extraction

Included in the 1997 report, this alternative was proposed by Mr. Ernie Brown, North Shore, California, in a letter dated August 8, 1995, in response to public workshops held in August and September 1995. It proposes to apply a low voltage direct current to metal plates suspended in the Sea to remove salt and precious metals. No analysis or detailed test data or cost and performance analysis were provided, and only a very small scale test was reported to have been made. Removal of salt and precious metals alone also does not control the elevation.

Therefore, this alternative does not meet the salinity target and the elevation target criteria and does not use a proven technology for this application.

Alternative 53 Mexican Cleanup of New River

Included in the September 1997 report, this alternative was presented by Mr. Narenda N. Gunaji, Commissioner, International Boundary and Water Commission, United States and Mexico, in a letter dated July 31, 1991. This alternative basically addressed the water quality problem in the New River at the Mexican border.

This proposal failed to satisfy the target salinity requirement of achieving and maintaining 40 ppt.

Alternative 54 Land Speed Racetrack

Included in the September 1997 report, this concept was presented in a letter dated April 4, 1994, to the Salton Sea Authority by Mr. Ken Mack, representing California Timing Association (1995). This alternative suggested the use of salt to build a racecourse for setting land speed records.

This proposal was a brine disposal option only. The proposal failed to achieve and maintain the target salinity of 40 ppt and would not address elevation, but could be used with an alternative needing a disposal component.

New Alternatives

Other alternatives were presented to Reclamation in 1998 to consider in solving the salinity and water surface elevation problems in Salton Sea. The alternatives that could be considered for elimination from this group follow.

New Alternative Recovering Salts from the Salton Sea

This proposal was presented in a letter dated June 10, 1998, to the Imperial Irrigation District by Mr. Gerald Grott of Superior Salt, Inc., Twentynine Palms, California. This alternative is for a saltworks to be built adjacent to evaporation ponds to reclaim and market the salt.

This proposal failed to satisfy both the salinity target and elevation target criteria but could be used with an alternative that produced salt. This could eliminate the very high cost of trucking large quantities of salt to the Pacific Ocean that is present in some of the alternatives.

New Alternative *$10 Million Award to Working Facility*

This proposal was presented in a letter dated June 5, 1998, to the Salton Sea Authority by Mr. Robert D. Adams, Desert Hot Springs, California. Mr. Adams also read his proposal on July 15, 1998, at a public scoping meeting in La Quinta, California. This proposal is an idea to set up a $10 million fund to be awarded to whomever can demonstrate, with a working facility, the means of producing potable water from the ocean in large quantities deliverable to consumers at marketable prices.

This proposal failed to satisfy both the salinity target, elevation target, and proven technology criteria.

New Alternative *Mining Minerals for Profit*

This proposal was presented in a letter dated June 22, 1998, to Congresswoman Mary Bono by Mr. Mark Russell, Indian Wells, California. This proposal includes a number of ideas, including mining salt, precious metals, and nitrogen; producing electricity; and setting up fish farms.

This proposal failed to satisfy both the salinity target and elevation target criteria. This could eliminate the very high cost of trucking large quantities of salt to the Pacific Ocean that is present in some of the alternatives.

New Alternative *Recreation Facilities / Impoundment / Injection Wells*

Carl B. Johnston of Johnston and Associates presented this proposal to the Salton Sea Authority by letter dated February 25, 1998. This alternative uses water pumped out of the Salton Sea for various recreational activities and uses earth injection procedures for brine disposal.

The flow rates discussed in the proposal would fail to satisfy both water surface elevations and salinity requirements. Additionally, trial of earth injection procedures is not a proven technology for the site. Using evaporation ponds may be useful as discussed elsewhere.

New Alternative *Solar Still / Solar Works Disposal*

This proposal was presented in a letter dated February 4, 1998, to the Salton Sea Authority by Mr. Victor M. Ponce of San Diego State University. It uses a solar still desalting plant with pump-in of the desalted water to the Sea and a pump-out system to dispose of the concentrate reject flow to evaporation ponds in a saltworks for ultimate disposal of the raw salt by railroad.

According to an unpublished study by NREL (1991), solar stills are not cost effective for large desalination plants when compared to conventional reverse osmosis desalination plants. This, then, is an unproven technology for large-scale plants needed for the Salton Sea.

New Alternative Gas Turbine / Hydro / Desalinization

This proposal was delivered to Ms. Valarie Richards of Coachella Valley Association of Governments on October 31, 1997, by Arthur Lowe of Eagle Crest Energy Company. It uses a combination of technologies, including a gas-fired combined cycle turbine that generates electrical power and steam for a MED desalting plant that is enclosed in a 50-story-tall concrete tower. The electrical power that is generated is used in combination with a pumped storage hydroelectric powerplant.

The proposed desalting plant is not a proven technology as Metropolitan Water District stated in a presentation at the American Desalting Association Conference on August 4, 1998, that only a small 2,000-gallon-per-day seawater test unit has been tested to date, but funding is currently being pursued to build and test a larger demonstration plant. The cost and performance of a demonstration plant need to be published before it can be determined whether this technology is cost effective when compared to a conventional seawater reverse osmosis plant and before it can be considered as a proven technology for use at the Salton Sea.

New Alternative Floating Solar Still Modules

This proposal was received in July 1998, by an undated letter, at the Salton Sea Authority from Mr. Mike Brady of Palm Springs, California. This alternative uses floating in-sea solar desalination modules (SDMs) to enhance evaporation rates and collect salt, and it uses solar batteries to supply electrical power for operation.

According to an unpublished study by NREL, solar stills are not cost effective for large desalination plants when compared to conventional reverse osmosis desalination plants. It is, then, an unproven technology for large-scale plants needed for the Salton Sea (NREL, 1991). The proposal also failed to meet the water surface elevation criteria. It uses an unproven technology to increase the evaporation rate to a required 4,380 inches per year. Using more SDMs to lower the required evaporation rate would not solve the failure to meet the unproven technology criteria.

New Alternative Geothermal Power Revitalization

This proposal was presented in a letter dated July 17, 1998, to the California Energy Commission by Mr. Walter Studhalter of Douglas Energy, Placentia, California. This alternative provides a list of ways that funding under the Salton Sea Project might be used to revitalize the geothermal industry in California. No analysis or data was provided to determine whether geothermal power would be a cost-effective way to provide heat for a thermal desalting plant or compete with grid power that is currently available at $0.0725 per kilowatthour. Grid power would be used for pumping in a reverse osmosis desalting plant or for pumping water in the pump-in/pump-out alternative. It also proposes using heat engines to operate on the temperature differences in the Salton Sea water. This operation would be less efficient than conventional geothermal power systems because the temperature difference would be much less. Without a detailed analysis, the methods proposed would have to be considered as unproven technologies for solving the problems at the Salton Sea.

New Alternative Solar Still / Hydro-Physical Technologies / Desalting Plant

This proposal was presented in a letter dated July 16, 1998, to the Salton Sea Authority by Mr. Michael H. Teeter of Hydro-Physical Technologies Inc., Las Vegas, Nevada. This alternative is a combination solar still desalting system and a proprietary OSU unit.

According to an unpublished study by NREL (1991), solar stills are not cost effective for large desalination plants when compared to conventional reverse osmosis desalination plants, so this is an unproven technology for large-scale plants needed for the Salton Sea.

New Alternative Create Salt Marsh

This proposal was presented in a letter dated July 18, 1998, to the Salton Sea Authority by Mr. Pierre F. Savineau, Cathedral City, California. This idea was to create a salt marsh to remove the salt from the Sea. No other information on the marsh was provided.

This proposal failed to satisfy both the salinity target and elevation target criteria.

New Alternative ***Use Stabilized Dredged Sediment Material***

This proposal was presented in a letter dated July 28, 1998, to the Salton Sea Authority by Mr. Derron L. LaBrake of Consolidated Technologies, Inc. (CTI), Blue Bell, Pennsylvania. Their process combines dredged material with either municipal solid waste ash or coal fly ash and lime kiln dust to make a grout material that binds the contaminants in the sediment for structural fill. The letter from CTI mentions "sediments with elevated concentrations of contaminants (selenium) that would be removed from the Sea and rendered inert." At present, contaminated sea-bottom sediment is not considered to be a problem to be addressed by any of the Salton Sea alternatives.

The potential use for this concept of stabilized dredged sediment appears to relate to the diked impoundment alternatives for the Salton Sea. The dredged sediment from the bottom of the Sea would be used to construct the dike embankment(s) creating the in-Sea impoundment(s). The use of dredged Sea-bottom sediment to construct the impoundment dikes has been judged technically infeasible due to seismic (earthquake) dike instability concerns. The information provided by CTI does not include any data related to placing their stabilized dredged sediment material into an ocean (Sea) water environment. Their stabilized dredged sediment product is placed into an upland containment facility, not the ocean. Thus, the potential use of stabilized dredged sediment to construct impoundment dikes in the Salton Sea, even though this process might improve on the strength of the dredged sediment, is an unproven technology. There are additional salinity and elevation problems with all of the diked impoundment alternatives.

This proposal failed to satisfy both the salinity target and elevation target criteria. Also, this appears to be an unproven technology for constructing impoundment dikes. There is a possibility of using this technology, and the designers could consider using it in higher level designs, if appropriate.

New Alternatives ***Floating Plastic Curtains / In-Sea Dikes***

This proposal was submitted at a public scoping meeting held on July 16, 1998, at La Quinta, California, by Mr. Shelton L. Stringer of Southland Geotechnical, Inc. This proposal is similar to alternatives 13 and 14 in the

September 1997 report. It included the use of a double membrane of high-density polyethylene to create a curtain or dam which isolates areas within the Sea into evaporation ponds.

This alternative did not use proven technology.

New Alternative Colorado River Water Conservation and Flood Prevention Project

Mr. Wieslaw Czajkowski of the Association of the Colorado River Waterway Recreation Project presented a copy of the title report by cover letter, dated July 18, 1998, to the Salton Sea Authority and Bureau of Reclamation. This alternative increases the salinity of the Salton Sea to salinity levels of the Dead Sea and then revitalizes it with ocean water and water from various other sources of water.

This proposal fails to satisfy the requirement to keep salinity below a reasonable level. It does, however, contain several features that are discussed above in this report. Most of the discussions can be found in chapters 3 and 5.

New Alternative Heat-Pump Evaporation / Condensation System

This proposal was E-mailed on August 13, 1998, to the Bureau of Reclamation by Mr. Scott A. Stormo of Earth Systems Consultants. His idea was to evaporate water in a heat pump and recapture the energy in a condenser system to heat the next batch of water. This proposal is similar to alternative 9 in the September 1997 report. Production costs are higher than alternative energy production methods.

This is unproven technology. Also, this proposal failed to satisfy both the salinity target and elevation target criteria.

Additional Ideas

Several ideas were mentioned by persons at the public scoping meetings held on July 15, 16, and 17 in the Salton Sea basin. The ideas are summarized below, followed by an evaluation.

Collect Irrigation Flows and Treat Before it Hits the Sea. This idea is not new. Alternative 33 in the September 1997 report addresses removing the salts before the water enters the Sea. Whether it is removal of salt or treating contaminants, the criteria for reducing the salinity of the Sea is not reached. The salinity of the irrigation flows is about 3 ppt, which is considered low compared to the 44 ppt of the Sea. A further reduction of the salinity of the flows would have little effect on the salinity of the Sea.

Construct Wetlands to Act as a Filter for Contaminants and Nutrients. The Bureau of Reclamation, Imperial Irrigation District, and Desert Wildlife Unlimited are working together on building a wetland pilot project on the New River. Again, this may help clean up some of the pollutants, but it will not reduce the salinity of the Sea.

Public / Private Partnership. A public/private partnership is currently being undertaken with the wetland pilot project mentioned above. This type of partnership is a possible option to be used on any selected alternative.

Chapter 9

Analysis of Effectiveness

This chapter presents the results of the Salinity Model analysis and shows the effectiveness of representative alternatives considered.

The alternatives were evaluated for 1.346 million and 1.0 million acre-feet of drainage annually, with the associated salt loads. The model runs assume that design and construction would take 9 years to complete. Therefore, the conditions of year 9 no action alternative were used for each of the drainage inflow quantities. Baseline conditions are shown in figure 18 for the 1.346 million acre-feet of drainage annually at a salinity of 2.8 ppt. This baseline simulation shows that the target elevation is exceeded and that the Sea elevation would continue to rise above the goal of -232 m.s.l. The Sea salinity would also continue to increase above the goal of 40 ppt.

Each of the graphs plotted from the salinity model results (including 15 and 17 in chapter 6) can be understood by noting that all pump-in flow, pump-out flow, and drainage inflow numbers in 1,000 acre-feet per year are read from the left axis. The change in Salton Sea water surface elevation is read from the right axis, and the passage of time is shown along the bottom from 0 to 100 years. The changing salinity concentration line is plotted with a salinity concentration (printed number) in parts per thousand near the beginning and at the end of the line.

The salinity concentration can also be calculated from the flow scale on the left by dividing total flow in 1,000 acre-feet by 10,000. For instance, in figure 19, the salinity line begins at about 450,000 on the flow scale. The 450,000 divided by 10,000 = 45, which in this case is close to the number 44 provided. The concentration of ocean water salinity is also provided at 35 ppt for a reference point.

Pump-Out / Pump-In Alternatives—Salinity Model Results

The pump-out and pump-in alternatives were evaluated for the same two drainage conditions of 1.346 million acre-feet (current conditions) at 2.8 ppt and water conservation at 1.0 million acre-feet at 3.5 ppt. Under these alternatives, the pump-in was balanced with the pump-out to meet the elevation targets. The pump-out for the 1.346 million acre-feet of drainage needed to exceed the pump-in by approximately 100,000 acre-feet per year to meet the -232-foot target elevation. If the pump-out volume was increased, the pump-in needed to be increased by the same amount.

In the conservation scenario (figure 29) for baseline condition, drainage already reduced the inflow to the Sea by 346,000 acre-feet per year; therefore, the pump-in needed to be approximately 200,000 acre-feet per year more than the pump-out flow to meet a target elevation of -232.3 feet in 100 years (figure 30). This is just slightly below the -232-foot target elevation.

The pump-out and pump-in alternatives covered ocean water exchange, wastewater pump-in from Point Loma near San Diego, Hyperion WWTP near Los Angles, and Yuma, Arizona, which would be wastewater from Tucson. The current estimate of wastewater availability from the Hyperion, Point Loma, and Yuma plants are 470,000 acre-feet per year plus, 268,000 acre-feet per year, and 67,000 acre-feet per year (Tucson only), respectively. A discussion of nontributary groundwater availability is covered in chapter 5 under the heading "Groundwater for the Salton Sea Restoration." Colorado River surplus flows are discussed briefly in chapter 5 under "Pump-In Sources."

The results of each alternative are summarized in table 5. Each source had a different salinity, with the Point Loma water having a salinity of 1.75 ppt, Hyperion's salinity being 0.925 ppt, and the Yuma water being 4.0 ppt. It was found that the Sea salinity was not very sensitive to input water salinity because all three sources gave approximately the same results.

The three freshwater pump-in sources of Point Loma, Hyperion, and Yuma had slightly different salinities, which were found to be insignificant in the salinity model results. Graphs are provided in figures 21, 22, and 23 for each water source. The primary goal was to meet the Sea target of 40 ppt in 15 years after the alternative was activated. Each source would accomplish this with an annual pump-out flow rate of 250,000 acre-feet per year and a pump-in flow rate of 153,000 acre-feet per year. After the Sea reaches 35 ppt, the pumping can be reduced to pump-out only at 93,000 acre-feet per year. Both Point Loma and Hyperion pumping could be reduced in year 30, and Yuma pumping could be reduced in year 32.

The water exchanges were also evaluated for meeting the Sea target of 40 ppt in 30 years from implementation of the alternative. The ocean pump-in source required 400,000 acre-feet of annual pump-out and 303,000 acre-feet of annual pump-in, with results shown in figure 24.

Table 5.—Pump-out/pump-in alternatives simulation results

Alternative	Salton Sea water elevation (feet)			Salton Sea salinity (ppt)			Pumping rates (acre-feet per year)	
Water source	15 years[1]	30 years[2]	100 years[3]	15 years[1]	30 years[2]	100 years[3]	In	Out
1.346 million acre-feet of drainage to the Salton Sea at 2.8 ppt								
Baseline	-227	-226.9	-226.0	55,900	63,000	90,600	0	0
Ocean	-230.7	-231.9	-232.3	40,700	37,000	35,400	600,000	700,000
Hyperion	-230.6	-231.7	-232.1	38,900	35,200	37,600	153,000	250,000
Yuma	-230.6	-231.7	-232.1	39,700	36,200	38,000	153,000	250,000
Point Loma	-230.6	-231.7	-232.1	39,100	36,200	38,000	153,000	250,000
Ocean	-230.6	-231.7	-231.9	44,800	40,400	39,800	303,000	400,000
Hyperion	-230.6	-231.7	-231.9	45,000	39,300	38,000	73,000	170,000
Yuma	-230.6	-231.7	-231.9	45,800	40,000	38,400	73,000	170,000
Point Loma	-230.6	-231.7	-231.9	45,500	39,500	38,100	73,000	170,000
Pump-out	-230.7	-231.7	-232.2	52,000	50,700	43,100	0	100,000
1.0 million acre-feet of drainage to the Salton Sea at 3.5 ppt								
Baseline	-240.5	-242.9	-241.1	91,600	114,300	153,400	0	0
Yuma	-232.9	-234.2	-233.3	47,100	39,700	39,700	405,000	205,000

[1] The values are taken from the 24th year of the simulation to represent 15 years after implementation of the alternative.
[2] The values are taken from the 39th year of the simulation to represent 30 years after implementation of the alternative.
[3] The values represent the final year of the simulation. It was assumed that quantities of pump-out and pump-in using ocean water would not change, based on the ocean source. The ocean salinity used was 35 ppt. If an ocean source less than 35 ppt could be found and used as the pump-in source, the flows could be reduced slightly. This was not evaluated because no source had been identified. This alternative required 700,000 acre-feet per year of pump-out from the Sea and 600,000 acre-feet per year of pump-in ocean water. The results graph is shown at the end of this chapter. The graph covers the water source and discharge locations of Camp Pendleton, Hyperion, and the Gulf of California. Larger pump-out/pump-in quantities would be needed under the conservation alternative.

The sources were the same as described above. The fresh water sources from Point Loma, Hyperion, and Yuma required 170,000 acre-feet of annual pump-out and 73,000 acre-feet of annual pump-in to meet the 30-year goal of 40 ppt. Point Loma, Hyperion, and Yuma pump-out was reduced to 93,000 acre-feet, and the pump-in was stopped in year 50. Each alternative Sea salinity stayed below 38 ppt during the remaining 50 years of simulation, which is below the target of 40 ppt. The model output graphs are contained in figures 25, 26, and 27.

Alternative 21 (figure 28) represents a pump-out only alternative with 1.346 million acre-feet of drainage annually. The salinity initially increases to 52 and eventually reaches 43.1 ppt. But this does not meet the criteria of 40 ppt.

The water conservation alternative was also evaluated to meet the 40-ppt target in 30 years after implementation (figure 29). The required pump-out for the Yuma water source was 205,000 acre-feet, and the pump-in was

405,000 acre-feet annually. The pump-out and pump-in could be reduced to 120,000 acre-feet and 345,000 acre-feet in year 38 to maintain the Sea below the 40 ppt target, respectively. The Point Loma and Hyperion sources would meet the target at the same flows and are not shown in the table. The Yuma graph is in figure 30.

Designers studied several pump-out only alternatives. All of these alternatives pumped-out at particular flow rates for the first 30 years after construction and then continued pumping at 100,000 acre-feet per year. The alternative that was chosen for cost pumped-out at a steady rate of 100,000 acre-feet per year. The reader should note that some salinity values exceed 50 ppt. The model indicates that the target elevation would be met and that salinity would reach 43 ppt in 90 years, which is 3 ppt above the 40-ppt target (figure 28).

Diked Impoundment Alternatives—Salinity Model Results

The model had some restrictions regarding the diked alternatives due to the way the worksheets were developed. The impoundment surface areas did not fit the specific alternatives in the 1997 report. Approximations were made to demonstrate if the alternatives would meet the acceptance criteria.

The specific evaporation pond simulation results are shown in table 6. The 30-square-mile evaporation pond with pump-out to Palen Dry Lake or some other evaporation pond had to be estimated, since the model was not set up for pump-out conditions with evaporation ponds. Without the pump-out, this alternative would exceed the elevation criteria, and the salinity would not be reduced to the selected targets (figure 31). The model had the capability to accept pump-in water but did not provide for pumping out. About 65,000 acre-feet were input and had significant improvements in the Sea salinity of 3 ppt in 30 years; however, the Sea elevation was raised 3 feet in the same 30 years. Estimates for the 100-year results were based on the pump-out information. The estimated results are shown for 50,000 and 100,000 acre-feet of pumping out to an external evaporation pond. It is estimated that the 100,000 acre-feet of water pumped out would meet or be very close to the elevation and salinity goals in 30 years. Table 6 shows that it would in the 100-year timeframe.

Table 6.—Diked impoundment alternatives simulation results

Alternative	Salton Sea water elevation (feet)			Salton Sea salinity (ppt)			Pumping rates (acre-feet per year)	
Surface area	15 years	30 years	100 years	15 years	30 years	100 years	In	Out
1.346 million acre-feet of drainage								
30	-226.9	-226.5	-226.3	46.2	44.7	42.8	0	0
30	-224.6	-223.5	-222.9	43.3	41.7	41.9	65,000	0
[1]30			-229			39.3	0	50,000
[1]30			-232			35.8	0	100,000
48.3	-226.3	-225.9	-225.8	41.1	36.6	27.9	0	0
142.2	-226.7	-226.0	-223.5	16.1	9.5	8.7	0	0
[6]142.2	-226.9	-226.8	-224.9	35.0	35.0	35.0	0	0
1.0 million acre-feet of drainage								
30	-239.6	-242.8	244.3	79.1	82.6	61.5	0	0
30	-231.9	-233.1	-233.6	60.4	61.2	56.2	200,000	0
48.3	-239.3	-241.2	-238.8	72.4	80.2	110.9	0	0
48.3	-225.6	-225.2	-229.3	45.0	41.2	38.0	[2]360,000	0
142.2	-239.0	-240.9	-241.5	22.5	10.6	8.8	0	0
[3]142.2	-239.1	-240.9	-241.5	35.0	35.0	35.0	0	0
142.2	-232.7	-233.6	-232.1	35.0	35.0	35.0	[4]175,000	0

[1] Estimates of the final 100-year salinity based on data from other spreadsheet output.

[2] Pump-in cut back to 280,000 acre-feet per year in year 41.

[3] The model feature for pumping from the evaporation pond to the Salton Sea was activated. The pumping started in year 9 and averaged about 63,000 acre-feet per year to maintain the salinity at 35 ppt.

[4] This pump-in is required to meet the elevation target. It increases the volume of pump-back water to maintain the Sea at 35 ppt.

[5] This value is incorrect due to a model instability that occurs when the impoundment volume is calculated as zero.

[6] The salinity was held at 35 ppt using the model option for pump-back from the evaporation pond. The quantity ranged from 464,000 acre-feet to 84,000 acre-feet.

The evaporation pond containing 48.3-square-mile surface area was used to simulate the 40- and 50-square-mile alternatives. The elevation target was exceeded and would be expected to be exceeded in both the 40- and 50-square-mile evaporation ponds under these drainage conditions. The 40-square-mile pond would be expected to meet the salinity target in 30 years but not in 15 years (figure 32). The 50-square-mile pond alternative may meet the salinity target in 15 years and more than meet the 30-year target. The model simulated the Sea salinity at 27.9 ppt in 100 years after construction of the dikes for the impoundments. The model has a pump-back feature that allowed evaporation pond water to be pumped back to the Sea to prevent the Sea salinity from going below 35 ppt. The Sea elevation may be increased due to sightly lower evaporation from the higher salinity Sea. This is shown in the 142.2-square-mile evaporation pond simulation results.

The 142.2-square-mile evaporation pond model setup was used to simulate the 127-square-mile alternative. The simulations again show (figure 33) that the elevation targets would not be met; however, the salinity target was easily met. The salinity level could be as low as 16 ppt in 15 years. The second line in the table for this size area shows that the salinity could be controlled at 35 ppt with the pump-back option or some other means of reducing flow to the evaporation pond.

It is expected that water conservation activities in the Salton Sea drainage area will take place and reduce the flow to the Sea by 346,000 acre-feet per year or reduce it to 1.0 million acre-feet per year from 1,346,000 acre-feet. The inflow is expected to be reduced by at least 20,000 acre-feet annually. This accounts for 200,000 acre-feet of the 346,000 acre-feet; the remaining 146,000 acre-feet were removed in the 10th year. This causes the drop in Sea water surface elevation shown in the conservation plots (figures 29 and 30). The salt load to the Sea would also be reduced. The inflow salinity was reduced in the simulation runs for the conservation alternatives was 300,000 tons per year. The salinity was reduced by the same percentage as the drainage during the same time period. The resulting salinity of the drainage was 3.5 ppt. The no action simulation for the Sea resulted in the salinity increasing at a much faster rate and the elevation dropping well below the target elevation. None of the in-Sea evaporation ponds under conservation will meet the elevation target without approximately 200,000 acre-feet of replacement water being input to the Salton Sea.

Under water conservation, the 30-square-mile evaporation pond could not be evaluated fully because the model did not have pump-out capability. The target elevation and salinity were not met as shown in table 6. With 200,000 acre-feet of pump-in, the elevation target was met, and the salinity improved by 20 ppt at 30 years (figure 34). Any water pumped to an external evaporation pond to meet the salinity target would have to be replaced to meet the elevation goals. This alternative could be made to meet the targets with proper pump-out and pump-in quantities.

The 48.3-square-mile evaporation pond which represents the 40- and 50-square-mile alternatives became unstable in the 21st year of the simulation and overestimated the Sea's salinity for the remaining simulation period (figure 35). This is due to the evaporation pond becoming dry, since it was located in a shallow part of the Sea. Adding 360,000 acre-feet per year of pump-in water improved conditions and raised the Sea elevation to 229.3 feet and lowered the Sea salinity to 41.2 ppt in year 30 (simulation year 39). The pump in was cut back to 280,000 acre-feet per year in simulation year 41. A small amount of pump-out would reduce the Sea salinity and probably meet the targets.

Conservation and the 142.2-square-mile evaporation pond (north end of Sea) went well below the target salinity and elevations. The pump-back was activated, and the Sea salinity was held at 35 ppt; however, the elevations were not improved. A pump-in volume of 175,000 acre-feet per year raised the Sea elevation to the target level and the pump-back was increased to maintain the Sea at 35 ppt.

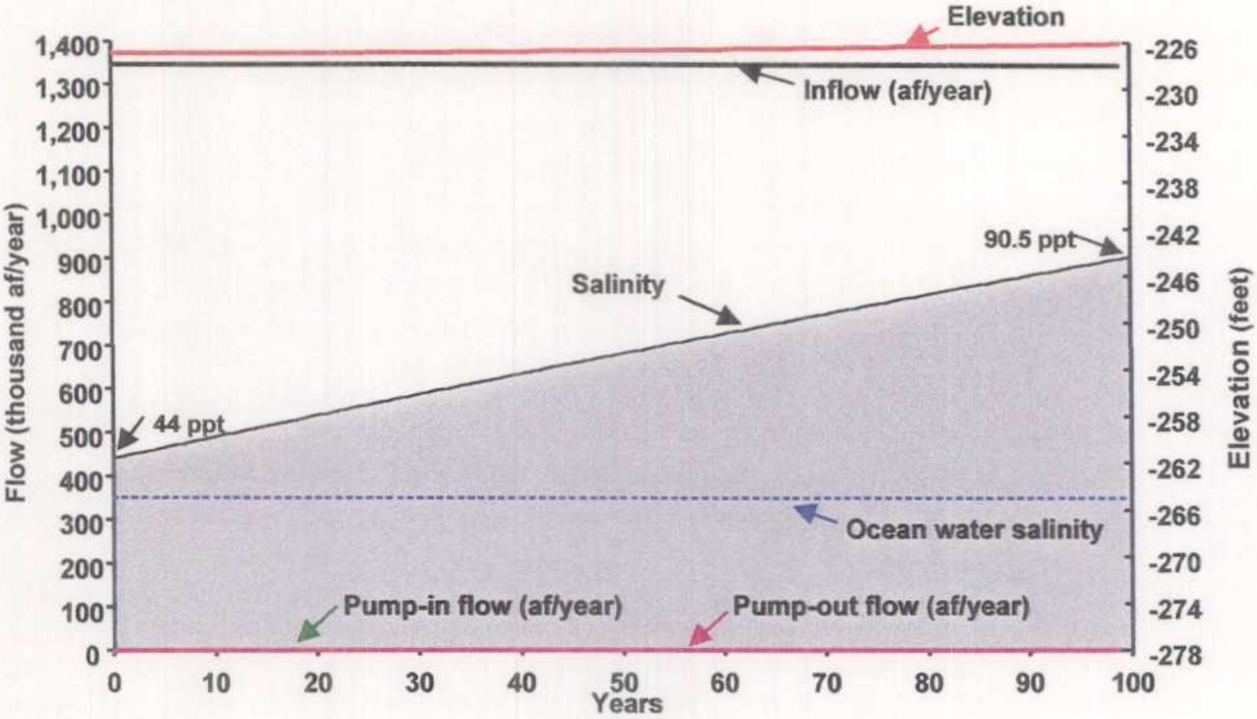


Figure 19.—Baseline conditions, no pump-out or pump-in with 1.346-million-acre-foot drainage inflow at 2.8 ppt.

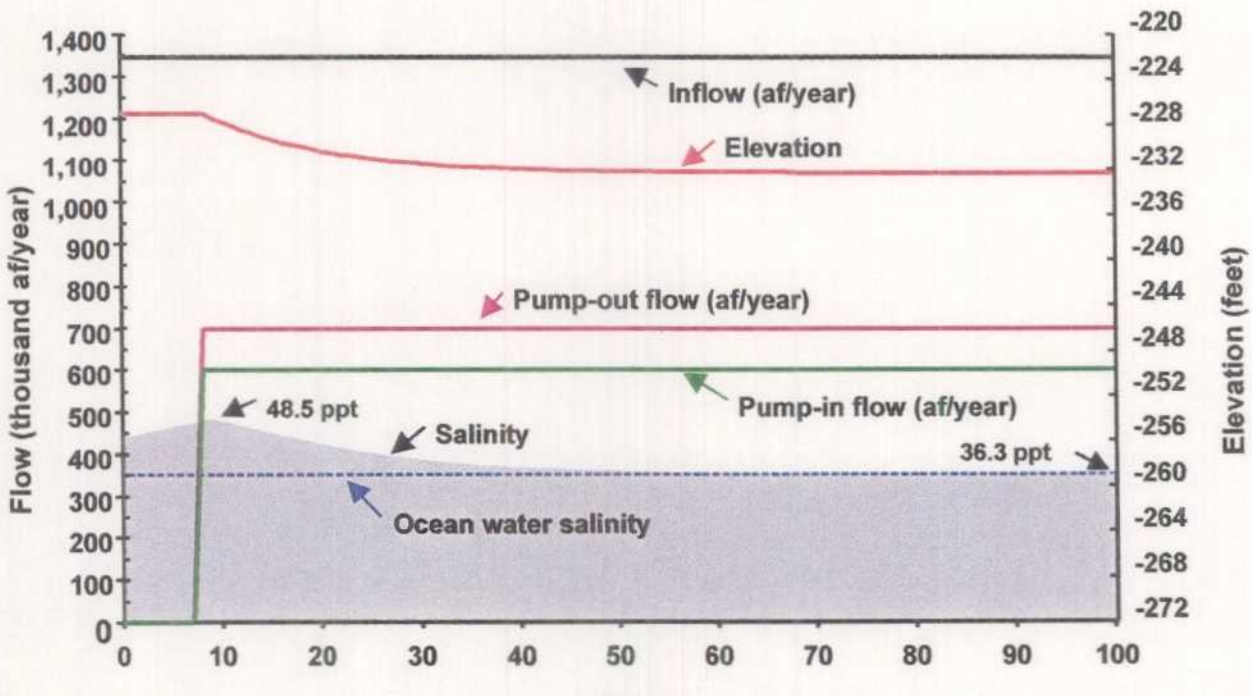


Figure 20.—Alternative 1 water exchange from Camp Pendleton—700,000-acre-foot pump-out with 600,000-acre-foot pump-in with 1.346-million-acre-foot drainage inflow at 2.8 ppt.

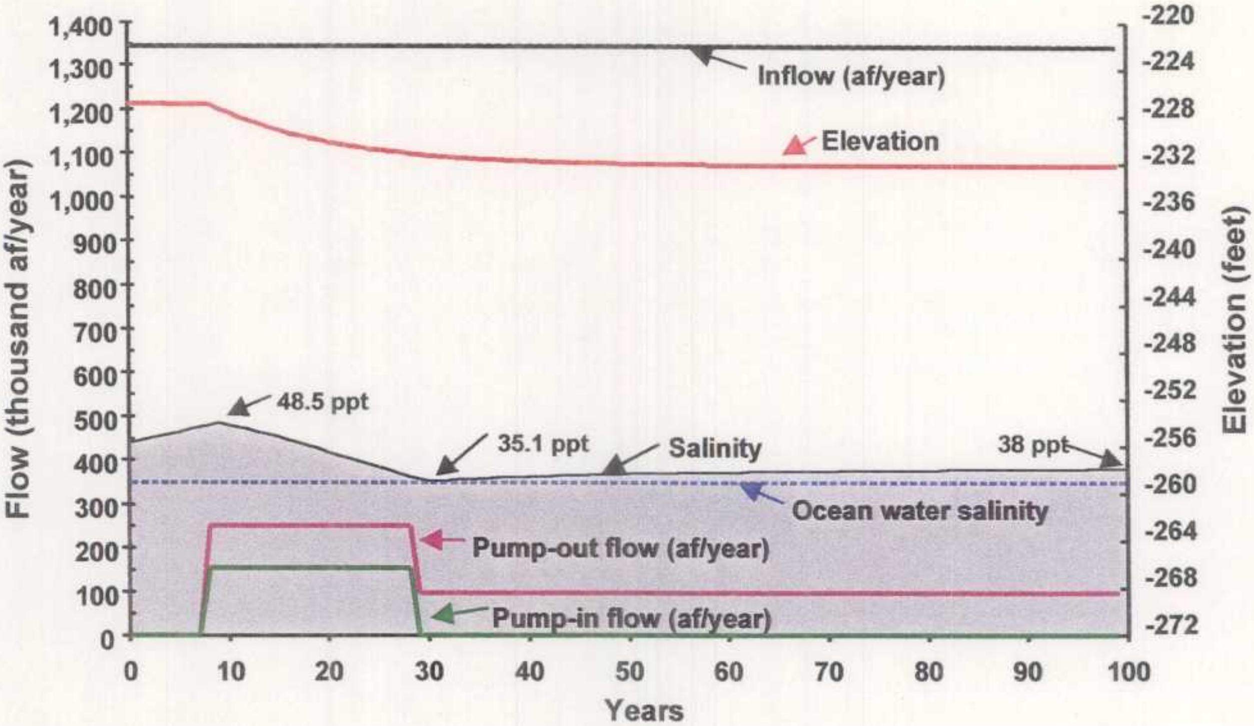


Figure 21.—Alternative 4 water exchange from Point Loma at 1.75 ppt—250,000-acre-foot pump-out with 153,000-acre-foot replacement with 1.346-million-acre-foot drainage inflow at 2.8 ppt.

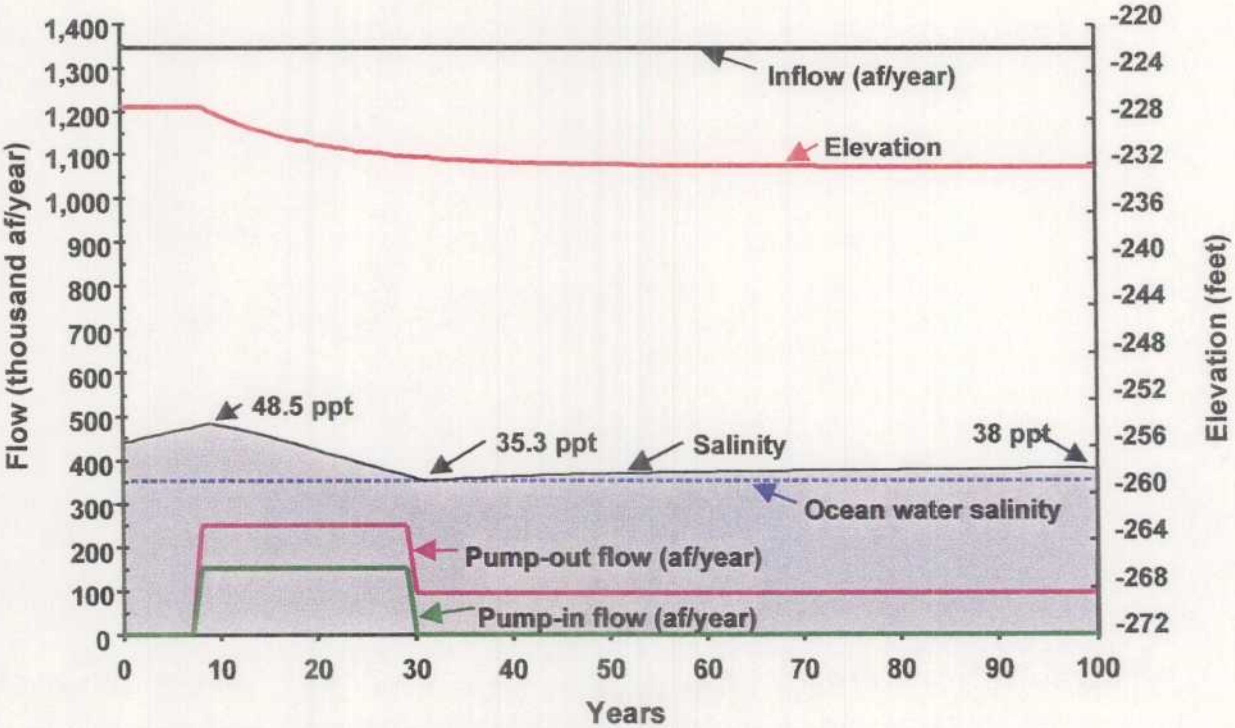


Figure 22.—Alternative 5 water exchange from Hyperion at 0.925 ppt—250,000-acre-foot pump-out with 153,000-acre-foot pump-in with 1.346-million-acre-foot drainage inflow at 2.8 ppt.

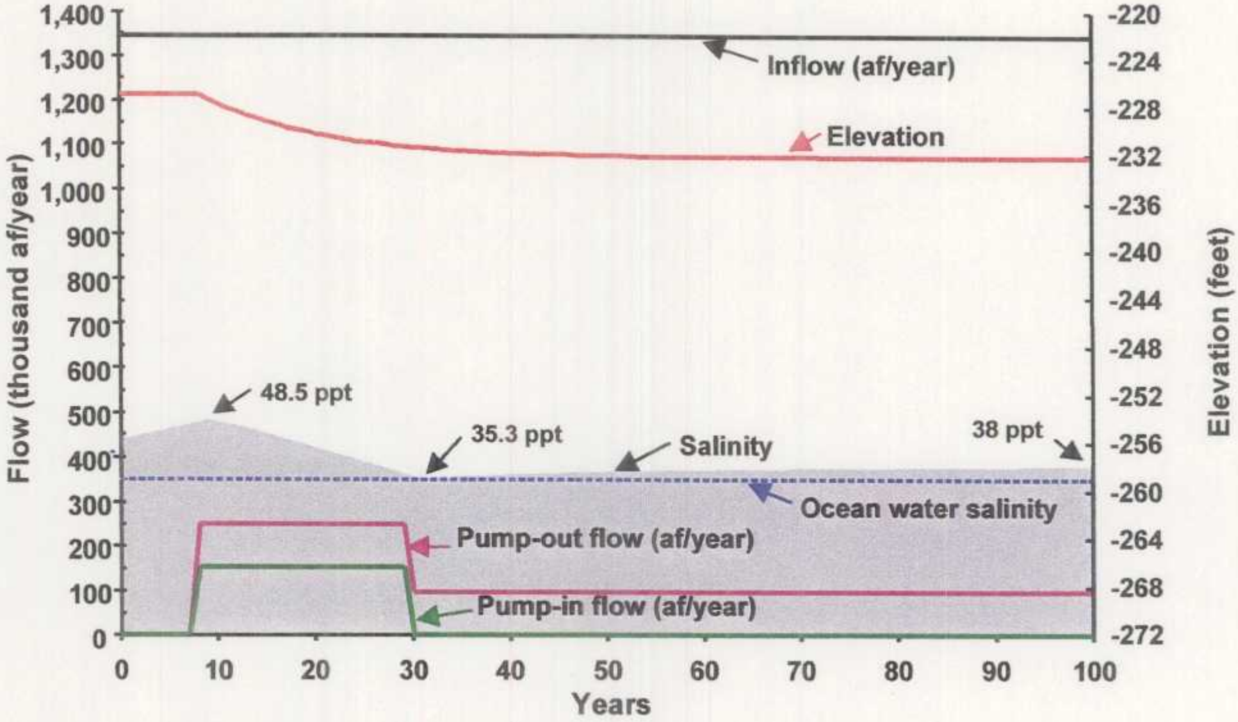


Figure 23.—Alternative 6 water exchange from Yuma at 4 ppt—250,000-acre-foot pump-out with 153,000-acre-foot pump-in with 1.346-million-acre-foot drainage inflow at 2.8 ppt.

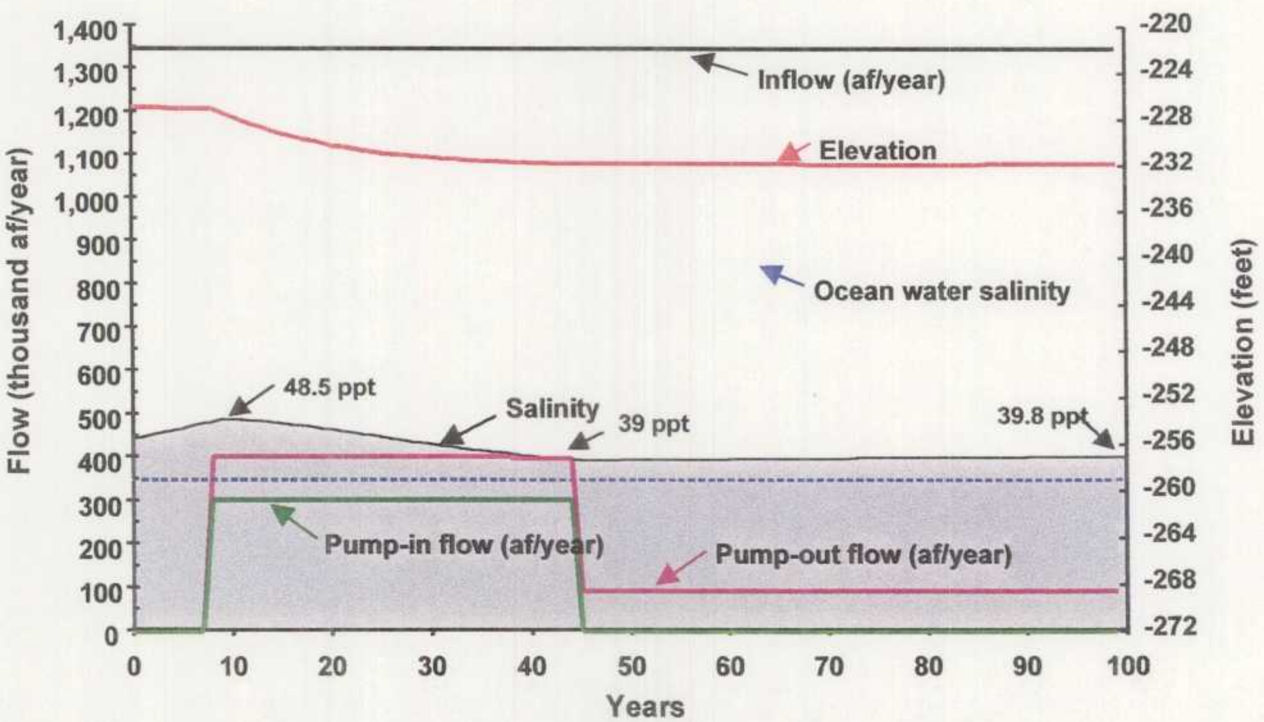


Figure 24.—Alternative 11 water exchange at Camp Pendleton at 35 ppt—400,000-acre-foot pump-out with 303,000-acre-foot pump-in with 1.346-million-acre-foot drainage inflow at 2.8 ppt.

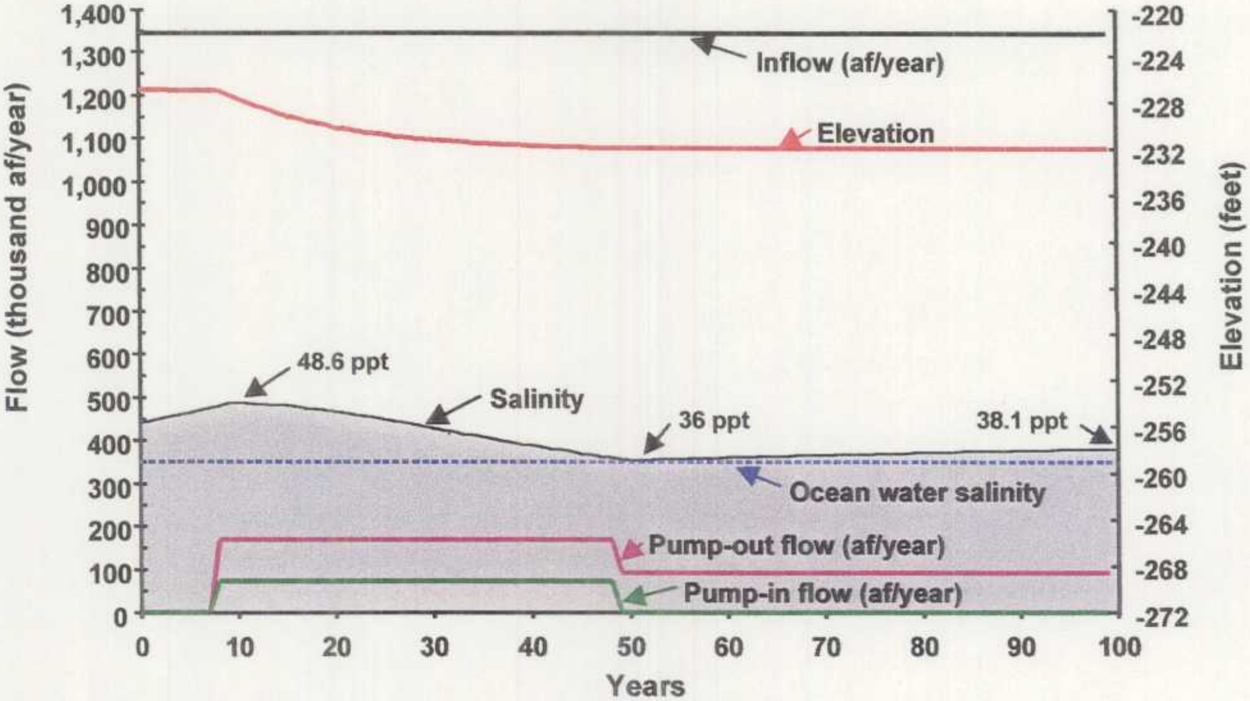


Figure 25.—Alternative 14 water exchange at Point Loma at 1.75 ppt—170,000-acre-foot pump-out with 73,000-acre-foot pump-in with 1.346-million-acre-foot drainage inflow at 2.8 ppt.

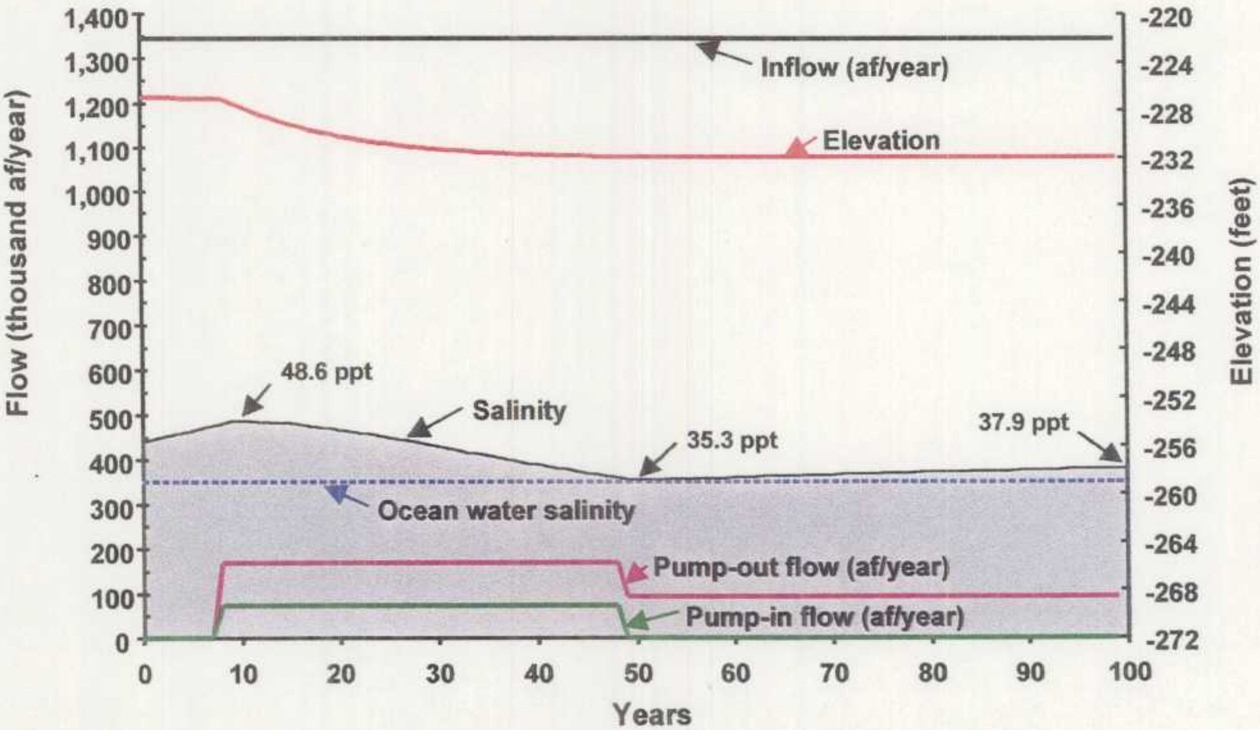


Figure 26.—Alternative 15 water exchange at Hyperion at 0.925 ppt—170,000-acre-foot pump-out with 73,000-acre-foot-pump-in with 1.346-million-acre-foot drainage inflow at 2.8 ppt.

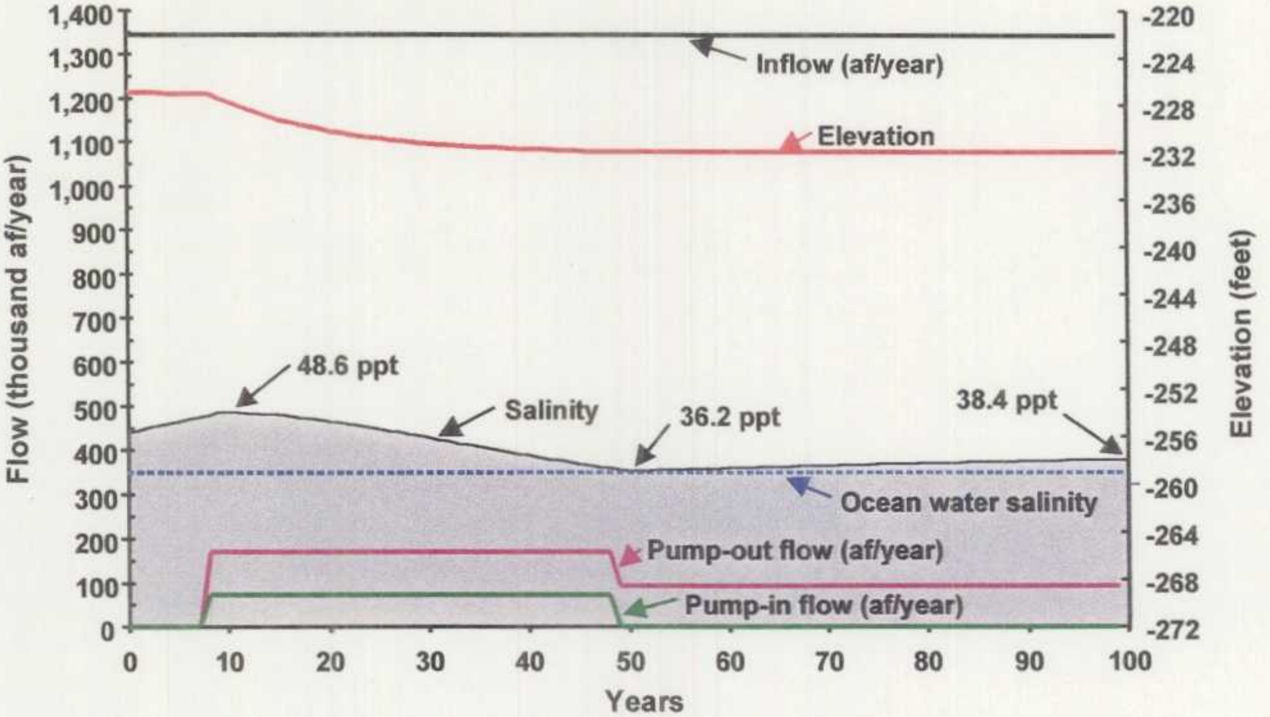


Figure 27.—Alternative 16 water exchange at Yuma at 4 ppt—170,000-acre-foot pump-out with 73,000-acre-foot pump-in with 1.346-million-acre-foot drainage inflow at 2.8 ppt.

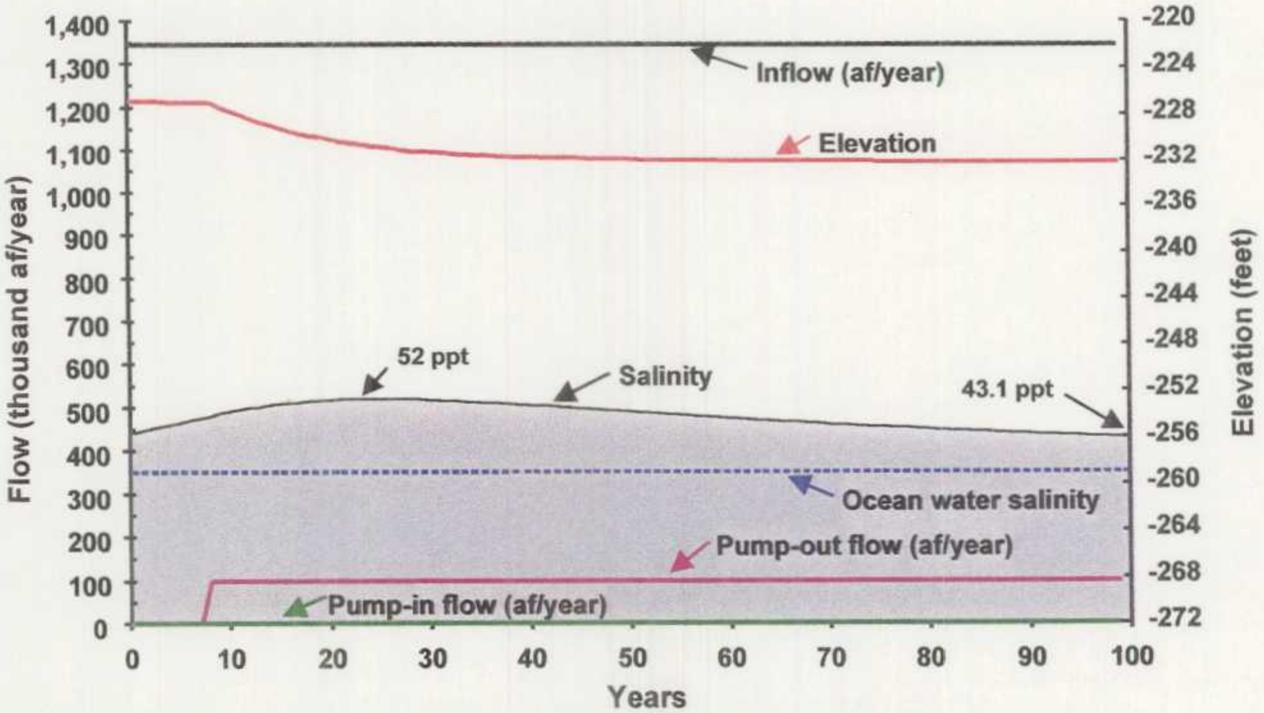


Figure 28.—Alternative 21 water exchange with pump-out only—100,000-acre-foot pump-out with 1.346-million-acre-foot drainage inflow at 2.8 ppt.

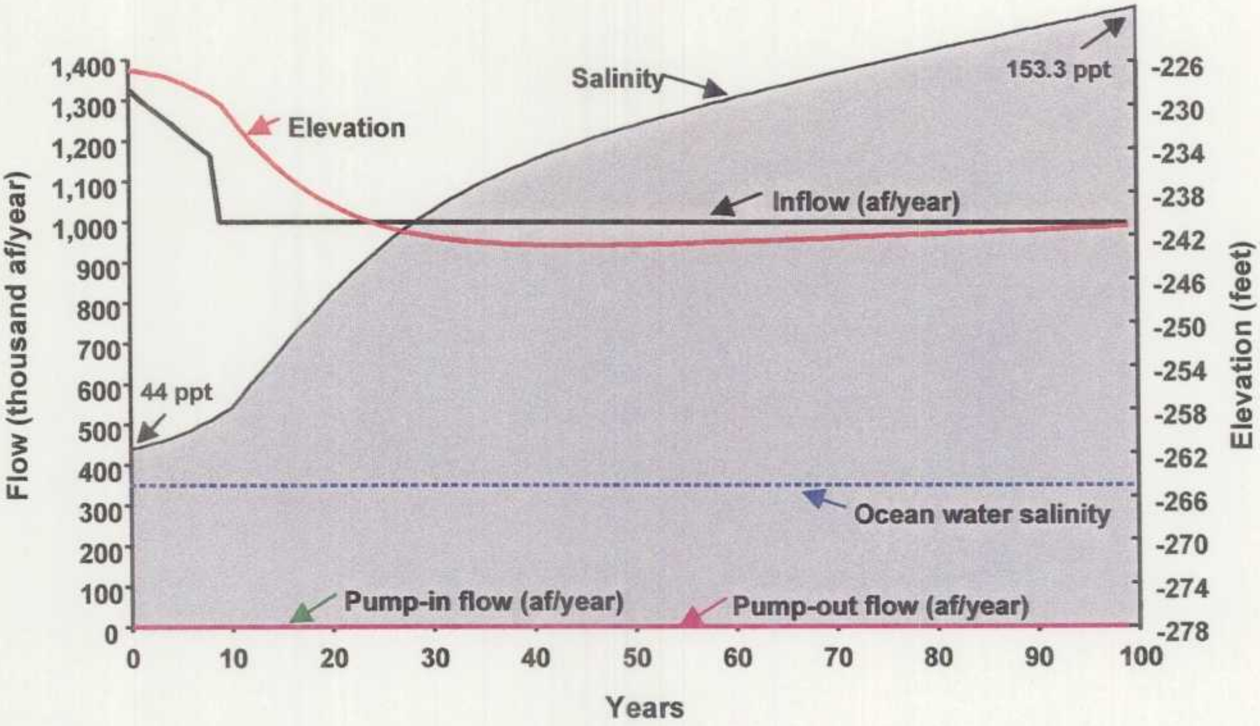


Figure 29.—Conservation baseline 1.0-million-acre-foot drainage inflow at 3.5 ppt.

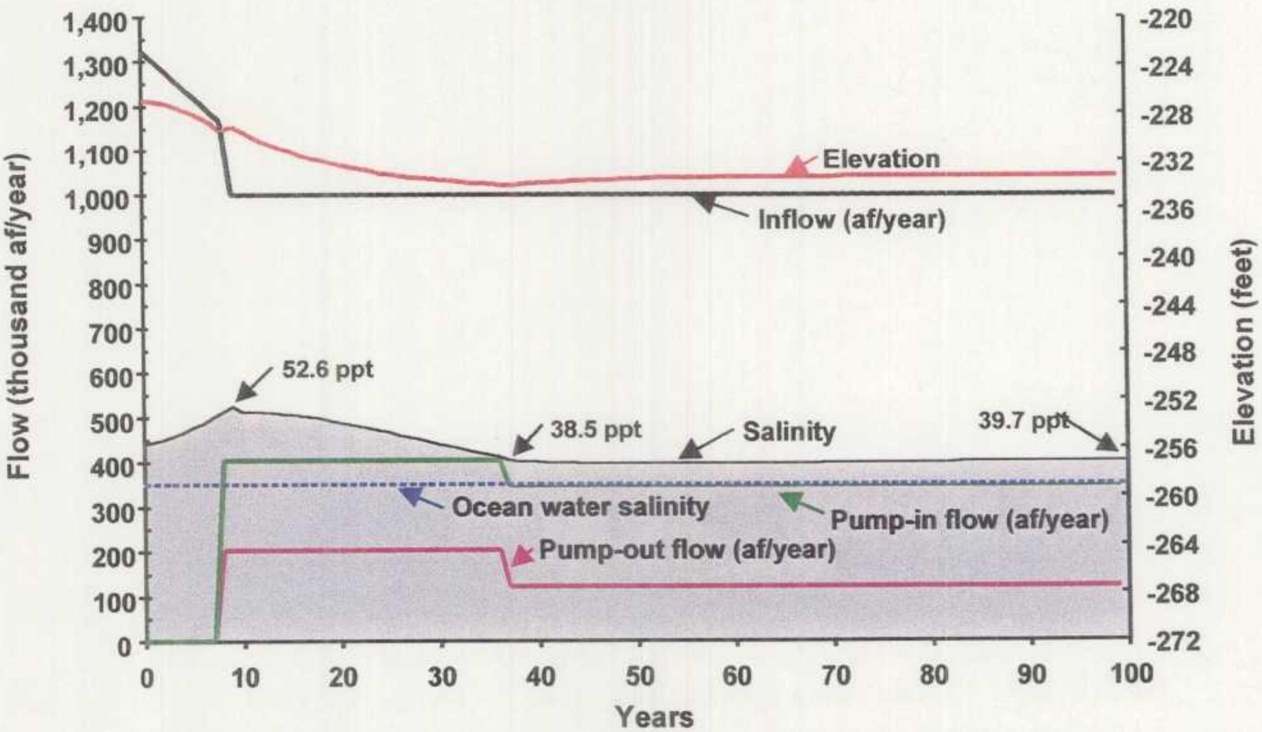


Figure 30.—Alternative 23 water exchange with conservation—205,000-acre-foot pump-out with 405,000-acre-foot pump-in at 4 ppt with 1.0-million-acre-foot drainage inflow at 3.5 ppt.

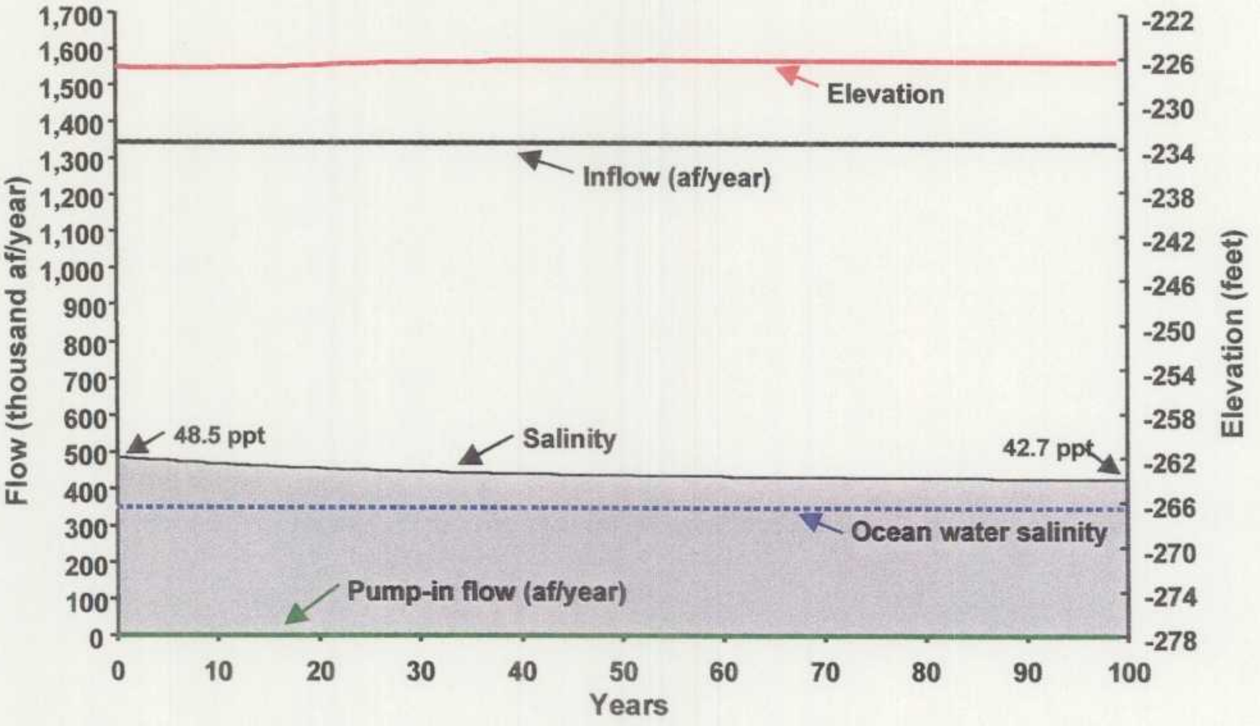


Figure 31.—Variable impoundment at 7.83-percent surface area or 30 square miles with 1.346-million-acre-foot drainage inflow at 2.8 ppt.

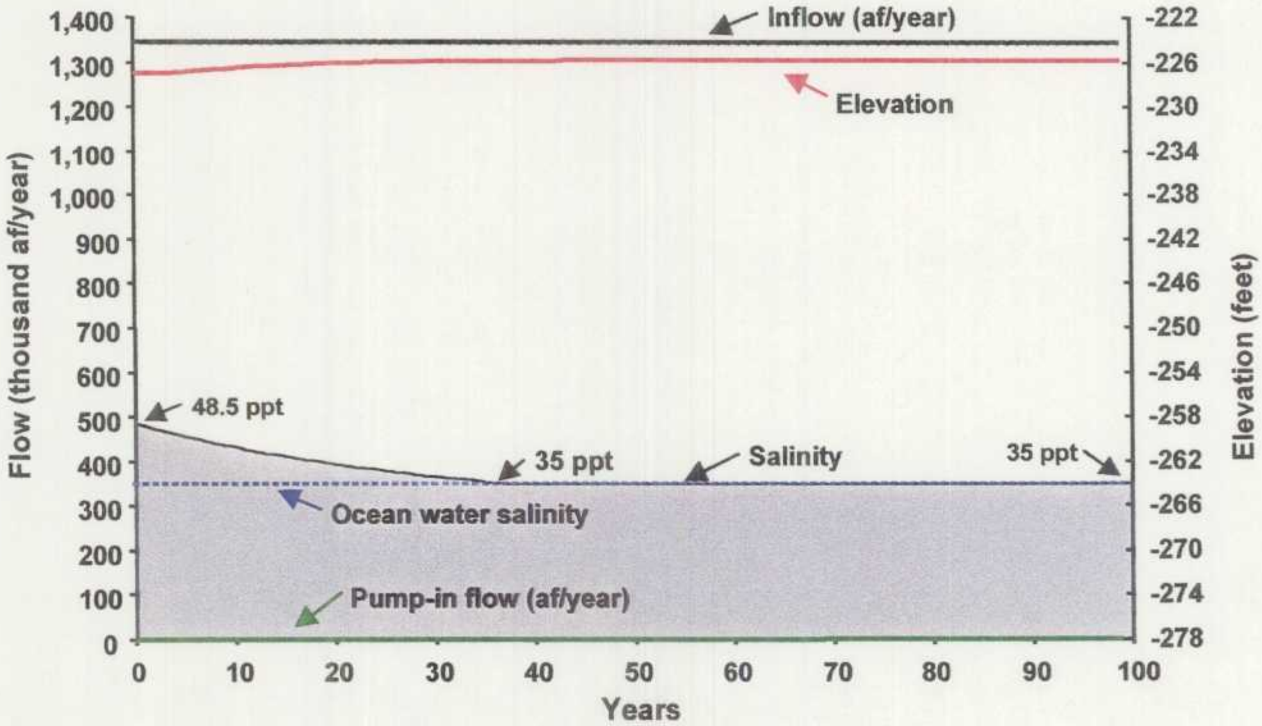


Figure 32.—48-square-mile impoundment; pump-back activated to maintain Sea at 35 ppt with 1.346-million-acre-foot drainage inflow at 2.8 ppt.

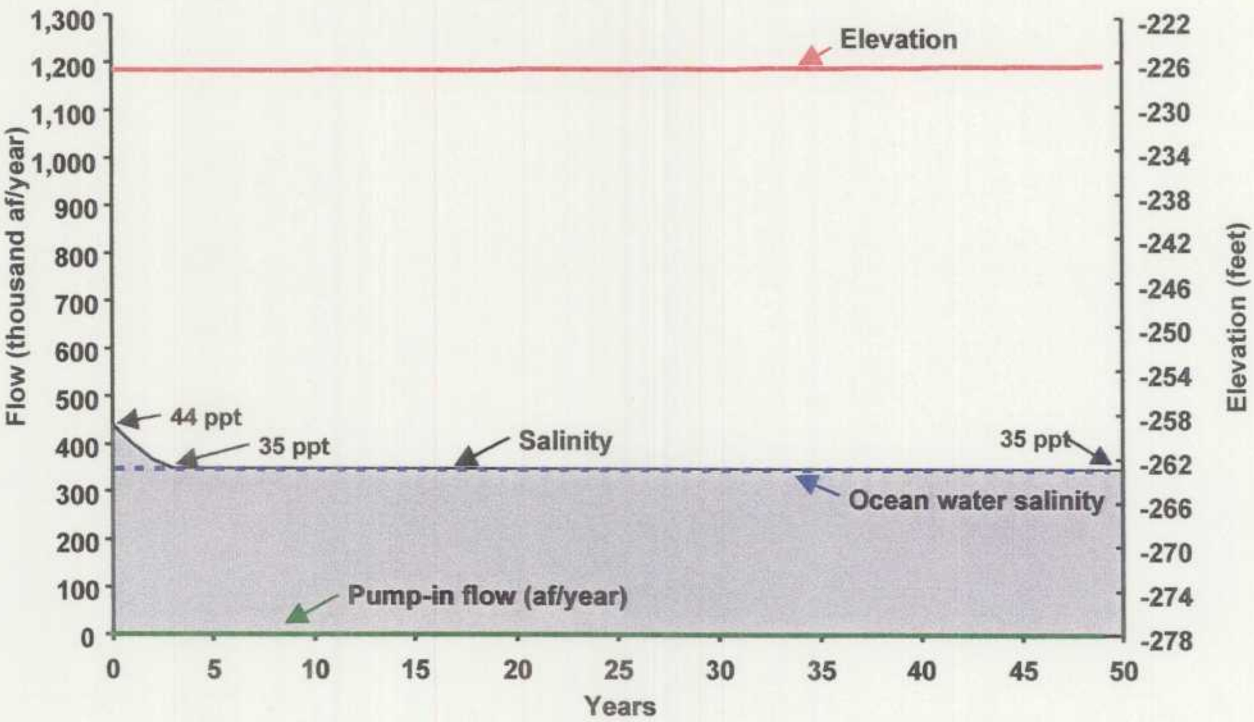


Figure 33.—142-square-mile impoundment; pump-back activated to maintain Sea at 35 ppt with 1.346-million-acre-foot drainage inflow at 2.8 ppt.

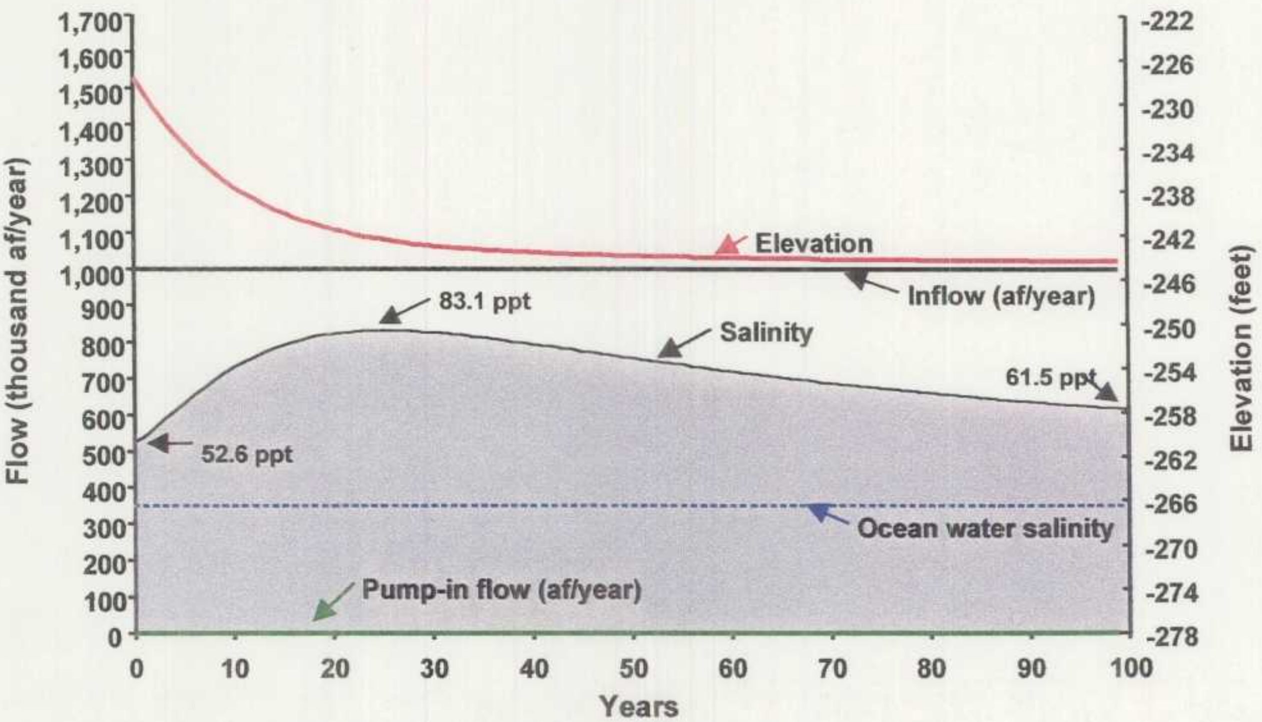


Figure 34.—Variable impoundment at 7.83-percent surface area or 30 square miles with 1.0-million-acre-foot drainage inflow at 3.5 ppt.

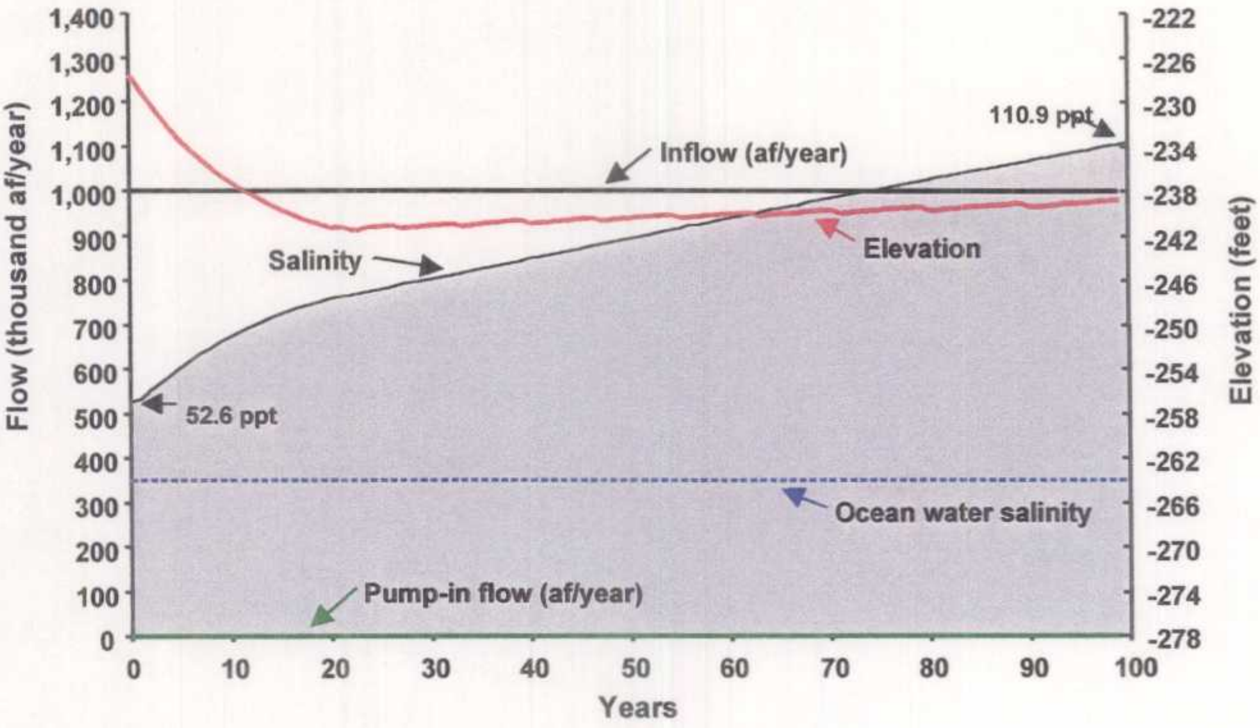


Figure 35.—48-square-mile impoundment with water conservation with 1.0-million-acre-foot drainage inflow at 3.5 ppt.

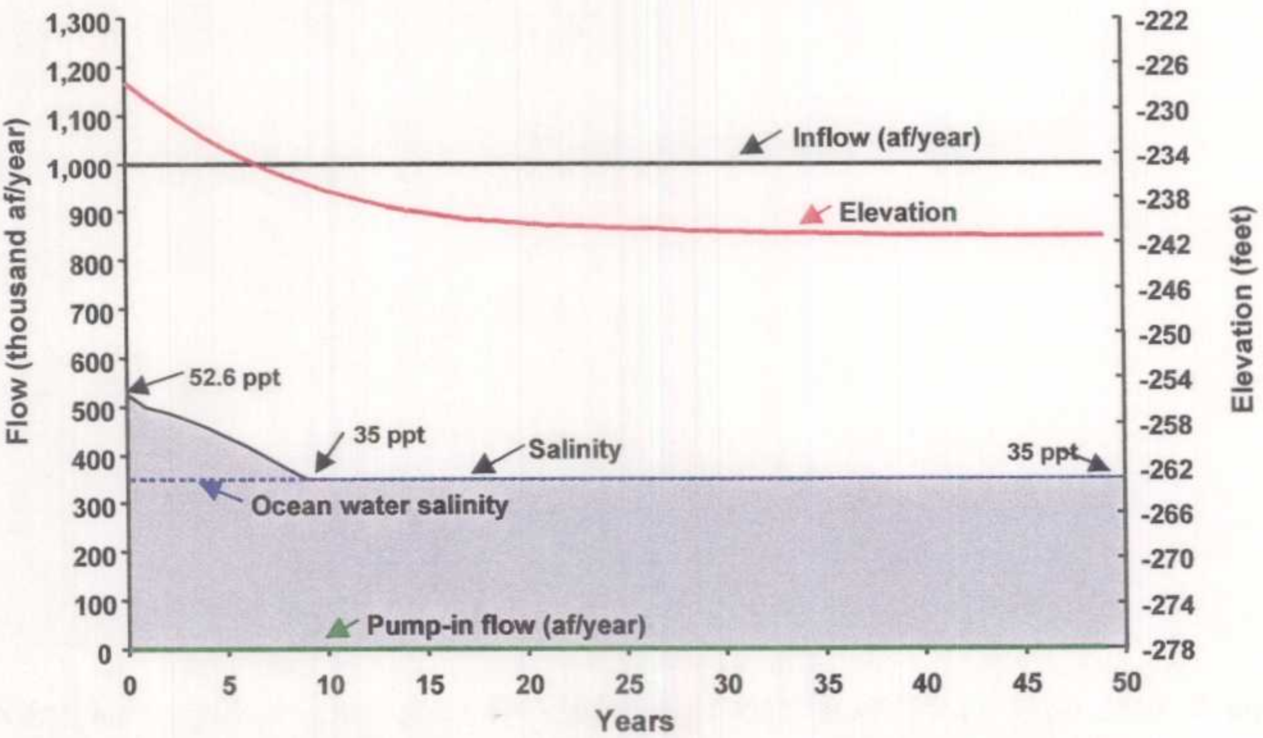


Figure 36.—142-square-mile impoundment; pump-back to maintain Sea at 35 ppt with 1.0-million-acre-foot drainage inflow at 3.5 ppt.

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