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**

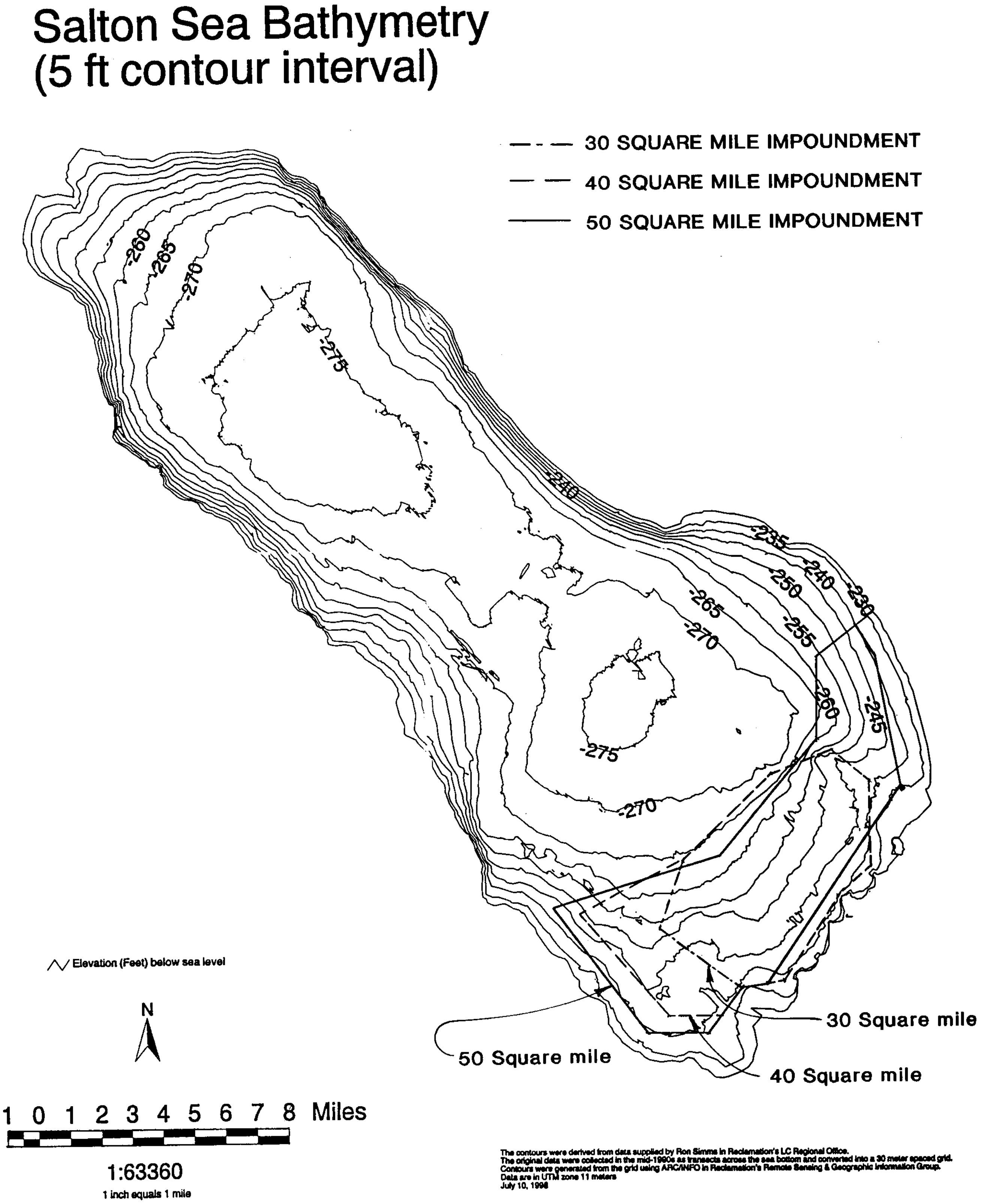
   This diked impoundment pond has a surface area of 50 mi^2 and is completely encircled by the dike at the south end of the Sea. The dike includes a deep-water segment, two intermediate-water segments, and a shallow-water segment along the southern shore side. One or two inlet structures to allow Sea water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

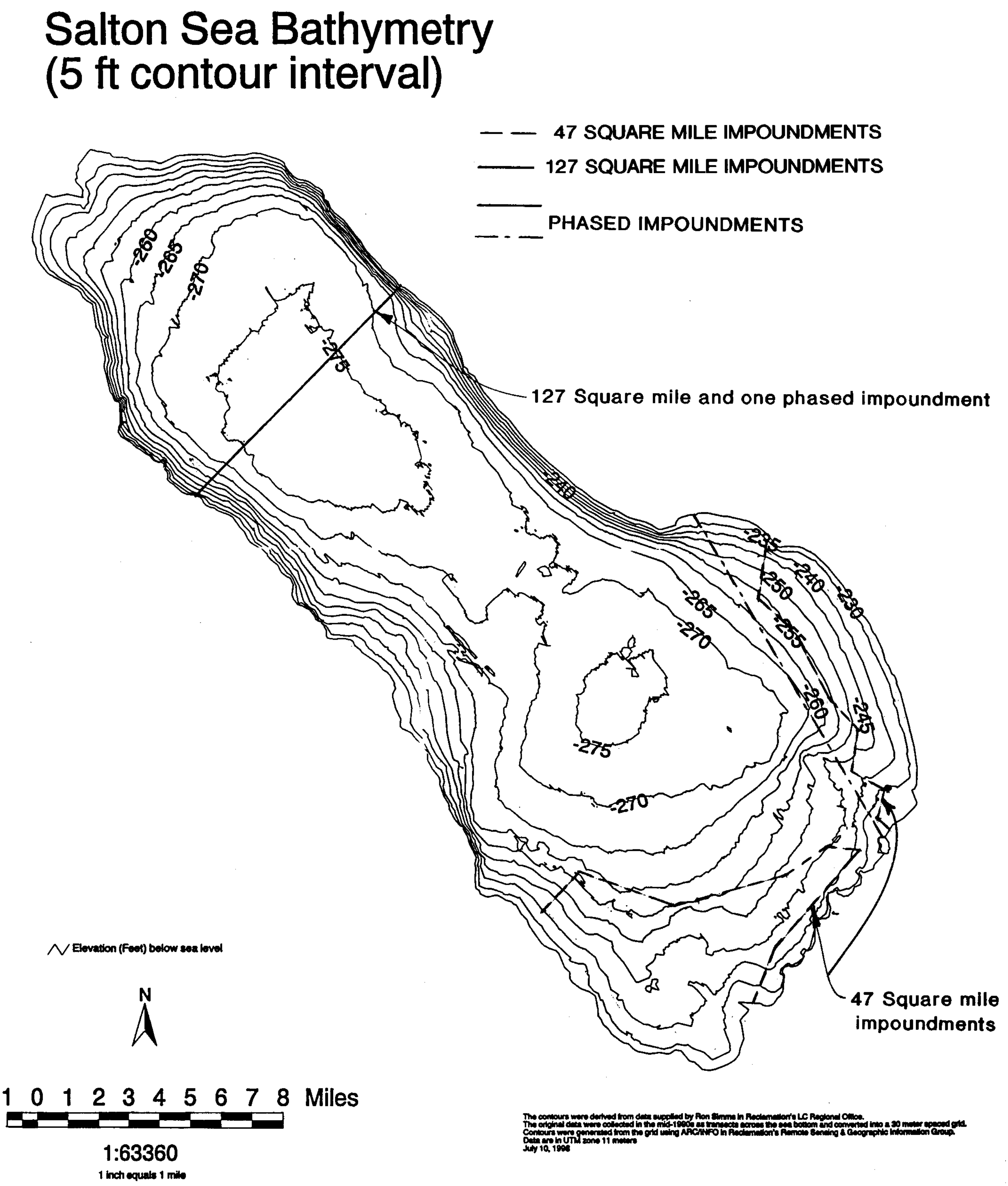
3. **127-mi^2 Pond at North End**

   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.



The contours were derived from data supplied by Ron Simms in Reclamation's LC Regional Office.
The original data were collected in the mid-1990s as transects across the sea bottom and converted into a 30 meter spaced grid.
Contours were generated from the grid using ARC/INFO in Reclamation's Remote Sensing & Geographic Information Group.
Data are in UTM zone 11 meters
July 10, 1998

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



Salton Sea Bathymetry
(5 ft contour interval)

The contours were derived from data supplied by Ron Simms in Reclamation's LC Regional Office.
The original data were collected in the mid-1990s as transects across the sea bottom and converted into a 30 meter spaced grid.
Contours were generated from the grid using ARC/INFO in Reclamation's Remote Sensing & Geographic Information Group.
Data are in UTM zone 11 meters
July 10, 1998

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

4. 47-mi^2 Ponds at South End

This alternative consists of two diked impoundment ponds and has a combined surface area of 47 mi^2. 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 mi^2 in the "East Bay" at the south end of the Sea, with the second diked impoundment of 127 mi^2 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-mi^2 Pond at South End, with Pumping to Palen Lake

This diked impoundment pond has a surface area of 30 mi^2 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-mi^2 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 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. 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

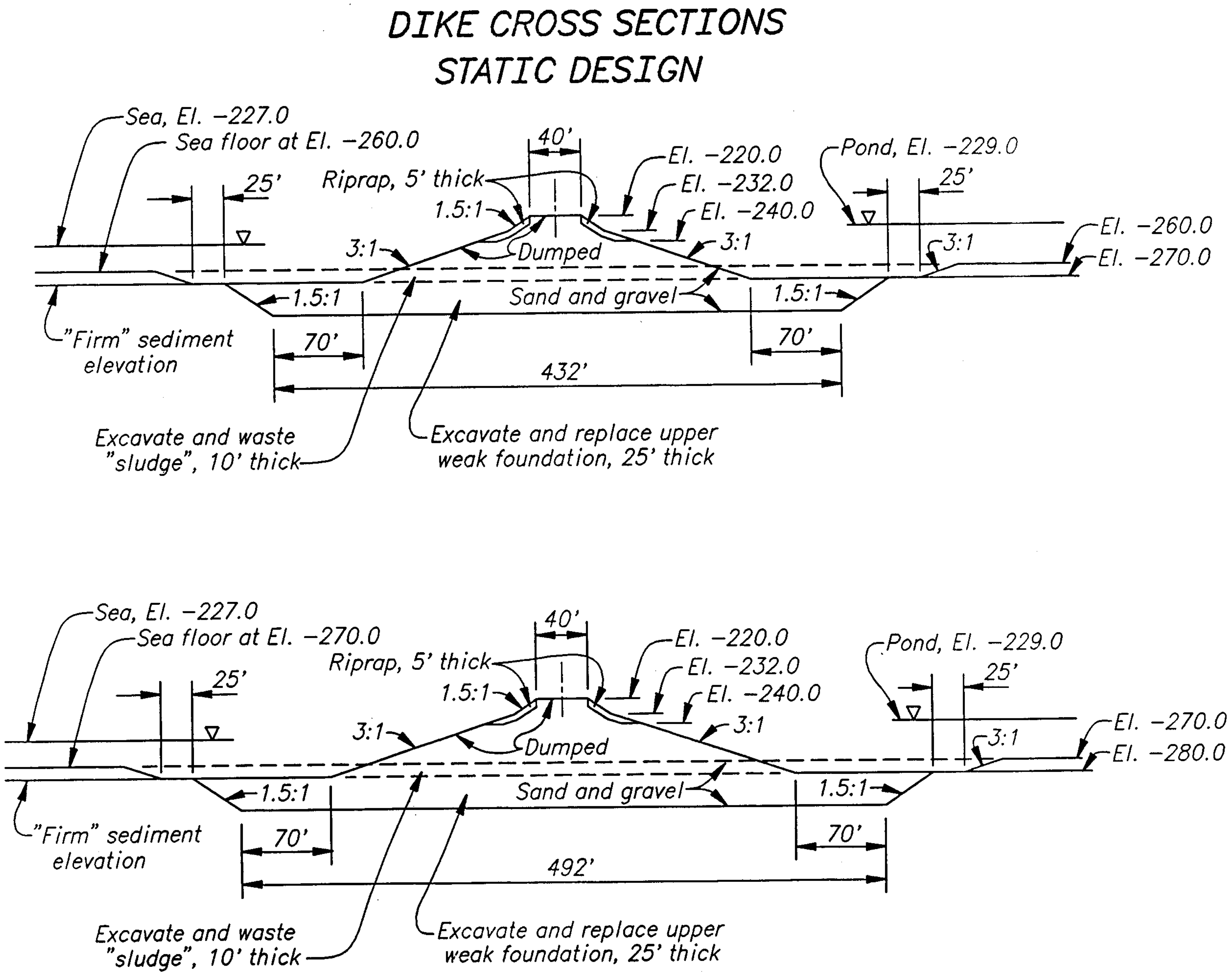


Figure 8.—Cross sections show different foundation elevations in Sea bottom.

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.

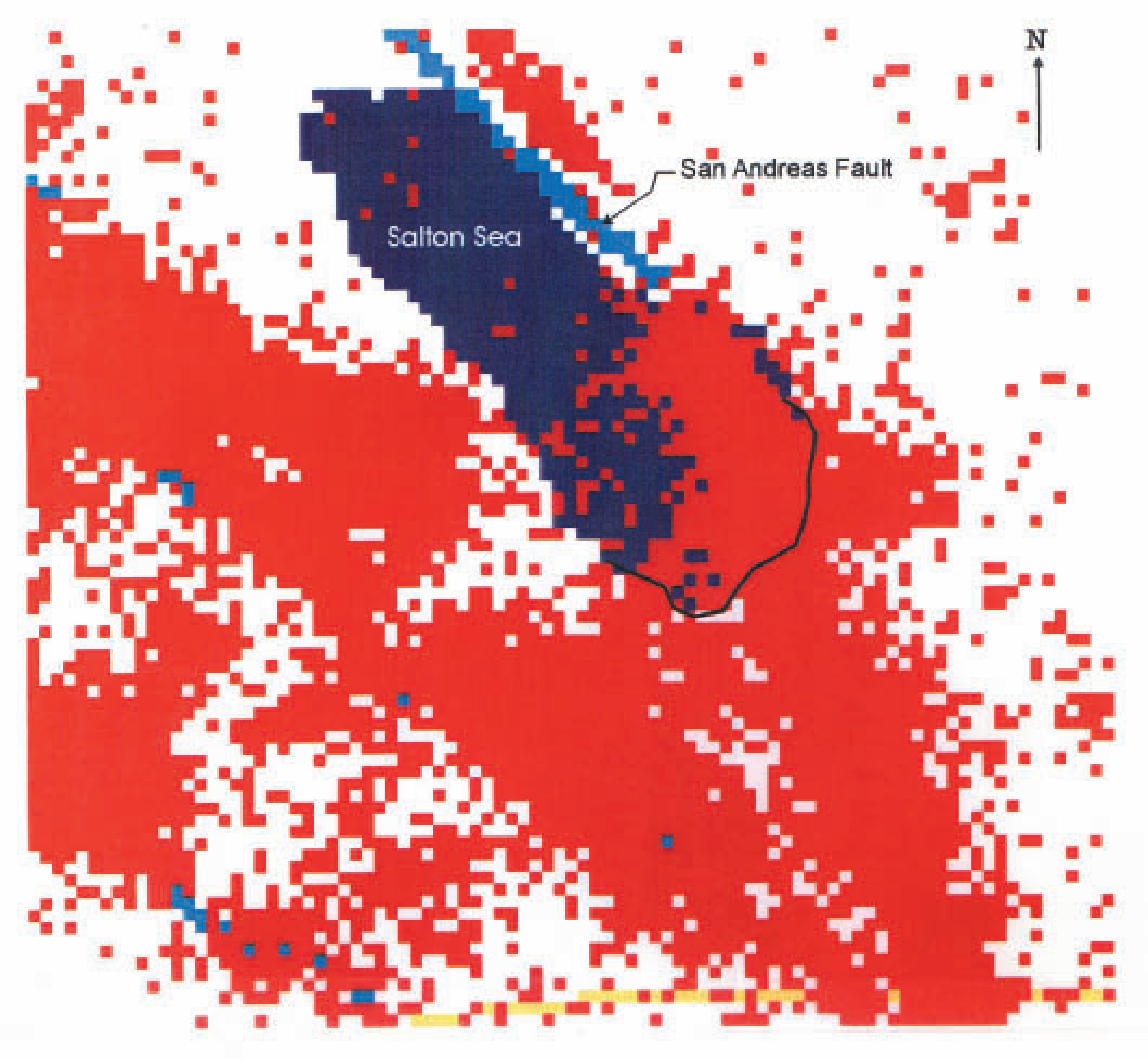
The potential consequence of this highly probable earthquake loading would be a slope failure along the dike. The potential magnitude of this slope failure could involve several miles of the impoundment dike. The waters formerly separated by the dike would then be allowed to mix, destroying the Sea water 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.)

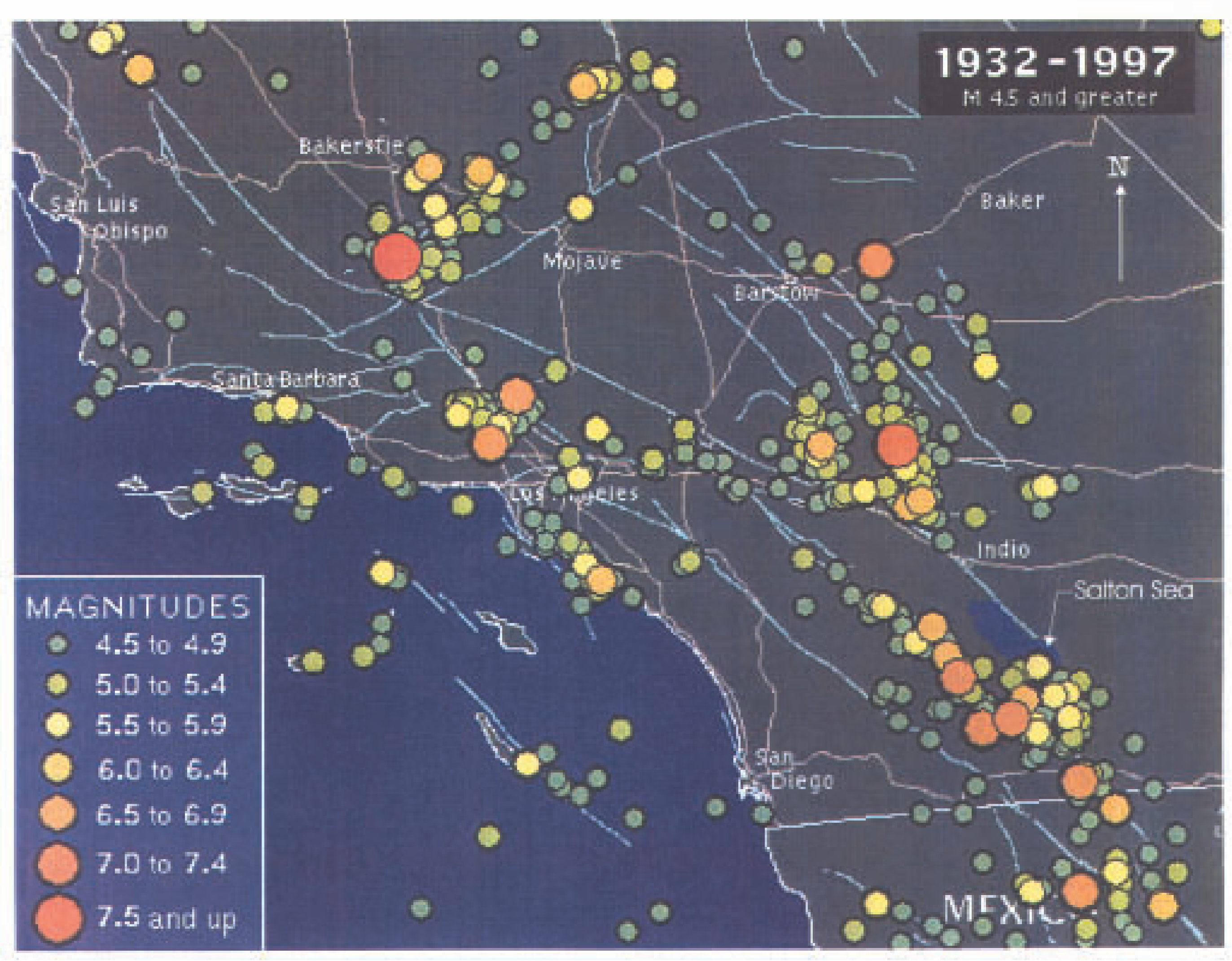
Based on the information available, the question is not whether an earthquake could occur that might affect the stability of the dike; the question is whether to design and construct a Sea dike that would withstand the highly probable earthquake loading that should be anticipated. If the dike were to 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

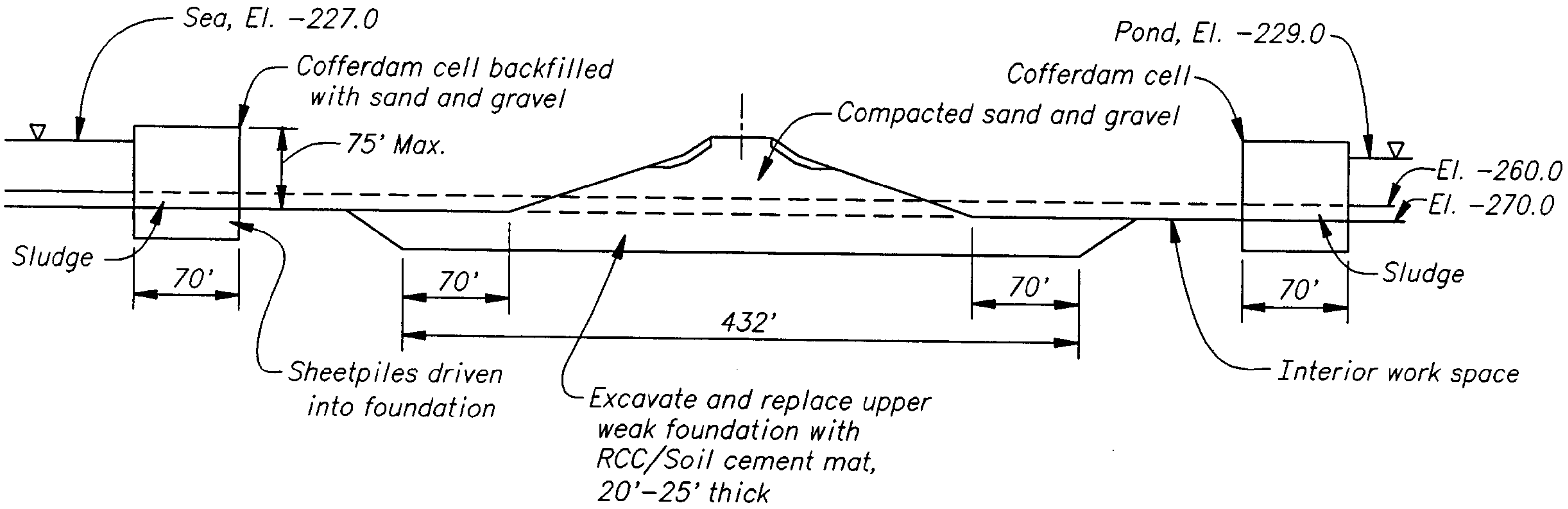


Figure 11.—Cross section showing earthquake design.

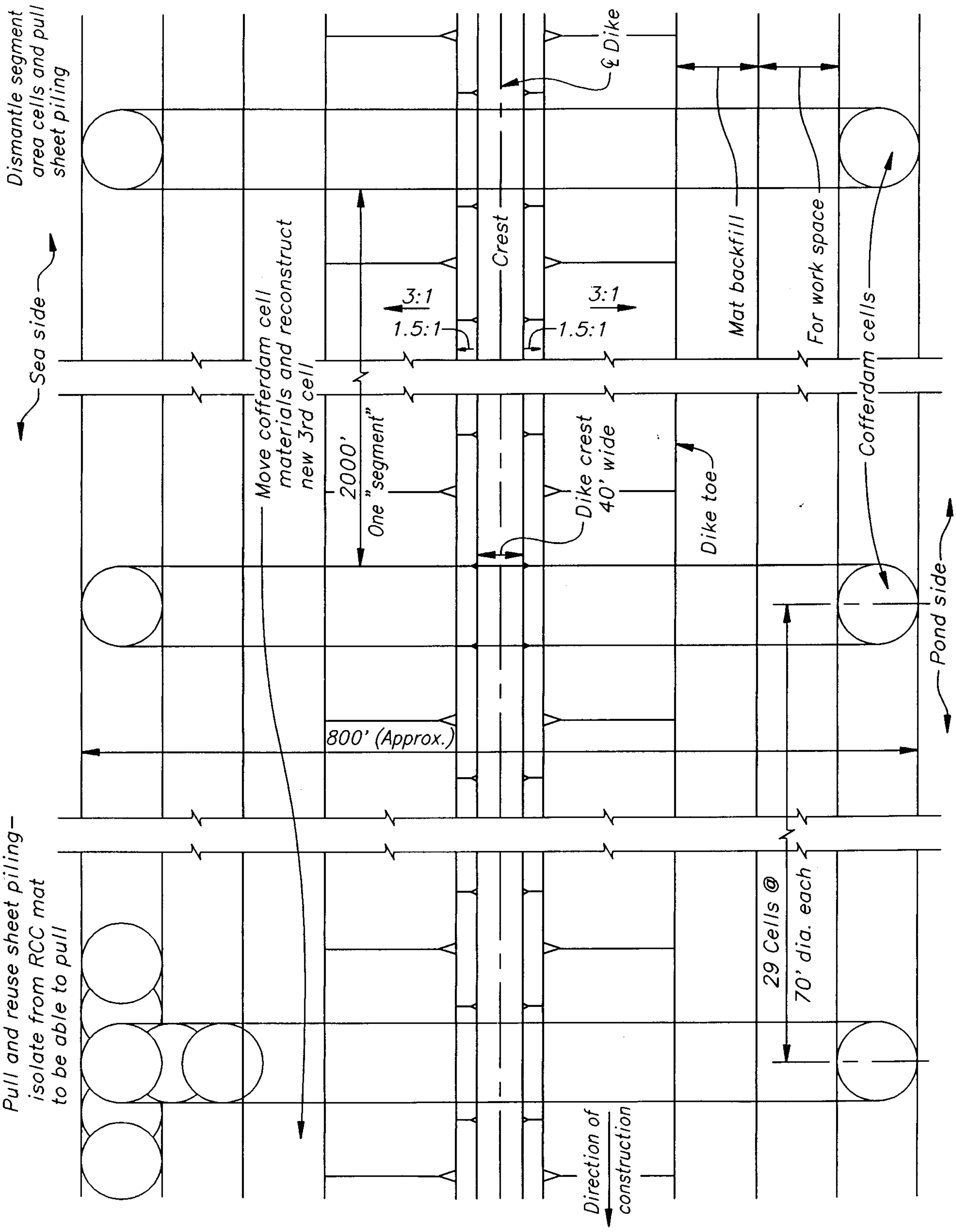


Figure 12.—Sketch shows plan earthquake design.

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.