9.0 Conclusions and Recommendations

A planning level evaluation of various embankment configuration options has been performed to support the formulation and evaluation of alternatives for the restoration of the Sea. The planning level evaluations included:

- ✓ Assessment of potential construction material sources (Appendix 2A)
- ✓ Detailed seepage and stability analyses (Appendix 2B)
- ✓ Deformation analyses using the computer program FLAC (Appendix 2C)
- ✓ Assistance to Reclamation's decision-making process for selection of a preferred embankment configuration option
- ✓ Risk analysis (Appendix 2D)
- ✓ Additional stability evaluations to finalize the "optimized sections for the various embankments (Appendix 2E)
- ✓ Development of cost estimates for the restoration alternatives and corresponding evaluation of constructability issues (Appendix 2F)

9.1 Preferred Embankment Dam Configurations

Two embankment dam configuration options have been developed that meet Reclamation's Public Protection Guidelines (Reclamation, 2003) and the established design criteria for planning level designs. The configuration options include:

Sand Dam with Stone Columns
Rockfill Dam with Jet Grouted Foundation

Modified "Rock Notches" Dams with minimum, and maximum seismic filters were also developed meeting all Reclamation criteria except the provision of "full filters" between the embankment rockfill and the foundation, which eliminated them from further consideration.

A series of seepage, stability, and deformation analyses and evaluations have been performed to support the development of these options, "optimization" of the cross-sections options, and selection of the preferred configuration. These analyses are summarized in technical reports presented in Appendices 2B and 2C. Supplemental stability analyses were performed to complete the optimization of the mid-Sea barrier, perimeter and concentric lakes dikes, and the north- and south-Sea dams and are presented in Appendix 2E.

An evaluation of these options determined that the sand dam with stone columns is Reclamation's preferred dam configuration option. The "optimized" cross-section for the sand dam with stone columns is shown on Figure 4.10. "Optimized" configurations for the south- and north-Sea dams, perimeter dikes, "significant" hazard concentric lakes dikes, and/or for the mid-Sea barrier (meeting static or combined static/seismic design criteria) were developed based on the sand dam with stone columns option and are summarized on Figures 5.1, 5.2, 5.3, and 4.14, respectively. Reclamation's preferred configuration for the habitat pond embankments from the 2005 appraisal level studies was further refined and "optimized" and is shown on Figure 5.4.

Seepage gradients within the dam and foundation for the various configuration options were evaluated assuming that a soil-cement-bentonite (SCB) cutoff wall, or an SCB wall with a membrane was constructed through the dam and penetrating into the upper stiff lacustrine deposit.

Seepage analysis of all of the rockfill mid-Sea dam options show the computed seepage gradients (i_{xy}) in the foundation and through the embankment are in general less than 0.4, with the exception of areas in the immediate vicinity of the cutoff wall. Seepage rate per lineal foot of the embankment for various mid-Sea-dam cross-sections ranges from $2.1x10^{-6}$ to $1.1x10^{-5}$ cfs/lineal foot. All configuration options produced similar results, indicating that the choice of foundation improvement (grouting, rock notches, etc) has a minimal impact on seepage analysis. On the other hand, the presence and integrity of the cutoff wall, plays a major role. The maximum seepage gradient (i_{xy}) occurs through the cutoff wall. Approximately 15 feet downstream of the wall along the embankment/foundation interface the gradient decreases to 0.4, and within 40 feet from the wall it reduces to 0.2. Permeability of the soft lacustrine deposits is 3 to 5 orders of magnitude lower than permeability of materials comprising the embankment and only one order of magnitude higher than that of a cutoff wall. Accordingly, seepage through the foundation is minimal and flow velocities are low, compared to flows through downstream shells.

To illustrate the effect of an installation defect in the slurry wall, seepage was evaluated with a 5-foot high "defect", or hole, in the slurry wall. As expected, relatively high seepage gradients would develop around the defect. For this case the seepage gradient contour with the value of 0.2 extended approximately 100 feet downstream of the cutoff wall or twice as far as in the case of an intact slurry wall. Thus, the integrity of the seepage cutoff wall is essential for control of the dam performance with respect to piping resistance.

Seepage gradients within the dam and foundation for the stone-column-reinforced sand embankment dams were evaluated assuming that a soil-cement-bentonite (SCB) cutoff wall, or an SCB wall with a membrane was constructed through the dam and penetrating into the upper stiff lacustrine deposit. The estimated seepage gradient through and around the wall changed as a result of the membrane. The estimated gradients were generally less than 0.3 except in the immediate vicinity of the bottom of the wall. The model suggests that a maximum gradient equal to 0.7 would occur at this location. Overall, incorporation of an impervious membrane would reduce the computed gradients by as much as ten times to those estimated with only a SCB slurry wall cutoff. A membrane would offer other advantages as described further below and should be evaluated further as designs progress.

Estimated "post-earthquake" factors of safety for each of the cross-section options are summarized in Table 4.10. In order to achieve the desired deformation performance of the embankments, it was necessary to develop cross-section configurations with yield accelerations that were greater than or equal to 0.17. Consequently, estimated "post-earthquake" factors of safety are substantially higher than 1.3. The "post-earthquake" factors of safety range from as low as 2.2 to over 3.2.

9.2 Deformation Analysis Results

Seismic deformation analyses of the "optimized" mid-Sea sand dam with stone columns, and Reclamation's rockfill perimeter dike option were completed using the commercial finite difference code FLAC. Model cases evaluated both liquefied and non-liquefied strengths of upper alluvial foundation materials and non-densified dam materials. The effect of a range of different material properties that would occur for various stone column improvement objectives (i.e. various target $N_{1,60}$ blow counts following densification) were also evaluated.

Conclusions from the deformation study were as follows:

1. In general, the displacements estimated with the FLAC models of two different embankment configuration options fall between the displacements estimated by simplified Newmark and Makdisi-Seed methods for the surface and deconvolved ground motions. Combining the FLAC results and the simplified Newmark and Makdisi- Seed results provides a sound basis to establish a planning level screening criteria for yield acceleration that can reliably and conservatively estimate adequate or marginal crest deformation performance based on the input ground motions as provided by Reclamation. For purposes of "optimizing" all cross-sections, a minimum yield acceleration criterion of 0.17 was selected.

2. The estimated crest deformations of the optimized mid-Sea sand dam will generally be less than the five feet of available freeboard included in the design. To achieve the require performance, the central portion of the dam will need to be densified to an equivalent $N_{1,60}$ of 20 achieving a target undrained strength (S_{us}) of at least 1,000 psf, or a drained strength friction angle of at least 32 degrees.

3. The estimated maximum strains along the centerline axis of the dam (the location of the slurry wall cutoff) will occur at the contact between the dam and the stiff lacustrine materials. The maximum strain occurring at this location would likely range from 0.15 to 0.2 percent. A soil-cement-bentonite (SCB) wall should be capable of withstanding this level of strain without significant rupture and offset that would threaten the safety of the dam. Future FLAC modeling efforts should include an explicit slurry wall to confirm the strain estimates of this study.

9.3 Risk Analysis Results

A risk analysis of the "optimized" embankment designs for the Salton Sea restoration project was completed to evaluate potential failure modes, loss-of-life potential and estimates of the annual probability of failure and the annualized loss-of-life. After the risks for all of the failure modes for each structure were evaluated, results were compiled to develop a "composite" risk for each restoration alternative. It was determined that the risk of failure of an alternative could be described by the risk associated with failure of the "weakest link" in the system.

The results of loss-of-life estimates are summarized in Table 9.1, below. Based on these estimates, the mid-Sea dam, the south-Sea dam, and the north-Sea dam, classify as "high hazard" structures. Because of the overall nature of the alternatives being considered, three fundamental hazard classification criteria (LOL, economic, and environmental/social) will be considered before a final determination is made on the appropriate hazard classification of each of the remaining embankment components of the various alternatives.

Table 9.1
LOL Estimates for Project Structures, Day/Night Averages

Component	Static Failure Modes, LOL	Seismic Failure Modes, LOL		
		Lower Bound	Best Estimate	Upper Bound
Mid-Sea dam	0	0.28	1.5	3.5
Mid-Sea barrier	0	0	0.04	0.08
Perimeter dikes	0	0	0.06	0.13
South-Sea dam	0	0.18	1.0	2.3
North-Sea dam	0	0.23	1.2	2.8
Concentric lakes dikes	0	0	0.05	0.10
Habitat pond embankments	0	0	0.02	0.03

In general, the risk analysis confirmed that the "optimized" designs would comply with Reclamation's Public Protection Guidelines (Reclamation, 2003) with the following two exceptions. First, upon careful consideration of the available subsurface information and the morphology of the seafloor deposits, the risk evaluation team determined that there is some likelihood that liquefiable (and erodible) layers and lenses exist within the upper stiff lacustrine deposits. This possibility was considered in the risk analysis as failure mode FM No.6. The "optimized" cross-sections evaluated as part of the risk analysis were developed to meet static and seismic design criteria should liquefaction occur within the upper alluvial and soft lacustrine deposits, but not within the upper stiff lacustrine deposits. Further refinement of the cross-sections would be required to meet seismic design criteria should future site explorations identify/confirm potentially liquefiable materials within the upper stiff lacustrine deposits. Risk analysis results confirmed that mitigation of this risk would be required. Mitigation would include expansion of explorations to identify any potential liquefiable layers in the upper stiff lacustrine deposit and adaptation of designs to mitigate liquefiable layers.

Second, the potential for fault offset that would translate through the seafloor deposits to the base of embankment structures crossing the Imperial / San Andreas Fault Transition Zone was identified in the risk analysis. This was considered as a potential failure mode FM No.12. Similar to FM No. 6 above, the risk analysis results confirmed that adaptation of the cross-sections of the embankments crossing this zone would be required to meet seepage design criteria and to reduce the potential for failure following a seismic event that would cause surface rupture of the seafloor deposits. An example of the adaptive design for the south-Sea dam is shown on Figure 5.1.

9.4 Construction Materials and Cost Estimates

Using the "optimized" cross-sections, additional evaluations of potential construction material sources were completed, and cost estimates were prepared for each of the five overall restoration alternatives and options under consideration by Reclamation. The results of our initial (Task 3) materials evaluation identified 3 possible sources for embankment materials (Appendix 2A). These sources include the Coolidge Mountain /API site on the west shore, the Eagle Mountain mine site located well northeast of the project and relatively small borrow sites located along the east shore near the Bombay Beach area. The Bombay Beach sites are relatively thin and after further evaluation were eliminated from consideration as a possible source for large scale aggregate and riprap production. Significant constraints have also been identified for the Eagle Mountain mine site. Subsequent construction material assessments and cost estimates where therefore focused on the Coolidge Mountain/API site.

The Coolidge Mountain / API site is located within the Torres Martinez Indian Reservation. API operates a sand and gravel pit and screening operation just west of Highway 86 near the northwest shore of the Sea and produces a variety of aggregate products including washed and natural sands, gravels for asphalt concrete and Portland cement concrete and similar rock products. The source is a natural sand and gravel deposit within a broad alluvial fan. Available information indicates that this site is promising for production of all of the required embankment materials with the exception of riprap.

West and upslope of the existing API pit, Coolidge Mountain rises above the alluvial fan. This area is also located within the Torres Martinez Indian Reservation. Geology within this area suggests that adequate sources of high quality rock exist for the production of all riprap required for the project.

A summary of the estimated subtotal project construction costs for the embankment portion of the overall restoration alternatives and options is as follows:

		Alternative	**Estimated Subtotal Embankment Construction Costs**
1.	Mid-Sea Dam/North Marine Lake		$ 3,339,066,140
2.	Mid-Sea Barrier/South Marine Lake:		
	2A	Static/Seismic design criteria	$ 898,087,677
	2B	Static/Non-seismic design criteria	$ 707,092,179
3.	Concentric Lake Dikes:		
	3A	Static/Seismic design criteria	$ 8,999,280,347
	3B	Static/Non-seismic design criteria	$ 6,944,914,735
4.	North-Sea Dam/Marine Lake		$ 5,021,163,338
5.	Habitat Enhancement without Marine Lake		$ 568,560,600

It should be noted that this planning level study has developed embankment configurations and cost estimates beyond what was accomplished in the 2005 appraisal level studies. However, because of the very limited amount of information on the stratigraphy and engineering properties of the Sea foundation deposits and potential construction material sources, the concepts and cost estimates are still appraisal level and not suitable to establish funding for the project. Funding level concept and cost estimate updates should be prepared when sufficient supplemental explorations are completed for this purpose. The concepts and cost estimates could change dramatically if additional exploration information indicates significant differences from the baseline assumptions that have been made.