State of California The Resources Agency

Memorandum

Date : **October 26, 2005**

To : Dale Hoffman-Floerke
Jerry Johns

From : David A. Gutierrez
Department of Water Resources

Subject: Salton Sea Dam Foundation Review

The Division of Safety of Dams (DSOD) was asked to review and comment on the Bureau of Reclamation's Salton Sea Restoration Project Feasibility Study. More specifically, the review was to focus on the need for treating the foundation for dams or barriers constructed in the Sea proper. Reclamation's design and corresponding costs for these structures were not reviewed. This review is cognizant that the studies by Reclamation were done at the appraisal level.

An October 11, 2005 letter report by URS, addressed to William R. Browlie, Tetra Tech, was reviewed. It is beyond the scope of this review to provide comments on this report.

USBR Restoration Alternatives and Associated Risk

Dams or barriers are required for each of the 8 alternatives for restoring the Sea, as identified by Reclamation. These alternatives serve to provide separate bodies of water having differing elevations and salinity. Because of the Sea's size, the length of barriers or dams is significant, ranging from 9 to 100+ miles. Hence, foundation treatment for these structures represents a significant undertaking.

Table I below identifies, for each alternative, the head differential, foundation treatment requirement identified by Reclamation, and whether these structures would fall under DSOD jurisdiction. It is noted that barrier alternatives do not require foundation treatment and do not fall under DSOD jurisdiction.

Table I Summary of USBR Alternatives

Alternative	Description	Differential Head, ft	Foundation Treatment	DSOD* jurisdiction
1	Dam - North Lake	35	Yes	Yes
2	Dam - South Lake	35	Yes	Yes
3	Concentric Rings	15	Yes	Yes
4	North Lake with Ring	35 - 15	Yes	Yes

5	Barrier – North Lake	5	No	No
6	Barrier – South Lake	5	No	No
7	Barrier – South Lake with Ponds	5	No	No
8	Evolving Sea with Ponds	8.5	Yes - Limited	Yes

* Jurisdictionality determined by DSOD

Reclamation used a risk analysis approach to evaluate the degree of risk posed by dams or barriers for each of the restoration alternatives. This approach is the same one used for Reclamation's Dam Safety Guidelines for Achieving Public Protection (PPG), and is used to justify implementation of risk-reduction actions when the annual probability of failure (APF) exceeds $1x10^{-4}$, or the annual loss of life (ALL) exceeds $1x10^{-3}$.

Table II below represents the mean risks for a Mid-Sea Dam utilized in Alternatives 1, 2 and 4, as taken from Reclamation's Table 20A, Reference 11.

Table II

Description	APF	ALL
Untreated Foundation	$9x10^{-3}$	$9x10^{-2}$
Treated Foundation	$3.5x10^{-5}$	$3.5x10^{-4}$

The postulated failure mode is a loss of strength of the dam's foundation over a large area during an earthquake, causing the dam to fail rapidly and breaching the reservoir in a very short time. The crest of the dam is described as serving as a roadway. As such, it was determined that there was a risk of loss of life. Based on these risks, Reclamation determined that "..... there is justification to implement risk reduction actions, such as treating the foundation."

In the case of the concentric ring alternative #4, the population at risk was determined to be recreational boaters. Hence, this alternative was also deemed to require foundation treatment to satisfy Reclamation's PPG.

In the case of Alternatives 5 – 7, the proposed structure is a barrier and not a dam. It is described as not serving as a roadway and having a significantly smaller differential in head than that for the dam. As a result, no loss of life was determined in case of failure. These structures were therefore anticipated to be classified as low hazard, not subject to Reclamation's PPG, and therefore not requiring foundation treatment.

In the case of Alternative 8, Evolving Sea with Ponds, it was concluded that at least one fatality would occur in the event of a failure and, therefore, that foundation treatment would be required for these structures. Foundation treatment is not as extensive as for the Mid-Sea dam due to the relative low height of these structures.

DSOD Risk Evaluation

The Division of Safety of Dams was established, per Division 3 of the Water Code, to protect life and property from an uncontrolled release of impounded waters. The Code does not provide for protection of the dam and appurtenances proper. The level of conservatism of a design for protection and/or maintenance of facilities over a project's life is a decision made by the owner.

In the case of jurisdictional impoundments for the restoration alternatives, the risk of loss of life or property downstream of a dam is determined to be minimal. An uncontrolled release of water would inundate a brine pool confining all waters to a footprint smaller than the current Sea. However, mitigations for air quality planned to be implemented by the State could be impacted by a dam failure.

It is understood that it is desirous, for purposes of air quality, to avoid disturbing the salt crust of any exposed Sea floor areas. It is therefore assumed that recreational access to these areas might be prohibited, further limiting life at risk. It is noted that one or more alternatives provide for the crest of a dam to serve as a highway. There are cases where jurisdictional dams serve as roadways. In these cases, the degree that life is at risk from a dam failure is not incorporated into a hazard evaluation.

It is noted that the appraisal level design of Mid-Sea dam is a rock fill dam and that varying slopes, inclined as low as 15:1, were considered. Reclamation, in assessing risk, postulated a rapid failure where the reservoir is breached in a very short time. This postulation would appear to be conservative, given the resistant nature of rock fill to erosion in conjunction with a very flat downstream slope of 15:1

Subsurface Conditions

The mode of failure postulated by Reclamation is based on a judgment that the upper foundation layers will lose strength over a large area. The foundation layers in question are described as an Upper Alluvial and Soft Lacustrine layer.

The Upper Alluvial layer is described as 0 to 26 feet thick, consisting of loose to dense, silty-fine sand, with interbedded silt and clay lenses. This layer is essentially non-existent in the central part of the Sea and east shore, and only exists near the western shore.

The Soft Lacustrine layer is similarly 0 to 26 feet thick and is described as soft to very soft, highly plastic clay. This deposit essentially dominates the entire seafloor. It is thickest in the central part and eastern shore, and thinnest near the western shore. Reclamation identified occasional lenses of silty sands within this layer.

Liquefaction Potential

Reclamation used the Standard Penetration Test and Cone Penetration Test to evaluate liquefaction potential. Of the two, the SPT determined values are more reliable indicators of liquefaction potential than those interpreted from the CPT. The SPT values obtained in the sandy layers were evaluated by DSOD and reported in Table III. The data show a range of corrected SPT values of 3 to 95 with a median of 21. It should be noted that the borehole

locations are spatially distributed throughout the Sea with the majority located in the middle. This data does not support an assessment that liquefaction will occur everywhere in the Sea's footprint given the single low value (3). The next highest value is 12 which would be classified as liquefiable using Reclamation's criteria of liquefaction occurring for values less than 15.

The Cone Penetration Test is primarily used to fill in between the Boreholes to determine a soil profile. The CPT interpreted (N1)60 values were compared to those determined from SPT. This comparison, shown in Table IV, indicates that the CPT (N1)60 values are significantly lower for sandy layers than those for the SPT. It should be noted in making this comparison that the borings and CPT holes are some distance apart. A review of the CPT logs indicate that the (N1)60 interpreted values are not sensitive as the cone is advanced thru varying layers. Hence, Reclamation's assessment of the extent of liquefiable materials, based on CPT results, is considered conservative. The reliability of using CPT data to assess liquefaction is questioned.

Table III SPT Values and Corrections

SPT Sample No.	Material Description Recovery	Elev. (ft)	N (blowcount)	Fines Content Passing #200 (%)	Depth (ft)	Effective Overburden (psf)	Correction for Overburden C_n	Correction for Rod Length C_r	$N_{1,60}$	$N_{1,60,CS}$	$N_{1,60,CS,R}$
B2	SAND	-268	13	20	9	473.4	2.06	0.82	22	25	23
	CH, CL	-283	28	20	24	1262.4	1.26	0.96	34	38	35
B5	SP, SC	-294	17	20	26	1367.6	1.21	0.97	20	23	21
	SM	-319	16	20	50	2630	0.87	0.99	14	16	15
B6	SC	-300	34	20	31	1630.6	1.11	0.98	37	41	38
	SM	-310	12	20	41	2156.6	0.96	0.99	11	13	12
B7	CH	-294	21	20	34	1788.4	1.06	0.98	22	25	23
	CH	-300	27	20	40	2104	0.97	0.99	26	29	27
B11	SM	-253	27	20	10	526	1.95	0.83	44	48	45
	SM	-258	86	20	15	789	1.59	0.89	94	102	95
	CL-ML	-263	37	20	20	1052	1.38	0.94	48	53	49
B17	CH	-259	10	20	15	789	1.59	0.89	14	16	15
	CH	-269	14	20	25	1315	1.23	0.97	17	19	18
B14	SM	-270	16	20	20	1052	1.38	0.94	21	23	22
	SM-ML	-276	14	20	26	1367.6	1.21	0.97	16	19	17
	SM-ML	-280	13	20	30	1578	1.13	0.98	14	16	15
B19	SM	-294	2	20	26	1367.6	1.21	0.97	2	4	3
B20	SM	-265	44	20	11	578.6	1.86	0.84	69	76	70
	CH	-270	12	20	16	841.6	1.54	0.90	17	19	18
	SM	-280	32	20	26	1367.6	1.21	0.97	38	42	39
B26	CH	-322	10	20	45	2367	0.92	0.99	9	11	10

Table III Comparison of (N1) Values

Depth (ft)	(N1)60 Boring 2		(N1)60 CPT8	Classifications
9	22		16	1" silty sand lens
24	34		22	CH, CL
	Boring 5	CPT 28	CPT 29	
26	20	7	8	SP, SC
50	16	10	-	SM
	Boring 6		CPT 29	
31	37		13	CH
41	11		8	SM
	Boring 7		CPT 8	
34	22		14	CH
40	26		22	CH
	Boring 11		CPT 10	
10	44		38	SM
15	94		17	SM
20	48		44	CL-ML
	Boring 14		CPT 13	
20	21		10	SM
26	16		11	SM-ML
30	14		-	SM-ML
	Boring 17		CPT 18	
15	14		11	CH
25	17		12	CH
	Boring 26		CPT 3	
45	9		10	CH

Residual Strength

Residual strength is the strength a material has after it has liquefied, sometimes it is referred to as a post earthquake strength. Based on the low and median corrected SPT values, residual strengths approximately range from 150 to 1200 psf based on strength relationship used by Reclamation. Except for a small percentage, spatially within the Sea's footprint where low shear strengths apply, the shear strength of the foundation is judged to be governed by the strength of the lacustrine layers.

DSOD Slope Stability Analyses

Independent slope stability analyses of the downstream slope for a Mid-Sea dam were performed by the Division. The analyses considered varying conditions such as slope inclination and residual strengths which were assigned for the entire footprint. Cases 1 and 2, shown in Table IV, replicate the geometry and soil parameters used by Reclamation. A comparison of results shows that, given the same input, DSOD determined safety factors are about 10 percent higher.

Table IV Comparison of Safety Factors

Case	Downstream Slope/Residual Strength	DSOD	Reclamation
1	15:1 slip surface in Lacustrine / 250 psf	1.07	0.95
2	15:1 slip surface in Alluvial/ 400 psf	1.53	1.39
3	7:1 slip surface in treated Lacustrine	-	7.60
4	15:1 pre-earthquake, static, Req'd FS = 1.5	8.94	-
5	15:1 0.15g pseudo-static, Req'd FS=1.1	1.78	-

Case 3 indicates the safety factor reported by Reclamation when the foundation is treated – it was stated that the amount of earthquake induced deformation was determined to be minimal.

Cases 4 and 5 indicate that a downstream slope inclined at 15:1 meets DSOD's guidelines for minimal safety factors for static and 0.15g pseudo-static conditions for low hazard dams of 1.5 and 1.1, respectively. In both cases, DWR's total strength value of 13.5 degrees friction was used for the foundation. In addition to meeting these minimal safety factors, it would have to be demonstrated that the available freeboard is sufficient to mitigate loss of freeboard due to earthquake loading and that shearing in the foundation is limited. DSOD does not have a requirement which identifies a minimum post earthquake factor of safety. Needless to say, it would have to be greater than 1.0 and would largely depend on the level of uncertainty of the foundation strengths.

Discussion and Summary

The appraisal level design by Reclamation is reflective of three conservative assessments. First, given the limited amount of subsurface data in conjunction with the size of the Sea, an assessment was made that liquefiable materials are present everywhere in the Sea's footprint. It would be more appropriate to assign a percentage which would correspond to a probability that foundation strengths are lower than those of the lacustrine layers.

Secondly, that a rock fill dam having up and downstream slopes of 10 and 15:1 would fail catastrophically, releasing all impounded waters in a very short time period resulting in a high probability of loss of life; and thirdly, that a design is required, everywhere within the Sea's footprint, which would result in minimal amount deformation during the maximum credible earthquake based on the lowest strength.

DSOD would require that a design meet the minimum safety factors, that the available freeboard is sufficient to mitigate the earthquake induced deformations, and that the deformations do not impair the dam's safety. Given a conservative assumption that liquefiable materials are present everywhere, these criteria can be met by utilizing slopes which are appropriately inclined, treating the foundation, or a combination of both.

The extent to which DSOD's design standards are exceeded is dependent on an owner's desired level of performance over the life of a project. Reclamation's appraisal level design exceeds DSOD's design standards and is judged to attain a high level of performance under all severe loading conditions. Regardless of the presence of liquefiable materials, a design having slopes of 7:1 without foundation treatment would not be acceptable due to the low strength of the lacustrine materials left in place.

References:

1. Letter from URS Corporation of San Diego, dated October 11, 2005, regarding URS Project No. 27663042.00006, the Proposed Mid-Sea Dam, Salton Sea Restoration Project, Riverside and Imperial Counties, California.

2. Letter from United States Department of the Interior, Bureau of Reclamation, dated September 30, 2005, regarding the Salton Sea Restoration Project, Feasibility Study – Phase 1 Reports.

3. Guidelines for Achieving Public Protection in Dam Safety Decisionmaking, United States Department of the Interior, Bureau of Reclamation, report dated June 15, 2003.

4. A Procedure for Estimating Loss of Life Caused by Dam Failure, DSO-99-06, Sedimentation & River Hydraulics, United States Department of the Interior, Bureau of Reclamation, Dam Safety Office, dated September 1999.

5. Draft of Risk Analysis Methodology, Appendix E, Estimating Risk of Internal Erosion and Material Transport Failure Modes for Embankment Dams, United States Bureau of Reclamation, Technical Service Center, Version 2.4, dated August 18, 2000.

6. Draft of Risk Analysis Methodology, Appendix J, Estimating Risk from Seismic Loading of Embankment Dams and Foundations, United States Bureau of Reclamation, Technical Service Center, dated May 27, 2005.

7. Dam Safety Risk Analysis Methodology, United States Department of the Interior, Bureau of Reclamation, Version 3.3, dated September 1999.

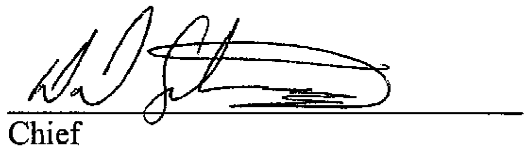
8. Draft of Salton Sea Restoration Project Feasibility Study – Phase 1, Alternatives Viability, Lower Colorado Region, from Reclamation, Managing Water in the West series, United States Department of the Interior, Bureau of Reclamation, Technical Service Center, dated October 5, 2005.

9. Draft of Salton Sea Restoration Project Feasibility Study – Phase 1, Supplemental Engineering Information, Lower Colorado Region, from Reclamation, Managing Water in the West series, United States Department of the Interior, Bureau of Reclamation, Technical Service Center, dated October 7, 2005.

10. Draft of Salton Sea Restoration Project Feasibility Study – Phase 1, Alternatives and Cost Estimates, Lower Colorado Region, from Reclamation, Managing Water in the West series, United States Department of the Interior, Bureau of Reclamation, Technical Service Center, dated September 30, 2005.

11. Draft of Salton Sea Restoration Project Feasibility Study – Phase 1, Risk Analysis Report, Lower Colorado Region, from Reclamation, Managing Water in the West series, United States Department of the Interior, Bureau of Reclamation, Technical Service Center, dated September 29, 2005.

12. Working Draft No. 3, Salton Sea Ecosystem Restoration Study, Conceptual Design for In-Sea Rock Barriers, Interim Report, State of California, The Resources Agency, Department of Water Resources, Colorado River and Salton Sea Office, dated March 2005.



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