Appendix C

Comparison of Piping Mitigation Alternative Concepts

C-1 BACKGROUND AND PURPOSE

Construction of the reservoir embankments at Webb Tract and Bacon Island is expected to cause significant settlement of the highly compressible peat soils in the existing levee and foundation. As a result of this settlement, there is a potential for cracking of the existing levee and/or new embankment fill materials. There is a concern that cracking could lead to piping of the embankment and levee materials. Piping could occur due to both inward seepage (when the slough water level is higher than the reservoir level) and outward seepage (when the reservoir level is higher than the slough level). Estimates of the probability of piping failure are presented in Appendix B.

The purpose of this technical memorandum is to present the results of a brief evaluation of alternative concepts to mitigate piping.

C-2 ALTERNATIVES

The following alternative concepts to mitigate piping potential were evaluated:

- Alternative 1: “Crackstopper” or crack filler
- Alternative 2: Granular filter
- Alternative 3: Filter fabric
- Alternative 4: Slurry wall
- Alternative 5: Vertical geomembrane
- Alternative 6: Pumping well system.

The comparison of the alternatives is shown in the attached Table C-1. The alternatives are described in this table and the evaluation factors considered in the table include: mechanism to mitigate piping; effectiveness during construction, operations, and earthquakes; constructibility issues; risk of poor performance; flexibility to add to the system; and construction cost.

C-3 LOCATIONS

The potential locations for the piping mitigation measures are as follows:

1. Areas where consequences are greatest (i.e., narrow slough areas).
2. Areas where foundation conditions, such as buried channels, could cause differential settlement and transverse cracking.
3. Areas where structures penetrate the existing levee or new embankment.
4. On both the reservoir and slough sides of the new embankments in the integrated facilities area (to reduce the potential for failure and damage to the integrated facilities).
5. Where there are sharp bends in the existing levee that may cause tension cracking.
6. Areas where sand is near the surface and could cause higher exit gradients.

7. Along the entire perimeter of the reservoir islands.

For this technical memorandum, the total lengths of the mitigation measures are about 37,000 feet at Webb Tract and 34,000 feet at Bacon Island, totaling 71,000 feet. These lengths represent about 54% of the total length of the Webb Tract reservoir embankment length and about 45% of the Bacon Island reservoir embankment length.

C-4 EVALUATION

The mitigation measures would need to protect against piping during both inward seepage (toward reservoir) and outward seepage (toward slough) conditions. The reservoir and slough water levels and differential heads are summarized below:

Seepage Direction	Slough-side W.L.	Reservoir-side W.L.	Differential Head
Inward, toward reservoir	+3.5 feet (high tide)	-18 feet (nearly empty; Sept. to Jan.)	21.5 feet
Outward, toward slough	-1.0 feet (low tide)	+4.0 feet (high water level; May to June)	5 feet

The greater differential head is when the slough water level is high and the reservoir level is low (inward seepage). This represents the more critical scenario for piping. Therefore, piping mitigation would be more important during this period than for the outward seepage condition. Furthermore, during the 100-year flood event, the slough-side water level would be at elevation +7.0, increasing the differential head to 25 feet.

The main points from the alternatives comparison in Table C-1 are summarized below:

- Alternative 1: Crackstoppers (or crack fillers) would have doubtful effectiveness to mitigate piping potential (Sherard and Dunnigan, 1985), and they would have the highest cost of the alternatives.
- Alternative 2: Granular filter blanket with finger drain outlets to the reservoir side would provide piping mitigation for the inward seepage condition. However, for the outward seepage condition, this system would likely increase piping potential because the filter would cause full hydrostatic head on the reservoir side of the levee.
- Alternative 3: Filter fabrics may be used for piping mitigation as they would prevent piping and could provide bridging over cracks. They also have the lowest cost compared to the other alternatives. However, filter fabrics are subject to tearing and separation at joints and their longevity is an issue.
- Alternative 4: Slurry walls could run or move into open cracks and there is a constructibility concern of slurry walls through peat, which could cause squeezing ground conditions.
- Alternative 5: Geomembranes are limited to a depth of 40 feet using vibratory installation, without pre-excavation.

- Alternative 6: The seepage wells would have to be operated continuously to be effective, and would not be reliably effective during earthquakes.

C-5 CONCLUSIONS AND RECOMMENDATIONS

Based on effectiveness, constructibility, and cost considerations, the preferred alternative to mitigate piping is Alternative 3, filter fabric. This alternative would provide piping protection for materials that are up-gradient of the fabric and they would have the lowest cost. The final determination on the selected locations along the reservoir embankments will be based on further engineering studies.

C-6 REFERENCES

Sherard, J.L. and Dunnigan, L.P. (1985). Filters and Leakage Control in Embankment Dams, in Seepage and Leakage from Dams and Reservoirs, Proceedings of the Geotechnical Engineering Division, ASCE. May, pp. 1-30.

URS (2003). In-Delta Storage Program, Embankment Design Analysis, April.

Table C-1

Comparison of Piping Mitigation Alternative Concepts

Evaluation Factors	Alternative 1: Crackstopper	Alternative 2: Granular Filter	Alternative 3: Filter Fabric	Alternative 4: Slurry Wall	Alternative 5: Vertical Membrane	Alternative 6: Pumping Well System
Description:	• Between new embankment fill and existing levee. • Well-graded material from gravel sizes to sand sizes. • Approx. 50-foot along slope between existing levee and new fill, 5 feet thick normal to slope.	• Between new embankment fill and existing levee, with finger drain outlets to reservoir side. • Sand-sized materials. • Approx. 50 feet along slope between existing levee and new fill, 2-feet thick normal to slope. • Finger drain outlets: 20’ wide x 2’ thick at 200’ intervals. • Finger drain outlets at approx. 200-foot intervals.	• Between new embankment fill and existing levee. • Use heavy-duty filter fabric. • Approx. 50 feet along slope between existing levee and new fill.	• Crest of embankment, and extended into top of the sand layer. • Soil bentonite in trench, 2 feet to 3 feet thick	• Crest of embankment, and extended into top of the sand layer. • Geomembrane (e.g., 80 mil to 100 mil thick, 4-foot wide panels of HDPE), vibrated into place with mandrel.	• Crest of embankment, and extended into sand layer. • 50-feet deep; spacing would not exceed 200 feet.
Mechanism to Mitigate Piping:	• Would fill cracks with sand to mitigate potential for piping.	• The filter gradation would be based on the materials that it would protect from piping.	• The filter fabric would protect embankments from piping, similar to Alternative 2.	• The slurry wall (soil-bentonite) would remain plastic and would disrupt the propagation of a crack through the embankment, and thereby prevent development of a pathway for concentrated seepage and piping.	• The geomembrane would disrupt the propagation of a crack through the embankment, and thereby prevent development of a pathway for concentrated seepage and piping.	• The pumping wells would drawdown the phreatic surface within the embankment to a low point within the embankment and thereby prevent an emerging seepage face. • Would need to operate system continuously for it to work.
Effectiveness:						
During construction (inward: slough level higher than reservoir level)	• Doubtful that this feature would be effective to control piping.	• Would prevent piping of new embankment and existing levee materials.	• Would prevent piping of existing levee materials.	• The slurry wall would need to be constructed from the crest of the new embankment fill to avoid potential damage due to displacement from settlement, and therefore, would not provide protection during construction.	• The geomembrane could be constructed from the crest of the existing levee to provide protection during construction. • May prevent piping of new embankment and existing levee materials.	• The wells would need to be constructed from the crest of the new embankment fill to avoid potential damage due to displacement from settlement, and therefore, would not provide protection during construction.
Operations (inward: slough level higher than reservoir level; outward: slough level lower than reservoir level)	• Same as during construction.	• Granular filter blanket with finger drain outlets to the reservoir side would provide piping mitigation for inward seepage. • For outward seepage, this system would likely increase piping potential because the filter would cause full hydrostatic head on the reservoir side of the levee.	• Would prevent piping of existing levee materials when slough-side water level is higher than reservoir level. • May prevent piping of new embankment materials when slough-side water level is lower than reservoir level.	• May prevent piping of new embankment and existing levee materials when slough-side water level is higher than reservoir level. • May prevent piping of new embankment and existing levee materials when slough-side water level is lower than reservoir level.	• May prevent piping of new embankment and existing levee materials when slough-side water level is higher than reservoir level. • May prevent piping of new embankment and existing levee materials when slough-side water level is lower than reservoir level.	• Would require operation of the pumping system to prevent piping of embankment materials when slough-side water level is higher than reservoir level. • Would require operation of the pumping system to prevent piping of embankment materials when slough-side water level is lower than reservoir level.

Table C-1

Comparison of Piping Mitigation Alternative Concepts

Evaluation Factors	**Alternative 1: Crackstopper**	**Alternative 2: Granular Filter**	**Alternative 3: Filter Fabric**	**Alternative 4: Slurry Wall**	**Alternative 5: Vertical Membrane**	**Alternative 6: Pumping Well System**
Earthquake (inward: slough level higher than reservoir level; outward: slough level lower than reservoir level)	• Same as during construction.	• Same as for operation condition.	• Same as for operation condition.	• Less likely than for operation condition.	• Less likely than for operation condition.	• Pump system would have to be in operation to provide protection. • Possibility that power would be unavailable and that some wells would be disabled due to earthquake; back-up power system would be needed. • Not reliably effective during earthquakes.
Constructability Issues:	• Straightforward to place crackstopper filter materials, as the embankment is raised.	• Straightforward to place filter materials, as the embankment is raised.	• Straightforward to place filter fabric, as the embankment is raised. • Need to overlap panels longitudinally and with elevation during fill placement. • Protect against sunlight and damage during fill placement.	• Peat may cause squeezing into the slurry trench.	• 40 feet is maximum depth for vibratory installation, greater depths would require pre-excavation and support. • Subcontractor likely needed for construction.	• Would have to raise well casings and protect them during fill placement to raise the levees (if installed prior to fill placement). • Subcontractor likely needed for construction.
Risks of Unsatisfactory Performance:	• Crackstopper material may enter crack and it may prop crack open and prevent it from closing.	• Filter material could run though an open crack.	• Filter fabric may tear or separate at joints due to settlement during construction. • Longevity issue with filter fabric materials.	• Stability of embankment with slurry wall may be reduced; stability would need to be assessed. • Slurry could run into open cracks.	• Stability of embankment with slurry geomembrane wall may be reduced; stability would need to be assessed. • Geomembrane may separate or tear at joints due to settlement during construction. • Longevity issue with geomembrane materials.	• Large settlement and deformation during construction and seismic events could damage the wells.
Flexibility to Add:	• Crackstopper is not accessible for future additions.	• Filter is not accessible for future additions.	• Filter fabric is not accessible for future additions	• Can add slurry wall from embankment crest.	• Can add geomembrane from embankment crest.	• Can add wells from embankment crest.
Costs:						
Unit costs and quantities	• $50/cy • Webb Tract: 1,150,000 cy • Bacon Island: 1,040,000 cy • Total: 2,190,000 cy (includes 20% additional volume)	• $50/cy • Webb Tract: 490,000 cy • Bacon Island: 445,000 cy • Total: 935,000 cy (includes 20% additional volume)	• $0.25/sf • Webb Tract: 5,680,000 sf • Bacon Island: 5,150,000 sf • Total: 10,830,000 sf (includes 10% additional area to allow for panel overlaps)	• $9/sf • Webb Tract 1,045,000 sf • Bacon Island: 1,080,000 sf • Total: 2,125,000 sf	• Material cost of $7/sf plus installation cost of $4/sf = $11/sf (vendor quote from GSE, Houston, TX) • Webb Tract 1,045,000 sf • Bacon Island: 1,080,000 sf • Total: 2,125,000 sf	• $25,000 per well, header and pump (spaced at 200 feet), or $125/lf. • Part of this cost is already included in the reservoir embankment cost; need an additional coverage of 21,500 lf for Webb Tract and 3,200 lf for Bacon Island (total = 24,700 lf).
Estimated total cost (for 71,000 lf)	• $109.5 million	• $46.8 million	• $2.7 million	• $19.1 million	• $23.4 million	• $3.1 million • Plus O&M costs