EBMUD-177
12a-12b.

EAST BAY MUNICIPAL UTILITY DISTRICT

DATE: October 23, 2007

MEMO TO: Board of Directors

THROUGH: Dennis M. Diemer, General Manager

FROM: Xavier J. Irias, Director of Engineering and Construction

SUBJECT: Strategy for Protecting the Mokelumne Aqueducts in the Delta

RECOMMENDED ACTION

1. Accept the attached staff report, "Strategy for Protecting the Mokelumne Aqueducts in the Delta," which discusses the hazards and risks to the aqueducts and evaluates alternative options to mitigate those hazards and risks.
2. Direct staff to use its findings and recommendations in planning future water conveyance capital improvement programs and technical studies, and participating in statewide Delta initiatives.

SUMMARY

The Mokelumne Aqueducts in the Delta area are a critical component of EBMUD's water system and the State of California's (State) overall water infrastructure. EBMUD has interconnections with the San Francisco Public Utilities Commission and the Contra Costa Water District, making the aqueducts a linchpin in an increasingly integrated regional water system. Consistent with this importance as a vital water supply element, over the years EBMUD has invested heavily in improving aqueduct security and making levee improvements to protect this facility. The efficacy of these measures depends upon the State continuing to maintain and repair the Delta levee system. With the advent of the Delta Vision process, the Department of Water Resources (DWR) and the State have clearly signaled that their future maintenance of the levees is not assured.

EBMUD has carefully evaluated the hazards and risks of aqueduct failure in the Delta, prompted in part by the limited prospects for a continuing DWR role in protecting the levee system. The findings of the evaluation identify the best long-term option as a tunnel below the Delta to enclose dual pipelines. This option would provide a high degree of protection against both flooding and seismic events, with a preliminary cost of approximately $650 million. The tunnel would take several years to plan, design and construct. Accordingly, interim measures are also recommended to maintain the levees and provide greater operational flexibility. The attached

Summary Report on this evaluation discusses the hazards and risks to the aqueducts in the Delta, the array of alternative options and the evaluation of each alternative.

Preliminary results of this evaluation were discussed at the Finance/Administration Committee on August 14, 2007.

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Attachment

Strategy for Protecting the Mokelumne Aqueducts in the Delta

Summary Report

Prepared By
East Bay Municipal Utility District
October 2007

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1. INTRODUCTION

1.1 Background

The East Bay Municipal Utility District's (EBMUD) Mokelumne Aqueducts traverse approximately 15 miles of the Sacramento-San Joaquin Delta area. See Figure 1 below.

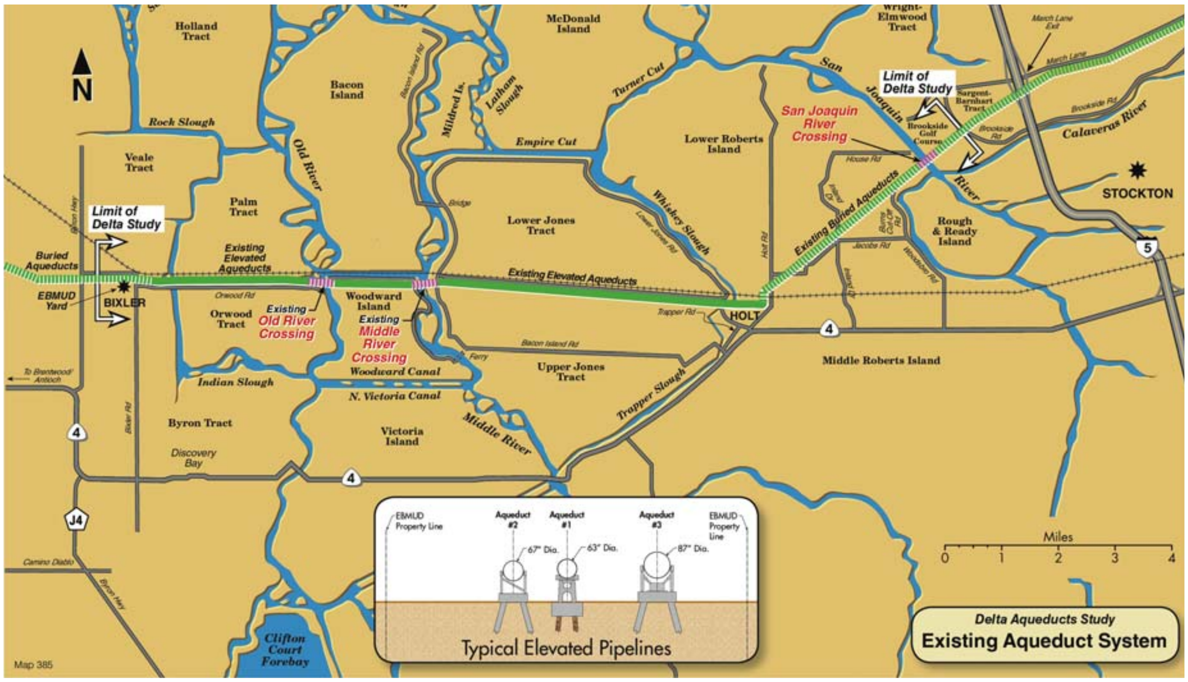

Figure 1: Existing Aqueduct System

The three aqueducts are a vital lifeline for EBMUD's 1,300,000 customers, carrying approximately 95 percent of their water supply. Accordingly, EBMUD has, over the years, taken a variety of measures to ensure the reliability of the aqueduct pipelines. Most recently, in 2004, EBMUD completed a $40 million seismic upgrade to the largest of the three aqueducts.

Even with those improvements, the continued reliability of the aqueducts depends upon the Delta levee system. In recent years, the future of that levee system has become doubtful, based on scientific assessments of the levees' fragility and of long-term threats to levee stability such as ground subsidence and global climate change. Compounding these structural issues are environmental concerns about the impact of water diversions on fisheries and other resources. In recognition of the need to proactively address the Delta's future, the State of California (State) is currently conducting studies on the Delta region as part of their Delta Vision, Delta Risk Management Strategy (DRMS) and Bay Delta Conservation Plan projects. The State's Delta Vision process will result in recommendations for sustainable management of the Delta region. In the meantime, in light of the staggering cost of levee repair for the 2004 Jones Tract levee failure, the State is examining whether or not it will commit to repairing future levee failures. This potential change in policy makes EBMUD's aqueducts in the Delta unsustainable in their current configuration.

This report recommends a strategy to secure EBMUD's water supply through the Delta region in light of the emerging State strategy for managing the Delta. It identifies a range of possible short-term and long-term alternatives and then evaluates each alternative for its cost as well as its risk reduction benefits.

1.2 Study Objective

The study objective is to recommend strategies, both short and long term, for protecting the aqueducts in the Delta region against a variety of hazards. The hazards include earthquakes, storm flooding, Delta island subsidence, and climatic changes driving sea level rise. The study considers the need to protect the aqueducts not only from direct impacts of each hazard, but indirect impacts caused by levee failure.

The project limits of this study consist of approximately 15 miles of aqueduct alignment across the Sacramento-San Joaquin Delta area. See Figure 1 for the map of the aqueducts in the Delta region and the project limits. This reach of the aqueducts consists of approximately 4.5 miles of buried pipeline, 10 miles of elevated pipeline, and 3 major river crossings with about 0.5 miles of submerged pipeline.

In seeking to protect EBMUD's water lifeline through the Delta, this study considers not only the probability of damage to the aqueducts in the Delta, but also the degree of damage. Specifically, the available aqueduct flow in a damaged state is considered, as well as the likely duration of repairs. One key criterion to evaluate alternatives is whether at least 177 million gallons per day (MGD) is available soon after a hazard event such as a flood or earthquake. This is the estimated flow available when Aqueduct No. 3 is the sole functioning aqueduct in the vulnerable Delta region; it also roughly matches winter-time average demands.

The strategies developed in this report will be used in EBMUD's decision-making as well as guiding its participation in regional Delta strategies advanced by the State or others.

1.3 Study Approach

A series of Technical Memoranda (TM) were prepared to study the following topics:

- Development of Alternatives (TM No. 1).
- Cost of Each Alternative (TM No. 2).
- Risk Evaluation of Alternatives (TM No. 3).
- Risk versus Benefit for Each Alternative (TM No. 4).

The next section of this report summarizes findings. The third and main section of this report follows a similar flow as the TMs, describing the developed alternatives, their costs, and their performance considering a full range of hazards. Individual TMs provide more detailed information and are available for review.

2. SUMMARY

The recommended long-term alternative is a tunnel below the Delta to enclose dual pipelines. By providing a high degree of protection against all identified hazards, the tunnel would provide a reliable water supply for EBMUD's customers.

The tunnel would be approximately 10.5 miles long, running parallel and approximately 80 feet beneath the existing aqueducts between Holt and Bixler. See Figure 2 below. The preliminary cost of this alternative is $445 to $950 million. This option was considered the best of all alternatives studied because of its:

- Reliability against flood and seismic hazards.
- Low life-cycle cost considering its reliability.
- Least risk of unacceptable service interruption.

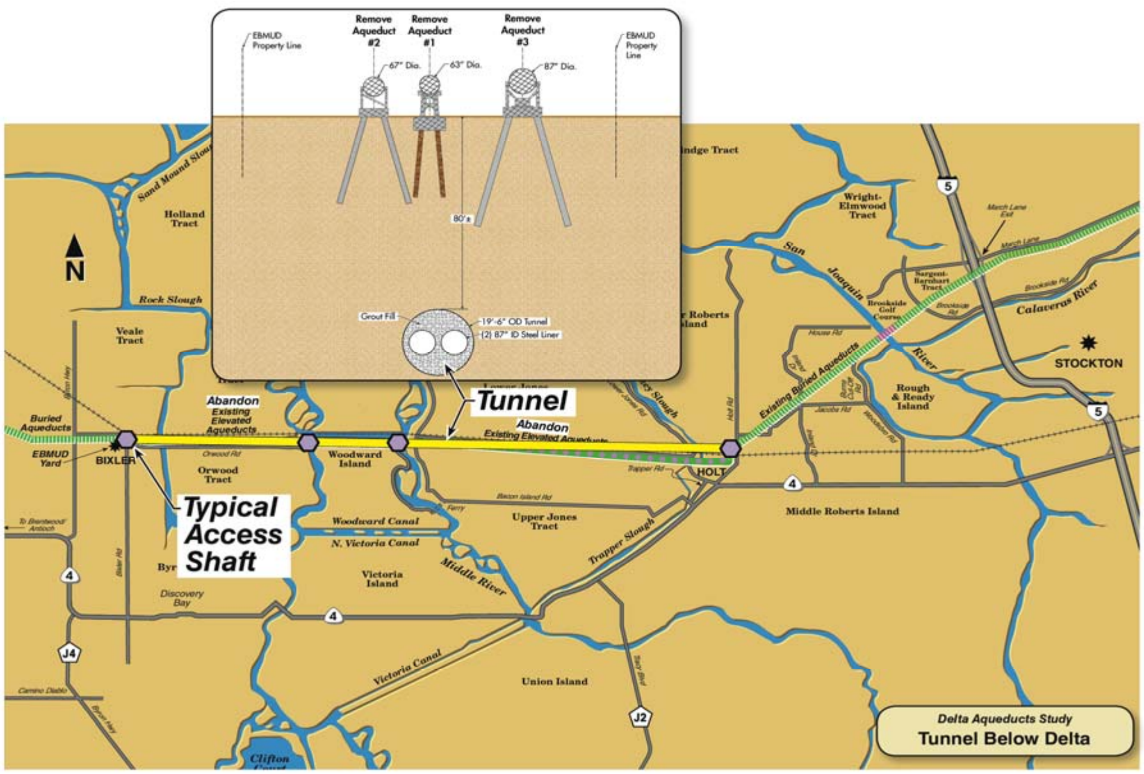

Figure 2: Recommended Alternative - Tunnel Below Delta

As it will take several years to implement the preferred long-term alternative even when funding issues are resolved, short-term, incremental improvements are also recommended. Those improvements provide interim security for EBMUD's water supply and are consistent with the recommended long-term alternative:

- Aqueduct Cross Connections: Install piping and valving to inter-connect Mokelumne Aqueduct Nos. 1, 2 and 3 on either side of the vulnerable Delta region. This work will improve hydraulic capacity and flexibility of the aqueducts during emergencies, for maintenance, and will continue to provide utility even after the proposed long-term alternative is constructed. To improve operational flexibility, this short-term alternative may also include aqueduct isolation valves upstream of the Walnut Creek East Portal crossover pipeline. The cost of this element is approximately $10 million.

- Additional Technical Studies: Complete preliminary planning, geotechnical, and conceptual design studies for the proposed tunnel; this will minimize emergency response time in the event of a catastrophic levee failure occurring over the next several years. The cost of this element is approximately $20 million.

  This alternative would include additional geotechnical studies that would be conducted between Holt and the San Joaquin River to further study the risk of liquefaction and potential for damage to existing buried aqueducts in that area. Depending on the results of these studies, the recommended tunnel alternative may need to be extended east beyond the San Joaquin River.

- Levee Improvements and Repair Materials: Reinforce river crossings by stabilizing the "river-side" of the levees, stockpile pipe and levee repair material, and install limited scour protection improvements (i.e., sheet piling) along the aqueduct alignment. This element is approximately $83 million.

The availability of state bond funding to help implement the short-term actions is being investigated.

3. TECHNICAL ANALYSIS

3.1 Development of Alternatives

A key assumption used in this study is that, in the long-term, all alternatives must be capable of supplying a raw water delivery capacity of 325 MGD, with pumping on all three aqueducts. An additional assumption is that under emergency conditions, the *minimum* needed raw water capacity, with Aqueduct No. 3 in service (with pumping) and Aqueduct Nos. 1 and 2 out of service through the Delta is 177 MGD, while a more desirable capacity is 192 MGD, which could meet year-round demands with 25 percent rationing per the Water Supply Management Program (WSMP) 2040 projections.

In TM No. 1, sixteen alternatives are identified to reduce risks associated with flood and seismic hazards to the Mokelumne Aqueducts through the Delta region. That TM discusses the relative advantages and disadvantages of the 16 alternatives. The alternatives are summarized in Table 1 below.

Table 1: List of Alternatives

Alt No.	Type of Alt. Short-Term	Type of Alt. Long-Term	Name	Objective	Description
1	✓		Existing system	Status quo	Maintains existing system without capital improvements.
2		✓	Levee scour protection	Minimize hazard of levee failures	Provides levee improvements (i.e., sheet piling) to prevent scour at levee breaches.
2A	✓		Levee improvements at river crossings and limited scour	Minimize hazard at river crossings and reduce scour risk along aqueduct	Provide “water-side” levee improvements (i.e., driven piles) to prevent failure of Aqueduct No. 3 at river crossings, and provide scour protection at railroad levee opening.
3	✓	✓	Aqueduct cross-connections	Improve emergency response	Provides piping and valving between aqueducts to allow water to by-pass aqueducts that are out of service.
4	✓		Aqueduct coating for flooded condition	Improve emergency response	Provides coating of aqueducts and support structures across Delta to extend life under submerged conditions.
5	✓		Stockpile pipe and levee repair materials	Improve emergency response	Provides material per Aqueduct Emergency Response and Recovery Plan.
6		✓	Parallel levees with pipes at existing ground-level	Minimize seismic and flood hazards	Provides new levees (10.5 miles) on both sides of existing aqueducts.
7		✓	Strengthen perimeter levees	Minimize flood hazard	Provide levee improvements to PL84-99 Ag. Levee Standards for up

Alt No.	Type of Alt.		Name	Objective	Description
	Short-Term	Long-Term			
			for flood protection		to 51 miles of levees near the aqueducts.
8		✓	Strengthen perimeter levees for seismic protection	Minimize seismic hazard (and also flood hazard)	Provide levee improvements, including new setback levees and foundation jet grouting for up to 51 miles of levees near aqueducts.
9		✓	Two elevated pipes in Delta	Minimize seismic and flood hazard	Provides two 87-inch diameter pipelines elevated above flood level across Delta (10.5 miles).
9A		✓	Two elevated pipes in Delta with scour protection	Minimize seismic and flood hazard	Provides two 87-inch diameter pipelines elevated above flood level across Delta with scour protection.
10		✓	Tunnel under Delta	Minimize seismic and flood hazard	Provides new 19.5 feet diameter tunnel with dual 87-inch carrier pipes at depth of 80 feet across Delta (10.5 miles).
11		✓	New earthen berm (causeway) with raised pipes	Minimize seismic and flood hazard	Provides a new levee with two 87-inch pipelines parallel to existing aqueduct alignment (10.5miles).
12	✓	✓	Pre-emptive planning and design	Improve emergency response	Provides planning and design for new long-term alternative to minimize response time following Delta emergency.
12A	✓	✓	Preliminary planning studies	Improve emergency response	Complete preliminary planning, geotechnical, and conceptual design studies for the proposed tunnel.
13		✓	Aqueducts by-passing the Delta	Minimize seismic and flood hazard	Provides two 99-inch diameter buried pipelines around the Delta (40 miles).
14		✓	Supply around Delta via State-owned canal	Minimize seismic and flood hazard	Provides connection to a State-owned canal with new intake, piping, treatment plant and pumping plant.
15		✓	Two buried pipelines in Delta	Minimize seismic and flood hazard	Provides two new 87-inch diameter pipelines that are buried to a depth of approximately 10 feet (10.5 miles).
16		✓	Bridge-supported pipelines	Minimize seismic and flood hazard	Provides two 87-inch pipes elevated by a new bridge across the Delta (10.5 miles).
16A		✓	Bridge-supported pipelines with scour protection	Minimize seismic and flood hazard	Provides two 87-inch pipes elevated by a new bridge across the Delta with scour protection.

Alternative 2A was added as a short-term, incremental improvement that could be implemented to reduce the potential for levee failures at river crossings and reduce the potential for structural failure to Mokelumne Aqueduct No. 3 due to scour damage.

Alternatives 9A and 16A (elevated pipes and bridge-support pipes) were added to evaluate them as long-term alternatives that would mitigate against all hazards, including scour, and to allow them to be compared against Alternative 10, which mitigates all hazards (see Section 3.3).

Staff conducted a preliminary evaluation and screening of alternatives and determined that Alternative 15 (two buried pipes in Delta) should not be carried further in subsequent analysis. The disadvantages of this alternative far outweigh the advantages and there are superior alternatives remaining. Disadvantages of this option include the need for significant additional property acquisition, difficult construction conditions (trenching for pipeline installations would require installation of continuous sheet pile walls and dewatering) and potential for extremely difficult access for maintenance and operations (could require below-water operation and maintenance in a flooded Delta).

3.2 Cost of Each Alternative

Capital Cost

In TM No. 2, preliminary capital cost estimates for the 15 alternatives carried forward from TM No. 1 were prepared. The cost estimates are "total project cost" and included costs for planning, design, construction management and construction, expressed in year-2007 dollars. Those estimates are summarized below in Table 2.

Table 2: Capital Costs of Alternatives

Alt. No.	Type of Alt.		Alternative Name	Preliminary Capital Cost [1] ($ million)
	Short-Term	Long-Term		
1	✓		Existing system	n/a
2		✓	Levee scour protection	205-440
2A	✓		Levee improvements at river crossings and limited scour	35-75
3	✓	✓	Aqueduct cross-connections	7-14
4	✓		Aqueduct coating for flooded condition	137-295
5	✓		Stockpile pipe and levee repair materials	22-47
6		✓	Parallel levees with pipes at existing ground-level	860-1,842[2]
7		✓	Strengthen perimeter levees for flood protection	447-959
8		✓	Strengthen perimeter levees for seismic protection	3,089-6,620
9		✓	Two elevated pipes in Delta	409-877

Alt. No.	Type of Alt.		Alternative Name	Preliminary Capital Cost [1] ($ million)
	Short-Term	Long-Term		
9A		✓	Two elevated pipes in Delta with scour protection	614-1,317[4]
10		✓	Tunnel below Delta	445-950
11		✓	New earthen berm (causeway) with raised pipes	1,390-2,976
12	✓	✓	Pre-emptive planning and design	58-125
12A	✓	✓	Preliminary planning studies	14-30
13		✓	Aqueducts by-passing the Delta	1,358-2,910
14		✓	Supply around Delta via State-owned canal	934-2,002
15		✓	Two buried pipelines in Delta	n/a[3]
16		✓	Bridge-supported pipelines	1,691-3,624
16A		✓	Bridge-supported pipelines with scour protection	1,896-4,064[4]

1. Cost range in accordance with EBMUD Engineering Standard Practice-Preliminary cost estimates are expressed in a cost range with accuracy of -30 percent to +50 percent.
2. Unit cost for new levees based on Mokelumne Aqueduct Seismic Upgrade Project, Technical Memorandum No. 3, by Roger Foott Associates, June 12, 1995; Levee geometry based on TM No. 1, Figure 8a, and DRMS Building Block 1.2: Upgraded Delta Levee Seismic Resistance Improvement Option 1, 2007.
3. Alternative 15, two buried pipelines in the Delta, was screened out prior to cost estimating, based on impracticability for maintenance should the Delta islands be permanently submerged.
4. Added scour protection to Alternatives 9 and 16 to fully mitigate Delta hazards. See Section 3.3.

Life-Cycle Cost Analysis

Operating and maintenance costs were estimated for each alternative and used in calculating the life-cycle costs. The costs were run out to the year 2082 to be on par with the likely asset life of many of the alternatives. Life-cycle costs for short- and long-term alternatives are summarized in Figures 3 and 4, respectively. It should be noted that short-term Alternatives 2A, 3, 5, 12, and 12A in Figure 3 also include the cost for operating and maintaining the existing system (i.e., Alternative 1) in order to present them as stand-alone alternatives.

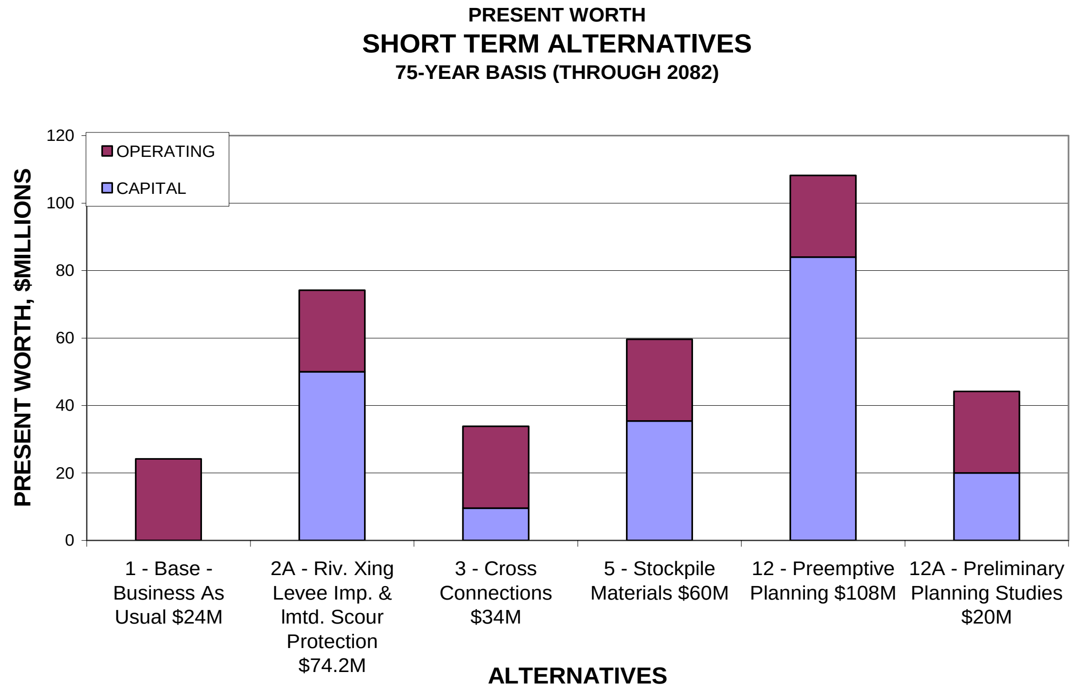

Figure 3: Life-cycle Costs – Short-Term Alternatives

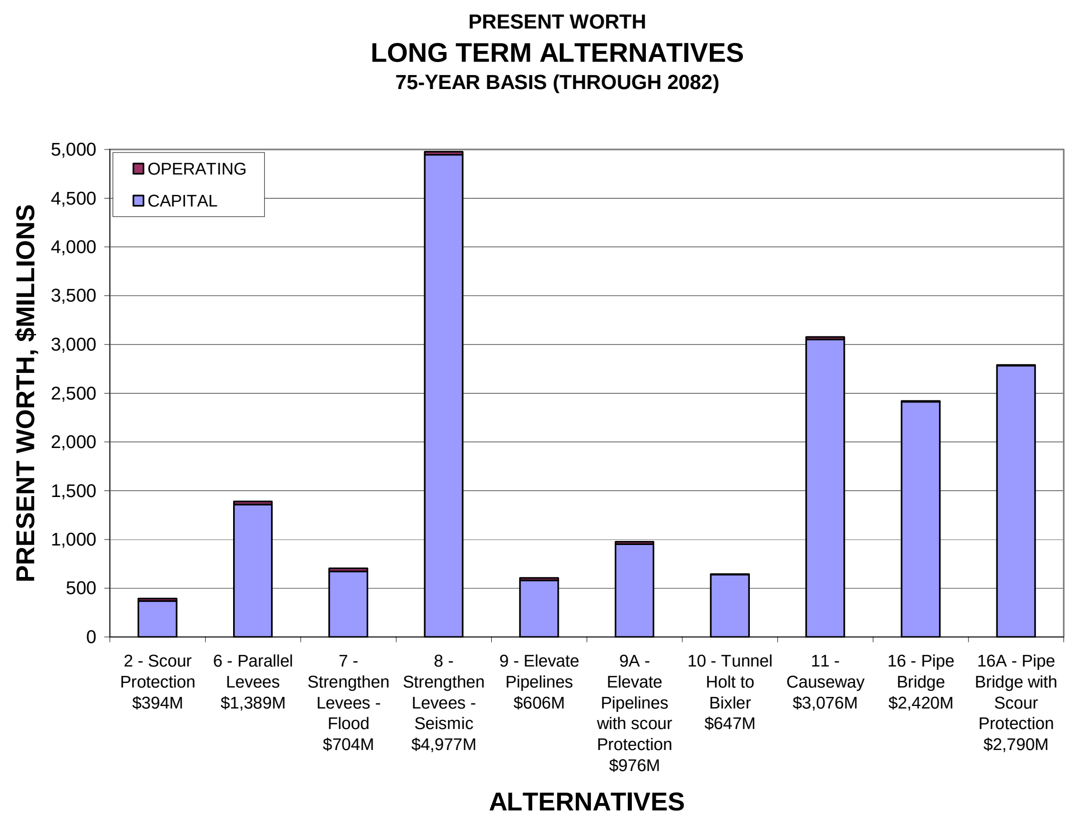

Figure 4: Life-cycle Costs – Long-Term Alternatives

The following alternatives were screened out based on costs and other reasons given below:

- Alternative 4: Aqueduct coating for flooded conditions. This alternative was not carried forward as it was considered impractical for staff to operate and maintain the aqueducts while in a flooded condition.

- Alternative 13: Aqueducts by-passing the Delta. This alternative was screened out because it is more expensive than other options (Alternatives 9 and 10) that provide at least as much risk mitigation. It would also require substantial property acquisition.

- Alternative 14: Supply around Delta via State-owned canal. This alternative was screened out because its capital and operating costs are staggering. Capital costs are $1.3 billion, and operations and maintenance costs are $48 million/year for pumping and water treatment beyond that experienced with today's aqueduct system.

3.3 Risk Analysis

In TM No. 3, the hazards associated with earthquakes and/or flooding and their respective probability of occurrence were identified and their associated risks were estimated. Six major hazards to the aqueducts in the Delta region are:

- Scour (SCR) – A levee failure in close proximity of the aqueducts would likely damage the aqueducts by scouring the foundation.
- Ground subsidence (SUB) – Ground subsidence contributes to increased water seepage through levees leading to levee instability and decreasing crest elevation of the levees, thereby making them more vulnerable to overtopping in the event of flooding.
- Earthquake ground shaking (EQ) – The aqueducts are vulnerable to direct structural damage from earthquake shaking.
- Flooding (FLD) – The aqueducts are not suited for long-term operation in flooded conditions as the system lacks protection from corrosion, wave impacts and buoyancy.
- Earthquake Induced Liquefaction (LIQ) – Aqueduct and levee foundation materials may liquefy during an earthquake.
- Earthquake-induced lateral spreading (LS) – Lateral spreading of levees caused by an earthquake could damage the aqueducts.

A vulnerability analysis of the aqueducts was conducted for these hazards under normal "sunny day" conditions, floods, and seismic events. Each of the project alternatives was able to mitigate one or more of the hazards in the Delta area. A summary of this evaluation is shown in Table 3. That table includes the probability, for each alternative, of various key failure modes. As indicated in the table, Alternative 10, a tunnel below the Delta, comprehensively mitigates all hazards. Other alternatives need to be combined or modified to mitigate all hazards. Scour protection was added to Alternatives 9 (resulting in Alternative 9A) and 16 (resulting in Alternative 16A). With scour protection, the cost of Alternatives 9A and 16A totals approximately $980 and $2,790 million, respectively, which is significantly higher than the estimated $650 million cost for the tunnel alternative. Including these modifications, Alternatives 9A, 10, 11 and 16A comprehensively mitigated all Delta hazards.

Alternatives 12 and 12A include additional geotechnical studies, between Holt and the San Joaquin River, to further study the risk of liquefaction and potential for damage to existing buried aqueducts in that area. Depending on the results of these studies, the scope of long-term Alternatives 9A, 10, 11 and 16A may need to be extended east beyond the San Joaquin River to mitigate the risk for damage to the existing aqueducts between Holt and the San Joaquin River.

Another key measure of performance, beyond probability of failure, is the estimated available flow following a hazard event. Table 3 tabulates this information in the rightmost column. As indicated, only Alternative 10 (tunnel below Delta) and Alternatives 9A, 11 and 16A, are likely to have the full 325 MGD capacity after a hazard event occurs. However, Alternative 3, aqueduct interconnects, does provide substantially more capacity (246 MGD) than most of the other alternatives.

The next section describes how the results of the risk analysis were used to formulate a recommended package of near- and long-term alternatives.

Table 3: Summary of Risk Mitigation for Each Alternative

Summary of Risks and Probabilities of Failure for Each Project Alternative						
Alt No.	**Alternative Description**	**Hazards (see Note 1)**		**% Probability of Flooding Due to Levee Failure (see Note 2)**	**% Probability of Structural Failure to Aqueduct No. 3**	**Flow Capacity (MGD) (see Note 3)**
		Mitigated	**Not Mitigated**			
1	Existing system	--	SCR, SUB, EQ, FLD, LIQ, LS	68-89	10-20	177
2	Levee scour protection	SCR	SUB, EQ, FLD, LIQ, LS	68-89	10-20	177
2A	Levee improvements at river crossings and limited scour	LIQ, LS, SCR (at isolated locations)	FLD, SUB, EQ	68-89	2	177
3	Aqueduct cross-connections	--	SCR, EQ, SUB, LIQ, LS	68-89	10-20	246
5	Stockpile pipe and levee repair materials	FLD	SCR, SUB, EQ, LIQ, LS	68-89	10-20	177
6	Parallel levees with pipes at ground level	FLD, LIQ, LS, SCR	SUB, EQ	2	10-20	177
7	Strengthen perimeter levees for flood protection	FLD	SCR, SUB, EQ, LIQ, LS	68-89	10-20	177
8	Strengthen perimeter levees for seismic protection	FLD, SCR	SUB, EQ, LIQ, LS	2	10-20	177
9	Two elevated pipes in Delta	SUB, EQ, FLD, LIQ, LS	SCR	2	10-20	177
9A	Two elevated pipes in Delta with scour protection	SUB, EQ, FLD, LIQ, LS, SCR	--	2	2	325
10	Tunnel below Delta	SCR, SUB, EQ, FLD, LIQ, LS	--	2	2	325
11	Earthen berm with raised pipes	SUB, EQ, FLD, LIQ, LS, SCR	--	2	2	325
12	Preemptive planning and design	--	SCR, SUB, EQ, FLD, LIQ, LS	N/A	20	177
12A	Preliminary Planning Studies	--	SCR, SUB, EQ, FLD, LIQ, LS	N/A	20	177
16	Bridge-supported pipelines	SUB, EQ, FLD, LIQ, LS	SCR	2	10-20	177
16A	Bridge-supported pipelines with scour protection	SUB, EQ, FLD, LIQ, LS, SCR	--	2	2	325

Notes: 1) Hazards abbreviations:

SCR	=	scour
SUB	=	subsidence
EQ	=	earthquake ground shaking
FLD	=	flooding
LIQ	=	liquefaction
LS	=	lateral spreading
N/A	=	not applicable

2) See TM No. 3 for additional risk assessment data and probability estimates for specific reaches.

3) See TM No. 3 results of hydraulic analyses and assumptions used to estimate flow capacities. Flow capacities presented as 177 MGD are for restored flow to Aqueduct No. 3 after emergency outages.

3.4 *Evaluation of Alternatives*

Three primary factors were used in identifying the preferred alternative: the level of risk reduction to hazards in the Delta, the corresponding flow rate (i.e., least impact to level of service) and benefit to cost ratio of implementing an alternative.

Table 3 on page 13 summarizes the performance of each alternative, expressing risks as percentages. Table 4 below distills this information into relative scores for the three criteria, and also presents a conceptual benefit-cost ranking for each alternative based on the results of analyses presented in TM No. 4.

Table 4: Summary of Risk Analysis

Alt. No.	Alternative	Risk Reduction	Benefit / Cost Ratio	Flow Rate
1	Existing System	Low	Low	Reduced
2	Levee scour protection	Low	Low	Reduced
2A	Levee improvements at river crossings and limited scour	Low	Medium	Reduced
3	Aqueduct cross-connections	Low	High	Reduced (but improved)
5	Stockpile pipe and levee repair materials	Low	Medium	Reduced
6	Parallel levees with pipes at existing ground	Low	Low	Reduced
7	Strengthen perimeter levees for flood protection	Low	Low	Reduced
8	Strengthen perimeter levees for seismic protection	Low	Low	Reduced
9	Two elevated pipes in Delta	Medium	Medium	Reduced
9A	Two elevated pipes in Delta with scour protection	High	Medium	Full
10	Tunnel below Delta	High	High	Full
11	Earthen berm (causeway) with raised pipes	High	Low	Full
12	Preemptive planning and design	Low	High	Reduced
12A	Preliminary planning studies	Low	High	Reduced
16	Bridge-supported pipelines	Medium	Low	Reduced
16A	Bridge-supported pipelines with scour protection	High	Low	Full

Long-term Alternatives

Alternative 10, the tunnel below the Delta, mitigates all hazards in the Delta region. It also offers a high benefit-cost ratio, despite its relatively large capital cost.

The tunnel would be 19.5 feet in diameter, built using a tunnel boring machine. The tunnel would be concrete and steel lined and is sized to accommodate dual 87-inch diameter pipelines. The anticipated depth of the tunnel would be approximately 80 feet in order to stay below the soil susceptible to liquefaction. There would be vertical tunnel shafts at either end of the work and intermediate vertical accessibility points between Holt and Bixler. The total tunnel length is approximately 10.5 miles.

Several levee-oriented alternatives were determined to be unsuitable. Alternatives 7 and 8, consisting of two alternative degrees of levee strengthening, both fail to provide benefit commensurate with their huge costs. Alternative 6, with parallel levees along existing aqueducts, while providing flood protection, fails to mitigate against structural damage to Aqueduct Nos. 1 and 2 caused by seismic hazards.

Alternatives 9 and 16 (elevated pipes and bridge-supported pipes, respectively) mitigated most hazards in the Delta region, but were still vulnerable to scour. These alternatives were modified to provide improved scour protection (Alternatives 9A and 16A), but the costs increased substantially (approximately 60 percent for Alternative 9A and 15 percent for 16A), bringing them far beyond that of Alternative 10.

Alternative 10, by virtue of being the alternative that addresses all hazards and having a cost that is competitive with other alternatives providing far less benefit, is currently the most promising long-term option.

It is estimated that at least several years, perhaps up to ten years, would be needed to plan, design and construct Alternative 10, or indeed any of the alternatives that involve major pipeline or levee construction. Accordingly, short-term alternatives were also developed as discussed below.

Short-term Alternatives

Several alternatives are recommended during the period in which the recommended long term alternative is being implemented. These recommendations are shown in Table 5 below. Staff will vigorously advocate funding assistance in current legislation or grants to support implementation of these alternatives.

Table 5: Recommended Short-term Alternatives

Alternative	Description	Cost ($ million)
2A & 5	Reinforce river crossings, stockpile pipe and levee repair material, and install limited scour protection	83
3	Aqueduct cross-connections	10
12A	Preliminary planning studies	20
	Total	113

Each element of the short-term package is discussed in more detail below.

Alternative No. 2A: Reinforce river crossings and provide limited scour protection

This alternative would reduce the potential for levee failures at river crossings and reduce the potential for structural failure to Mokelumne Aqueduct No. 3 due to scour damage. Under this alternative, piles would be driven to sound underlying materials to improve the stability of the levees at the existing aqueduct crossings at Old, Middle and San Joaquin Rivers. These piles would be installed on the water side of the levees to reduce the potential for lateral spreading due to liquefaction. By reinforcing the "river-side" of the levees, these improvements would significantly reduce the potential for flow interruptions due to a river crossing failures.

Limited scour protection for the elevated aqueduct pipelines is also planned under this alternative. Fast-moving water as it floods an island results in extensive scour and, therefore, could damage the aqueduct supports. Historical scour profiles have been measured at up to 1,000 feet long and several hundred feet wide, with up to 80-foot depths. The existing breach in the railroad causeway at Upper Jones Tract is one such location. This breach is the highest risk location along the aqueduct system as the opening would allow flood waters to pass from one tract to the other, resulting in ground scour in the immediate area of the aqueduct supports. Other areas of scour concern, which include the north side of the alignment where the railroad berm or levees exist, along approximately 54,000 feet across the Upper Jones Tract, Woodward Island, and Orwood/Palm Tract, are included under Alternative 2, but are not part of this recommended short-term alternative.

In this recommended alternative, sheet piling would be installed opposite the existing breach in the railroad causeway at Upper Jones Tract, which presents the highest risk of scour damage. The length of sheet piling would be limited to approximately 500 to 1,000 feet along the aqueducts directly in front of the existing railroad embankment opening.

Alternative No. 3: Aqueduct cross-connections

Cross-connections between the aqueducts would allow water to by-pass segments of the pipelines that are out of service. Aqueduct Nos. 1 and 2 are more likely to be out of service following an earthquake. Aqueduct No. 3 would then be the sole conveyance pipeline across the Delta since it is of modern construction and was recently strengthened. The points of connection would be at Brookside Road in the east, and near Bixler Road in the west.

This alternative does not lower the probability of damage to the facilities, but reduces the consequence of damage and hence reduces total risk. These cross-connections will increase water supply rates following an emergency outage of Aqueduct Nos. 1 and 2 and, therefore, extend the duration of supply from terminal storage. Hydraulic studies have determined that cross-connections between Aqueduct Nos. 1, 2 and 3 could increase available flow from 177 MGD without the cross-connection to as much as 246 MGD.

This is a substantial benefit, given that 192 MGD is the minimum capacity to hold rationing at 25 percent or less during an extended outage, according to preliminary WSMP 2040 analyses.

Alternative No. 5: Stockpile pipe and limited levee repair materials

The reclamation districts maintain small supplies of levee repair and flood fighting materials such as sand, sand bags and rock rip-rap. Also, EBMUD has a limited inventory of pipeline replacement materials. EBMUD recently developed an Aqueduct Emergency Response and Recovery Plan to prepare for a major aqueduct failure. The plan, which focuses on pipe repair scenarios, outlines the initial response and provides conceptual repair plans for Mokelumne Aqueduct No. 3 in the Delta region. This plan was developed to bring the aqueducts back into service, but does not address the levee repairs that would be needed in the event of a breach. The materials that EBMUD needs to stockpile consist largely of replacement parts for the aqueducts. Enhancing the stockpile of materials will be considered as part of this alternative.

Under this alternative, limited amounts of levee repair materials would be identified, purchased and stockpiled at strategic locations around the islands to improve emergency response. This alternative does not directly lower the probability of levee failure, but may offer a quicker flood response, reduced damage and shortened dewatering timelines should one of the islands flood.

Alternative No. 12A: Preliminary Planning Studies

This alternative consists of conducting preliminary planning, geotechnical, and conceptual design studies for the proposed tunnel. Preliminary planning and conceptual design activities, include sizing and lay-out of tunnel facilities, more detailed review and analysis based on existing data, and updated cost estimates. Geotechnical studies would include soil investigations between Holt and the San Joaquin River to further study the risk of liquefaction and potential for damage to existing buried aqueducts in that area. Results of the geotechnical studies will be used to determine if the recommended tunnel alternative needs to be extended east beyond the San Joaquin River. The anticipated benefit derived from this alternative is a shorter repair time after a flood or earthquake that damages the aqueducts or levees.