TABLE OF CONTENTS

Tables

Figures

12.1 INTRODUCTION

12.1.1 Background

State Route (SR) 4 is the main east-west roadway through the south-central part of the Sacramento–San Joaquin River Delta (Delta); this highway provides a direct connection between Antioch to the west and Stockton to the east. SR 4 passes through the towns of Oakley, Brentwood, and Discovery Bay before traversing low-lying Delta areas, including Victoria Island, Middle Roberts Island, and Drexler Tract. To the north of SR 4, another east-west corridor that includes the BNSF Railway (BNSF) railroad, the East Bay Municipal Utility District (EBMUD) Mokelumne Aqueduct system, and the Kinder Morgan pipeline runs mostly parallel to SR 4 through the Delta, though in some places SR 4 and this corridor are up to 5 miles apart.

The Mokelumne Aqueduct system, which consists of three large-diameter steel pipelines (the pipeline diameters are 63 inches, 67 inches, and 87 inches [EBMUD 2007]), conveys water through the Delta to the San Francisco Bay Area. Within the Delta region, about 10 miles of the aqueduct system are aboveground pipelines that are supported by pipe saddles or bents.

The Kinder Morgan petroleum product pipeline, an underground steel pipeline that is 10 inches in diameter, is located about 10 feet south of the property line of the aqueducts and runs in parallel to the aqueducts within the Delta. The majority of the BNSF railroad was built on levee embankments across the Delta.

Pacific Gas and Electric Company (PG&E) has large-diameter gas pipelines in the vicinity that connect its gas storage and recovery facility on McDonald Island to other facilities in the Brentwood area. These pipelines are located north of the other facilities discussed here and are not considered as part of this building block.

All of the infrastructure just described is susceptible to flood damage because significant portions of these facilities are located at elevations below the 100-year flood elevations, according to Federal Emergency Management Agency (FEMA) flood insurance rate maps. Also, a significant portion of the existing levee network that currently protects this infrastructure is not seismically resistant.

Figure 12-1 shows the flash card for Building Block 2.2: Construct Armored Infrastructure Corridor Across Central Delta.

12.1.2 Purpose and Scope of Building Block

To reduce the risk that this essential infrastructure will be lost due to flooding, seismic activity, or both, this section evaluates the feasibility of constructing an armored infrastructure corridor with new levees. The new levees would be seismically resistant and would have elevations above the 100-year FEMA flood elevation. The threatened infrastructure would be relocated as part of the building block. Two options are considered technically feasible for the placement of the relocated infrastructure:

- Option 1: Construct two levees(a northern levee and a southern levee) across the central Delta. Construct SR 4 on the new southern levee and the BNSF railroad on the new northern

levee. The existing Mokelumne Aqueduct system and the Kinder Morgan pipeline would be unaffected by Option 1, unless the owners decide to seismically harden these facilities at additional cost.

- Option 2: Construct a single, larger levee to the south of the existing Mokelumne Aqueduct system. This new levee would carry the new SR 4, the BNSF railroad, the Mokelumne Aqueduct system, and the Kinder Morgan pipeline.

A conceptual layout, cross section, and cost estimate are prepared for each option.

Because of the conceptual nature of this study, the following aspects of this improvement have not been evaluated:

- Local access to the relocated SR 4 (would require ramps onto the new levees)
- Future expansion plans for the infrastructure, if any
- Source of funding

12.1.3 Objective and Approach

The primary objectives of the building block are to:

- Reduce the risk of the potential loss of SR 4, the BNSF railroad, the Mokelumne Aqueduct system, and the Kinder Morgan pipeline due to levee breaches caused by a flood or an earthquake
- Provide for uninterrupted operation of the infrastructure for water supply, fuel supply, emergency response, and freight transport.

12.2 CONCEPTUAL DEVELOPMENT OF IMPROVEMENT

12.2.1 Analysis Criteria and Basis of Design

The limits of the armored infrastructure corridor are determined by comparing the FEMA 100-year flood elevations with the ground elevations along the proposed alignment of the corridor. Figure 12-2 shows the locations of the existing infrastructure and the limits of the new levees. The new levees would be constructed in locations where the peat layer has an average thickness of 10 feet. All new levees considered in Options 1 and 2 would be seismic–resistant levees. As described in Section 4, Building Block 1.2: Upgraded Delta Levees, the design of a seismic-resistant levee should incorporate a slope of 3 horizontal to 1 vertical (3H:1V) for side slopes of the embankment. The design criteria for seismic-resistant levees are also discussed in Section 4.

The new levees would have a crest elevation of 13 feet. The crest elevation is calculated based on a freeboard of 3 feet over the 100-year FEMA flood elevation, which is at about 10 feet within the limits of the corridor.

Under Option 1, both the northern levee and the southern levee would have a crest width of 50 feet. The northern levee would carry the relocated BNSF railroad, and the southern levee would carry the relocated SR 4. To prevent flooding within the corridor, the existing levees that cross the corridor would be raised and upgraded to seismic–resistant levees. Figure 12-3a shows the layout for Option 1. Section 4 discusses the design criteria for the new levees.

Option 2 would involve constructing one large levee that would include the relocated SR 4, BNSF railroad, Mokelumne Aqueduct system, and Kinder Morgan pipeline. Crash-resistant barrier walls would be needed between the new SR 4 and the new BNSF railroad. According to Draft Technical Memorandum No. 2 of the Strategy for Protecting the Aqueducts in the Delta, prepared by EBMUD (2007), two new 87-inch-diameter pipelines can be used to replace the existing three pipelines, two of which have –diameters smaller than 87 inches. The new levee would have a crest elevation at 13 feet and a crest width of 180 feet, which includes 50 feet for the Mokelumne Aqueduct system, 50 feet for the BNSF railroad, 50 feet for SR 4, and 30 feet for the Kinder Morgan pipeline. Figure 12-3b shows the layout for Option 2.

A typical cross section for Option 1 is shown on Figure 12-4a, and a typical cross section for Option 2 is shown on Figure 12-4b.

12.2.2 Analysis Results and Design Layouts

As stated above, the new armored infrastructure corridor would follow the general alignment of the BNSF railroad, the Mokelumne Aqueduct system, and the Kinder Morgan pipeline, as shown on Figure 12-2. SR 4 would be relocated about 5 miles to the north onto the new levee. The new levees would begin at the northwestern corner of Orwood Tract and end in Middle Roberts Island at Daggett Road on SR 4. The following two options for placement of the relocated infrastructure are considered technically feasible.

12.2.2.1 Option 1: Northern and Southern Levees

SR 4

About 15 miles of SR 4 would need to be relocated to the top of the new levee. Caltrans would design and construct the connection of the existing SR 4 with the west end of the relocated SR 4 (see Figure 12-1) in collaboration with local authorities, and therefore this connection is not included in this study.

Two new highway drawbridges would need to be constructed across Old River and Middle River, with spans of 800 and 1,000 feet, respectively.

BNSF Railroad

About 15 miles of BNSF railroad would be relocated on top of the new northern levee. The limits of improvement are similar to those of SR 4.

Two new railroad drawbridges would need to be constructed across Old River and Middle River, with spans of 800 and 1,000 feet, respectively.

Mokelumne Aqueduct System

Under Option 1, the aqueducts would remain unaffected except for the parts in Orwood Tract, where 1 mile of the aqueducts would need to be relocated to the south (see Figure 12-3a) to allow for construction of the new northern levee.

Kinder Morgan Pipeline

Like the Mokelumne Aqueduct system, the Kinder Morgan pipeline would remain unaffected except for the portion in Orwood Tract, where 1 mile of the pipeline would need to be relocated to the south to allow for construction of the new northern levee.

One of the new levees would require relocation of about 1 mile of a 500-kilovolt PG&E electric transmission line, which would involve the relocation of five transmission towers. Land acquisition would be required for the two new levees and the space created between the two new levees.

12.2.2.2 Option 2: Single Levee

SR 4

The new SR 4 would be built on top of the new 180-foot-wide levee. Other features are similar to those for SR 4 in Option 1.

BNSF Railroad

The new BNSF railroad would be built on top of the new 180-foot-wide levee. Other features are similar to those for the BNSF railroad in Option 1.

Mokelumne Aqueduct

Option 2 would require the construction of about 10 miles of two 87-inch-diameter aboveground pipelines on pipe saddles on top of the new levee. The limits of improvement for the Mokelumne Aqueduct system would be between the northwestern part of Orwood Tract and the border of Lower Jones Tract and Lower Roberts Island. Two new siphons for each aqueduct pipeline would be needed to cross under the Old and Middle rivers (see Figure 12-3b).

Kinder Morgan Pipeline

Option 2 would require the construction of about 10 miles of a below-ground, 10-inch-diameter pipeline along the crest of the new levee. The limits of improvement for the pipeline are the same as those for the Mokelumne Aqueduct system. Two new crossings would be needed to cross under the Old and Middle rivers.

This option would require relocation of the 500-kilovolt PG&E electric transmission line in a manner similar to that described for Option 1. Land acquisition would also be required for the levee.

12.2.3 Description of Values, Benefits, and Constraints

Placing valuable infrastructure either between or on top of newly designed seismic-resistant levees would allow movement of freight and emergency supplies during the critical period right after levee breaches occur as a result of a severe flood or earthquake. Also, trips through the Delta would not be forced to detour around the Delta after flood- or earthquake-induced levee breaches. The second benefit is the reduction of routine maintenance costs due to recurrent

flooding of these areas. The Mokelumne Aqueduct system and the Kinder Morgan pipeline would not be seismically hardened under Option 1; they would simply be protected from damage due to levee breaches and the resultant scouring and flooding. The relocation of these facilities under Option 2 would create an opportunity to implement a seismic-resistant design. (However, the cost estimate provided for this building block does not assume a seismic-resistant design.)

Potential constraints to the improvements considered under this building block include:

- Local access to the relocated SR 4: The levee that carries the new SR 4 may be as high as 40 feet from the original ground in some areas. Existing access points (such as entrances, exits, and driveways) would need to be maintained along the existing SR 4.
- The design of Option 2 requires more detailed analysis. The interface between the new levee and the raised pipelines (the Mokelumne Aqueduct system and the Kinder Morgan pipeline) would need further evaluation.

12.3 COST ESTIMATE

12.3.1 Summary of Quantities

Table 12-1 lists the comparable quantities of infrastructure affected by the two options.

12.3.2 Material Source Analysis

Levee earthfill can be obtained from sources with short haul distances.

12.3.3 Construction Considerations

It would be crucial to maintain service to the users and customers of the infrastructure during construction. No demolition of the infrastructure would be able to occur before the new facility is in place and operational.

The existing local roadways may be used for construction access, and the shoulder area may be used as a laydown area for the contractor. K-rails may be used as a temporary barrier between the construction zone and vehicular traffic. One-way traffic may be necessary. Significant coordination efforts would be required during construction because utility companies such as Kinder Morgan and PG&E prefer to relocate their own facilities.

12.3.4 Cost Estimate Tables

12.3.4.1 Capital Cost

The unit cost of the new seismic-resistant levees is based on Section 4, Building Block 1.2: Upgraded Delta Levees. For a new levee with a 50-foot-wide crest, the unit cost per mile is $45.2 million, with an additional $7.4 million per mile for the cost of peat excavation. For the new levee with a 180-foot-wide crest, the unit cost per mile is $94.6 million, with an additional $12.4 million per mile for the cost of peat excavation.

The unit costs of a new SR 4 (at grade), a new BNSF railroad (at grade), and a new Kinder Morgan pipeline are based on the Delta Risk Management Strategy (DRMS) Phase I Impact to Infrastructure Technical Memorandum (URS/JBA 2007f).

The unit cost of a new double 87-inch-diameter pipeline Mokelumne Aqueduct system is $30 million per mile (EBMUD 2007).

A unit cost of $1,000 per square foot was used for the proposed new highway and railroad drawbridges. This cost was then converted to a unit cost of $210 million per mile for a width of 40 feet and $260 million per mile for a width of 50 feet.

According to 2007 real estate sales data, the average cost of open land is $10,000 per acre. Assuming a width of 400 feet for the new right-of-way for both Options 1 and 2 of the armored infrastructure corridor, the cost of land is calculated to be $0.5 million per mile of highway.

Table 12-2 provides the conceptual cost estimate summary.

12.3.4.2 Operation Cost

No significant additional operation costs are anticipated for the armored infrastructure corridor or the improved infrastructure.

12.4 ESTIMATE OF RISK REDUCTION

12.4.1 Direct Risk Reduction

This building block would reduce the risk of the potential loss of SR 4, the BNSF railroad, the Mokelumne Aqueduct system, and the Kinder Morgan pipeline due to levee breaches caused by floods or earthquakes. Also, the armored infrastructure corridor would provide for the operation of this infrastructure for emergency response and normal uses.

12.4.2 Estimation of Risk Reduction

The impacts due to the loss of SR 4 may not be significant in comparison to impacts due to the loss of other infrastructure. This finding is based on the observation that traffic can use Interstate 205 to the south or SR 12 to the north if SR 4 is closed. However the economic costs and impacts attributable to those detours have been estimated. The loss of the BNSF railroad was assumed to transfer products to trucks via interstates. The loss of the petroleum pipeline was assumed to transfer products to trucks from the Bay Area or other sources. The assumptions developed for the DRMS Phase 1 analyses did not include any disruption of service impacts for EBMUD.

These failure cases do not represent the worst-case conditions or average conditions. Each case would need to have its avoided costs or impacts multiplied by its probability of occurrence and the results would need to be summed over all possible cases. A more comprehensive assessment of risk reduction benefits is needed to ascertain whether the corridor concept is economically justified.

The avoided direct economic costs and indirect economic impacts of this building block are evaluated in the context of the scenarios in Section 18.

12.5 FINDINGS, CONCLUSIONS, AND RECOMMENDATIONS

This analysis finds that the estimated capital costs for new levees and infrastructure relocation under Option 1 would be about $3.3 billion. The estimated capital costs for Option 2 are $3.9 billion. The building block strategy is similar to the strategy of EBMUD for protecting the aqueducts (Alternative #11) (EBMUD 2007).

If this building block is given further consideration, it is recommended that additional studies be conducted on the following areas:

- The number of local access points needed along SR 4, the BSNF railroad, and the Mokelumne Aqueduct system
- Future plans for all involved infrastructure facilities (future traffic volumes on SR 4 or future planned capacity increase in the pipelines)
- A comprehensive evaluation of avoided costs and impacts for a full range of potential cases
- Availability of funding

Tables

Table 12-1 Summary of Quantities of Infrastructure Affected by Options 1 and 2

Infrastructure	Option 1 Length of Improvement (miles)	Option 2 Length of Improvement (miles)
SR 4 (at grade)	15	15
Drawbridge across Old and Middle rivers	0.2	0.2
BNSF railroad (at grade)	15	15
Drawbridge across Old and Middle rivers	0.2	0.2
Mokelumne Aqueduct system	1.0	10
Kinder Morgan pipeline	1.0	10
New levee (50-foot crest width)	30	N/A
New levee (180-foot crest width)	N/A	15
Relocated PG&E electrical transmission line	1.0	1.0

BNSF = BNSF Railway
PG&E = Pacific Gas and Electric Company
SR = State Route

Table 12-2 Armored Infrastructure Corridor: Cost Estimate Summary

OPTION 1		Using Imported Fill Material				
Items Included	**Length (mile)**	**Unit Cost ($million/mile)**	**Amount ($million)**	**Unit Cost ($million/mile)**	**Amount ($million)**	**Unit Cost Reference**
Northern levee (50-foot crest width)	15	45.2	677.9	-	-	Section 4, Building Block 1.2: Upgraded Delta Levees
Southern levee (50-foot crest width)	15	45.2	677.9	-	-	Section 4, Building Block 1.2: Upgraded Delta Levees
Excavation for northern levee	15	-	-	7.4	111.0	Section 4, Building Block 1.2: Upgraded Delta Levees
Excavation for southern levee	15	-	-	7.4	111.0	Section 4, Building Block 1.2: Upgraded Delta Levees
SR 4 – 40 feet wide, at grade	15	-	-	1.0	15.0	URS/JBA 2007f
SR 4 – 40 feet wide, drawbridge	0.2	-	-	210.0	42.0	URS data research
BNSF railroad – double track, at grade	15	-	-	3.0	45.0	URS/JBA 2007f
BNSF railroad - 50-foot-wide drawbridge	0.2	-	-	260.0	52.0	URS data research
EBMUD Mokelumne Aqueduct system	1	-	-	30.0	30.0	EBMUD 2007
Kinder Morgan gasoline pipeline	1	-	-	1.1	1.1	URS/JBA 2007f
PG&E electrical transmission line	1	-	-	1.7	1.7	URS/JBA 2007f
Land cost	15	-	-	0.5	7.5	Recent property sales data
Items subtotal			1,772.1			
Mobilization (10%)			177.2			
Subtotal			1,949.3			
Contingency (30%)			584.8			
Construction cost			2,534.1			
*Soft costs (30%)			760.2			
Total capital cost ($million)			**3,294**			

* Soft costs include cost of surveys, design, construction management and administration.

Table 12-2 Armored Infrastructure Corridor: Cost Estimate Summary

OPTION 2		Using Imported Fill Material				
Items Included	**Length (mile)**	**Unit Cost ($million/mile)**	**Amount ($million)**	**Unit Cost ($million/mile)**	**Amount ($million)**	**Unit Cost Reference**
Large levee (180-foot top width)	15	94.6	1418.5	-	-	Section 4, Building Block 1.2: Upgraded Delta Levees
Excavation for levee	15	-	-	12.4	186.0	Section 4, Building Block 1.2: Upgraded Delta Levees
SR4 – 40 feet wide, at grade	15	-	-	1.0	15.0	URS/JBA 2007f
SR 4 – 40-foot-wide drawbridge	0.2	-	-	210.0	42.0	URS data research
BNSF railroad – double track, at grade	15	-	-	3.0	45.0	URS/JBA 2007f
BNSF railroad – 50-foot-wide drawbridge	0.2	-	-	260.0	52.0	URS data research
EBMUD Mokelumne Aqueduct system	10	-	-	30.0	300.0	EBMUD 2007
Kinder Morgan gasoline pipeline	15	-	-	1.1	16.5	URS/JBA 2007f
PG&E electrical transmission line	1	-	-	1.7	1.7	URS/JBA 2007f
Land cost	15	-	-	0.5	7.5	Recent property sales data
Items subtotal			2,084.2			
Mobilization (10%)			208.4			
Subtotal			2,292.6			
Contingency (30%)			687.8			
Construction cost			2,980.3			
*Soft costs (30%)			894.1			
Total Capital Cost ($million)			**3,874**			

* Soft costs include cost of surveys, design, construction management and administration.

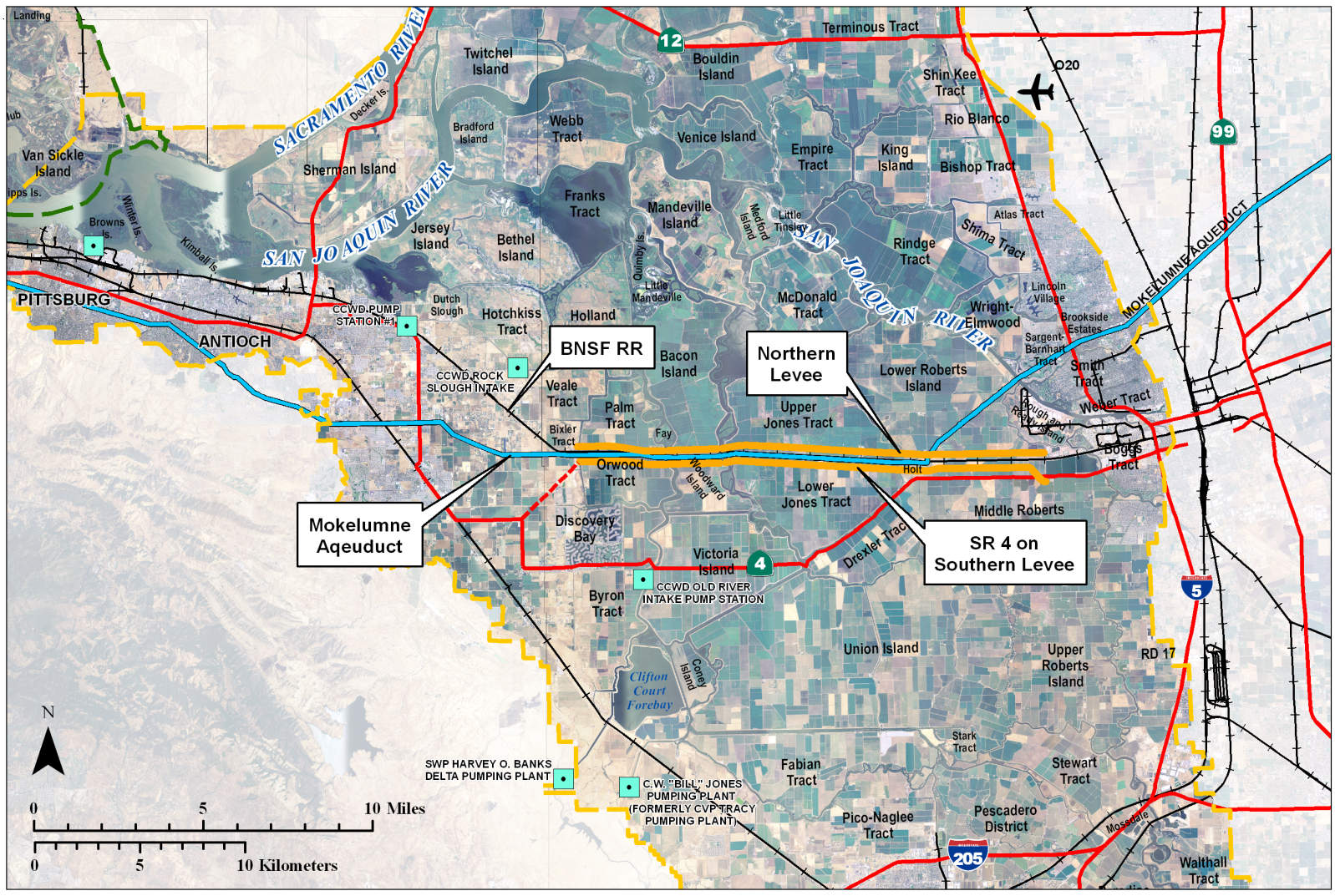
Table 12-2 Armored Infrastructure Corridor: Cost Estimate Summary

Note:
Unit costs of the 50-foot top width and 180-foot top width levees are based on the unit costs of the 20-foot top width levee provided in Section 4, Building Block 1.2: Upgraded Delta Levees. The following relationships were used for the unit cost conversion:

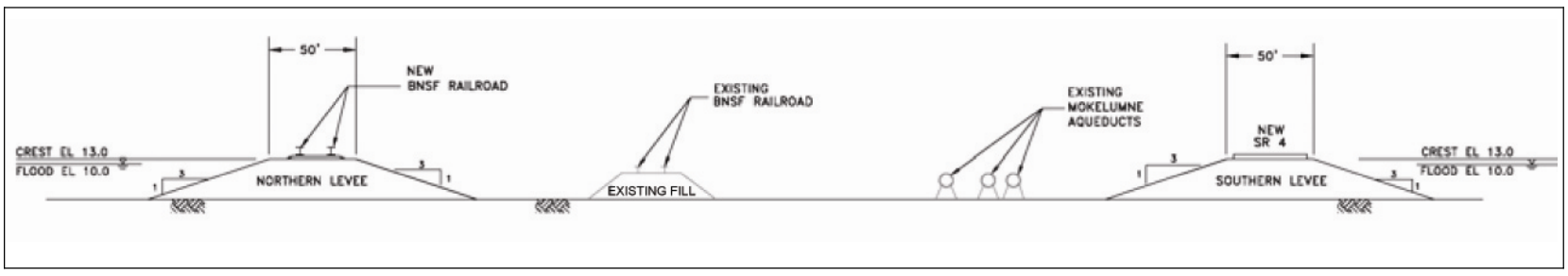
Volume of a levee with 50-foot-wide crest = 1.3 x volume of a levee with 20-foot-wide crest
Volume of a levee with 180-foot-wide crest = 2.8 x volume of a levee with 20-foot-wide crest

BNSF = BNSF Railway
EBMUD = East Bay Municipal Utility District
JBA = Jack R. Benjamin & Associates, Inc.
PG&E = Pacific Gas and Electric Company
SR = State Route

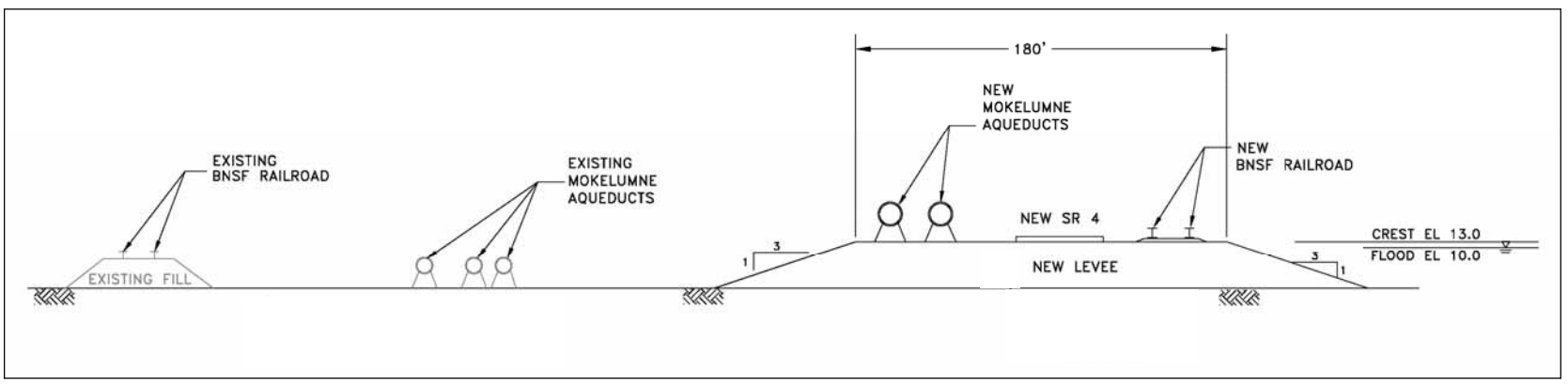
Figures



PLAN
(FOR OPTION 1; SIMILAR PLAN FOR OPTION 2)



TYPICAL SECTION – OPTION 1



TYPICAL SECTION – OPTION 2

OBJECTIVES

- Reduce the risk of potential loss of SR 4, BNSF railroad, Mokelumne Aqueduct, and Kinder Morgan pipeline due to flooding and earthquake
- Provided for the uninterrupted operation of these transportation corridors for emergency response and normal uses

BENEFITS

- Benefits = avoided economic costs and impacts resulting from infrastructure damage and loss of use in the full range of levee breach events

Note: Project costs may be truncated (reduced) when combined with other building blocks in scenarios.

PROJECT INFORMATION

Project proposes an armored infrastructure corridor across central Delta. The length of the corridor is approximately 15 miles. The crest elevation of the new levee is 13.0 feet, with 3 feet of freeboard above the 100-year FEMA flood level. The peat layer is on average 10' thick along the corridor.

PROJECT COSTS

Option 1:
Construct a northern and southern levee across the central Delta. Relocate SR 4 onto the new southern levee and the BNSF railroad onto the new northern levee. Both levees will be seismically resistant.
Construction Cost = $3.3 billion

Option 2:
Construct a larger levee that can carry the relocated SR 4, BNSF railroad, and Mokelumne Aqueduct. This levee will be seismically resistant.
Construction Cost = $3.9 billion

URS	26815935 Delta Risk Management Strategy (DRMS) Phase 2	BUILDING BLOCK 2.2: CONSTRUCT ARMORED INFRASTRUCTURE CORRIDOR ACROSS CENTRAL DELTA	Figure 12-1

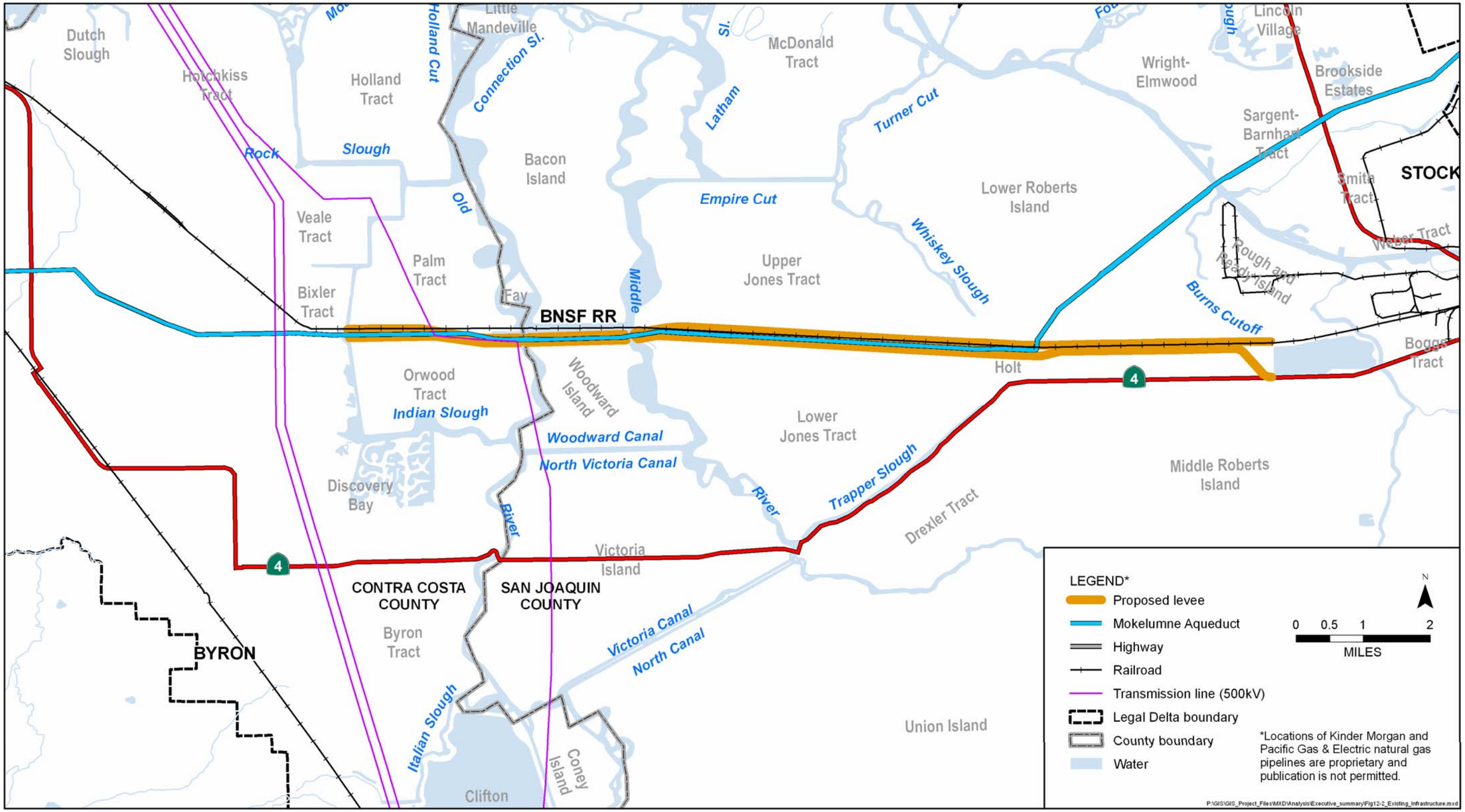


Figure 12-2 Existing Infrastructure and Limits of New Levees

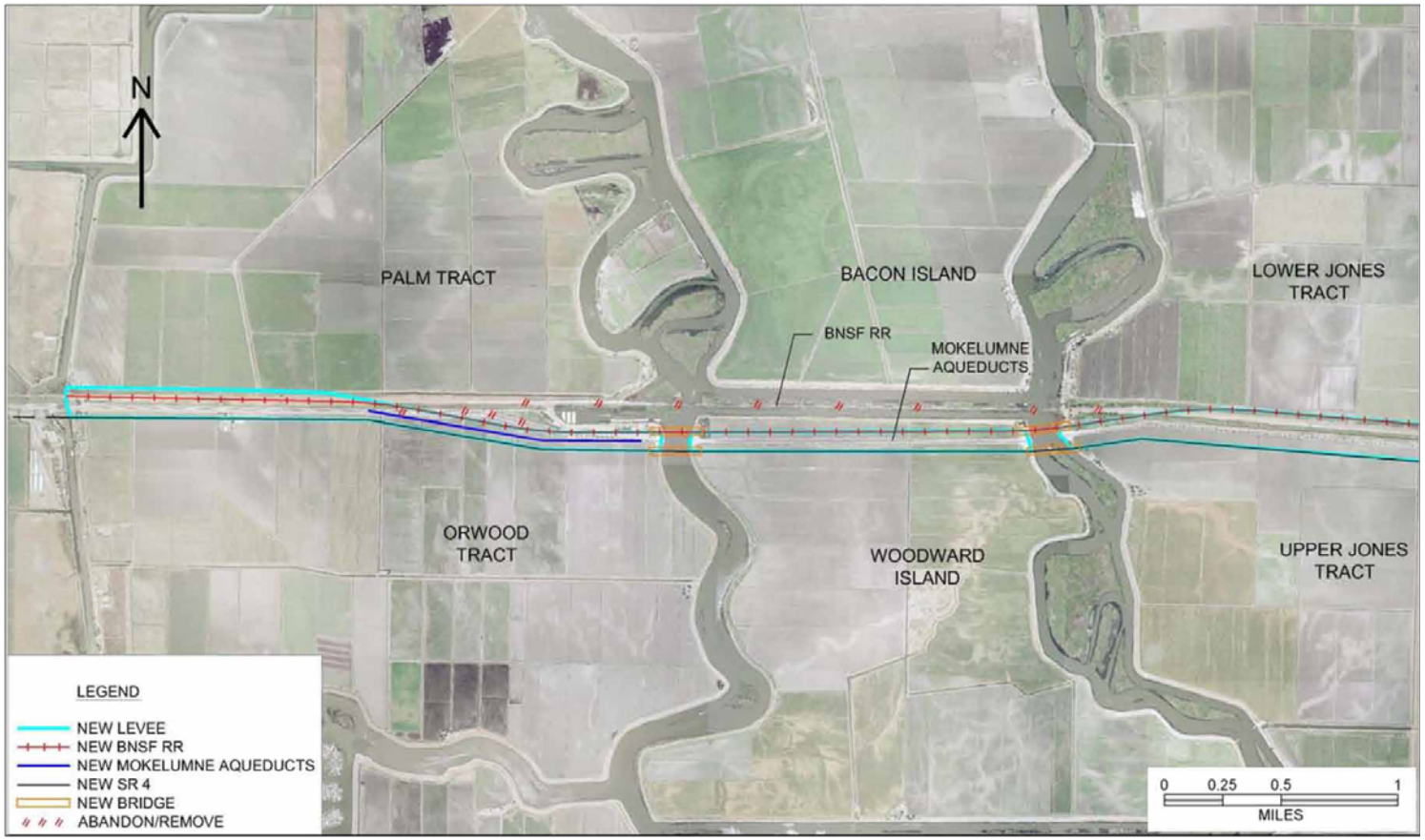


Figure 12-3a Layout of Armored Infrastructure Corridor, Option 1

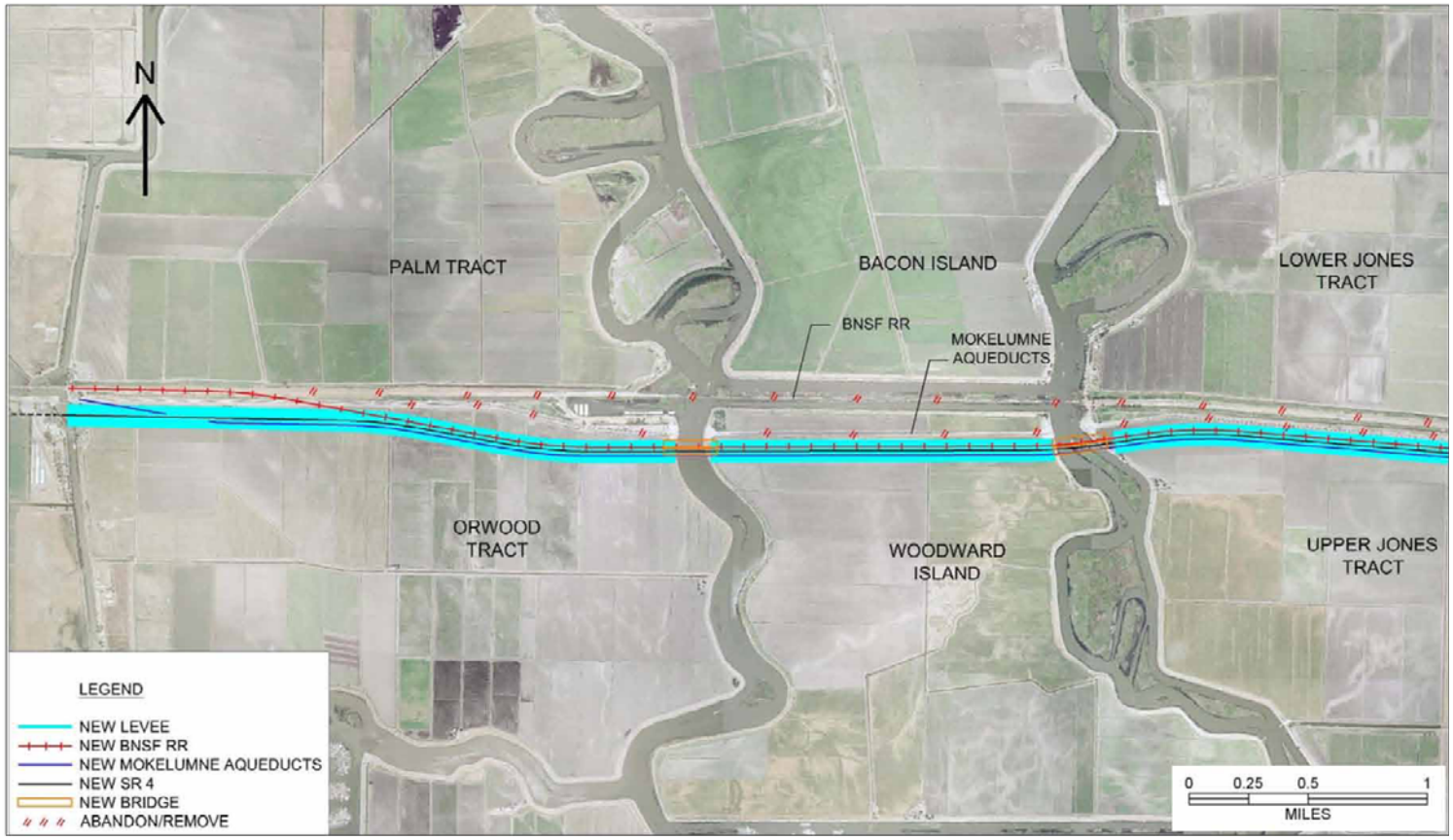


Figure 12-3b Layout of Armored Infrastructure Corridor, Option 2

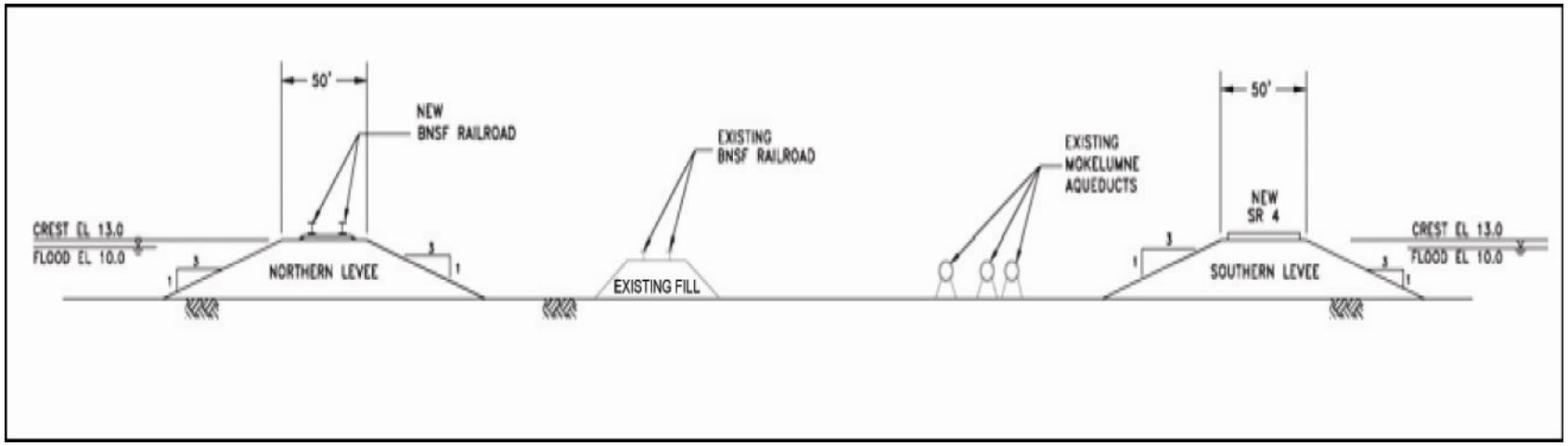


Figure 12-4a Typical Cross Section of Armored Infrastructure Corridor, Option 1

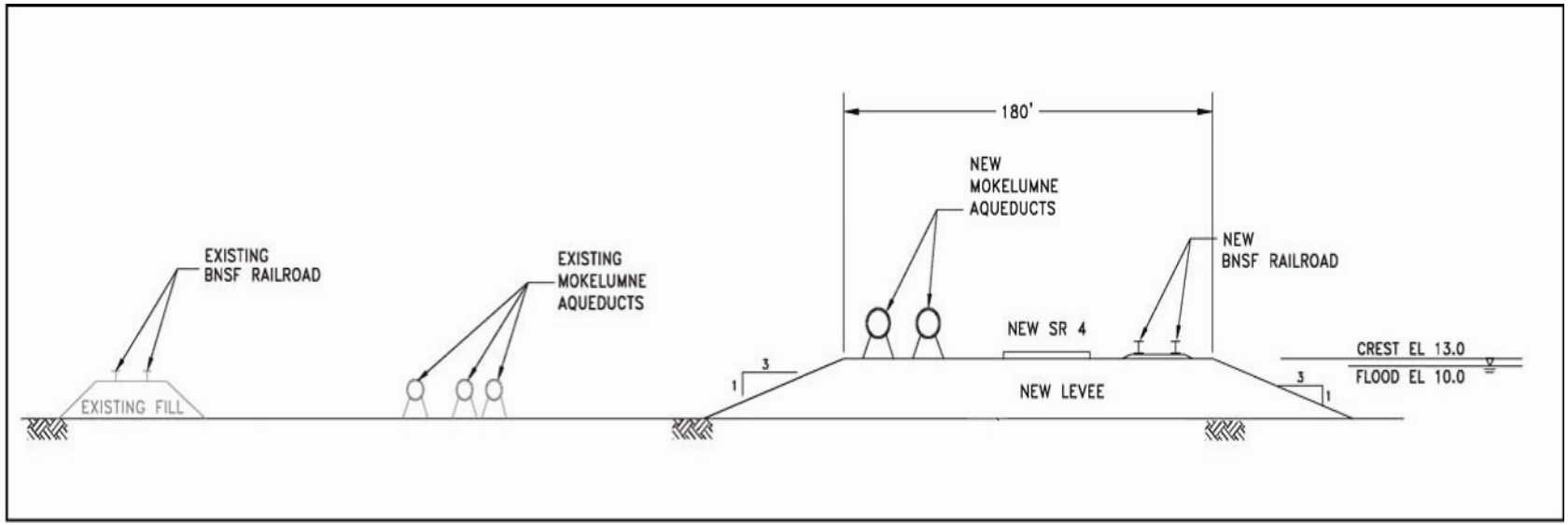


Figure 12-4b Typical Cross Section of Armored Infrastructure Corridor, Option 2